WEED MANAGEMENT IN WHEAT-MUNGBEAN-RICE CROPPING PATTERN UNDER CONSERVATION AGRICULTURE IN DROUGHT-PRONE AREAS

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Abstract

Conservation Agriculture (CA) is promoted as a sustainable alternative to systems involving conventional tillage. Adoption of CA changes weed dynamics and communities and therefore necessitates adjusting weed control methods. A field experiment was conducted at Regional Wheat Research Centre, Bangladesh Agricultural Research Institute, Rajshahi, Bangladesh to develop sustainable and effective weed management strategies for Wheat-Mungbean-T. *Aman* rice under CA systems. Four weed management treatments (WM_1: Pre-plant herbicide (Glyphosate: Roundup) for Wheat + Pre-plant herbicide (Glyphosate: Roundup) followed by (fb) Pre-emergence herbicide (Ethoxysulfuron: sunrise) for mungbean + Pre-plant herbicide (Glyphosate) followed by (fb) post-emergence herbicide (Bensulfuron methyl and Accetachlor:Nirmul-18WP) for rice; WM_2: Post-emergence herbicide (Carfentrazone-ethyl+isoproturon: Affinity) for wheat + Post emergence (Fenoxapropp-ethyl Whipsuper) for mungbean + Post-emergence (Bensulfuron methyl and Bispyribac Sodium: Serious Plus 30 EC) for rice; WM_3: One hand weeding at 25-30 DAS for wheat; 15-20 DAS for mungbean and 30-35 DAS for rice and WM_4: No weeding as control) were compared for five tillage options (ZT: Zero Tillage, ST: Strip Tillage, Permanent Raised Bed (PRB), PTOS: minimum tillage and CT: Conventional tillage). The study identified a significant effect of tillage treatments on wheat and mungbean; however, non-significant effect was observed on T. *Aman* rice. The ST and PRB gave a higher grain yield of wheat (4.01 and 4.07 t ha^{-1}, respectively) compared to ZT (3.73 t ha^{-1}), PTOS tillage and CT having lower weed population (insert data) and biomass were slightly higher in ZT, PTOS, and CT systems over PRB and ST. The highest yield of all component crops of Wheat-Mungbean-T. *Aman* rice pattern was attained from weed management treatments WM_1 and WM_2. Both the treatments also had the lowest weed population and dry weed biomass. Treatment PRB and ST with WM_2 offered higher yield, gross margin and gross return for all the crops of wheat-mungbean-T. *aman* rice pattern compared to the other treatments.

Keywords: Weed management, grain yield, seed yield, cropping pattern, rice, mungbean, drought

INTRODUCTION

Conservation Agriculture (CA) has been said to result in sustainable farming systems due to savings of time, economic inputs and conserving natural resources (Baker *et al*., 2005; Camarotto *et al*., 2018; Bell *et al*., 2019; Page *et al*., 2020). There has been an increasing trend toward CA to enhance sustainability without compromising land productivity over the last decade in South Asia (Kassam *et al*., 2015; Jat *et al*., 2014). However, the adoption of CA is greatly influenced by heavy weed infestation (Chuhan *et al*., 2006; Buhler, 1995). Weed control is a greater challenge to achieving the success of CA. The behavior of weeds under CA is complex and not fully understood. Generally, in CA weed seed bank remains at the surface soil. Weed seeds at the soil surface are more prone to withering. In addition, crop residues are a pillar of CA that could suppress or delay weed emergence (Sosnoski *et al*., 2006; Boscutti *et al*., 2015) and allow the crop to gain early vigor over weeds. Further, crop residues may also intercept a considerable proportion of pre-emergence

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herbicides may result in lower herbicide efficacy (Chauhan and Abugho, 2012; Banks and Robinson, 1986). However, it is critical to control weeds to achieve the success of CA in Bangladesh.

Still, now less effort has been taken for managing weeds and improving crop yields in CA systems particularly in South Asia. Hence, the present investigation has been undertaken to find out the effective and sustainable weed management strategy for increasing the yield of cropping patterns in the CA system in Bangladesh.

