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LONG-TERM RESIDUE RETENTION INCREASES WATER USE EFFICIENCY AND ECONOMIC PROFITABILITY IN THE WHEAT-RICE-RICE SYSTEM

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Abstract

Long–term conservation agriculture (CA) increases soil fertility and crop productivity but there has been limited study of its effects on water productivity and economic benefit in the intensive rice–based cropping systems. In a long-term experiment, crops and water were sampled for the wheat-rice-rice cropping pattern during 2018-19 (crops 25-27) and 2019-20 (crops 28-30). The plots were treated with (A) minimum soil disturbance (strip planting = SP) and intensive tillage (conventional tillage = CT), (B) farmer's current practice of residue (low residue = LR) and high residue retention (HR = 40 cm). From 2018 sub-plots were split with (C) current recommended dose (RD) of S and 150% RD (higher dose = HD) of S in a drought prone terrace soil on the High Barind Tract (HBT). The system water productivity (total, considering leaching and irrigation water) was 6-8% and 2-4% higher and system benefit-cost ratio (BCR) was 7% and 3% higher in HR and HD of S, respectively than in LR and RD of S. In wheat, water productivity was 18-23% higher and BCR was 9% higher in SP than in CT, but the reverse was found in T. Aus rice where water productivity was 11-34% and BCR was 10% higher in HR with HD of S than LR with RD of S. In the intensive rice-based cropping systems on the HBT which involve significant crop residue removal and water scarcity, there is an opportunity to increase water use efficiency and economic benefit of crops through the practice of residue incorporation.

Keywords: Barind Tract, Crop residue, Economic benefit, Minimum tillage, Water productivity

1. Introduction

The High Barind Tract (HBT) of Bangladesh is characterized by terrace soil, lower rainfall and higher temperature compared to those of other parts of the country. These soils are drought prone, acidic in nature, low organic matter content and nutrient deficient (Kumar *et al.,* 2022, 2024). Most of the parts of this tract is used for wetland rice production and this intensive rice–based land is now shown with high yielding varieties (HYV) which is cultivated during dry season (Bell *et al.,* 2019). These HYV's of rice require high volume water and excess demand of water is fulfilled by withdrawal of groundwater. Due to overexploitation and lack of replenishment of groundwater, increase in overall temperature and evaporation, decrease in summer precipitation and soil-moisture, water table progressively has declined (Islam *et al.,* 2012) and the area is being turned hydro-meteorologically into a semi-arid zone with low to moderate groundwater potential zone. This problem posed different issues like land use and urban development, with variable dimensions in the groundwater for irrigation in the area which effect negatively on economic profitability of crops. Hence, now it is a great need to increase water use efficiency for decreasing water demand by introducing new crop cultivation technique Conservation Agriculture (CA) in the intensive rice–based cropping system in the terrace soil of HBT. Water-use-efficiency is a crucial consideration for HBT due to the limited soil water-holding capacity, recent depletion of groundwater reserves, limited surface water catchment and increasing effects of climate change (Ali, 2018). The promising technology, CA practice specially increased crop residue retention can modify soil structure and aggregate stability; as a result, soil hydraulic conductivity and infiltration rate get higher (Mahmud, 2021). Hence, it is required to determine the long–term increased crop residue retention levels and minimum soil disturbance whether water use is efficient for wheat-rice-rice system.

Producing more food or getting more profits by using the minimum amount of water is the main concern at present because of water scarcity in this area (Islam *et al.,* 2012). The high clay content and high bulk density of HBT soils have the tendency to develop crack on drying which increases the surface area and evaporation may occur, thus accelerating soil drying. Conservation Agriculture technique involves minimum tillage that leads to a compromise between avoiding deeper tillage (e.g. below 5 cm) and disturbing the surface soil enough to close cracks. Accumulation of crop or plant residues on the soil surface, as part of conservation agriculture practices, would also reduce soil water evaporation. However, this would require a drastic culture change from the present practice of residue removal, mainly for fuel purposes (Ali, 2018). Minimum tillage (SP) system can improve soil water content and crop yields by comparing with conventional tillage (CT) system (Sainju *et al.,* 2017). So, it is hypothesized that long-term increased residue retention (HR) and minimum soil disturbance (SP) together with increased S nutrient might give higher water productivity and economic profitability by increasing water use efficiency and crop yield in the wheat-rice-rice system. Therefore, this study was carried out to determine the effects of minimum tillage, residue retention and S dose on the water productivity and economic benefit in the wheat-rice-rice system.

2. Materials and Methods

2.1 Location, climate and soil characteristics of the experiment

The study was undertaken on a long-term experiment with continuous Conservation Agriculture (CA) and conventional tillage (CT) practices at Godagari under Rajshahi district in Bangladesh (240 31' 32.1'' N, 880 22' 32.8'' E) on a nearly level poorly-drained terrace, belonging to Vertic Normaquepts (Kumar *et al.,* 2022). The textural class, reaction and organic carbon content of the surface soil (0-15cm) were silt clay loam, slightly acidic (pH-5.8-6.1) and low (0.9-1.2%), respectively (Kumar *et al.,* 2022). The climate is subtropical monsoon type with long term total annual rainfall of 1,254 mm. Average maximum temperature is 36.1°C in April, while average minimum temperature is 10.5°C in January

