Bangladesh Rice J. 18(1&2): 44-53, 2014

Conservation Agriculture Options for a Rice-Maize Cropping Systems in Bangladesh

A K M Saiful Islam[1]*, M M Hossain[2] and M A Saleque[1]

ABSTRACT

Over the last two decades, Rice *(Oryza sativa* L.)-Maize *(Zea mays* L.) cropping systems have become one of the most dominant cropping systems in Bangladesh. This has coincided with the expansion in use of two-wheel tractors, which has facilitated options for minimum tillage. A three-year trial examined the prospects of conservation agriculture practices for Rice-Maize cropping in Bangladesh, with respect to minimum tillage and residue retention. Main plot tillage treatments of conventional full tillage, single pass wet tillage in rice (rotated with zero tillage in maize), bed planting and strip tillage were combined with residue retention treatments of 0, 50 and 100% in sub-plots. Compared to conventional tillage, minimum tillage saved 60-66% of fuel and 70-74% of labour required for land preparation. Although minimum tillage reduced the land preparation cost significantly through saving fuel and labour, weed infestation was higher compared to conventional tillage, which influenced the cost of production. Rice seedlings transplanted under unpuddled strip tillage required more time than in conventional or single pass wet tillage due to poor visibility of strips and the hard surface of untilled soil. Bed planting incurred the lowest production cost. Tillage methods and residue treatment produced no significant grain yield differences. Rice grown with single pass wet tillage and maize grown with strip tillage gave the highest gross margin over time. Despite lack of treatment effects on yields, the results suggest that profitability of Rice-Maize cropping could be increased with minimum tillage, provided there is adequate control of weeds by herbicides.

Key words: Minimum tillage, residue retention, transplanting, weeds

INTRODUCTION

Conservation agriculture (CA) is an approach of cropping that involves minimal soil disturbance for placing seeds and fertilizers, practicing diverse crop rotations and maintaining permanent soil cover using crop residues or plant canopies (Hobbs *et al.*, 2008; Kassam *et al.*, 2009). It is aimed at maintaining or improving crop yields while improving the soil resource base, minimizing inputs and increasing profitability (Baker and Saxton, 2007). There has been widespread adoption of these practices in large-scale commercial farming around the world and possibilities for use of CA in smallholder farming are now emerging (Johansen *et al.*, 2012).

A major cropping system that has evolved in Bangladesh over the last two decades is transplanted monsoon season rice followed by irrigated maize in the winter season (Ali, 2008). Although this system is high yielding, it is input intensive, exploitative of the soil and subject to declining factor productivity and profitability. Also during this period the use of two wheel tractors (2WT) has become widespread in Bangladesh, but originally used for full rotary tillage. These are ideal for use in the small fields of the country (approx. 0.1 ha) and these are estimated to be about 550,000 2WT in Bangladesh (Alam *et al.*, 2011). Over the last decade there has been experimentation with various seed and fertilizer delivery attachments to these 2WT, including options for minimum tillage (Johansen *et al.*, 2012). A recent innovation has been the Versatile Mullti-crop Planter (VMP), which is a unit that can be modified to undertake zero tillage (rotor blades removed with only tynes disturbing the soil), strip tillage (rotor blades only directly in front of tynes to ease soil entry of tynes), bed planting (rotary tillage and bedshaping) and conventional rotary tillage (Haque *et al.*, 2011). The advent of the VMP allows evaluation of various minimum tillage options for the Rice-Maize rotation in Bangladesh, in comparison with the conventional practice of using 2WT only for rotary tillage.

[1]Bangladesh Rice Research Institute, Gazipur, Bangladesh. [2]Bangladesh Agricultural University, Mymensingh, Bangladesh. *Corresponding author's email: akmsaifulislam68@gmail.com.

Residue retention is also an important component of CA, however, rice and maize straw are usually removed from fields in Bangladesh at harvest for uses as fodder, fuel and building material. Nevertheless, the efficacy of retaining at least some crop residue, in combination with minimum tillage needs to be assessed. This study was designed to determine the extent to which minimum tillage options combined with crop residue retention affect input requirements, yield and profitability of a Rice-Maize cropping system in Bangladesh over three cropping cycles.

