



Research Article

Resource conservation technology for sustainable productivity of intensive rice-based cropping pattern in Bangladesh

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Abstract

Exhaustive conventional tillage and removing residues of previous crops in the rice-based cropping system are labor intensive, costly, soil destructive and non-ecofriendly. In recent years, increased concerns for healthier food production and environmental quality, and increased emphasis on sustaining the productive capacity of soils, have raised concern in the maintenance and improvement of soil organic matter through appropriate land use and management practices. Strip tillage with the application of herbicides and crop residue mulching are being developed to overcome this challenge. A two-year experiment of the summer rice-mustard-winter rice (R-M-R) system was conducted at the farmers' field in the northern Bangladesh during 2014-2016. Summer rice (*BRR1 hybrid dhan6*), mustard (*BARI Mustard 14*) and winter rice (*BRR1 dhan28*) were grown under, T₁: Conventional tillage (CT) + three hand weeding (Control) and T₂: Pre-plant herbicide (PRE) + strip tillage (ST) + pre-emergence herbicide (PE) + post-emergence herbicide (PO) with two levels of crop residue mulching, M₀: no-mulch and M₅₀: 50% standing mulch. The CT consisted of two primary tillage operations by a two-wheel tractor, and ST had done by a Versatile Multi-crop Planter in a single-pass process. The PRE (glyphosate) and PE (pendimethalin) in all crops and the PO (ethoxysulfuron-ethyl in rice and isoproturon in mustard) were applied at recommended dose and time. The combination of applied PRE, ST, followed by PE and PO herbicide and the retention of 50% mulch fetched the highest yield and economic returns of individual crop and the productivity of the summer rice-mustard-winter rice system.

Introduction

Planting of crops in exhaustive tilled soil after removing the residues of previous crops is the most common traditional cropping practice in Bangladesh. Generally, rice grown in the soil is usually puddled, followed by manual transplanting. Non-rice crops (mustard, wheat etc.) are grown in heavily pulverized soils. These traditional practices pose concerns regarding the sustainability of crop production. Intensive tillage degrades soil

structure, depletes Soil Organic Matter (SOM), and increases labor and fuel requirements and overall production costs [1]. It also lags the establishment of succeeding crops, leading to reduced yield. Further, there is a growing concern regarding labor scarcity for agriculture due to less profit and migration from rural to urban areas within and outside the countries [2]. Thus, there is an urgent need for labor and other input-efficient alternate systems that produce more at fewer costs. Without a new and more sustainable increase to productivity,

agricultural supply will hardly keep pace with the rapidly rising demand caused by increasing population and changing consumer preferences with income growth. Potential strategies to tackle these challenges could be the Resource Conserving Technology (RCT).

The RCT primarily focus on soil resource savings through minimal tillage, ensuring soil nutrients and moisture conservation through crop residues and adoption of spatial and temporal crop sequencing [3]. Reduced tillage with residue retention can improve soil physical, chemical, and biological properties, facilitate timely planting, and decrease production costs related to labor, fuel, and machinery. The use reduced tillage can also reduce drudgery and sustain profit [4]. However, a meta-analysis of a large set of global data demonstrated RCT may potentially tackle labor and energy shortage in agriculture of Bangladesh.

The summer rice-mustard-winter rice rotation is the principal cropping system in Bangladesh. In this system, summer rice is grown during the warm rainy season (June-September), followed by winter rice during January-May, keeping the land fallow for three months in October-December. There is potential to grow a short duration crop of 85-90 days life span like the mustard under summer rice-mustard-winter rice (R-M-R) system, providing important benefits to food security. While the potential for R-M-R systems has received considerable attention in Bangladesh utilizing the advantages of RCT principles.

In RCT, several minimum soil disturbing options could establish crops, and the Strip Tillage (ST) is one of them which involves 15-25% disturbance of soil surface with a slot up to 6 cm deep and 4-6 cm wide [5]. The farmers are showing interest in growing crop with ST because it reduces cultivation cost, protects soil degradation, and saves water without yield sacrifice. But the ST is criticized due to the inefficient control of weeds. Because the conventional intensive tillage controls the existing weeds by burying them and their seeds into the soil, resulting in the less early emergence of weeds [6]. By contrast, for effective weed control in ST, pre-plant non-selective herbicides must be used to kill the existing weeds. Subsequently, pre-emergence herbicide followed by a post-emergence also needs to apply because of remaining viable weed seeds on the surface still after pre-plant herbicide application [7].