2.2 Experiment set up

Details of the experimental design and prior treatment effects were previously reported by Alam *et al.* (2018), Kumar *et al.* (2022, 2024) and Islam *et al.* (2022). Briefly, the experiment was laid out as a split plot design with two factors since 2010. The main factor was soil disturbance levels comprising strip planting (SP) or conventional tillage (CT). Sub-plots were split for low residue retention (LR=15 cm residue height for cereal crops; corresponds to current farmer's practice in the region) and high residue retention (HR=40 cm residue height). During the 2018-19 and 2019-20 cropping seasons, plots were split for S dose making a split-split-plot design. Sub-sub plots were treated with the current dose of S (RD=according to FRG, 2018) or a 50% higher dose of S (HD=150% of RD). Powder–form gypsum fertilizer mixed with other required fertilizers was used as a basal application during final land preparation. This was a triple cropped experiment with four replications and a diversified cropping sequence. The cropping pattern for 2018-19 and 2019-20 was Wheat –T. Aus (Transplanted Aus rice) –T. Aman (Transplanted Aman rice). All management operations for each crop were done according to FRG (2018). Data of the yield and yield contributing characters were collected from each crop. Details about crop experiments are given in Table 1.

Table 1. Crop sequence, crop variety, sowing/transplanting and harvesting time, seed rate and fertilizer dose

Crop Sequence	Crop variety	Sowing/ transplanting time	Harvesting time	Seed rate (kg ha^{-1})	Recommended fertilizer dose (kg ha^{-1})
Wheat	BARI Gom 28	11 December 2018 and 2019	30 March 2019 and 2020	120	N_{120} P_{24} K_{90} S_{10} Mg_4 $Zn_{1.5}$ B_1
T. Aus rice	BRRI dhan 48	10 April 2019 and 2020	11 July 2019 and 2020	25	N_{72} P_8 K_{60} S_6
T. Aman rice	BRRI dhan 51	20 July 2019 and 2020	23 November 2019 and 2020	25	N_{90} P_{10} K_{75} S_8 Zn_1

Crops and water samples were collected during 2018-19 and 2019-20 cropping seasons. Wheat and rice grain and straw samples were collected from each plot after harvesting of crops. Irrigation water was measured by an irrigation flow meter fitted to a pump and supplied from a nearby deep tube-well. Rain water volume was measured by a rain gauge installed near the experiment. Leaching water was measured and collected by installing four lysimeters (two in SP and two in CT plots) as outlined by Amin *et al.* (2021). The leaching water was collected every day at 11 a.m. in a plastic jar and then measured.

2.3 Calculation of water requirement and water productivity

The following equations were used for water productivity calculation which is a little modification of Mahmud (2021) and Alam *et al.* (2017).

Water requirement considering leaching water (L kg^{-1}) = $\frac{(A+B)-C}{D}$ Eqn. 1

Water requirement without considering leaching water (L kg^{-1}) = $\frac{(A+B)}{D}$ Eqn. 2

Water requirement only supplied irrigation water (L kg^{-1}) = $\frac{A}{D}$ Eqn. 3

Water productivity considering leaching water (kg m^{-3}) = $\frac{D}{(A+B)-C}$ Eqn.4

Water productivity without considering leaching water (kg m^{-3}) = $\frac{D}{A+B}$ Eqn. 5

Water productivity only supplied irrigation water (kg m^{-3}) = $\frac{D}{A}$ Eqn. 6

Where, A= Volume of irrigation water supplied (m^{-3}) during crop season

B = Volume of rain water (m^{-3}) during crop season

C = Volume of leachate (m^{-3}) collected through crop season

D = Crop yield (kg ha^{-1})

2.4 Calculation of economic benefit of the wheat-rice-rice system

Cost of production under different tillage practices and residue retention levels was calculated based on total production volume and total production cost. Price of produce and production costs were used to calculate net return, gross margin and benefit-cost ratio (BCR) of the wheat-rice-rice system. The benefit-cost ratio was computed as the gross return divided by total input cost whereas net return was calculated by subtracting the total input cost from gross return and gross margin was calculated by subtracting the total variable cost from gross return (Chowdhury *et al.,* 2012).

2.5 Statistical analysis

Significance of treatment effects on the water requirement, water productivity, gross return, gross margin, net return as well as on the BCR were determined by analysis of variance (ANOVA) for Split-Split-Plot design. Where the F test was significant, treatment means were separated by Duncan's Multiple Range Test (DMRT) using the statistical package Genstat and Statistix 10 at 5% level of significance.

3. Results

Details of the soil fertility status and crop yields for 2018-19 and 2019-20 under the different treatments were previously reported by Kumar *et al.* (2022, 2024).

3.1 Water requirement and water productivity

Mean total amount of water required for crop production in 2018-19 and 2019-20 is reported in Table 2. The water requirement (total, considering leaching and irrigation water) of crops for grain production were significantly influenced by tillage practice, residue retention and S dose in the wheat-rice-rice system . In wheat, water requirements (all three) were about 18-23% higher in CT than in SP. On the other hand, SP plots required for T. Aman rice about 11-19% higher amount of water compared to CT plots. The water requirements for wheat and T. Aman cultivation were 9% higher in LR retention than in HR retention. Similarly, these were 2% higher in wheat and 4% higher in T. Aman rice in RD of S than in HD of S. The interaction effect of tillage, residue retention and S dose showed significant variation on water requirements in T. Aus rice crop and these were about 32-40%, 28-36%, 27-34%, 19-26%, 12%, 6% and 6% higher in SP-LR-RD, SP-HR-RD, SP-LR-HD, SP-HR-HD, CT-LR-RD, CT-LR-HD and CT-HR-RD, respectively than in CT-HR-HD (Fig. 1). The system water requirements (all three) were about 8-17% higher in SP than in CT, about 8% higher in LR than in HR and about 4% higher in RD than in HD of S.