MATERIALS AND METHODS

A field experiment was conducted at Regional Wheat Research Centre, Bangladesh Shyampur, Rajshahi, Bangladesh to develop sustainable and effective weed management strategies for Wheat-Mungbean-T. Aman rice under CA systems. The soil of the experimental plots belongs to AEZ 11. A two-factorial experiment was conducted to achieve the objectives of the study. Four weed management treatments were evaluated under five tillage options has mentioned. There were twenty treatment combinations in the experiment. A split-plot design with three replications was used, with tillage options as main plots and weed management treatment as sub-plots. Thus, the field experiment was comprised of 60 unit plots. The factors and treatments were

Factor A: (Tillage options): ZT: Zero tillage, ST: Strip tillage, PRB: Permanent Raised Bed, PTOS: minimum tillage, CT: Conventional tillage. Factor B: (Weed management options): Weed management options varied in different crops. The weed management treatment combinations were detailed below:

Treatments	Wheat	Mungbean	Rice
WM_1	Pre-plant: Glyphosate (Round- up)	Pre-plant: Glyphosate (Round- up) Pre-emergence: Sunrise	Pre-plant: Glyphosate (Round- up) Pre-emergence: Benzosulfuran methyl + Accetachlor (Nirmol -18 WP)
WM_2	Postemergence: Carfentrazone- ethyl plus isoproturon (Affinity)	Post emergence: Fenoxaprop-p-ethyl (Whipsuper)	Post-emergence: Benzosulfuranmethyl + Bispyricbac Sodium (Sirious Plus 30 EC)
WM_3	Hand weeding at 25-30 DAS	Hand weeding at 15- 20 DAS	Hand weeding at 30-35 DAS
WM_4	Absolute control	Absolute control	Absolute control

Different weed management strategies were applied as per the treatment specimen. In the case of T. *aman* rice, glyphosate (Round-up) was applied as a blanket to the entire zero, strip, permanent raised bed (PRB), minimum tillage field to kill exiting weeds. Fertilizer doses for different crops were used as per Fertilizer Recommendation Guide 2015. The crops were grown on a permanent layout. The crop cycle was started with wheat as the first crop in late November 2018. The unit plot size was 5 m x 3 m. The details of the crop varieties and cultural operations adopted in different crops are given in Table 1. For wheat two-thirds of urea and all other inorganic fertilizers were applied at the time of final land preparation. The rest of the urea was applied 20 days after sowing just after irrigation. For mungbean, all the inorganic fertilizers were applied at final land preparation and mixed with soil. In the case of T. *Aman* rice, all the fertilizers except urea were applied as basal. Urea was applied as a top dressing in three equal splits at 15, 30, and 45 days after transplanting. Intercultural operations viz. thinning, irrigation, fungicide, and insecticide spray were done to support normal plant growth. After picking the pod the remaining plant parts were incorporated into the experimental plot in situ. Data on yield and yield contributing characters of each crop were recorded from 10 randomly selected plants per plot. The yield of the main and by-products of each crop

under various treatments was measured in each plot (6 m^2) at the physiological maturity stage. For weed count data, four permanent 0.20 m^2 (40 cm x 50 cm) quadrated were established in each of the plots after planting each crop. Weed data was taken from four permanent quadrats for each crop. Weed was counted separately as grasses, broadleaf, and sedges. For the first observation, weed count was done from all four quadrats and weed biomass from only two quadrats. For the second observation, weed biomass was converted to a gram per square meter. Data on the yield of various crops were recorded and converted into tons per hectare (t ha^{-1}). Total system productivity was calculated as the summation of the individual (component) crop yield of each cropping cycle. The productivity of different crops in the sequence was compared by calculating their rice equivalent yield (REY) using the formula given by Ahlawat and Sharma (1993), as follows:

$$\text{REY} = \frac{\text{Yield of each crop (t/ha) x Economic value of respective crop (Tk/ha)}}{\text{Price of rice grain (Tk/t)}}$$

The data were analyzed statistically with the CropStat program.