Now-a-days farmers are switching to herbicidal weed control as it is a quick, effective, and low-cost weed control method to address the crisis of labor availability with high wages during peak demand periods [8]. Previous studies confirmed the application of pre-plant, pre-emergence and post-emergence herbicides ensured continuous and effective control of weeds and provided the better yield over manual weeding [9]. But, the repeated use of herbicide with the same mode of action may lead to developing quick herbicide resistance in weeds, making weed control more difficult [10]. Moreover, herbicides' persistence in the soil and its detrimental effects on succeeding crops is a significant issue. Furthermore, shifts in weed populations due to continuous use of a particular

herbicide, less availability of appropriate herbicide molecules with the higher prices, and environmental pollution-related issues urge the need to adopt integrated weed management strategies to increase the sustainability of ST. Agronomic options like crop residues and crop intensification had reported earlier to manage weeds in ST practice [11].

There are many pieces of evidence that crop residue retention and crop intensification promote nutrient cycling, increase nutrients availability to crops, and increases SOM content, additionally suppress weeds and increases soil water content, and reduce irrigation water requirements by suppressing soil evaporation [12]. Residue retention could also play an important role in R-M-R systems, where the residues of both crops are generally removed from the fields. High yielding R-M-R systems are more extractive of nutrients, particularly N, P, or K than rice-rice systems. Further, the inclusion of mustard in the system and its' residue retention can improve the nitrogen economy of the following crop.

However, although there are several studies on the effects of ST and residue mulching options on the productivity of different cropping systems, the research work on this practice under R-M-R system is not done on a large scale in Bangladesh. Thus, the current two years of study were conducted with the R-M-R systems with alternative tillage and residue management options to identify Bangladesh's most productive and profitable options.

Materials and methods

Experimental site and season with the edaphic, and climatic condition

A two-year crop sequence (summer rice-mustard-winter rice) experiment was conducted at the farmers' field located at Durbachara village of Bhangnamari union, situated at Gouripur sub-district under Mymensingh district of Bangladesh (24°75' N and 90°50' E at 18 m altitude) during 2014-15 and 2015-16 consecutive years.

The experiment site is situated on the Old Brahmaputra Floodplain of predominantly dark grey non-calcareous alluvium soils under the *Sonatala* series. The experimental field was flood-free medium-high land, and the pH of sandy clay loam soil (50% sand, 23% silt, 27% clay) was 7.2.

The area generally receives 172 mm mean annual rainfall, about 95% of which occurs from May to September (Figure 1). Total rainfall was the highest during the summer rice season and lowest in the winter rice season in both years. Sometimes maximum temperature was above about 33°C in the month of April-May and the minimum temperature about 12°C in January. Sunshine hours were maximum during the month October-November and March in both years.

Experimental materials, treatments, and design

A summer season (June-September) rice (*Oryza sativa* L.) - rabi (October-December) season mustard (*Brassica napus* L.) - winter season (January-May) rice (*Oryza sativa* L.) cropping