MATERIALS AND METHODS

Experimental site

A field experiment with a Rice-Maize rotation was conducted during 2009-2012 at the Bangladesh Rice Research Institute (BRRI), regional station, Rajshahi, Bangladesh (24°69′N and 88°30′E). The soil is classified as High Ganges River Flood Plain - soil type is calcareous dark grey and soil texture sandy loam (Brammer, 1996). Initial bulk density at 0-0.75 m depth was 1.24 Mg m^{-3} at 39.7% gravimetric water content and bulk density at 0.75-1.5 m depth was 1.51 Mg m-3 at 26.3% gravimetric water content. The soil pH in the experimental field was 7.96 and organic carbon was 7.9 g kg^{-1}. The soil exchangeable potassium (m equivalent 100 gm $soil^{-1}$), total nitrogen (%) and available phosphorus (mg gm $soil^{-1}$) at initiation of the experiment were 0.28, 0.05 and 15.1 respectively. Figure 1 presents the monthly rainfall and mean maximum and minimum temperatures at the experimental location during the course of the study.

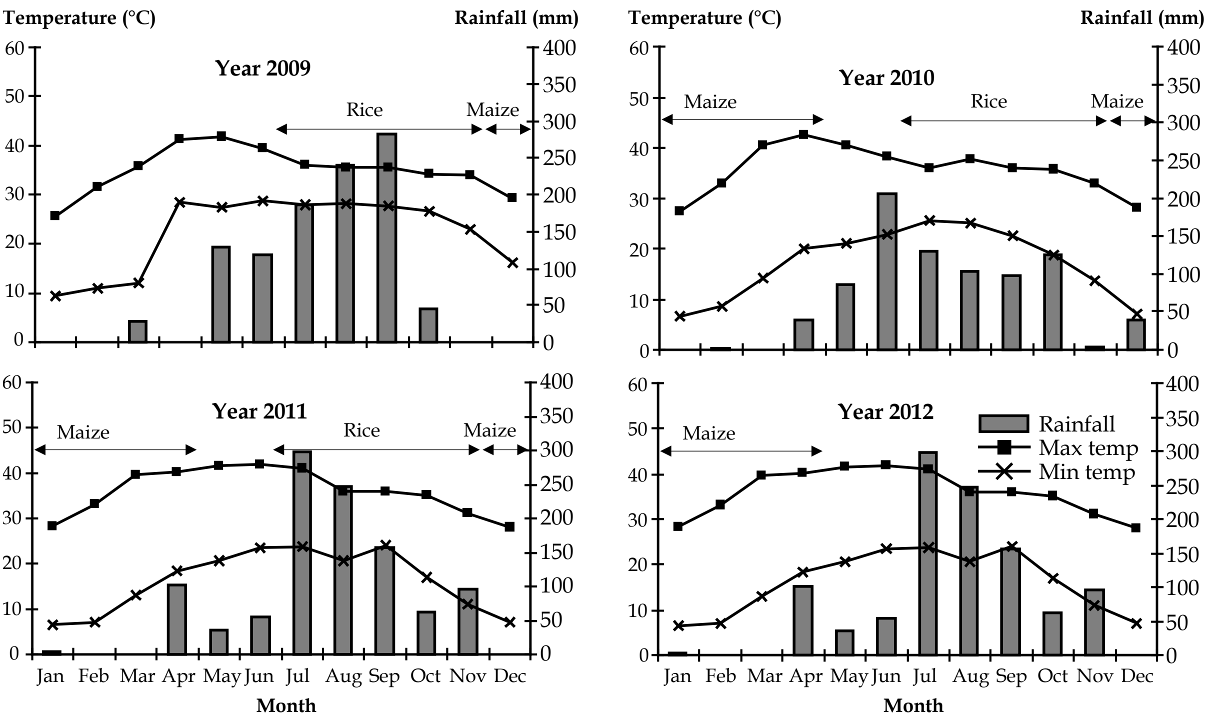

Fig. 1. Mean monthly minimum and maximum temperature and rainfall at the experimental site at Rajshahi (2009-2012).

