International Journal of Agronomy and Agricultural Research (IJAAR)
ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 18, No. 3, p. 11-19, 2021

RESEARCH PAPER

OPEN ACCESS

Impact of unpuddled transplanting and crop residue mulching on the yield of rice (*Oryza sativa* L.)

Mohammad Mobarak Hossain*[1], Mahfuza Begum[2], Md. Moshiur Rahman[2], Abul Hashem[3], Richard W. Bell[4]

[1]*Rice Breeding Platform (Breeding for Favorable Environment), International Rice Research Institute, Dhaka, Bangladesh*

[2]*Department of Agronomy, Bangladesh Agricultural University, Mymensingh, Bangladesh*

[3]*Department of Primary Industries and Regional Development, Industry and Economic Development, York Road, Northam WA, Australia*

[4]*School of Veterinary and Life Sciences, Murdoch University, South St, Murdoch WA, Australia*

Article published on March 23, 2021

Key words: Crop residues, Strip tillage, Unpuddled, Yield

Abstract

On-farm research was conducted at the Gouripur upazila under Mymensingh district of Bangladesh during *boro* (mid November- June) season in 2013-14 and 2014-15 to evaluate the performance of unpuddled rice cultivation with crop residue retention. 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 *viz.,* "no" residue (R_0) and 50% residue (R_{50}). The experiment was devised in a randomized complete block design with four replications. Results showed no significant yield differences between tillage practices and residue levels in 2013-14. But in the following year, ST yielded higher grains (5.72t ha^{-1}), which was about 9.36% higher compared to CT. The higher grain yield in ST leading to 22.23% higher BCR than CT. Retention of 50% residue increased yield by 3.15% over no-residue, contributing to 10.58% higher BCR. The ST combined 50% residue produced the highest grain yield (5.81 t ha^{-1}), which was credited to obtain the highest BCR (1.06).

* **Corresponding Author:** Mohammad Mobarak Hossain ✉ mm.hossain@irri.org

Introduction

Most of the farmers in the Asian continent cultivate rice (*Oryza sativa* L.) by transplanting seedlings in puddled soil for comfortable crop establishment. Lands are prepared by single or two passes in dry conditions followed by exposure to the sun for a couple of days. After flooding, the final field is prepared by plowing, cross plowing, and laddering in standing water. However, this traditional puddling method is labor, fuel, time, and capital intensive (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 the 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). To overcome these destructive issues, adopting minimum tillage unpuddled transplanting may be a perfect alternative to puddled transplanting as it is using widely for many crops around the world (Singh *et al.,* 2014).

This technology has the potentials to allow saving in labor, energy, water, and time during rice establishment and improve 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 micro-organisms 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 the Bangladesh context. Therefore, the present study was conducted to examine the performance of rice to unpuddled transplanting system with the retention of crop residues.

Materials and methods

Experimental site and season

The experiment was conducted on a farmers' field located at Durbachara village, Gouripur upazila in the Mymensingh district of Bangladesh during mid November- June in 2013-14 and 2014-15. Geographically site was located at latitude 24.75°N and longitude 90.50° E) at 18 m altitude (Fig. 1).

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

Edaphic and climatic conditions

The experiment site is situated on the Old Brahmaputra Floodplain of predominantly dark grey non-calcareous alluvium soils under the *Sonatala* series (Brammer, 1996). It was a medium-high land of silty loam texture having pH 6.71. Soil characteristics have been presented in Table 1. Rainfall and thermal condition data were collected from the nearest weather station and are illustrated in Fig. 2. which described that there was much variation in weather during 2013-2015. The maximum temperature varies from 32.3-33.5°C during April-June while January was the coldest month. About 95% rainfall was received during April-September. The rest of rainfall was very unevenly distributed and mostly uncertain. Sunshine hours differed much in 2013 and 2014 in December and January.

