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Yield potentials and economics of rice (*Oryza sativa* L.) as affected by unpadded transplanting and crop residue retention

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ABSTRACT

Aim: The study was conducted to evaluate the performance of unpadded rice cultivation with crop residue retention.
Materials and Methods: The rice var. BRRI dhan28 was transplanted by two tillage practices viz., puddled conventional tillage (CT) and non-puddled strip tillage (ST) and two levels of crop residues- no residue (R_0) and 50% residue (R_{50}). The experiment was devised in a randomized complete block design with four replications.
Results: There were no significant yield differences between two tillage practices and two levels of residue in 2013-14. But in the following year, ST yielded higher grains (5.72 t ha^{-1}), which was about 9.36 % higher than CT, leading to 22.23% higher BCR. On the other hand, retention of 50% residue increased yield by 3.15% compared to no-residue, contributing to 10.58% higher BCR. The ST combine with 50% residue retention yielded the highest grain yield (5.81 t ha^{-1}), consequently credited to obtain the highest BCR (1.06).
Conclusion: It was concluded that un-puddled rice transplanting with the retention of crop residues may be an excellent alternative to existing conventional tillage operation and farmers are likely to benefit by adopting this practice.

Keywords: Crop residues, non-puddled, strip tillage, yield.

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Introduction

In the Asian region, farmers cultivate rice (*Oryza sativa* L.) by seedlings transplanting in puddled soil for comfortable crop establishment. Fields are prepared by single or two passes in dry conditions followed by exposure to the sun for a couple of days. After inundation, the final land is prepared by plowing, cross plowing, and laddering in standing water. However, this traditional puddling method is labor, fuel, time, and capital consumption (Islam et al., 2014).Nowadays, most of the tillage operations for puddling soil in Bangladesh are done by power tiller and is detrimental to physical soil conditions through destroying soil aggregates, breaking capillary pores, and dispersing the soils (Miah et al., 2002). Cloddy soil structure with less soil moisture and inadequate seed-soil contact resulted from the puddling makes land preparation difficult for the following crops (Islam et al. 2012).

Not only that, puddled rice transplanting consumes about 20-40 % of the total water required for raising crops, and it also promotes the formation of hardpan (Singh et al., 2014). It also reduces soil organic carbon at a double rate, thus decreases soil fertility has losses of irrigation water, and damages the ecological environment (Sayre and Hoobs, 2004). Adopting minimum tillage unpuddled transplanting may be an excellent alternative to puddled transplanting to overcome these destructive issues, as it is using widely for many crops worldwide (Singh et al., 2014). This technology has the potentials to allow saving in labor, energy, water, and time during rice establishment as well as improves soil fertility (Islam et al., 2012). Concerning the soil health, another agronomic option is the retaining the residues of previously cultivated crops are a significant factor for crop production through their effects on soil physical, chemical, and biological functions and water and soil quality and increase crop yield (Kumar and Goh, 2000). Residue practice maintains soil microorganisms and microbial activity, which can also lead to weed suppression by the biological agents leading to increase crop yield (Shrivastav et al., 2015). Considerable research has been done on puddle transplanting, but there is limited information on unpuddled rice transplanting with crop residue retention under Bangladesh's condition. Therefore, the present study was conducted to examine the performance of rice to an unpuddled transplanting system with the retention of residues of the previous crop.

Materials and Methods

The experiment was conducted at farmer's field of Durbachara, Gouripur, Mymensingh, Bangladesh (the latitude of 24.75^0 N and the longitude of 90.50^0 E) (Fig. 1) during *boro* (Mid November-June) season in 2013-14 and 2014-15. This experimental area belongs to the Old Brahmaputra Flood plain, characterized by dark grey non-calcareous alluvium soils and these soils are mostly sandy loam under the *Sonatala* series (Brammer, 1996). Soil characteristics have been presented (Table 1). Climatic (rainfall and thermal condition) data were collected from the nearest weather station and are illustrated (Fig. 2). The treatments were: (i) puddled condition conventional tillage (CT) and (ii) unpuddled condition strip tillage (ST) and two levels of crop residue viz., no residue (R_0), and 50% residue (R_{50}). The treatments were laid out in a randomized complete block design with four replications using unit plots of 9 m × 5 m. In tillage practice, CT consisted of two passes, primary tillage by two-wheeler tractor (2WT), and exposed to the sun for two days, followed by flooding the whole plot and puddling did by a 2WT with two passes to complete land preparation. A versatile multi-crop planter did ST in single pass operation before flooding the field. Three days before ST, pre-plant glyphosate herbicide was applied @ 75 ml / 10 L water. After ST, the land was inundated with 3-5 cm standing water one day before the transplanting of seedlings for making the soil soft enough (Islam et al., 2014). Thirty-five days old seedlings of rice var. BRRI dhan28 were transplanted. Fertilizers were applied according to the recommendation of BRRI (2014). A spacing of 25 cm × 15 cm was maintained for both tillages with 2 / 3 seedlings hill^{-1}. The crops were harvested at maturity from 3m × 3m each, and then data were recorded. Grain yields were adjusted to 14% moisture content. Data were subjected to ANOVA using STAR software and means were separated by Duncan's Multiple Range Test (Gomez and Gomez, 1984).