Experiment design and treatments

The experiment was laid out in a strip plot design (Gomez and Gomez, 1984) with tillage options as main plot treatments and crop residue retention in subplots, with three replications, to explore the interaction between tillage and residue retention. The tillage treatments were: puddled conventional tillage for rice and maize (CT), puddled single pass wet tillage for rice and zero tillage (ZT) for maize (SPWT), unpuddled bed planting (BP) for rice and dry BP for maize (BP), unpuddled strip tillage (ST) for rice and dry ST for maize (ST). The crop residue retention treatements in subplots were 100% (CR100), 50% (CR50) and 0% (CR0). Subplot size was 8.5 × 8 m.

There was a 1 m wide trench between blocks to allow irrigation water flow.

For rice cultivation, CT consisted of two passes of primary rotary tillage by 2WT, inundating the whole plot after two days and puddling with two passes of rotary tillage. In SPWT, there was one pass of 2WT rotary tillage after inundating the field. ST and BP for rice were done by Multi-crop Planter (VMP) in a single pass operation, but without placing seed and fertilizer, before inundating the field. In maize cultivation, CT consisted of two passes of primary rotary tillage by 2WT and after two days, another two passes of secondary tillage. ZT, BP and ST were done in a single pass operation by VMP.

The land in unpuddled plots was fully inundated one day before transplanting of rice seedlings for both puddled (CT and SPWT) and unpuddled (BP and ST) treatments. Seedling spacings were (cm): for CT 25 × 15, SPWT 25 × 15, BP 29 × 15 and ST 20 × 15. Maize seeding was done manually at 60- × 20-cm spacing. Rice variety BR11 and maize variety NK40 were grown. Table 1 presents the transplanting dates, rice seedling age, maize seed sowing and harvesting dates of both the crops. As per treatment sequence, previous crop residue was spread in between rows of rice and maize at 20 days after transplanting/seeding. Residue treatments began after the first rice crop.

Table 1. Date of transplanting/seeding and harvesting of rice and maize.

Crop	Date of transplanting/seeding	Seedling age (day)	Date of harvesting
1st rice	19 Aug 09	27	30 Nov 09
1st maize	18 Dec 09		15 May10
2nd rice	9 Jul 10	25	09 Nov 10
2nd maize	16 Dec 10		25 May11
3rd rice	12 Jul 11	30	11 Nov 11
3rd maize	20 Nov 11		28 Apr12

Table 2 presents fertilizer application rates for rice and maize following the recommendations of BRRI (2011) and Mondal *et al.* (2011). In both crops fertilizer was applied manually. In rice cultivation, the entire amount of triple super phosphate (TSP), muriate of potash (MP), gypsum and zinc sulphate was broadcast and incorporated into the soil at final land preparation. In BP and ST, fertilizers were broadcast before tillage operation. Urea was top dressed in three equal installments. In maize cultivation, one third urea and full dose of other fertilizers were applied during last ploughing. In case of ZT, BP and ST, fertilizer was applied in rows by hand after seeding at one centimeter distance from seed to avoid seed and fertilizer contact. One third of urea was applied at the 8-10 leaf stage and the rest at the 20-22 leaf stage. Weed infestation was severe in all the plots during first rice and maize crop. Hand weeding was done twice in rice and maize crops. Roundup® (a.i. 73.3% glyphosate and 2.9% diquat) was applied @ 3.75 L ha^{-1} from the second rice and maize crop one day before land preparation. Roundup® reduced the severity of weed infestation in all tillage trials but it did not reduce the number of weeding operations in rice and maize crops. In the second and third rice crop, pre-emergence weedicide Rifit® (a.i. 50% pretilachlore) was applied @ 1 L ha^{-1} at four days after transplanting. The insecticide Sabion® (a.i. 10% diazinion) was applied @ 16 kg ha^{-1} at the vegetative stage to control stem borer *(Scirpophaga incertulas)* during rice cultivation. In rice cultivation, irrigation water was applied when needed, in measured quantities. In maize cultivation, the first, second and third irrigation was done at the 3-5, 8-10 and 20-22 leaf stages respectively. The fourth irrigation was done 15-20 days after the third irrigation. Grain yield was recorded after harvest from a pre-selected, but randomly chosen, 10 m^2 area and was adjusted to 14% moisture content for both rice and maize. Border areas of all sides of the plot were excluded from samples to avoid edge effects.

Table 2. Fertilizer application rate (kg ha^{-1}) for rice and maize.