3.2 Water productivity in the wheat–rice–rice system

There were significant effects of tillage practice, residue retention and S dose on water productivity (total, considering leaching and irrigation water) of crops for grain production in the wheat-rice-rice system (Table 3). In T. Aus rice and T. Aman rice, CT plots showed about 19-29% and about 1-20% higher water productivity, respectively compared to SP plots (Fig. 1). The water productivity was 2% higher in wheat and 3-5% higher in T. Aman rice in HD of S than in RD of S. The interaction effect of tillage × residue retention in wheat and residue retention × S dose in T. Aman rice showed significant variation on water productivity (Table 3). In wheat, these were about 29-34%, 17-22% and 8% higher in SP-HR, SP-LR and CT-HR, respectively than in CT-LR (Fig. 2). In T. Aus rice, water productivity was about 7-11%, 3-5% and 3-4% higher in HR-HD, LR-HD, HR-RD, respectively than in LR-RD. The system water productivity was about 8-16% higher in CT than in SP and about 12%, 7% and 3% higher in HR-HD, HR-RD and LR-HD, respectively than in LR-RD (Fig. 3).

Table 2. Water requirements of crops production in the wheat – T. Aus rice – T. Aman rice system as influenced by tillage, residue retention and S dose. Values are the means of two years and four replicates

Factor and Treatment	Water requirement (L kg^{-1})					System water requirement (L kg^{-1})		
	Total		Considering leaching	Irrigation water		Total	Considering leaching	Irrigation Water
	Wheat	T. Aman	T. Aman	Wheat	T. Aman			
Tillage								
SP	388	2772	930	278	1670	2174	720	1497
CT	458	2495	923	341	1402	1967	670	1277
SEM (±)	2.11	21.3	-	1.52	12.8	8.24	2.74	5.62
Residue retention								
HR	405	2523	887	297	1472	1992	669	1335
LR	441	2744	965	323	1600	2148	721	1439
SEM (±)	2.52	33.3	11.2	1.83	19.9	12.9	4.28	8.82
S dose								
HD	419	2585	909	307	1508	2034	683	1363
RD	426	2682	943	312	1564	2106	707	1411
SEM (±)	1.43	8.97	3.21	1.05	5.18	4.01	1.34	2.70

Legend: SP – strip planting and CT – conventional tillage; HR – high residue retention; LR – low residue retention; HD – 150% of recommended dose; RD - recommend dose

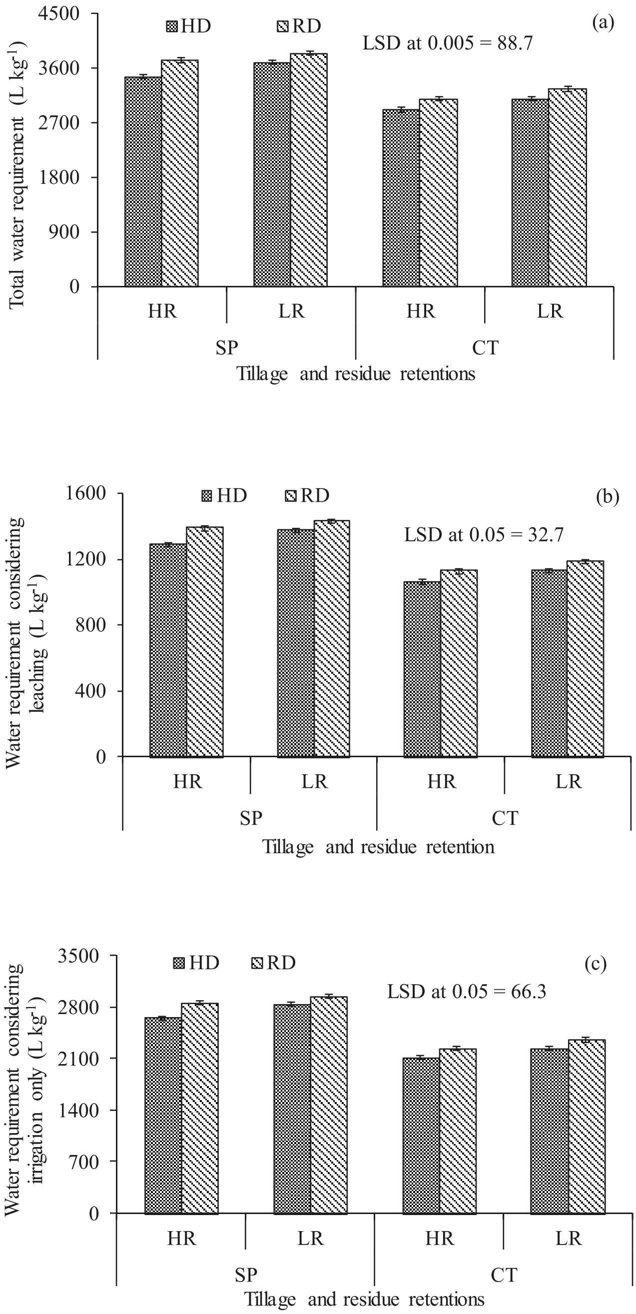

Fig. 1 *Water requirement of T. Aus rice grain production as influenced by tillage, residue retention and S dose. [Legends: SP – strip planting and CT – conventional tillage; HR – high residue and LR – low residue; HD –high S dose and RD – recommended S dose. Vertical bars represent LSD (P < 0.05).]*

Table 3. Water productivities of crops production in the wheat –T. Aus rice - T. Aman rice system influenced by tillage, residue retention and S dose. Values are the means of two years and four replicates.