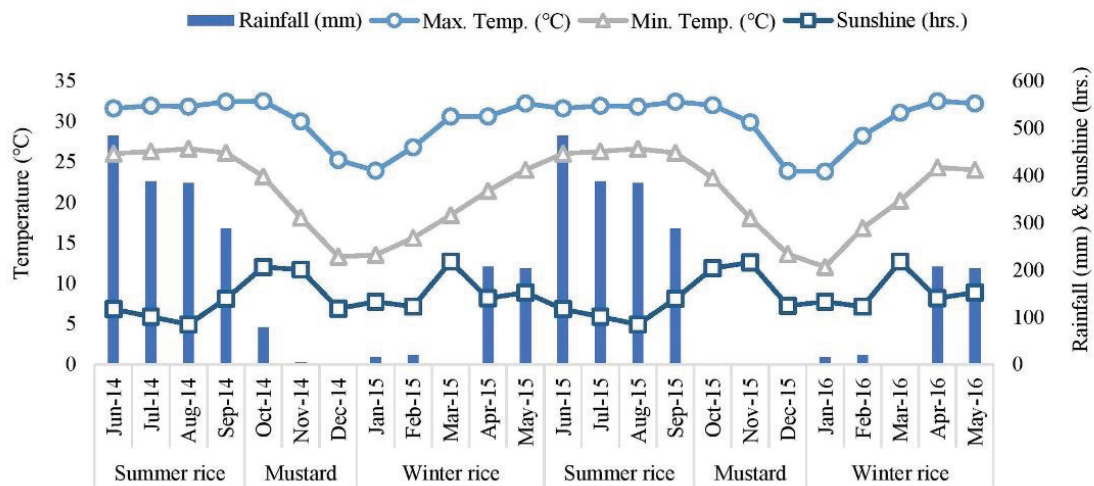


Figure 1: Monthly average temperature and rainfall and sunshine distribution pattern in 2014-2016.

pattern was practiced instead of summer rice-winter rice pattern. The present study deals with these three crops grown in two consecutive years on the same plots with two weed control practices and two levels of residues of previous crops as mentioned below:

Factor A: Crop establishment method

Conventional Practice (CP) = Conventional tillage (CT) with 3 hand weeding (HW): CT + 3 HW

RCT practice = Combination of applied Pre-plant herbicide (PRE) in strip tillage (ST), followed by sequential application of a pre-emergence herbicide (PE) and a post-emergence herbicide (PO): PRE + ST + PE + PO

Factor B: Crop residue retention levels

M_0 : No-mulch (Farmers' practice)

M_{50} : 50% standing mulch of previous crops

Treatments were replicated four times and arranged in a randomized complete block design.

Planting operations

In each 9 m × 5 m plot, CT was done using a two-wheel tractor (2 WT) by four plowings and cross plowing followed by sun-drying for two days, finally flooding and leveling. The ST had done by a Versatile Multi-crop Planter (VMP) in a single pass operation. Four rows each of 6 cm wide and 5 cm deep were made at a time at the row spacing of respected crop. Three days before ST operation, glyphosate herbicide had applied at the recommended dose. In CT, we did 3 HWs at 25, 45, and 65 DAT/S. Herbicides had applied in ST by hand-operated knapsack sprayer fitted with a flat-fan nozzle at a spray volume of 300 L ha⁻¹. The herbicides of different groups used in this experiment had mentioned in Table 1. Among the all herbicides, only ethoxysulfuron-ethyl was applied in standing water condition in the field while rest others were applied in field capacity condition.

Table 1: Herbicides and rates of application used in the experiment.

Group	Herbicides Name	Dose (ha ⁻¹)			Time of application
		Summer rice	Mustard	Winter Rice	
Pre-plant	Glyphosate	3.7 L			3 DBT/S
Pre-emergence	Pendimethalin	2.5 L			3 DAT in rice, IAS in mustard
Post-emergence	Ethoxysulfuron-ethyl	100 g	-	100 g	25 DAT/S
	Isoproturon	-	650 ml	-	

Notes: DBS: Days Before Seeding; DBT: Days Before Transplanting; IAS: Immediately After Seeding; DAS: Days After Seeding; DAT: Days After Transplanting

In the no-residue treatment, planting was done without retaining residues of previous crop. In 50% residue practice rice and mustard was harvested keeping 50% plant standing in the respective plots. Summer rice (cv. *BRR1 hybrid dhan6*), mustard (cv. *BARI Sharisha 14*) and winter rice (cv. *BRR1 dhan28*) were grown in this study. In rice (after harvest mustard and rice, respectively), the final field was prepared by additional flooding and laddering in CT. After ST, the land was inundated with 3-5 cm water one day before transplanting to allow the strips to be soft enough to transplant rice seedlings. Then seedlings were transplanted (single seedling of summer hybrid rice and 2/3 seedling of winter rice hill⁻¹) in the raised furrows. Seeds of mustard (after summer rice harvest) was sown in lines on the same date using VMP in ST and manually in CT. In this study, 10 kg and 20 kg seeds of summer hybrid rice and winter rice, respectively, was used. 25- and 35-days aged seedling of summer and winter rice seedlings were transplanted at 25 cm × 15 cm distance. Seven kg seeds of mustard were sown continuously seeding at 20 cm apart lines.