Crop	Urea	Muriate of potash	Triple super phosphate	Zinc sulphate	Gypsum
Rice	175	110	80	10	100
Maize	185	277	277	17	185

Economic analysis

A simple economic analysis was done based on total production. Production cost included rental charge of the land and input cost. The input cost was calculated by considering cost of seed, fuel, fertilizers, weedicide, hiring charges of labour. Fuel consumption was measured by filling the fuel tank twice, before and after each operation, with the re-filled volume being the actual fuel consumption. The gross income and net returns were calculated on the basis of market price for rice and maize grain, straw and stover. Price of the product was based on local market to compute total production cost, gross return, gross margin and benefit-cost ratio. The net returns were calculated by subtracting total variable costs from the gross income. Rice equivalent yield (REY) was computed by converting the maize yield into rice yield on the basis of prevailing market price of the individual crops with the following equation (1):

$$REY = \frac{Y_{maize} \times P_{maize}}{P_{rice}} + Y_{rice} \qquad (1)$$

where, Ymaize is the maize yield (t ha^{-1}), Pmaize is the maize price (Tk t^{-1}), Yrice is the rice yield (t ha^{-1}) and Price is the rice price (Tk t^{-1}).

Statistical analysis

One way analysis of variance was done according to Gomez and Gomez (1984). Data were analysed by using statistical software Mstat-C. Means were compared using least significant difference (LSD).

RESULTS

Fuel consumption

Tillage treatment showed a significant effect on fuel consumption in land preparation for rice and maize cultivation over three seasons (Table 3). Fuel consumption was the highest in CT 39-50 L ha^{-1} for rice and 35-49 L ha^{-1} for maize and the lowest in ST 10-24 L ha^{-1} for rice and ZT 6-9 L ha^{-1} for maize. Fuel consumption followed a similar trend in all rice and maize seasons. Averaged over three years, the fuel consumption for minimum tillage operations saved 66% compared to CT for ST in both crops and SPWT in rice and 60% for ZT in maize. BP saved the least amount (38%) of fuel compared to CT.

Table 3. Tillage effect on fuel consumption (L ha^{-1}) in land preparation in Rice-Maize cropping sequences, from 2009 to 2012.

Tillage	Rice 2009	Maize 2010	Rice 2010	Maize 2011	Rice 2011	Maize 2012
CT	39	49	37	35	50	45
SPWT/ZT	40	0	18	6	23	9
BP	27	28	24	20	27	23
ST	10	17	19	8	24	15
CV (%)	10.4	17.6	10.6	4.3	3.1	2.4
$LSD_{0.05}$	6.0	8.2	5.1	1.5	1.9	1.1

CT=Conventional tillage, SPWT=Single pass wet tillage, ZT=Zero tillage, BP=Bed planting, ST=Strip tillage.

Labour requirement in land preparation

Minimum tillage procedures significantly reduced labour requirement for land preparation in Rice-Maize cropping systems (Table 4). In rice cultivation, labour requirement was the highest in CT (70-100 person-hr ha^{-1}) followed by SPWT (39-60 person-hr ha^{-1}), BP (16-20 person-hr ha^{-1}) and ST (9-12 person-hr ha^{-1}). In maize cultivation land preparation included tillage, seeding and leveling, whereas in rice cultivation land preparation included tillage only. The labour requirement for land preparation for maize varied between seasons due to labour efficiency and field condition. BP and ST by VMP saved 73 and 61% labour in land preparation compared to CT. SPWT in rice followed by ZT in maize saved most labour (39%) compared to CT in land preparation.

Labour requirement in transplanting

The time required for transplanting seedlings in unpuddled ST (174-296 person-hr ha^{-1}) was almost double the time needed in CT and SPWT (Table 4). Transplanting time was lower in the second and third seasons due to improved labour efficiency.

Table 4. Labour requirement (person-hr ha^{-1}) in land preparation and transplanting in Rice-Maize cropping systems.