	Water productivity (kg m^{-3})								System water productivity (kg m^{-3})		
Factor and Treatment	Total			Considering leaching		Irrigation water			Total	Considering leaching	Irrigation water
	Wheat	T. Aus	T. Aman	T. Aus	T. Aman	Wheat	T. Aus	T. Aman			
Tillage											
SP	2.59	0.27	0.36	0.73	1.08	3.60	0.35	0.60	0.46	1.39	0.67
CT	2.19	0.32	0.40	0.89	1.09	2.93	0.45	0.72	0.51	1.50	0.78
SEM (±)	0.013	0.001	0.002	0.001	0.008	0.019	0.001	0.004	0.002	0.005	0.003
Residue retention											
HR	2.49	0.31	0.40	0.83	1.13	3.41	0.41	0.69	0.50	1.50	0.75
LR	2.28	0.29	0.37	0.79	1.04	3.13	0.38	0.63	0.47	1.39	0.70
SEM (±)	0.016	0.003	0.004	0.008	0.013	0.022	0.004	0.007	0.003	0.008	0.004
S dose											
HD	2.41	0.31	0.39	0.83	1.10	3.30	0.41	0.67	0.49	1.47	0.74
RD	2.37	0.29	0.37	0.79	1.06	3.24	0.39	0.65	0.48	1.42	0.71
SEM (±)	0.007	0.001	0.001	0.003	0.004	0.01	0.001	0.003	0.001	0.003	0.001

Legend: SP – strip planting and CT – conventional tillage; HR – high residue retention; LR – low residue retention; HD – 150% of recommended dose; RD - recommended dose

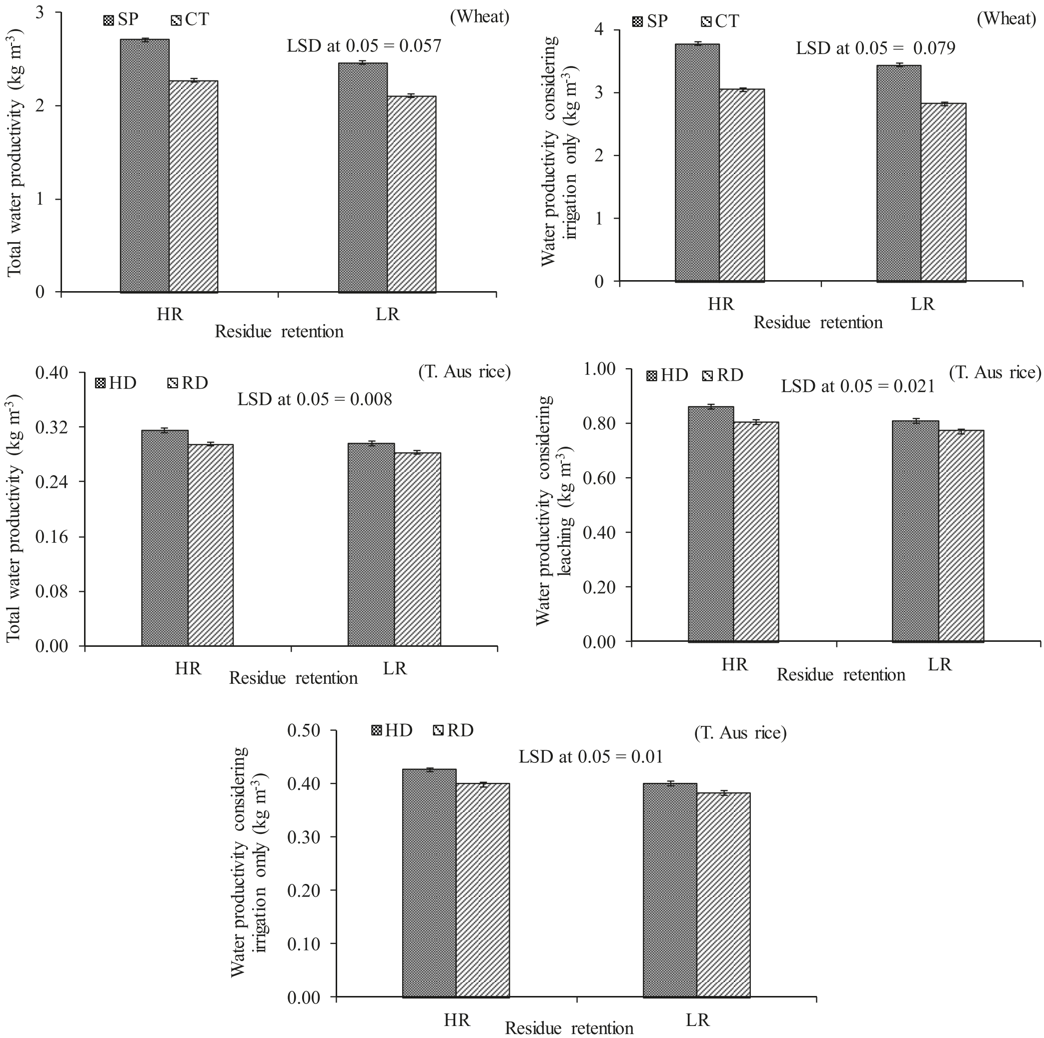

Fig. 2 *Water productivity influenced by tillage × residue retentions in wheat and residue retentions × S doses in T. Aus rice. [Legends: SP – strip planting and CT – conventional tillage; HR – high residue and LR – low residue; HD –high S dose and RD – recommended S dose. Vertical bars represent LSD (P < 0.05).]*