Table 1: Details of cultural practices adopted for different crops in field experiments

Crop	Cultivar	Seed rate (kg ha^{-1})	Spacing (cm^2)	Seeding/ planting date	Harvesting date
Wheat	BARI Gom-33	120	Seeding by individual machine with 20 cm spacing	28 Nov 2018	27 March 2019
Mungbean	BARI Mung-6	30	Seeding by individual machine with 30 cm spacing	30 March 2019	16-29 June 2019
Rice	BRRI dhan71	40	25*15 cm row to row and plant to plant spacing	25 July 2019	27 October 2019

RESULTS AND DISCUSSION

Before experimentation, initial soil sample was collected and analyzed to know the nutrient status and the results were presented in Table 2. The soil was slightly alkaline (7.8 pH) having low organic matter content (0.94%) and the total N & boron content was very low (0.05% & 0.27 µg). The overall soil fertility status was low.

Table 2. Fertility status of initial soil sample of the experimental site at RWRC, BARI, Rajshahi

Sample	pH	OM (%)	Total N (%)	K	P	S	Zn	B
				Meq/100g	µg g^{-1}			
Value	7.8	0.94	0.05	0.21	10	23.3	0.14	0.27
Critical level	-	-	0.12	0.12	10	10.0	0.60	0.20
Interpretation	Slightly Alkaline	Very low	Very low	Medium	Low	Opt.	Very low	Very low

Wheat

Effect of tillage options on weed population and biomass at 40 DAS in the wheat field

The effect of tillage options on weed population and weed dry biomass at 40 days after sowing (DAS) of wheat in Wheat-Mungbean-T. *aman* rice was significant (Table 3). The total no. of weeds (54.17) and dry biomass (15.52 g m^{-2}) were significantly higher in CT plots while the number of broadleaf and sedges were higher in CT plots and the number of grass also in CT plots. The lower number of total weeds (25.22) and dry biomass (7.14 g m^{-2}) were recorded in the ST plot followed by PRB (29.1) and biomass (7.43 g m^{-2}). The previous studies have also reported higher number weeds in heavy tillage than the minimum tillage (Yenish *et al*., 1992; O'Donovan and McAndrew, 2000) because weed seeds from the weed seed bank of sub-surface soil comes up in the surface layer of soil due to heavy pulverization of soil in CT.

Table 3. Weed population and dry biomass as influenced by different weed management treatments at 40 DAS of wheat in Wheat-Mungbean-T. *aman* rice cropping pattern

Treatments	Grass		Broadleaf		Sedge		Total	
	No.	Biomass (g^{-2})	No.	Biomass (gm^{-2})	No.	Biomass (g^{-2})	No.	Biomass (gm^{-2})
ZT	8.12	2.15	21.54	6.22	7.12	1.98	36.78	10.35
ST	6.78	1.79	13.75	4.12	4.76	1.23	25.22	7.14
PRB	5.12	1.45	10.42	3.89	4.12	1.09	29.1	7.43
MT	11.27	3.74	18.34	6.05	8.32	2.32	37.93	12.11
CT	14.73	4.11	29.32	8.21	9.12	2.83	54.17	15.52
LSD	1.087	0.45	1.17	0.87	1.121	0.67	4.325	3.17
CV (%)	8.78	11.21	10.57	7.89	12.32	10.58	13.25	11.87

WM_1= Pre-plant, WM_2= Post Emergence, WM_3= Hand weeding, and WM_4 =No weed control

Effect of weed management on weed population and biomass at 40 DAS in the wheat field

Weed management treatment had a significant impact on weed population and weed dry biomass in wheat fields at 40 DAS (Table 4). The WM_4 which indicates the number weed control showed the highest number of total weeds (44.0) and weed dry biomass (12.11 g m^{-2}). The WM_2 that included Carfentrazone-ethyl (Affinity) recorded the least no. of total weeds (8.5) and total dry biomass (3.07 g m^{-2}). The Carfentrazone-ethyl (Affinity) was applied to 30 DAS that controlled weeds successfully at a later stage. Zahan *et al*. (2021) also found the superior weed controlling efficacy of Carfentrazone-ethyl plus isoproturon in wheat. However, The WM_1 showed similar performance of weed suppression as WM_2.