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

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

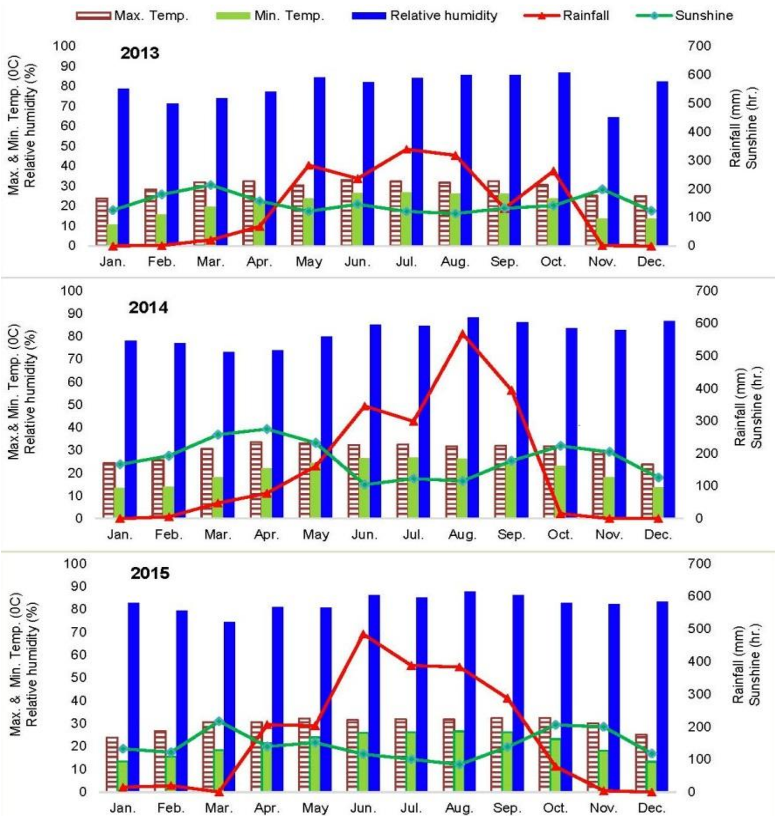

Fig. 2. Monthly average temperature, total rainfall, relative humidity and sunshine hours of the experimental site in 2013-2015

Experimental treatments and design

This study comprised two types of tillage *viz.*, puddled condition conventional tillage (CT) and unpuddled condition strip tillage (ST) and two levels of crop residue *viz.*, "no" residue (R_0), and 50% residue (R_{50}). The treatments were arranged in a randomized complete block design with four replications using unit plots of 9 m×5 m.

Seed sowing and transplanting

In 2013-14, seeds were sown in the nursery on 25 November 2013, and seedlings were transplanted but in 2014-15, the seeding and transplanting were done one week earlier than the dates of 2013 to avoid rainfall before harvest on 18 November 2014 and 23 December 2014, respectively. A Row distance of 25 cm×15 cm was maintained, allocating 2-3 seedlings hill^{-1} in both CT and ST.

Tillage operation

CT was done using a two-wheel tractor (2 WT). The land was prepared by four plowings and cross plowings followed by sun-drying for two days, finally by inundation and laddering. Strip tillage (ST) was done by a Versatile Multi-crop Planter (VMP) in a single pass operation. Strips had prepared for four rows, each of 6 cm wide and 5 cm deep made at a time. Three days before ST operation, glyphosate had applied @ 3.7 L ha^{-1}. After ST, the land had flooded with 3-5 cm standing water one day before transplanting to allow the strips to soften enough for transplanting seedlings (Islam *et al.,* 2014).

Residue mulching practice

Two levels of residue mulch of mustard were used in this study. In no-residue practice, rice transplanted without retaining mulch while in 50% mulch practice, 875 kg ha^{-1} dried residue of previously harvested mustard was used. This amount of mulch was spread over the plots after tillage operation but before transplanting.

Cultural operations

The land was fertilized with phosphorus, potassium, sulfur, and zinc @ 25, 40, 15, and 2.0 kg ha^{-1} as triple superphosphate, muriate of potash, gypsum, and $ZnSO_4$, respectively at final plowing.

Nitrogen was applied @ 80kg ha^{-1} as urea in three equal splits at 25, 45, and 60 DAT. Rice was irrigated four times at 20, 35, 50, and 65 DAT due to scare rainfall throughout the crop growing season. Adequate plant protection measures were taken as per the recommendation of the BRRI (2014).