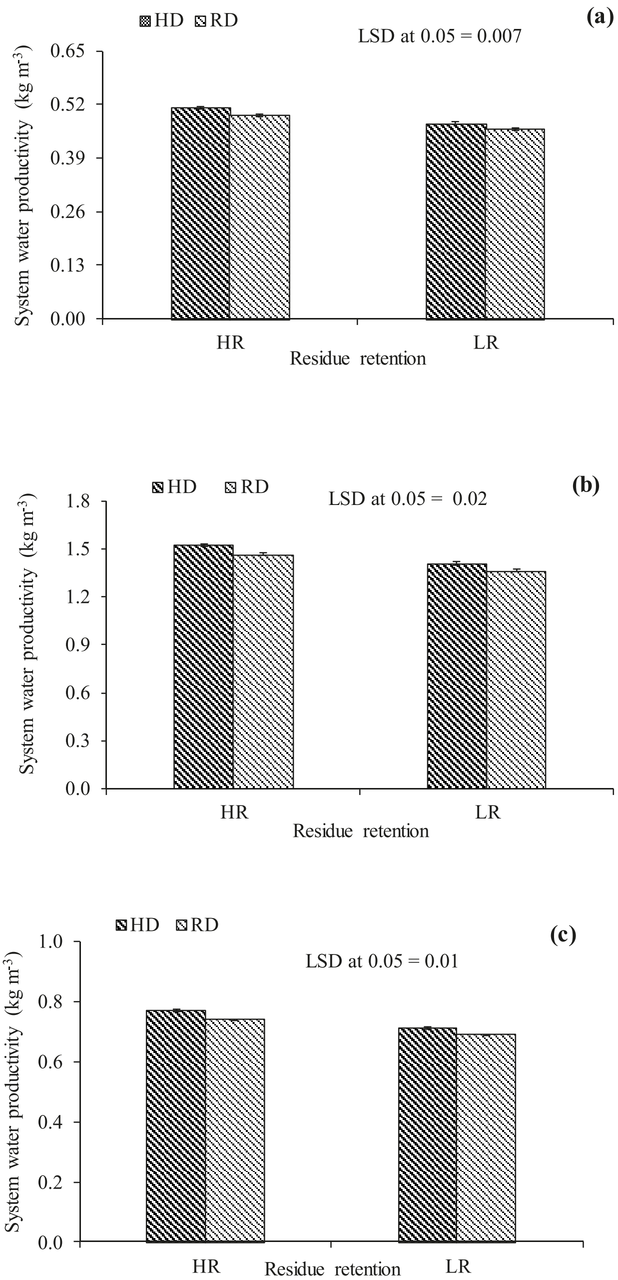

Fig. 3 *(a) System total water productivity, (b) system water productivity considering leaching water and (c) system irrigation water productivity influenced by tillage × residue retentions in the wheat-rice-rice system. [Legends: HR – high residue and LR – low residue; HD –high S dose and RD – recommended S dose. Vertical bars represent LSD (P < 0.05).]*

3.3 Profitability of the wheat-rice-rice system

3.3.1 Wheat

Relative profitability (gross return, gross margin, net return and BCR) of wheat production varied significantly due to different tillage practices, residue retentions and S doses but their interaction was not significant (Table 4). Mean gross return, was 7%, higher in SP than in CT, 9% higher in HR than in LR and 2% higher in HD of S than in RD of S. Mean gross margin was 21% higher in SP than in CT, 21% higher in HR than in LR and 3% higher in HD of S than in RD of S. Mean net return was 42% higher in SP than in CT, 40% higher in HR than in LR and 5% higher in HD of S than in RD of S. Similarly, mean BCR was 9% higher in SP than in CT, 9% higher in HR than in LR and 1% higher in HD of S than in RD of S.

3.3.2 Transplanted Aus rice

Relative profitability (gross return, gross margin, net return and BCR) of T. Aus rice production varied significantly due to different tillage practices, residue retentions and S doses (Table 4). Mean gross return, gross margin, net return and BCR were 5%, 11%, 38% and 4%, respectively higher in CT than in SP. The interaction effects of residue retention and S dose showed significant variation on the relative profitability of T. Aus rice production (Table 4). Mean gross return was 11%, 4% and 4 % highest in HR-HD, HR-RD and LR-HD, respectively than in LR-RD of S (Fig. 4a). Mean gross margin was 44%, 16% and 17 % highest in HR-HD, HR-RD and LR-HD, respectively than in LR-RD of S (Fig. 4b). Mean net return was 227%, 84% and 86 % highest in HR-HD, HR-RD and LR-HD than in LR-RD of S (Fig. 4c). On the other hand, mean BCR was 11%, 4% and 4 % highest in HR-HD, HR-RD and LR-HD than in LR-RD of S (Fig. 4d).