Cultural operations

The recommended dose of Nitrogen (N), Phosphorus (P), Potassium (K) and Sulfur (S) was applied to the respective crop. The N in the form of urea was applied @ 80 and 20 ha⁻¹ in rice and mustard, respectively. A basal dose of phosphorus (22 and 22 kg ha⁻¹) from triple super phosphate, potassium (35 and 15



kg ha⁻¹) from muriate of potash and sulfur (12 and 10 kg ha⁻¹) from gypsum was applied to rice and mustard, respectively. The entire amount of P, K, and S was broadcasted before seeding/transplanting and mulching in all crops. In rice, N was applied in three equal installments at 15, 30 and 45 DAT. While in mustard the full amount of N was applied before seeding.

In summer rice, no additional irrigation was required due to sufficient rainfall. In winter rice, three irrigations were applied at 20, 55 and 80 DAT. In mustard, two irrigations with proper drainage were done at 25 and 45 DAS. Adequate plant protection measures were taken throughout the crop growing season as per the recommendations.

Measurements

Yield contributing characters of rice (number of panicles m⁻², number of grains, and sterile spikelets panicle⁻¹ and 1000-grains weight) and mustard (number of plants m⁻², and siliqua plant⁻¹ and 1000-seeds weight) have transcribed from randomly selected ten hills in rice and 10 plants from mustard before harvest of each crop. Harvesting had done at maturity when 80% of rice grains and mustard siliqua became golden yellow, from the central 3 m × 1 m area from 3 spots of each plot. The weight of 1000 grains/seeds and yield was calculated at 14% moisture content. Finally, the grain/seed yield had converted to t ha⁻¹. Total pattern productivity of the cropping pattern was estimated by calculating rice equivalent yield (REY) as follows.

$$REY (t ha^{-1}) = \frac{\sum \text{yield of individual crop (t ha}^{-1}) \times \text{market price of that crop (Tk. t}^{-1})}{\text{market price of rice (Tk. t}^{-1})}$$

The economics of crop production was estimated following the partial budgeting system. 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, residues, fertilizer, irrigation, etc. The gross return was calculated based on the market price of grain and byproducts. The gross benefit was calculated by deducting the variable cost from the gross recovery. The benefit-cost ratio (BCR) was calculated by computing the ratio of gross income to total costs of production.

Data analysis

Data were subjected to analysis of variance where; treatment means were separated by the Duncan's Multiple Range Test at P<0.05. The statistical package program STAR was used to analyze research data.

Results and Discussion

Effect of treatments on the yield of summer and winter rice, and mustard

In this section, we have presented the mean data of the two-year study. Data revealed that tillage systems, weed control practice and residue mulching exerted significant (P<0.05) effect the number of productive tillers m⁻² and grains panicle⁻¹ and grain yield were influenced significantly (P<0.05)

of both summer and winter rice, whereas the number of hill m⁻², sterile spikelets panicle⁻¹ and 1000-grains weight were statistically non-significant (Tables 2,3). The highest number of productive tillers m⁻² and grains panicle⁻¹ was recorded in PRE + ST + PE + PO plus 50% residue, followed by the same treatment without residue. While the lowest value was recorded in CT + 3 HW without residue, followed by CT + 3 HW with 50% residue. Differences in the number of productive tillers m⁻² and grains panicle⁻¹ had attributed the yield of rice on these treatments, respectively. About 14% higher yield in PRE + ST + PE + PO than CT + 3 HW and 6% higher yield in 50% residue than no-residue was found.