Harvesting and data recording

The crop was harvested at maturity (when 80% of grain became golden yellow) on 9 May in 2014 and 2 May in 2015, from randomly selected three spots of each 3 m × 1 m area in each plot. Plant height, No. of effective and non-effective tillers m^{-2}, length of panicle, number of grains, and sterile spikelets panicle^{-1} were recorded from randomly selected ten hills before harvest.

The weight of 1000-grains, grain and straw yields was recorded. Grain yield was adjusted at 14% moisture content using the formula (USDA, 1979) as follows.

$$\text{Adjusted yield} = \frac{100 - \text{harvested moisture (\%)}}{100 - \text{adjusted moisture (\%)}} \times \text{harvested yield}$$

Economic analysis

The economics of crop production was estimated following the partial budgeting system (Perrin *et al.*, 1988). The variable costs were calculated based on labor requirement for sowing/transplanting, weeding, harvesting and threshing, irrigation, fertilization, and all other input costs like seed, fertilizer, irrigation, etc.

The gross return was calculated based on the market price of grain and by-products. The gross benefit was calculated by deducting the variable cost from the gross recovery. The benefit-cost ratio (BCR) was calculated by using the formula (Price, 1985) as follows:

$$\text{BCR} = \frac{\text{Gross return per unit area}}{\text{The total cost of production per unit area}}$$

Statistical instrument

Data were subjected to analysis of variance (ANOVA), and Duncans' Multiple Range Test compared means at P<0.05, using the statistical package program *STAR* (IRRI, 2014).

Results

Effect of tillage practice on yield attributes, yield, and economics of rice

In 2013-14, none of the parameters except BCR varied significantly due to tillage practices. By contrast, in 2014-15, yield contributing characters were significantly affected except the plant height, panicle length, and 1000 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, which attributed to higher yield (9.36% higher) in ST than CT. The higher yield in ST might have credited the higher BCR (22.23% higher) than CT (Table 2).

Table 2. Effect of tillage practice on yield attributes, yield, and BCR 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 (g)	Grain yield (t ha^{-1})	BCR
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 figures with similar letter do not differ significantly, whereas dissimilar letter differ significantly. CT= Conventional Tillage, ST= Strip Tillage, LSD= Least Significant Difference, CV= Co-efficient of Variance

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

During the first year of experimentation, there was no significant effect of residues on the yield and yield attributes of rice. But in the second year, retention of 50% residue improved the number of the effective tiller m^{-2} and grain $panicle^{-1}$ while declined the numbers of the non-effective tiller m^{-2} and sterile spikelets $panicle^{-1}$, compared to no-residue (Table 3). Retention of 50% residue yielded around 3.15% higher rice, attributed to earning 10.58% higher BCR in 2014-15 (Table 3).

Table 3. Effect residue level on yield attributes, yield and BCR 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 (g)	Grain yield (t ha^{-1})	BCR
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 figures with similar letters do not differ significantly, whereas dissimilar letter differ significantly. R_0= No residue, R_{50}= 50% residue, LSD= Least Significant Difference, CV= Co-efficient of Variance

Combination effect of tillage practice and residue levels on yield attributes, yield, and economics of rice

The combination of tillage practices and residue levels exerted a significant effect only on 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, the number of sterile spikelets panicle^{-1}, and weight of 1000 grain (Table 4). The ST retained 50% residue produced the highest BCR, which might have 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}. The retention of 50% residue produced the higher values of these parameters compared to no-residues. 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. Combination effect of tillage practices and residue levels on yield attributes, yield and BCR 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 (g)	Grain yield (t ha^{-1})	BCR
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 figures with similar letter do not differ significantly, whereas dissimilar letter 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

Discussion

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 the 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), about 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 forms hardpan by exerting massive pressure. Hence, leading to loss of structure and fusing the cultivated layer resulting in the disruption of the soil pores. On the other hand, crop yield increase in MT might have occurred from the improved soil structure and stability. They were moreover facilitating better water holding capacity and drainage that reduces the extremes of waterlogging and drought (Holland, 2004), ultimately improving soil fertility by sequestering organic carbon in 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, soil total 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 residues can increase the amount 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. Improved soil fertility and water availability might occur from the supplies of organic matter from straw residue for heterotrophic N fixing micro-organisms, which could be utilized by the crops, consequently results 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). Such interpretations of all climatic parameters during various phonological stages of rice *viz.,* germination to transplanting, tillering, and anthesis to physiological maturity exerted definite stresses on the growth and development of rice. Such stresses might have influenced the yield to be varied in two consecutive years by controlling the variation of yield attributes such as the number of effective and non-effective tillers m^{-2} and grains and sterile spikelets panicle^{-1} (Safdar *et al.,* 2013).