Table 4. Profitability of wheat, T. Aus rice and T. Aman rice production as influenced by tillage, residue retention and S dose. Values are the means of two years and four replicates

Factors and treatments	Gross return (Tk ha^{-1})			Gross margin (Tk ha^{-1})			Net return (Tk ha^{-1})			BCR			
	Wheat	T. Aus	T. aman	Wheat	T. Aus	T. aman	Wheat	T. Aus	T. aman	Wheat	T. Aus	T. aman	System
Tillage													
SP	122406	119453	148463	55725	34660	62886	33947	9015	40604	1.38	1.08	1.38	1.28
CT	114406	118832	149549	45775	31348	65662	23945	12399	43425	1.27	1.12	1.41	1.27
SEM (±)	1120	202	-	1120	202	-	1120	202	-	0.012	0.002	-	-
Residue Retention													
HR	123462	122161	154745	55632	36022	70013	33823	13725	47754	1.38	1.13	1.45	1.32
LR	113349	116125	143266	45868	29986	58534	24069	7689	36275	1.27	1.07	1.34	1.23
SEM (±)	929	1275	1963	929	1275	1963	929	1275	1963	0.011	0.012	0.018	0.013
S Dose													
HD	119349	122344	151633	51506	36093	66751	29697	13793	44487	1.33	1.13	1.42	1.29
RD	117463	115941	146379	49995	29915	61797	28195	7621	39541	1.32	1.07	1.37	1.25
SEM (±)	398	445	560	398	890	560	398	445	560	0.005	0.004	0.005	0.005

Legend: SP – strip planting and CT – conventional tillage; HR – high residue retention; LR – low residue retention; HD – 150% of recommended dose; RD - Recommended dose. Wheat and rice grain price = 22 Tk. and 23 Tk. kg^{-1}, respectively; wheat and rice straw price = 2 Tk. and 4 Tk. kg^{-1}. Total input cost for rice production in HR, LR, SP and CT were 89639 Tk., 89280 Tk., 88459 Tk. and 90461 Tk., respectively. Total input cost for wheat production in HR, LR, SP and CT were 107288 Tk., 107288 Tk., 108701 Tk. and 106172 Tk., respectively.

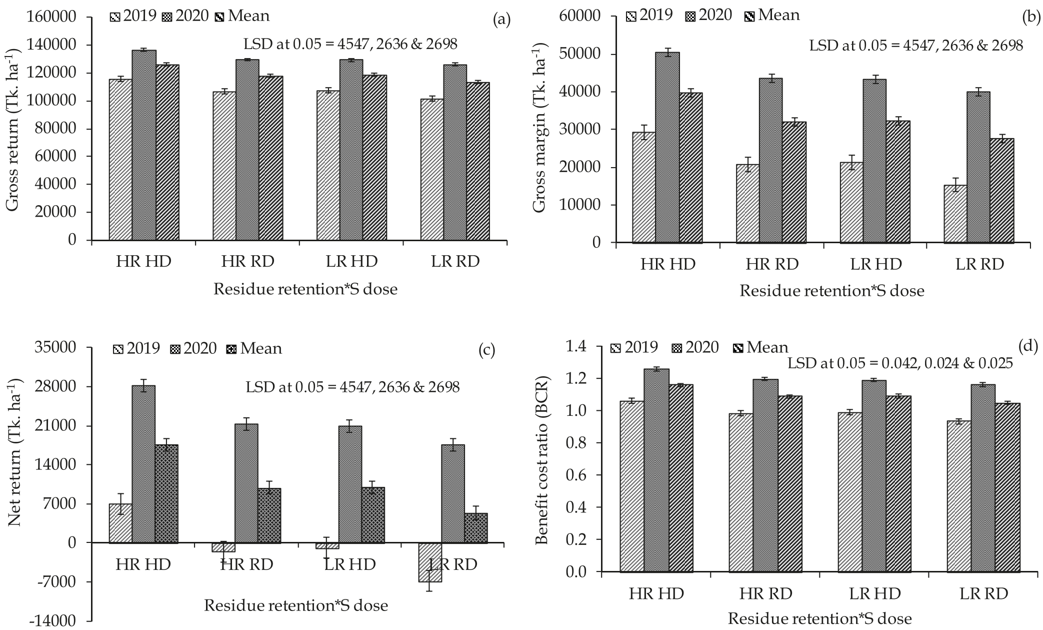

Fig. 4 *(a) Gross margin, (b) gross return, (c) net return and (d) benefit cost ratio (BCR) of T. Aus rice production influenced by residue retentions and S doses. [Legends: HR –high residue retention and LR – low residue retention; HD – 150% of recommended dose and RD – recommended dose. Vertical bars represent LSD (P < 0.05).]*

3.3.3 Transplanted Aman rice

There were significant variations in relative profitability (gross return, gross margin, net return and BCR) of T. aman rice production due to different residue retentions and S doses whereas tillage practices did not show significant effect (Table 4). Mean gross return, gross margin, net return and BCR were 8%, 20%, 32% and 8%, respectively higher in HR than in LR and 4%, 7%, 13% and 7%, respectively higher in HD of S than in RD of S. Mean BCR of wheat - T. Aus - T. Aman rice system varied significantly due to different residue retentions and S doses, but not due to tillage practices. Mean system BCR was 7%, higher in HR than in LR and 3% higher in HD of S than in RD of S.