Table 4. Weed population and dry biomass as influenced by different weed management treatments at 40 DAS of wheat in Wheat-Mungbean-T. *aman* rice cropping pattern

Treatments	Grass		Broadleaf		Sedge		Total	
	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})
WM_1	2.2	0.90	4.5	1.87	1.8	0.30	8.5	3.07
WM_2	2.3	0.94	5.3	1.92	2.5	0.82	9.8	3.60
WM_3	5.2	1.31	3.4	1.12	3.2	0.62	11.8	3.05
WM_4	11.8	3.25	21.4	5.32	10.8	3.54	44.0	12.11
LSD	0.32	0.21	1.13	0.132	1.32	0.32	2.77	1.32
CV (%)	11.23	8.89	7.79	12.32	10.58	13.24	12.24	9.97

WM_1= Pre-plant, WM_2= Post Emergence, WM_3= Hand weeding, and WM_4 =No weed control

Grain yield and yield components of wheat as influenced by tillage options with 30% straw retention

Grain yield is the cumulative effect of spike m^{-2}, grains $spike^{-1}$, and 1000 grain weight. Yield and yield components data were shown in Table 5. Tillage systems with straw retention had a significant influence on grain yield and yield components except for spike m^{-2} and spikelet $spike^{-1}$. The maximum grain yield was 4.47 t ha^{-1} from raised bed systems with 30% straw retention and the similar yield was also found from the strip-till method at 4.41 t ha^{-1}. The lowest yield 3.73 t ha^{-1} was also found from conventional tillage with 30% straw retention. Grain yield was higher due to higher yield attributes and get more photosynthesis with the border effect. The minimum yield was found from conventional tillage practice due to lower yield components and less photosynthesis with border effect. Yield components like spike m^{-2} and spikelet $spike^{-1}$ did not get any significant effect on different tillage options but other attributes like grains $spike^{-1}$ and TGW were also a significant effect on tillage options with straw retention. Rice equivalent yield (REY) was higher in both strip and raised bed systems with 30% straw retention and lower REY was found in the conventional method with 30% straw retention.

Table 5. Yield and yield components of wheat as influenced by different tillage options and straw retention in 2018-19, 2019-20 & 2020-21 (Pooled data)

Treatments	Spikes m^{-2}	Spikelet $spike^{-1}$	Grains $spike^{-1}$	TGW (g)	Grain yield (t ha^{-1})	REY (t ha^{-1})
Zero × 30% straw	317	18.3	49.2	53.6	4.08	4.53
Strip × 30% straw	319	18.5	50.3	53.8	4.41	4.90
Bed × 30% straw	312	18.6	51.4	54.2	4.47	4.97
PTOS × 30% straw	325	18.2	49.8	52.8	4.14	4.60
Conv. × 30% straw	322	17.7	48.3	52.4	3.73	4.14
CV (%)	9.76	6.85	8.45	5.75	10.25	-
LSD (0.05)	0.132	0.32	1.325	1.024	0.245	-

Table 6. Effect of weed management practices on the yield and yield attributes of wheat in Wheat-Mungbean-T. aman rice cropping pattern in 2018-19, 2019-20 and 2020-21(Polled data)

Treatments	Spike m^{-2}	Spike length (cm)	Grains $spike^{-1}$	1000 grain wt. (g)	Grain yield (t ha^{-1})	Biomass (t ha^{-1})	REY (t ha^{-1})
WM_1	386.3	12.16	45.8	48.8	4.41	8.58	4.82
WM_2	372.5	11.66	44.3	47.8	4.54	8.75	5.01
WM_3	363.7	11.23	45.1	46.2	4.39	8.04	4.73
WM_4	349.4	10.99	41.3	42.3	2.93	5.64	3.25
LSD	1.92	14.09	0.86	1.815	0.37	0.23	-
CV (%)	9.75	10.65	11.25	8.78	7.68	10.45	-

WM_1= Pre-plant +Pre-emergence, WM_2= Post Emergence, WM_3= Hand weeding and WM_4= No weed control