Tillage	Rice 2009	Maize 2010	Rice 2010	Maize 2011	Rice 2011	Maize 2012
			Land preparation			
CT	77	275	100	243	70	354
SPWT/ZT	69	202	60	114	39	195
BP	16	61	17	89	20	102
ST	9	71	11	118	12	223
CV (%)	19.2	17.6	7.5	9.1	2.4	5.6
$LSD_{0.05}$	16.4	53.6	7.1	25.7	1.7	24.8
			Transplanting			
CT	151		107		102	
SPWT/ZT	168		107		111	
BP	201		122		111	
ST	296		187		174	
CV (%)	27.3		3.4		2.5	
$LSD_{0.05}$	15.7		8.9		6.1	

CT=Conventional tillage, SPWT=Single pass wet tillage, ZT=Zero tillage, BP=Bed planting, ST=Strip tillage, NS=Not significant.

Labour requirement in weeding

Weeding time for maize was the greatest in the first year as no herbicide was used (Table 5). In the second rice crop, herbicide was applied during cloudy weather and rainfall which resulted in ineffective weed control. Weeding time was the highest in unpuddled BP and ST in the rice crop and in ZT and ST in maize cultivation. Weed infestation in rice cultivation was more severe in unpuddled plots (BP and ST) than puddled plots (CT and SPWT). Crop residue retention did not significantly affect weeding time in rice cultivation, whereas in maize cultivation weeding time decreased as the level of crop residue retention increased (Table 5).

Table 5. Effect of tillage and residue retention on weeding time (person-hr ha^{-1}) in Rice-Maize cropping system.

Tillage	*Year 1*							
	Rice 2009				Maize 2010			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
				Year 1				
CT				229	613	659	685	653
SPWT/ZT				202	1370	1576	2762	1903
BP				680	639	847	1025	837
ST				582	916	1160	2258	1444
Mean					885	1061	1683	
$LSD_{0.05}$	Tillage (T) = 221.9				Tillage (T) = 617 Residue (CR) = 84.7 T X CR = 160.2			
CV (%)	18.67				7.45			
				Year 2				
	Rice 2010				Maize 2011			
CT	578	576	555	570	156	165	175	166
SPWT/ ZT	599	622	558	594	364	357	354	359
BP	609	670	614	631	318	325	330	325
ST	659	635	621	639	127	130	126	128
Mean	611	626	587		241	244	246	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = 130 Residue (CR) = NS T × CR = NS			
CV (%)	5.4				8.7			
				Year 3				
	Rice 2011				Maize 2012			
CT	283	289	278	283	185	254	374	271
SPWT/ ZT	460	446	450	452	215	221	407	281
BP	476	477	461	471	199	205	341	248
ST	370	394	381	382	197	221	437	285
Mean	397	402	393		199	225	390	
$LSD_{0.05}$	Tillage (T) = 66.8 Residue (CR) = NS T×CR = NS				Tillage (T) = 26.9 Residue (CR) = 96.1 T × CR = 86.3			
CV (%)	3.42				17.89			

CT=Conventional tillage, SPWT=Single pass wet tillage, ZT=Zero tillage, BP=Bed planting, ST=Strip tillage, CR=Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100, 50 and 0% previous crop residue retention, NS=Not significant.

Water productivity

Table 6 presents water productivity with respect to irrigation plus rainfall. Tillage treatment showed an inconsistent effect on water productivity in rice cultivation. Water productivity for rice was the highest in BP and ST in the first year, in SPWT and BP in the second year and in CT and ST in the third year. Water productivity increased as the tillage passes decreased in maize cultivation. Water productivity in maize was the highest in BP in the first year, and in ST in the second and third years.

Table 6. Water productivity (kg grain mm water^{-1}) in Rice-Maize cropping systems.

Tillage	Year 1		Year 2		Year 3	
	Rice	Maize	Rice	Maize	Rice	Maize
CT	4.73	98.01	4.66	57.42	7.20	66.55
SPWT/ZT	4.87	89.27	5.49	64.03	6.91	67.68
BP	6.59	108.34	5.09	56.66	6.56	64.66
ST	6.16	95.84	4.37	68.36	7.03	79.26

CT=Conventional tillage, SPWT=Single pass wet tillage, ZT=Zero tillage, BP=Bed planting, ST=Strip tillage.

Grain yield of rice and maize

There were no significant effects of tillage treatment or residue retention, or interaction between them, on rice or maize yields, or rice equivalent yield, in any season (Table 7).

Bangladesh Rice J. 18(1&2): 44-53, 2014

Table 7. Rice and maize grain yields and rice equivalent yield (REY) (t ha^{-1}) in Rice-Maize cropping systems.