In mustard, the number of siliqua plant⁻¹ and seed yield were influenced significantly (P<0.05), whereas the number of plants m⁻², seeds siliqua⁻¹, 1000-seeds weight was statistically non-significant by the combined effect of tillage, weed control and residue levels (Table 4). The maximum number of siliqua plant⁻¹ was recorded in PRE + ST + PE + PO with 50% residue followed by the same treatment without residue. The lowest number was recorded in CT + 3 HW without or with 50% residue. The highest seed yield recorded in PRE + ST + PE + PO with 50% residue followed by the same treatment without residue. While the lowest yield was recorded in CT + 3 HW without residue followed by CT + 3 HW with 50% residue. The variation of yield might have attributed to the number of siliquas plant⁻¹. About 20% higher yield in PRE + ST + PE + PO than CT + 3 HW and 9% higher yield in 50% residue than no-residue was recorded.

Table 2: Effect of treatments on the yield attributes and yield of summer rice.

Treatments	Hills m ⁻² (no.)	Tillers m ⁻² (no.)	Grains panicle ⁻¹ (no.)	Sterile spikelets panicle ⁻¹ (no.)	1000-grains weight (g)	Grain yield (t ha ⁻¹)	
CT + 3 HW	M ₀	27	323 ^d	202 ^c	49	33.2	7.41 ^c
	M ₅₀	27	340 ^c	224 ^b	46	33.8	7.59 ^b
PRE + ST + PE + PO	M ₀	27	399 ^b	269 ^a	45	35.9	8.34 ^{ab}
	M ₅₀	27	411 ^a	273 ^a	28	36.4	8.55 ^a
LSD _(0.05)	1.93	9.21	11.75	5.05	3.80	0.23	

Notes: CT: Conventional Tillage; HW: Hand Weeding; PRE: Pre-Plant Herbicide; ST: Strip Tillage; PE: Pre-Emergence Herbicide; PO: Post-Emergence Herbicide; M₀: no-mulch; M₅₀: 50% mulch; LSD: Least Significant Difference.

Table 3: Effect of treatments on the yield attributes and yield of winter rice.

Treatments	Hills m ⁻² (no.)	Tillers m ⁻² (no.)	Grains panicle ⁻¹ (no.)	Sterile spikelets panicle ⁻¹ (no.)	1000-grains weight (g)	Grain yield (t ha ⁻¹)	
CT + 3 HW	M ₀	27	234 ^d	147 ^c	36	29.60	5.37 ^c
	M ₅₀	27	246 ^c	163 ^b	33	30.23	5.50 ^b
PRE + ST + PE + PO	M ₀	27	289 ^b	195 ^a	33	32.10	6.05 ^{ab}
	M ₅₀	27	298 ^a	198 ^a	21	32.48	6.20 ^a
LSD _(0.05)	1.93	6.68	8.52	3.66	3.40	0.17	

Notes: CT: Conventional Tillage; HW: Hand Weeding; PRE: Pre-Plant Herbicide; ST: Strip Tillage; PE: Pre-Emergence Herbicide; PO: Post-Emergence Herbicide; M₀: no-mulch; M₅₀: 50% mulch; LSD: Least Significant Difference.

**Table 4:** Effect of treatments on the yield attributes and yield of mustard.

Treatments		Plants m ⁻² (no.)	Siliques plant ⁻¹ (no.)	Seeds siliqua ⁻¹ (no.)	1000-seeds weight (g)	Seed yield (t ha ⁻¹)
CT + 3 HW	M ₀	60	41 ^c	10	40.6	1.33 ^{cd}
	M ₅₀	62	40 ^c	10	40.8	1.41 ^c
PRE + ST + PE + PO	M ₀	62	44 ^b	10	41.1	1.73 ^b
	M ₅₀	63	48 ^a	11	41.3	1.82 ^a
LSD _(0.05)		15.25	3.24	0.56	0.89	0.21

Notes: CT: Conventional Tillage; HW: Hand Weeding; PRE: Pre-Plant Herbicide; ST: Strip Tillage; PE: Pre-Emergence Herbicide; PO: Post-Emergence Herbicide; M₀: no-mulch; M₅₀: 50% mulch; LSD: Least Significant Difference.