Effect of weed management on wheat yield and yield components

Weed management had a significant impact on yield attributes and the yield of wheat (Table 6). The WM_2 which includes pre-plant herbicide Glyphosate (round-up) and post-emergence herbicide Carfentrazone-ethyl plus isoproturon (Affinity) gave the maximum grain yield (4.54 t ha^{-1}) followed by WM_1 (4.41 t ha^{-1}) which contained pre-plant herbicide Glyphosate (round-up). The hand weeding (WM_3) also gave a similar grain yield (4.39 t ha^{-1}) among the treatments and no weed control (WM_4) treatments showed statistically less grain

yield 2.93 t ha^{-1} among the treatments. A similar trend was observed for straw yield. The number of spike m^{-2}, grains $spike^{-1,}$ and 1000-grain weight was higher in WM_1 and WM_2 which contributed to higher grain yield in the treatments. Rice equivalent yield (REY) was higher in WM_2 treatment and lower REY was found from the control plot.

Mungbean

Effect of tillage options on weed population and biomass at 40 DAS in mungbean field

The effect of tillage options on weed population and weed dry biomass at 40 days after sowing (DAS) of mungbean in Wheat-Mungbean-T. *aman* rice was significant (Table 7). The total no. of weeds (5677) and dry biomass (16.53 g m^{-2}) were significantly higher in CT plots while the number of broadleaf and sedges were higher in conventional tillage (CT) plots and the number of grass was also higher in CT plot. The lower number of total weeds (16.05) and dry biomass (5.01 g m^{-2}) were recorded in raised bed system followed by strip tillage (22.19) and biomass (6.74 g m^{-2}).

Table 7. Weed population and dry biomass as influenced by different weed management treatments at 40 DAS of Mungbean in Wheat- Mungbean-T. aman rice cropping pattern

Treatments	Grass		Broadleaf		Sedge		Total	
	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})
ZT	12.17	3.45	10.24	3.12	6.12	1.78	28.53	8.35
ST	8.78	2.59	7.15	2.32	6.26	1.83	22.19	6.74
PRB	6.21	1.95	5.42	1.87	4.42	1.19	16.05	5.01
MT	17.23	5.24	14.30	4.15	8.72	2.42	40.25	11.81
CT	24.43	7.05	19.32	6.05	13.02	3.43	56.77	16.53
LSD	1.317	0.75	1.09	1.07	1.32	0.87	3.375	2.19
CV (%)	5.78	9.21	11.57	8.89	10.32	9.58	11.25	9.87

WM_1= Pre-plant, WM_2= Post Emergence, WM_3= Hand weeding, and WM_4 =No weed control

Effect of weed management on weed population and biomass at 40 DAS in mungbean field

Weed management treatment had a significant impact on weed population and weed dry biomass in mungbean fields at 40 DAS (Table 8). The WM_4 which indicates the number of weed control showed the highest number of total weeds (52.0) and weed dry biomass (24.11 g m^{-2}). Both pre and post-emergence herbicide having treatments (WM_1+WM_2) that had Carfentrazone-ethyl (Affinity) provided the least no. of total weeds (14.0) and total dry biomass (6.48 g m^{-2}). The Carfentrazone-ethyl (Affinity) was applied to 30 DAS that controlled weeds successfully at a later stage.

Table 8. Weed population and dry biomass as influenced by different weed management treatments at 40 DAS of mungbean in Wheat-Mungbean-T. aman rice cropping pattern

Treatments	Grass		Broadleaf		Sedge		Total	
	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})
WM_1	10.2	5.90	7.5	2.87	5.8	2.38	23.5	11.15
WM_2	5.3	2.94	5.2	1.72	3.5	1.82	14.0	6.48
WM_3	5.2	2.81	4.4	1.52	3.2	1.62	12.8	5.95
WM_4	21.8	13.25	19.4	6.32	10.8	4.54	52.0	24.11
LSD	0.32	0.21	1.13	0.132	1.32	0.32	2.77	1.32
CV (%)	11.23	8.89	7.79	12.32	10.58	13.24	12.24	9.97