Tillage	Rice				Maize				REY			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
					Year 1							
CT	4.61	4.48	4.19	4.43	7.21	8.38	7.67	7.75	9.53	10.19	9.42	9.71
SPWT/ZT	4.66	5.21	3.82	4.56	7.17	7.51	6.32	7.00	9.55	10.33	8.13	9.33
BP	4.64	5.10	3.90	4.55	8.43	8.71	8.29	8.48	10.39	11.04	9.55	10.33
ST	4.47	4.65	3.80	4.30	6.43	7.62	7.53	7.19	8.85	9.85	8.93	9.20
Mean	4.60	4.86	3.93		7.31	8.06	7.45		9.58	10.36	9.01	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	7.9				9.1				6.1			
					Year 2							
CT	4.27	3.71	3.68	3.89	7.15	7.34	7.15	7.22	9.15	8.71	8.56	8.81
SPWT/ZT	5.06	4.37	3.86	4.43	7.65	7.77	7.54	7.66	10.28	9.67	9.00	9.65
BP	4.42	4.05	4.04	4.17	7.08	7.46	7.19	7.24	9.25	9.14	8.94	9.11
ST	3.94	3.87	4.00	3.94	7.80	7.83	7.88	7.84	9.26	9.21	9.37	9.29
Mean	4.42	4.00	3.90		7.42	7.60	7.44		9.48	9.18	8.97	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV,%	8.8				3.7				3.7			
					Year 3							
CT	7.00	6.69	6.70	6.80	11.33	11.28	11.19	11.27	14.73	14.38	14.33	14.48
SPWT/ZT	6.69	6.45	6.52	6.55	11.34	11.24	11.09	11.22	14.42	14.11	14.08	14.20
BP	6.57	6.26	6.20	6.34	11.00	10.86	11.12	10.99	14.07	13.66	13.78	13.83
ST	6.69	6.62	6.39	6.57	12.99	12.93	13.00	12.97	15.55	15.44	15.25	15.41
Mean	6.74	6.51	6.45		11.66	11.58	11.60		14.69	14.41	14.36	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	6.3				6.3				4.7			

CT=Conventional tillage, SPWT=Single pass wet tillage, ZT=Zero tillage, BP=Bed planting, ST=Strip tillage, CR=Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100, 50 and 0% previous crop residue retention, NS =Not significant.

Economic analysis

Economic analysis of Rice-Maize cropping systems under different tillage practices was done based on the total cost of production and average grain and straw yield (Table 8). The total cost of production was the highest in CT in the second year. Over three years, BP incurred the lowest cost in the overall Rice-Maize cropping system. Gross return was the highest in BP in the first year, SPWT followed by ZT in the second year and ST in the third year due to higher grain yield. Gross margin was the highest in BP in the first year, and in ST in the second and third years. In the third year, benefit-cost ratio (BCR) was increased in all tillage options due to higher yield in that year. The highest BCR was observed in BP (1.43) in the first year and ST (1.41 and 2.27) in the second and third years because of higher gross return and lower total cost of production.

Table 8. Economic productivity of Rice-Maize cropping systems as affected by tillage treatment.

Treatment	Total cost (US$ ha^{-1})*	Gross return (US$ ha^{-1})	Gross margin (US$ ha^{-1})	BCR
		Year 1		
CT	1690	2371	681	1.40
SPWT/ZT	1942	2295	353	1.18
BP	1753	2523	757	1.43
ST	1841	2270	416	1.23
		Year 2		
CT	1703	2157	454	1.26
SPWT/ZT	1703	2346	643	1.38
BP	1677	2220	542	1.32
ST	1627	2295	668	1.41
		Year 3		
CT	1690	3519	1841	2.09
SPWT/ZT	1652	3481	1829	2.11
BP	1614	3368	1741	2.08
ST	1665	3771	2106	2.27

CT=Conventional tillage, SPWT=Single pass wet tillage, ZT=Zero tillage, BP=Bed planting, ST=Strip tillage, NS=Not significant. *1 US$ = Tk 80.