Fig 1. Map of Bangladesh showing the site of on-farm experiments

Table 1: The morphological, physical, and chemical properties of soil (0-15 cm) of the experimental field

A. Morphological characteristics			
i.	Soil Tract	:	Old Brahmaputra Alluvium
ii.	Soil Series	:	Sonatola Series
iii.	Parent materials	:	Old Brahmaputra River Borne Deposit
B. Physical characteristics of soil			
i.	Sand (2.00-0.50 mm)	:	25.2%
ii.	Silt (0.5-0.002 mm)	:	72.0%
iii.	Clay (< 0.002 mm)	:	2.8%
iv.	Textural class	:	Silty loam
C. Chemical characteristics of soil			
i.	p^H	:	6.71
ii.	Organic matter (%)	:	0.93
iii.	Total matter (%)	:	0.13
iv.	Available sulfur (ppm)	:	13.9
v.	Available phosphorus (ppm)	:	16.3
vi.	Exchangeable potassium (ppm)	:	0.28

Results and Discussion

Effect of tillage practices on yield attributes, yield and BCR of rice

In 2013-14, none of the parameters except BCR varied significantly due to tillage practices. During this time, about 22 % higher BCR in ST than CT was recorded. On the other hand, in 2014-15, yield contributing characters were affected significantly except the plant height, panicle length, and thousand-grain weight (Table 2). The highest and lowest numbers of effective and non-effective tillers m^{-2}, respectively, and the highest and lowest numbers of grains and sterile spikelets panicle^{-1}, respectively, were recorded from the ST. The variation of these parameters might have attributed to a higher yield (9.36% higher) in ST than CT. The higher yield in ST might have credited the higher BCR (22.23 % higher) over CT.

Effect of residue levels on yield attributes, yield, and BCR of rice

During the first year of experimentation, there was no significant effect of residues on all the parameters had studied. But in the second year, retention of 50% residue improved the numbers of effective tillers m^{-2} and grain $panicle^{-1}$. At the same time, it declined the numbers of non-effective tillers m^{-2} and sterile spikelets $panicle^{-1}$, compared to no-residue (Table 3). Retention of 50% residue yielded around 3.15 % higher rice which might have attributed to earning10.58% higher BCR.

Table 2. Effect of tillage practice on yield attributes, yield, and benefit-cost ratio of rice

Tillage practices	Plant height (cm)	No. of effective tillers m^{-2}	No. of non-effective tillers m^{-2}	Panicle length (cm)	No. of grains $panicle^{-1}$	No. of sterile spikelets $panicle^{-1}$	1000 grain weight (gm)	Grain yield (tha^{-1})	Benefit-Cost Ratio
2013-14									
CT	110.4	209	44	24	159	47	30	5.20	0.72b
ST	109.9	211	44	25	157	49	31	5.17	0.88a
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	0.13
CV (%)	2.74	12.6	11.7	2.4	3.47	2.27	1.32	0.34	4.72
2014-15									
CT	107.3	361b	70a	23.9	114b	41	21.9	5.23b	0.81b
ST	105.6	382a	56b	24.4	126a	40	23.0	5.72a	0.99a
$LSD_{(0.05)}$	NS	4.59	3.00	NS	8.29	NS	NS	0.09	0.03
CV (%)	4.60	1.20	5.68	3.84	5.14	8.88	6.83	2.10	1.24

In a column, the figure with similar letter do not differ significantly, whereas dissimilar letters differ significantly
CT= Conventional tillage, ST= Strip tillage, LSD= Least Significant Difference, CV=Co-efficient of variance