4. Discussion

4.1 Water productivity

The system water productivity (total, considering leaching and irrigation water) for wheat-rice-rice system was about 6-8% higher in high residue (HR) retention than in low residue (LR) retention. That means, in wheat-rice-rice cropping system, HR retention practices required about 8% less water than LR retention. The main cAuses of higher water use efficiency in HR plots are due to higher system rice equivalent yield (REY). In this study, 10 years of HR retention plot gave 8% higher system REY due to higher soil fertility than LR retention (Kumar *et al.,* 2022, 2024). In other study, it was observed that grain yield of wheat under residue retention was higher due to longer rooting and higher moisture content in the upper soil layers (Bisen *et al.,* 2002). Incorporation of increased residue (40 cm) after 10 years reduces the bulk density of surface soil (0-15 cm) and its values were more (1.31 g cm^{-3}) as compared to current residue (1.37 g cm^{-3}) retention (Kumar *et al.,* 2022). The low bulk density accrued as account of the incorporation of straw increase infiltration rate at Ludhiana (Singh *et al.,* 2012). Long-term accumulation of crop or plant residues on the soil surface, as part of conservation agriculture practices, would reduce soil water evaporation which increases water use efficiency for crop production (Ali, 2018).

In wheat, the water productivity was about 18-23% higher in SP than in CT which indicates 18-23% less water required in SP than in CT. On the other hand, SP plot required about 19-26% higher water in T. Aus rice and about 11-19% higher water in T. Aman rice than in CT which reduces system water productivity 8-16% in SP than in CT. The plough pan of wet land rice field which is formed due to intensive cultivation in CT plots decreases infiltration rate, whereas long-term conservation tillage (SP) damages this plough pan (Kumar, 2022) and increases infiltration rate into sub-surface soil (data not shown) which increases water requirement and decreases water productivity in rice. On the other hand, quick intrusion (horizontal expansion) of irrigation water in SP plots due to lower bulk density and higher soil organic carbon (Kumar *et al.,* 2022, 2024) in upland wheat crop reduces water requirement which increases water productivity. In rice production, higher leaching water lost in long-term SP due to breakdown of plough pan than in CT is the consequence of higher irrigation water requirement in SP which reduces water productivity in rice cultivation. Singh *et al.* (2012) stated that the highest value of cumulative intake (12.05 cm h^{-1}) of water for 6 hours recorded under minimum tilled plots followed by single cultivation (8.85 cm h^{-1}) and 4 cultivations (7.90 cm h^{-1}) on a sandy soil of Ludhiana. Similarly the infiltration rate under minimum tilled condition was more in different soils as compared to tilled conditions and higher infiltration rate in minimum tilled plots was observed than CT plots in different cropping systems (Pandey *et al.,* 2003; Parihar, 2004). In another study, it was observed that the infiltration was 60% higher in minimum tillage than CT on a silty loam soil (Prasad *et al.,* 2002).

Similarly, the water productivity was 2-6% higher in HD of S than in RD of S for all three crops. In this intensive cereals-based cropping system, increased S together with increased residue retention improved system REY suggesting there is potential to increase yield in these systems of the High Barind Tract (HBT) especially on soils such as the present one that was deficient in available S (about 14 – 19 mg kg^{-1}) (Choudhary *et al.,* 2021). The role of increased S and residue in conserving soil moisture coupled with enhanced the nutrient supply through decomposition may have also contributed to increased yield (Choudhary *et al.,* 2019) which decreases water requirement and increases water productivity. In our study, wheat requires 165 mm irrigation water as a dry season crop. Whereas, semi rainy season rice T. Aus and rainy season rice T. Aman require 975 mm and 769 mm, respectively irrigation water. But, dry season rice (Boro rice) cultivation in the HBT requires over 2,000 mm ha^{-1} of irrigation water, and up to 2,650 mm water ha^{-1} in some high land situations (Ali, 2018). By contrast, T. Aman rotating with upland crops like wheat, onion, garlic, chickpea, chilli, cowpea or water melon needs only 400-600 mm water ha^{-1}. Average net financial return per unit of water use is lowest for dry season rice production (Ali, 2018). Hence, Conservation Agriculture (CA) practices with wheat-rice-rice based crop rotation are more water efficient cropping pattern than dry land rice (Boro rice) based patterns.

4.2 Crop profitability

Variation in economic profitability was mainly due to effect of grain and straw yields on gross return. Long-term (10 years) high residue retention (40 cm) increased wheat, T. Aus rice and T. Aman rice yield by 9%, 11% and 9%, respectively than the 15 cm residue retention (Kumar *et al.,* 2024) which may be attributed to the 75% higher soil organic carbon (SOC) and other nutrients in the HR plots of this experiment (Kumar *et al.,* 2022, 2024).

Conventional tillage (CT) plots showed the highest total input cost principally due to cost of increased land preparation. So, variation of economic profitability was due to gross return and also due to input costs including land preparation. In this experiment, wheat yield was 7% higher in SP than in CT (Kumar *et al.,* 2024) which is another responsible factor for increasing economic benefit in wheat in minimum tillage (SP) plots. On the other hand, the yield of rice crops was 0.5-0.7% lower in SP than in CT which might due to water stress (data not shown) in SP plots, although system productivity was 2% higher in SP practice plots (Kumar *et al.,* 2024). However, system BCR of wheat-rice-rice cropping pattern was 7% higher in HR and 3% higher in HD of S plots whereas, it was not affected by tillage system.