DISCUSSION

Minimum tillage consumed less fuel compared to CT. Hernánz *et al.* (1995) and Sijtsma *et al.* (1998) similarly reported that a decrease in tillage intensity resulted in significant fuel savings. The time required for transplanting seedlings in unpuddled ST (174-296 person-hr ha^{-1}) was almost double the time needed in CT and SPWT. Poor visibility of strips under muddy flood water caused difficulties for labour when transplanting seedlings in the hard surface of untilled soil. Labourers complained that they had to apply more pressure to place seedlings in unpuddled fields than puddled ones. In the first year, transplanting time was the highest in unpuddled than puddled plots due to inexperience in transplanting seedlings in unpuddled condition. From the next rice crop, transplanting time was reduced due to experience gained from the first year. Similar problems were encountered when transplanting seedlings in BP. The whole plot was inundated one day before transplanting so the soil was not soft enough to push the seedling roots into the soil easily. Sandy soil may regain high strength after wetting much faster than clay soils and this hampered manual transplanting in unpuddled land if it was delayed (White *et al.*, 1997).

Weeds also more severely infested in less intensive tillage (ZT and ST) of maize. Pre-planting post-emergence herbicide was not applied before the first rice and maize crop. Weed infestation was drastically reduced due to application of herbicide (glyphosate) after first rice and maize cultivation. Crop residue retention had no significant effect on weeding time in rice cultivation with application of pre-emergence weedicide (pretilachlore) at four days after transplanting. The effect of crop residue retention on weed infestation was significant in maize cultivation. However, weeding time was decreased as the level of crop residue retention increased. Crop residue acted as mulch, which suppressed weeds. Weed control was a major determinant in conservation tillage. Proper selection of herbicide and its time of application might reduced the severity of weeds.

Yield variation was inconsistent with no significant treatment difference between puddled and unpuddled transplanting. Watkins *et al.* (2004) and Linquist *et al.* (2008) reported similar rice yields in some seasons but not in others between reduced/zero and conventional tillage. Yield variation was also not significantly affected by tillage in three maize crops. Research in Iowa, USA found no consistent difference in maize yields between strip till and no-till (Pierce *et al.*, 1992). On the other hand, Ghuman and Sur (2001) reported that maize grain yield increased with minimum tillage and residue retention after a production period of two years when compared with conventional tillage. In the second year of the current study, an overall decrease in grain yield was observed as compared to the first year. In this year, the application of crop residue had variable effects and maize yield appeared higher in 50% residue retention plot but this was not significant. Although residue retention had an inconsistent effect on maize yield, it had a positive effect on rice yield. In the third year, rice and maize yield was higher than the earlier years in all treatments. This could be attributed to favourable weather, increased soil fertility due to residual effects of previously applied fertilizers and low pest and disease infestation. Maize was grown immediately after harvesting rice, which enabled it to escape cold injury.

The total cost of production was the highest in CT in second year. In the first rice and maize crop, weed infestation was severe and weeding cost influenced the total production cost. In other seasons, weed infestation was drastically reduced due to application of preplanting post-emergence herbicide (glyphosate). It was observed that minimum tillage reduced the land preparation cost significantly through saving fuel and labour, whereas the weed infestation was higher with less intensive tillage compared to conventional tillage causing an increase in cost of production. The highest BCR was observed in BP in the first year and ST in the second and third years because of higher gross return and lower total cost of production. Where weeds can be managed by use of herbicides, minimum tillage treatments are generally more remunerative than the conventional tillage, with strip tillage appearing most promising. However, in the third year, the SPWT/ZT and BP treatments were not superior to CT.

CONCLUSIONS

Rice and maize yield did not differ significantly among various tillage and residue retention treatments during study period. Minimum tillage (SPWT, ZT, BP and ST) with residue retention saved fuel (38-61%) and labour (39-73%) in Rice-Maize cropping systems. Although no yield advantages of minimum tillage over conventional tillage were apparent in this study, production costs can generally be lowered, and profitability increased with minimum tillage, provided there is effective herbicide control of weeds.

ACKNOWLEDGMENTS

This study was a part of the senior author's PhD research under Bangladesh Agricultural University, Mymensingh, Bangladesh. The authors acknowledge the funding support from NATP-Phase 1, Bangladesh Agricultural Research Council and Australian Centre for International Agricultural Research (ACIAR) Project (LWR/2005/001). The authors also acknowledge Dr Chris Johansen for his comments on the manuscript.