WM_1= Pre-plant, WM_2= Post Emergence, WM_3= Hand weeding, and WM_4 =No weed control

Plant height and biomass production of mungbean crop

Both biomass productions and plant height were significantly influenced under different tillage options with 30% straw retention (Table 9). The higher plant height (77.4 cm) from raised bed with 30% straw retention was at par with zero tillage with 30% straw retention. Maximum fresh biomass weight (20.2 t ha^{-1}) was found from raised bed tillage system followed by zero tillage (19.3 t ha^{-1}) and the strip till method. The three years average oven-dry biomass yield (3.87 t ha^{-1}) was also found from raised bed system and it was zero (3.80 t ha^{-1}) and strip-till (3.66 t ha^{-1}) method. Sayre *et al*. (2005) also reported similar results from their study with permanent and zero tillage systems. Despite of having lower grain yields, zero tillage mungbean always produced higher biomass with taller plants compared to the conventional tillage treatment followed by raised bed system. It might be an indirect benefit for soil in zero tillage and raised bed planting methods. Excessive vegetative growth in mungbean in zero tillage might reduce the grain yields.

Table 9. Plant height and fresh biomass at 40 DAS with three years of dry biomass production at final harvest of mungbean at different tillage options with straw retention in 2018-19, 2019-20 and 2020-21

Tillage options	Plant height (cm)	Fresh biomass yield (t ha^{-1})	Dry biomass yield (t ha^{-1})			
			2018-19	2019-20	2020-21	Average
Zero tillage	76.3	19.3	3.72	3.80	3.82	3.80
Strip tillage	72.6	18.5	3.58	3.66	3.75	3.66
Raised bed	77.4	20.2	3.77	3.93	3.91	3.87
Minimum tillage	73.5	17.2	3.43	3.53	3.65	3.54
Conventional	68.2	16.4	3.27	3.37	3.41	3.35
LSD (0.05)	5.75	1.112	0.348	0.360	0.412	-
CV (%)	14.52	10.56	10.35	10.23	9.87	-

Seed yield and yield components of mungbean

Conservation agriculture is influenced by the different characteristics of mungbean. Consequently, pod plant^{-1}, seeds pod^{-1}, 1000-seed weight, and seed yield were influenced significantly whereas plants m^{-2} was statistically insignificant (Table 10). The maximum pod plant^{-1} was recorded in the raised bed with 30% straw retention (22.3) which was statistically identical to that of the strip and minimum tillage with 30% straw retention. The minimum pods plant^{-1} was found from conventional with 30% straw retention. Similarly, maximum seeds pod^{-1}, 1000 seed weight, and seed yield were recorded from both raised bed and strip-till with 30% straw retention. This might be due to the border effect with more uptakes of nutrients. 26% yield increased from raised bed with 30% straw retention and it was identical to the strip and minimum tillage. Zero tillage did not give a higher yield increase but it was higher than conventional with 30% straw retention.

Table 10. Average three years yield and yield components of mungbean as influenced by different tillage options and straw retention from 2018-19, 2019-20& 2020-21 (Pooled data)

Treatments	Plant stands m^{-2}	Pods plant^{-1}	Seeds pod^{-1}	TSW (g)	Seed yield (t ha^{-1})	(%) Yield increase over conv.
ZT+ 30% SR	38.5	17.8	7.87	50.8	1.02	-
ST+ 30% SR	37.8	18.5	8.70	51.2	1.12	8.0
PRB+ 30% SR	39.2	21.7	9.12	52.0	1.25	18.0
MT+ 30% SR	38.9	22.3	10.24	52.4	1.37	26.0
CT+ 30% SR	39.3	21.4	9.04	50.3	1.21	15.0
CV (%)	11.63	10.42	3.48	2.32	3.47	-
LSD (0.05)	ns	3.24	0.595	0.892	0.213	-

ns; *f*-test was not significant

T. *aman* (monsoon) rice

Effect of tillage options on weed population and biomass at 40 DAS in T. *aman* field

The effect of tillage options on weed population and weed dry biomass at 40 days after sowing (DAS) of T. aman in Wheat-Mungbean-T. *aman* rice was significant (Table 11). The total no. of weeds (54.55) and dry biomass (20.15 g m^{-2}) were significantly higher in CT plots while the number of broadleaf and sedges were higher in CT plots and the number of grasses was also in CT plots. The lower number of total weeds (13.56) and dry biomass (3.49 g m^{-2}) were recorded in the PRB systems plot followed by strip tillage (18.29) and biomass (4.23 g m^{-2}).