Differences in the yield among the treatments might be attributed to the variation in yield contributing characters of crops like the number of productive tillers m⁻², and grains panicle⁻¹ both summer and winter rice while the number of siliqua plant⁻¹ in mustard. The higher yield in ST of present study agrees the research findings of previous study found the higher crop yield in ST than CT due the beneficial effect of ST on grain yield could be attributed to that change in soil properties. Higher total soil porosity, better soil moisture conservation and better soil physical environment favored the root growth and nutrient uptake resulted in increase in grain yield [13]. It was also reported that the higher and more stable crop yields in ST than CT occurred from the formation of surface crust by heavy pulverization of the surface soil [14], leading to loss of structure and homogenization of the cultivated layer, which resulting in discontinuity of the conducting pores and compaction of the soil below the cultivated layer due to the pressure from the tractor wheels in CT.

In addition to that, crop yield increase in ST may also reported through improving soil fertility by conserving soil and water and sequestering organic carbon in farmland soils that reduces the extremes of water logging and drought [15,16]. In another study, yield increase in ST also might be associated with the improvement of soil structure and stability thereby facilitating better drainage and water holding capacity. The higher infiltration rates and propitious moisture dynamics supported up to 30% yield increase in maize [7,18] due to increase of soil organic carbon, soil total nitrogen and soil total phosphorus by 25, 18 and 7%, respectively in the ST than CT. These findings have implications for understanding how conservation tillage practices increase crop yield by improving soil quality and sustainability in ST of conservation agriculture practices.

The physical shock or disturbance in normal growth of crop plants occurred during hand weeding CT plots which may retards the development of crops for short times and ultimately yield might be affected [19]. By contrast, herbicides did not exert any shock to crop plant. Herbicides applied at field rates, also have hormetic effect [20,21] influencing the growth and development of crops which may have attributed to obtains better crop yields in this study. Glyphosate can increase plant growth, induce shikimic acid accumulation, increase photosynthesis and stomatal opening which leads to increase seed production with shortening the plant life cycle [22]. On the other hand, glyphosate was reported to inhibit rust

diseases in crop thus improving grain yield [23]. The results of glyphosate, together with the pendimethalin can induce 25% higher stimulation in total biomass growth in crop plant [24] while pendimethalin and ethoxysulfuron-ethyl [25] is reported to contribute total biomass in rice led to produce higher number of tillers m⁻² area and higher yield. The above discussed reasons might lead to obtain higher seed yield of mustard by pendimethalin and isoproturon, in ST than CT in the present study.

In this study, retention of 50% crop residue increased grain yield of summer and winter rice and mustard by about 3-4% over no-residue. This might be due to the beneficial effect of crop residues on the soil fertility, which is associated with the betterment of crop yield. Because crop residues are an important source of SOM that can be returned to soil for nutrient recycling, and to improve soil physical, chemical and biological properties. Retention of plant residues has been found to have many long-term benefits around the world. These crop stubble constitutes a mulch cover that protects the soil against run-off and erosion and increases the percentage of SOM and nutrients in the surface soil layer [26]. The capacity of the soil surface to intercept rainfall is improved because of changes in soil roughness, soil surface porosity, and hydraulic conductivity of the topsoil. Mulching also reduces temperature extremes and direct evaporation [15]. Thus, crop residues regulate the nutrient cycles within the soil. Moreover, the effects of residue return to soil and associated tillage on soil physical, chemical and biological properties occur concurrently and hence are difficult to separate from each other. Another study has shown that 80% of changes in soil C levels under cropping were attributable to tillage (conservation vs. conventional) and 20% to residue management (stubble retained vs. burnt) [27]. The cumulative effect of conservation tillage and crop residue mulching might have enhanced the better yield in 50% residue retention practice than no-residue in this study. Hence, the above discussed points confirm the result of present study that one pre-plant herbicide before ST, followed by one pre- and a post-emergence herbicide with 50% crop residues, is an excellent alternative to obtain the higher crop yield CT with manual hand weeding without retaining residue.