REFERENCES

Alam, M M, M A Matin, M H Khan, M N I Khan, I N Khan, C K Saha and F H Khan. 2011. Agricultual technology and industrial development of Bangladesh: Oppurtunities and constraints. Paper presented in "AgroTech Bangladesh-2011" International Exhibition held at 22-24 september 2011 in Rural Development Academy (RDA), Bogra, Bangladesh.

Ali, M Y, S R Waddington, D Hodson, J Timsina and J Dixon. 2008. Maize-Rice cropping systems in Bangladesh: Status amd research opportunities. Mexico, D. F.: CIMMYT.

Baker, C J and K E (Eds.) Saxton. 2007. No-tillage seeding in conservation agriculture, 2nd edn. CAB International and FAO. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. pp. 326.

Brammer, H. 1996. 'The geography of the soils of Bangladesh'. University Press Limited: Dhaka.

BRRI (Bangladesh Rice Research Institute). 2011. Adhunik Dhaner Chash (Cultivation of Modern Rice), 16th edition, BRRI, Gazipur, Bangladesh. pp. 5-72.

Ghuman, B S and H S Sur. 2001. Tillage and residue management effects on soil properties and yields of rainfed maize and wheat in a subhumid subtropical climate. Soil and Tillage Research 58: 1-10.

Gomez, K A and A A Gomez. 1984. Statistical Procedures in Agricultural Research, New York, Chichester, etc.: Wiley, 2nd edition, pp. 680.

Haque, M E, R W Bell, A K M S Islam, K Sayre and M M Hossain. 2011. Versatile multi-crop planter for two-wheel tractors: An innovative option for smallholders. 5th World Congress of Conservation Agriculture incorporating 3rd Farming Systems Design Conference, September 2011 Brisbane, Australia.

Hernánz, J L, V S Girón and C Cerisola. 1995. Long-term energy use and economic evaluation of three tillage systems for cereal and legume production in central Spain. Soil and Tillage Research. 35: 183-198.

Hobbs, P R, K Sayre and R Gupta. 2008. The role of conservation agriculture in sustainable agriculture. Phil. Trans. R. Soc. Lond., B, Biol. Sci. 363: 543–555.

Islam, A K M S. 2012. Development of multi-crop planter. PhD thesis, Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh, Bangladesh.

Johansen, C J, M E Haque, R W Bell, C Thierfelder and R J Esdaile. 2012. Conservation agriculture for small holder rainfed farming: Opportunities and constraints of new mechanized seeding systems. Field Crops Research 132: 18-32.

Kassam, A, T Friedrich, F Shaxson and J Pretty. 2009. The spread of conservation agriculture: justification, sustainability and uptake. Int. J. Agric. Sustainability 7: 292–320.

Linquist, B A, A Fischer, L Godfrey, C Greer, J Hill, K Koffler, M Moeching, R Mutters and C van Kessel. 2008. Minimum tillage could benefit California rice farmers. Cal. Agric. 62 (1) 24-29.

Mondal, M R I, M S Islam, M A J Bhuiyan, M M Rahman, M S Alam and M H H Rahman. 2011. Krishi Projukti Hatboi (Handbook on Agro-technology), 5th edition, Bangladesh Agricultural Research Institute, Gazipur, Bangladesh. pp. 33-83.

Pierce, F L, M C Fortin and M J Staton. 1992. Immediate and residual effects of zone tillage in rotation with no-tillage on soil physical properties and corn performance. Soil and Tillage Research 24: 149-165.

Sijtsma, C H, A J Campbell, N B McLaughlin and M R Carter. 1998. Comparative tillage costs for crop rotations utilizing minimum tillage on a farm scale. Soil and Tillage Research 49: 223–231.

Watkins, K B, M M Anders and T E Windham. 2004. An economic comparison of alternative rice production systems in Arkansas. J. Sustainable Agric. 24 (4) 57-78.

White, P F, T Oberthür and S Pheav. 1997. The soils used for rice production in Cambodia. Cambodia-IRRI-Australia Project Phnom Penh, Cambodia.

Xu, Y, L Nie, R J Buresh, J Huang, K Cui, B Xuc, W Gong and S Peng. 2010. Agronomic performance of late-season rice under different tillage, straw, and nitrogen management. Field Crops Research 115: 79-84.