Effect on the benefit-cost ratio (BCR) of rice

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$ 32.54 ha^{-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 over CT. Savings in ST 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 might be concluded that unpuddled rice transplanting with the retention of crop residues may be an excellent substitute to the existing conventional tillage operation, and farmers are likely to benefit by adopting this practice.

Acknowledgments

This study was a part of the Ph.D. research work of the corresponding author funded by the Australian Center for International Agricultural Research (ACIAR).

References

Al-Kaisi M, Licht A. 2004. Effect of strip tillage on corn nitrogen uptake and residual soil nitrate accumulation compared with no-tillage and chisel plow. Agronomy Journal **96,** 1164-1171.

Brammer H. 1996. The geography of the soils of Bangladesh. The 1st edition. The University Press Limited, Dhaka, Bangladesh p. 287.

BRRI (Bangladesh Rice Research Institute). 2014. Modern Rice Cultivation. The 16th edition. BRRI, Joydebpur, Gazipur-1701, Bangladesh pp. 5-28.

Devasinghe, DAUD, Premarathne KP, Sangakkara UR. 2011. Weed management by rice straw mulching in direct-seeded lowland rice (*Oryza sativa* L.). Tropical Agricultural Research **22(3),** 263 - 272.

Govaerts B, Fuentes M, Mezzalama M, Nicol JM, Deckers J, Etchevers JD, Figueroa SB, Sayre KD. 2007. Infiltration, soil moisture, root rot and nematode populations after 12 years of different tillage, residue, and crop rotation managements. Soil and Tillage Research **94,** 209-219.

Haque ME, Bell RW, Islam MA, Rahman MA. 2016. Minimum tillage unpuddled transplanting: an alternative crop establishment strategy for rice in conservation agriculture cropping systems. Field Crops Research **185,** 31-39.

Holland JM. 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture, Ecosystems and Environment **103(1),** 1-25.

Hossain MI, Sarker MJU, Haque MA. 2015. Status of conservation agriculture-based tillage technology for crop production in Bangladesh. Bangladesh Journal of Agricultural Research **40(2),** 235-248.

Hossainmm, Begum M, Rahmanmm, Hashem A. 2016. Response of T. *Aman* and *Boro* rice to residue retention under strip tillage. Bangladesh Agronomy Journal **18(2),** 39-44.

Huang G, Chai Q, Feng F, Yu A. 2012. Effects of different tillage systems on soil properties, root growth, grain yield and water use efficiency of winter wheat (*Triticum aestivum* L.) in Arid Northwest China. Journal of Integrative Agriculture **11(8),** 1286-1296.

IRRI (International Rice Research Institute). 2014. Statistical Tool for Agricultural Research (STAR), Biometrics and Breeding Informatics, PBGB Division, IRRI, Los Baños, Laguna, The Philippines 2014.

Islam AKMS, Hossainmm, Saleque MA, Rahman MA, Karmakar B, Haque ME. 2012. Effect of minimum tillage on soil properties, crop growth and yield of aman rice in drought prone northwest Bangladesh. Bangladesh Agronomy Journal **15(1),** 43-51.

Islam AKMS, Hossainmm, Saleque MA. 2014. Effect of unpuddled transplanting on the growth and yield of dry season rice (*Oryza sativa* L.) in High Barind Tract. The Agriculturists **12(2),** 91-97.

Kaschuk G, Alberton O, Hungria M. 2010. Three decades of soil microbial biomass studies in Brazilian ecosystems: lessons learned about soil quality and indications for improving sustainability. Soil Biology and Biochemistry **42,** 1-13.

Kumar K, Goh KM. 2000. Crop residues and management practices: effects on soil quality, soil nitrogen dynamics, crop yield and nitrogen recovery. Advances in Agronomy **68,** 198-209.