Table 3. Effect residue level on yield attributes, yield and benefit-cost ratio of rice ratio of rice

Residue levels	Plant Height (cm)	No. of effective tillers m^{-2}	No. of non-effective tillers m^{-2}	Panicle length (cm)	No. of grains $panicle^{-1}$	No. of sterile spikelets $panicle^{-1}$	1000 grain weight (gm)	Grain yield (tha^{-1})	Benefit-Cost Ratio
2013-14									
R_0	110.6	208	44	24.6	160	53	29.90	5.20	0.76
R_{50}	109.5	209	43	24.5	159	54	29.88	5.19	0.79
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	2.74	12.67	11.71	2.40	3.47	2.27	1.32	0.34	4.72
2014-15									
R_0	104.9	368b	56b	24.4	115b	41	22.7	5.39b	0.85b
R_{50}	106.3	376a	69a	24.5	130a	40	22.9	5.56a	0.94a
$LSD_{(0.05)}$	NS	2.65	1.73	NS	4.78	NS	NS	0.05	0.018
CV (%)	4.60	1.20	5.68	3.84	5.14	8.88	6.83	2.10	1.24

In a column, the figure with similar letter do not differ significantly, whereas dissimilar letters differ significantly
R_0= no residue, R_{50}= 50% residue, LSD= Least Significant Difference, CV=Co-efficient of variance

The combined effect of tillage practices and residue levels on yield attributes, yield, and BCR of rice

A combination of tillage practices and residue levels significantly affected BCR, while the rest of the parameters did not vary significantly during 2013-14. Whereas in 2014-15, the combination of treatments significantly impacted all the parameters except plant height, panicle length, several sterile spikelets $panicle^{-1}$, and weight of thousand grains (Table 4). The ST retained 50% residue produced the highest BCR, which might have been credited from the highest grain yield. The highest grain yield might have attributed from the highest number of effective tillers m^{-2} and grains $panicle^{-1}$, and the lowest numbers of non-effective tillers m^{-2}. CT or ST with residue yielded the higher values of these parameters compared to no-residues. The CT without residue produced the lowest grain yield, consequently the lowest BCR. Also, about 5.19% higher yield was noticed in 2014-15 than 2013-14.

Table 4. The combined effect of tillage practices and residue levels on yield attributes, yield and benefit-cost ratio of rice

Tillage practice	Residue levels	Plant height (cm)	No. of effective tillers m^{-2}	No. of non-effective tillers m^{-2}	Panicle length (cm)	No. of grains $panicle^{-1}$	No. of sterile spikelets $panicle^{-1}$	1000 grain weight (gm)	Grain yield (tha^{-1})	Benefit-Cost Ratio
2013-14										
CT	R_0	109.3	207	45	24.2	162	53	29.5	5.21	0.73b
	R_{50}	111.5	211	43	24.6	158	54	29.2	5.19	0.71b
ST	R_0	110.8	209	43	24.6	158	53	29.8	5.20	0.80a
	R_{50}	109.1	207	44	24.5	160	55	30.3	5.20	0.88a
$LSD_{(0.05)}$		NS	NS	NS	NS	NS	NS	NS	NS	0.18
CV (%)		2.74	12.67	11.71	2.40	3.47	2.27	1.32	0.34	4.72
2014-15										
CT	R_0	108.3	359c	84a	24.3	100c	41	21.6	5.17d	0.78bc
	R_{50}	106.3	363c	70b	24.5	121b	39	22.2	5.29c	0.83c
ST	R_0	104.2	376b	53c	24.4	129ab	41	22.9	5.60b	0.92b
	R_{50}	106.3	388a	41d	24.2	139a	40	23.0	5.81a	1.06a
$LSD_{(0.05)}$		NS	6.50	4.25	NS	11.72	NS	NS	0.13	0.045
CV (%)		4.60	1.20	5.68	3.84	5.14	8.88	6.83	2.10	1.24

In a column, the figure with similar letters do not differ significantly, whereas dissimilar letters differ significantly

CT= Conventional tillage, ST= Strip tillage, R_0= no residue, R_{50}= 50% residue, LSD= Least Significant Difference, CV=Co-efficient of variance CV= Co-efficient of variance

Effect on the yield of rice

The higher yield in ST might be attributed to the changes in soil properties viz. the higher porosity and better soil moisture conservation in ST favored more robust root growth, and nutrient uptake resulted in increasing grain yield. These results agree with Huang et al. (2012),stating that minimum tillage (MT) unpuddled conditions provide a more favorable soil physical environment for better crop growth than CT. Pittelkow et al. (2015) and Qi et al. (2011) also reported higher and more stable crop yields in MT than CT. In CT, heavy grinding of the surface soil by 2 WT exerts extreme pressure upon it and makes the cultivated layer more compact. This compaction leads to a loss of soil structures and disruption in blending the cultivated layers. Moreover, it also causes the minimizing the nutrient conducting pores in the soil.