Minimum tillage increased wheat yield of 4688 and 3527 kg ha^{-1} as compared to CT with yield of 3718 and 3075 kg ha^{-1} with the markedly better net returns and BCR (Singh *et al.,* 2001). Whereas, minimum tillage technology increased the farmer's margin to extent of Rs.1882 ha^{-1} and saving of inputs in wheat. Several past researchers have reported 60-70% time saving and 67-80% fuel saving with minimum tillage seeding technique over CT (Singh *et al.,* 2012; Singh *et al.,* 2002) in wheat. However, from Hisar (India), it was reported that wheat sown by minimum tillage system required 5.5 times less energy and production cost and gave 17% higher yield than CT (Singh *et al.,* 2012; Tomar *et al.,* 2003) whereas, there was 28% cost saving under minimum tillage in wheat production, reported from New Delhi (Singh *et al.,* 2012). The SP technology has positive and significant impact on environment and sustainability of system through improved soil quality and reduction in use of inputs like chemical fertilizers, irrigation water and energy resulted in higher profit in cropping systems.

The gross return, gross margin, net return and BCR in wheat were 2%, 3%, 5% and 1%, respectively higher, in T. Aus rice were 6%, 21%, 81% and 4%, respectively higher and in T. aman rice were 4%, 7%, 13% and 7%, respectively higher in HD of S than in RD of S application plots. In this experiment, wheat, T. Aus rice and T. aman rice yields were 2%, 11% and 4%, respectively higher in HD of S than in RD of S application plots (Kumar *et al.,* 2024) which is another responsible factor for increasing economic benefit in wheat-rice-rice system in 150% S of RD.

4.3 Implication to water input utilization and fertilization

The positive effects of high residue retention on yield was well reflected through increased economic profitability both for rice and wheat production and thus for the system as well. Increased system productivity (Kumar *et al.,* 2024) and economic profitability of wheat-rice-rice system just by adopting minimum tillage (SP) in wheat has also been reported by other researchers (Jat *et al.,* 2014; Gathala *et al.,* 2013). This benefit comes mainly due to saving in cost of production in wheat with additional yield due to adoption of SP.

The study evaluated CA especially increased residue retention technologies and resources such as labour, water and energy for tillage and irrigation were saved compared to CT practices, resulting in reduced production cost. The results clearly indicated that full or partial CA based sustainable intensification practices consumed less investment and provided higher profit. Similar results of producing more grain with less environmental impact have been demonstrated for intensive cereal systems in China (Shen *et al.,* 2013; Chen *et al.,* 2014). Crops grown in wheat-rice-rice rotation responded better to CA practices in South Asia (Chaudhary *et al.,* 2021) and CA practice performed better in terms of resource productivity and sustainability compared to CT in Nepal (Chaudhary *et al.,* 2018). Conservation Agriculture based Sustainable Intensification (CASI) practices in wheat-rice-rice rotation prevented burning of rice and wheat straw, and added organic matter for upcoming crops. In addition, the practices also saved at least one week of turn around period for timely wheat sowing. Though water productivity and economic advantage were lower in SP for rice crops in the present study, a significant gain in input use efficiency and economics was reflected with benefit-cost ratio under CA practice especially in HR retention plots. The net return was 40% higher in wheat, 78% higher in T. Aus rice and 32% higher in T. Aman rice under 40 cm residue retention from cereal crops over 15 cm residue retention. On the other hand, SP practices plot give 42% higher net return in wheat than CT practices plots but, it was reverse in rice. Past studies (Chaudhary *et al.,* 2018; Ladha *et al.,* 2015) also demonstrated that yield advantages were not always achieved with CASI alone over the short period while inputs use efficiency and economic benefits were attainable.

The CA practices in wheat-rice-rice system saved resources significantly and contributed to higher profits without penalty in crop yields and soil ecology. Thus, it has a bright prospect for its dissemination in upland crops in terrace soil of the HBT where wheat-rice system is a major cropping pattern (Bell *et al.,* 2019; FRG, 2018). However, knowledge and skills regarding water and fertilizer input management and residue retention under CA practices are crucial for the successful adoption of the technology in the area. So, training programs along with awareness campaign and sensitization (demonstration, adaptive trial, leaflet, pamphlet, etc.) are needed for promotion the technologies to wider areas in the region. It is also necessary to strengthen capacity and capability of service providers for operation, repair and maintenance of machinery to make the practices sustainable and profitable.

5. Conclusions

The present study demonstrates that Conservation Agriculture based practices especially residue retention in a wheat-rice-rice rotation reduced drudgery and production cost, and conserved natural resources i.e. soil, water and environment. The practice produced positive impact on resource productivity and contributed to higher farm benefits compared to conventional practice. The result supports our hypothesis that increased residue retention together with 150% S of current recommended dose (RD) would significantly increase water productivity and economic profitability through increasing yield of wheat-rice-rice system. Our study has also shown that minimum tillage (SP) practices with 40 cm cereal straw incorporation and 150% S of RD reduced water requirement in wheat but in rice, water requirement is little bit higher in SP than in conventional tillage (CT). We suggest that the adoption of 40 cm cereal straw incorporation and appropriate S application, may be a promising water management practice to enhance crop yield and resolve water scarcity to improve the agricultural sustainability of wheat–rice-rice rotation fields.

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Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

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