Liu EK, Zhao BQ, Mei XR, So HB, Li J, Li XY. 2010. Effects of no-tillage management on soil biochemical characteristics in northern China. The Journal of Agricultural Science **148(2),** 217-223.

Miah MAM, Islam MS, Miah MTH. 2002. Socio-economic impacts of farm mechanization on the livelihoods of rural labourers in Bangladesh. Journal of Farm Economics **12,** 147-162.

Mvumi C, Ndoro O, Manyiwo SA. 2017. Conservation agriculture, conservation farming and conventional tillage adoption, efficiency and economic benefits in semi-arid Zimbabwe. African Journal of Agricultural Research **12(19),** 1629-1638.

Perrin R, Winkelmann D, Moscardi E, Anderson J. 1988. The partial budget. *In*: From Agronomic Data to Farmer Recommendations: An Economic Training Manual (Ed Cassaday, K.). CIMMYT, Mexico. 2008, pp. 13-20.

Pittelkowcm, Liang X, Linquist BA, Van Groenigen KJ, Lee J, Lundy ME, van Gestel N, Six J, Venterea RT, van Kessel C. 2015. Productivity limits and potentials of the principles of conservation agriculture. Nature **517,** 365-368.

Price GJ. 1985. Economic analysis of agricultural projects. The World Bank, Economic Development Institute. Washington D. C. **76,** 119-168.

Qi YB, Huang B, Darilek JL. 2011. Impacts of agricultural land management on soil quality after 24 years: a case study in Zhangjiagang County, China. New Zealand Journal of Agricultural Research **54(4),** 261-273.

Qin SP, He XH, Hu CS, Zhang YM, Dong WX. 2010: Responses of soil chemical and microbial indicators to conservational tillage versus traditional tillage in the North China Plain. European Journal of Soil Biology **46,** 243-247.

Safdar ME, Noorka IR, Tanveer A, Tariq SA, Rauf S. 2013. Growth and yield of advanced breeding lines of medium grain rice as influenced by different transplanting dates. The Journal of Animal and Plant Sciences **23(1),** 227-231.

Sayre KD, Hoobs P. 2004. The raised-bed system of cultivation for irrigated production conditions. In: Lal R, Hobbs PR, Norman U, Hansen DO Eds. Sustainable agriculture and the intonational rice-wheat system, CRC Press pp. 337-355.

Sharma P, Abrol V, Sharma RK. 2011. Impact of tillage and mulch management on economics, energy requirement and crop performance in maize–wheat rotation in rainfed sub humid Inceptisols, India. European Journal of Agronomy **34,** 46-51.

Shrivastav N, Basnet KB, Amgain LP, Karki TB, Khatri N. 2015. Weed dynamics and productivity of spring maize under different tillage and weed management methods. Azarian Journal of Agriculture **2(5),** 118-122.

Singh A, Kumar R, Kang JS. 2014. Tillage system, crop residues and nitrogen to improve the productivity of direct seeded rice and transplanted rice. Current Agriculture Research Journal **2(1),** 14-29.

Thomas GA, Titmarsh GW, Freebairn DM, Radford BJ. 2007. No-tillage and conservation farming practices in grain growing areas of Queensland-a review of 40 years of development. Australian Journal of Experimental Agriculture **47,** 887-898.

USDA (United States Department of Agriculture). 1979. Conversion Factors and Weights and Measures for Agricultural Commodities and Their Products. Economic Research Service Agricultural Handbook. The National Agricultural Statistics Service, U.S. Department of Agriculture. Statistical Bulletin No. 616, 1979. Available online at: https://ageconsearch.umn.edu/record/154304/files/sb616.pdf. Accessed: August 16, 2018.

Wiatrak PJ, Wright DL, Marois JJ. 2005. Evaluation of strip tillage on weed control, plant morphology, and yield of glyphosate-resistant cotton. The Journal of Cotton Science **9,** 10-14.

Zheng C, Jiang Y, Chen C, Sun Y, Feng J, Deng A, Song Z, Zhang W. 2014. The impacts of conservation agriculture on crop yield in China depend on specific practices, crops and cropping regions. The Crop Journal **2(5),** 289-296.