On the other hand, crop yield increase in MT might improve soil structure and stability. It was thereby facilitating better water holding capacity and drainage that reduces the extremes of water logging and drought (Holland, 2004), ultimately improving soil fertility by sequestering organic carbon in farmland soils (Zheng et al., 2014). This finding supports the research result of Liu et al. (2010) who found a 20% higher maize yield in MT than CT due to an increase of soil organic carbon, total soil nitrogen, and total soil phosphorus by 25, 18 and 7%, respectively. These results have implications for understanding how conservation tillage practices increase crop yield by improving soil quality and sustainability in unpuddled strip tillage practices and clinched by Hossain et al. (2016) and Mvumi et al. (2017). Some research findings also concluded no yield differences between ST and CT. Haque et al. (2016) found a similar grain yield of rice in unpuddled ST transplanting and CT, which confirms the earlier findings of Hossain et al. (2015), who also found no yield penalty of wheat and rice between ST and CT. In another study, Sharma et al. (2011) also reported similar rice yield in unpuddled transplanting to the CT. Wiatrak et al. (2005) found identical cotton yield in ST and CT, while Al-Kaisi and Licht (2004) found a similar corn and soybean yield in ST, NT, and CT. The finding of these studies confirms the result of the present study where no significant yield loss was found in the 2013-14 year.

In this study, retention of 50% of crop residues increased the grain yield of rice by about 3.15% over no-residue. Research findings of Shrivastav et al. (2015) confirm this, stating residue converts to mineralized nutrients, which causes sufficient crop growth and facilitates higher yield over no-residue. Kaschuk et al. (2010), in support of Qin et al. (2010), concluded straw residue retention directly increases the input of organic matter and nutrients into the soil, in turn improving soil nutrient availability for crop growth and better yield over no-residue. The earlier study of Thomas et al. (2007) and Govaerts et al. (2007) also found the benefits of residue retention on crop yield derived from the improved soil fertility and water availability. These benefits usually occurred form the supplies of organic matter from straw residue for heterotrophic N fixing microorganisms, which could be utilized by the crops, resulting in the higher yield. Straw residues for controlling weeds in different crops have been suggested by Devasinghe et al. (2011) and Hossain et al. (2016) concluded residues prevent weed growth and thus retards crop weed completions. Hence, the crop is grown stronger and favored to higher yield.

In this study, a 5.19 % higher yield in the 2014-15 year than 2013-14 might be due to the variation of monthly average temperature, rainfall, relative humidity, and sunshine hours of the experimental site during 2013-2015 (Fig. 2).The difference of all climatic parameters during various phonological stages of rice viz., germination to transplanting, tillering and anthesis to physiological maturity are reported to exert definite stresses on the growth and development and have influenced the yield to be varied in two consecutive years by influencing the variation of yield attributes such as the number of effective and non-effective tillers m^{-2} and grains and sterile spikeletspanicle^{-1} (Safdar et al., 2013).