Table 11. Weed population and dry biomass as influenced by different weed management treatments at 40 DAS of T. aman rice in Wheat-Mungbean-T. *aman* rice cropping pattern

Treatments	Grass		Broadleaf		Sedge		Total	
	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})
ZT	6.12	2.05	7.54	2.22	6.12	1.58	19.78	5.85
ST	7.78	1.98	5.75	1.12	4.76	1.13	18.29	4.23
PRB	5.12	1.45	4.42	1.02	4.02	1.02	13.56	3.49
MT	11.27	3.74	9.34	3.05	8.32	2.72	28.93	9.51
CT	24.73	9.11	12.70	4.21	17.12	6.83	54.55	20.15
LSD	1.212	0.54	1.27	0.78	1.087	0.87	4.412	3.325
CV (%)	9.87	8.78	10.52	8.89	10.32	8.58	11.25	9.87

Effect of weed management on weed population and biomass at 40 DAS in T. *aman* field

Weed management treatment had a significant impact on weed population and weed dry biomass in T. *aman* field at 40 DAS (Table 12). The WM_4 which indicates the number of weed control showed the highest number of total weeds (39.0) and weed dry biomass (12.81 g m^{-2}). The WM_2 that included Carfentrazone-ethyl (Affinity) recorded the least no. of total weeds (11.1) and total dry biomass (4.18 g m^{-2}). The Carfentrazone-ethyl (Affinity) was applied to 30 DAS that controlled weeds successfully at a later stage. However, hand weeding WM_3 showed a similar performance of weed suppression as WM_2.

Table 12. Weed population and dry biomass as influenced by different weed management treatments at 40 DAS of T. aman rice in Wheat-Mungbean-T. *aman* rice cropping pattern

Treatments	Grass		Broadleaf		Sedge		Total	
	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})	No.	Biomass (g^{-2})
WM_1	7.2	2.90	3.5	1.27	6.4	3.30	17.1	7.47
WM_2	4.3	1.94	3.3	1.12	3.5	1.12	11.1	4.18
WM_3	5.2	2.01	3.4	1.12	3.3	1.12	11.9	4.25
WM_4	14.8	5.25	11.4	3.72	12.8	3.84	39	12.81
LSD	1.372	0.67	1.03	0.235	1.08	0.45	2.14	1.72
CV (%)	9.67	7.89	5.79	7.32	10.88	11.24	10.34	9.94

WM_1= Pre-plant, WM_2= Post Emergence, WM_3= Hand weeding, and WM_4 =No weed control

Grain yield and yield components of T. *aman* (monsoon) rice

Conservation agriculture is influenced by different characteristics of T. *aman* rice. Consequently, grains panicle^{-1} and 1000 grain weight were influenced significantly whereas hill m^{-2}, panicles hill$^{-1,}$ and grain yield were statistically insignificant (Table 13). The maximum grains panicle^{-1} (133.8) was recorded in a raised bed with 30% straw retention which was statistically similar (127.2 & 124.6) with that of strip and PTOS with 30% straw retention. The minimum grains panicle^{-1} (122.4) was found from strip tillage with 30% straw retention and it was similar to conventional with 30% straw retention. Similarly, the highest 1000 grain weight (25.2 g) was recorded from both raised bed and strip-till (24.8 g) with 30% straw retention. Similar findings are also being reported by Gupta *et al.* (2006) in their experiments. Average of two years' maximum grain yield was recorded (4.40 t ha^{-1}) from raised bed systems and it was identical to that of minimum tillage by PTOS (4.38 t ha^{-1}) and strip-till (4.26 t ha^{-1}) with 30% straw retention. The average minimum grain yield (4.24 t ha^{-1}) was obtained from the zero tillage.