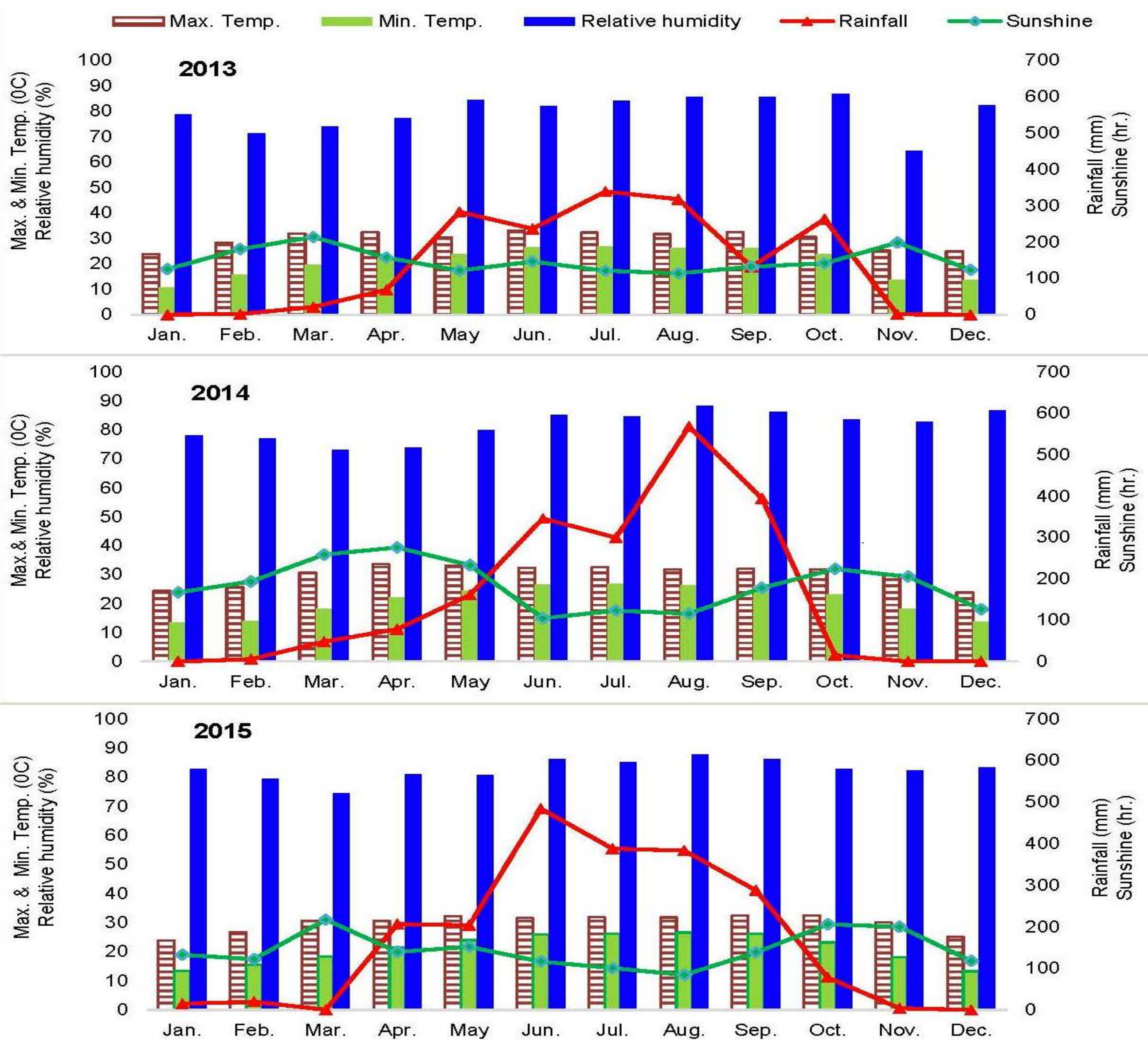

Fig 2. Monthly average temperature, rainfall, relative humidity and sunshine hours of the experimental site in 2013-2015

Effect on the economics of rice production

Partial economic analysis disclosed that, among the treatments, ST with 50% residue earned the highest profit. Variation in BCR might be attributed to the variation in grain yield and the cost required for rice cultivation. One hector land preparation in CT required US$ 190.80 while ST required US$ 35.80. Thus, ST saved around 68% cost for land preparation. This estimation is in line with Haque et al. (2016) estimating 70% savings in land preparation in ST over CT, showing the lowest land preparation cost was recorded in ST (US$ 32.54ha^{-1})while the maximum land preparation cost was incurred in CT (US$110.29 ha^{-1}). Islam et al. (2014) estimated 49% savings from land preparation in ST than CT. The higher costs in CT might have happened due to the more significant number of tillage passes and fuel consumption for land preparation in CT.

On the other hand, ST reduced fuel and labor requirements during land preparation. About 10.58% higher profit in 50% residue might have occurred solely from 3.15% higher grain yield than no-residue. Therefore, the study claimed that rice cultivation through practicing unpuddled strip tillage with the retention of 50% crop residue could achieve a higher profit compared to existing conventional tillage of rice cultivation in Bangladesh.

Conclusion

Based on the results of this study, it was concluded that unpuddled rice transplanting with the retention of crop residues may be an excellent alternative to existing conventional tillage operation and farmers are likely to benefit by adopting this practice.

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