Table 13. Grain yield and yield components of T. *aman* rice as influenced by different tillage options and straw retention in 2019-20 and 2020-21

Treatments	Hill m^{-2}	Panicles hill^{-1}	Grains panicle^{-1}	TGW (g)	Grain yield (t ha^{-1})		Av. two years grain yield (t ha^{-1})
					2019-20	2020-21	
ZT+ 30% SR	28.7	18.1	126.8	23.8	4.26	4.21	4.24
ST+ 30% SR	27.5	17.7	122.4	23.7	4.19	4.32	4.26
PRB+ 30% SR	29.5	19.2	127.2	24.8	4.41	4.39	4.40
MT+ 30% SR	29.8	19.4	133.8	25.2	4.43	4.32	4.38
CT+ 30% SR	28.7	18.2	124.6	23.7	4.33	4.19	4.26
CV (%)	9.76	6.85	8.45	5.75	10.87	9.56	10.77
LSD (0.05)	ns	ns	0.325	0.422	ns	ns	ns

Grain yield and Economic analysis of different treatment combinations

Grain yield and economic analysis of different tillage options shown in Wheat-Mungbean-T. *aman* rice cropping pattern has been given in Table 14. The higher gross return (Tk. 89400 ha^{-1}) and gross margin (Tk.57350 ha^{-1}) were obtained from raised bed planting followed by the strip-tillage method (Tk. 56980 ha^{-1}). The lower gross return (Tk. 74600 ha^{-1}) and gross margin (Tk. 40115 ha^{-1}) from conventional tillage practice.

Table 14. Grain yield and economic analysis of different tillage options

Treatments	Grain yield (t ha^{-1})	Gross return (Tk. ha^{-1})	Total cost (Tk. ha^{-1})	Gross margin (Tk. ha^{-1})
Conv. X 30% straw	3.73	74600	34485	40115
Zero X 30% straw	4.08	81600	29235	52365
Strip X 30% straw	4.41	88200	31220	56980
Bed X 30% straw	4.47	89400	32050	57350
PTOS X 30% straw	4.14	82800	33150	49650

On the other hand, the highest gross return (Tk. 90800 ha^{-1}) and gross margin (Tk. 55040 ha^{-1}) were obtained from the weed management option in WM_2 (pre-plant weed management) followed by WM_1 (Tk. 88200 and Tk. 50715 ha^{-1}, respectively) (Table 15). The lower gross return (Tk. 58600 ha^{-1}) and gross margin (Tk. 24115 ha^{-1}) from WM_4 weed management practices and hand weeding practices.

Table 15. Grain yield and economic analysis of weed management options

Treatments	Grain yield (t ha^{-1})	Gross return (Tk. ha^{-1})	Total cost (Tk. ha^{-1})	Gross margin (Tk. ha^{-1})
WM_1	4.41	88200	37485	50715
WM_2	4.54	90800	35760	55040
WM_3	4.39	87800	42650	45150
WM_4	2.93	58600	34485	24115

** Price: Wheat Tk. 25 kg^{-1}
Urea: Tk.16 kg^{-1}, TSP: Tk. 22 kg^{-1}, MoP: Tk.15 kg^{-1}, Gypsum: Tk.7 kg^{-1}, Boron: Tk.220 kg^{-1}
Strip tillage cost 400Tk $bigha^{-1}$
Conventional tillage cost = l000Tk $bigha^{-1}$
Round up (500 m1) = 400 Tk, Affinity (100g) = 170 Tk.

CONCLUSION

The study concludes that both strip tillage and raised bed planting with both pre and post-emergence weedicides (Carfentrazone-ethyl Plus isoproturon: Affinity) for wheat + Post emergence (Fenoxapropp-ethyl: Whipsuper) for mungbean + Post-emergence (Bensulfuron methyl and Bispyribac Sodium: Serious Plus 30 EC) for rice can be a promising option for controlling weed species effectively and also for getting attainable crop yields as well maximum economic benefits in wheat-mungbean-rice cropping pattern in Bangladesh.

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