Effect of treatments on the benefit-cost ratio (BCR) of summer and winter rice, and mustard

In all the three crops, the maximum average BCR had transcribed from the PRE + ST + PE + PO plus 50% residue followed by the same treatment without residue. While the lowest BCR was recorded from the CT + 3 HW without residue, followed by the same treatment with 50% residue (Figure 2). The treatment PRE + ST + PE + PO achieved about 39, 21 and 30% higher BCR than CT + 3 HW in summer and winter rice and mustard, respectively. On the other hand, 50% mulching increased the BCR by about 7% than no-mulching in all the crops. The highest BCR in PRE + ST + PE + PO was attributed to the highest yield and lowest production cost in this treatment. The lowest production cost was calculated due to considerable savings in the cost of tillage costs, weeding and labor requirements in all the crops (Table 5).

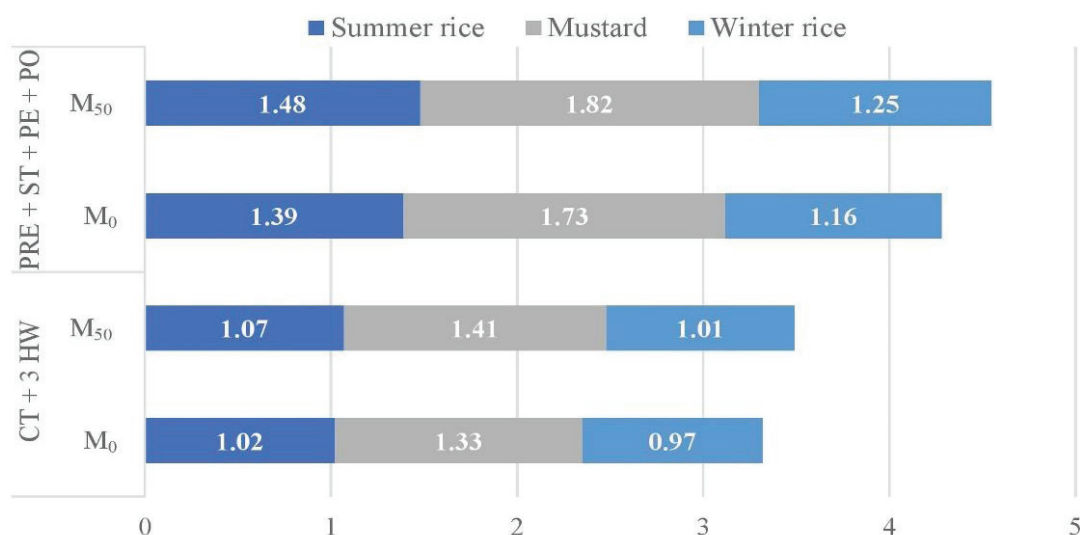


Figure 2: Effect of treatments M on the benefit-cost ratio (BCR) of summer and winter rice and mustard.

Partial economic analysis disclosed that PRE + ST + PE + PO, with 50% residue, earned the highest profit over CT + 3 HW without residue. Variation in BCR might be attributed to the variation in grain yield and cost required for cultivation in CT and ST. Savings in the PRE + ST + PE + PO over CT + 3 HW might have attributed to the savings from tillage operations (56, 45, 67%), weeding costs (21, 40 and 58%) and labor requirements (25, 29 and 22%) in summer rice, mustard, and winter rice, respectively (Table 5).

This estimation is in line with previous study estimating 70% [28] and 49% [29] savings in land preparation in ST over CT. Where the ST recorded the lowest land preparation cost (ranging from US\$ 32.541 to US\$ 33.25 ha⁻¹) and the CT incurred the maximum cost (corresponding to US\$ 88.24 ha⁻¹ to US\$110.29 ha⁻¹) due to the greater number of tillage passes and fuel consumption. On the other hand, ST reduced fuel and labor requirements in land preparation and fertilizer application due to limited tillage operations and TSP fertilizer applied with VMP during tillage operation. Labors have not encountered any difficulty in transplant seedlings in ST due to soil softness by inundating the field. At the same time mustard were sown simultaneously during ST operation by the VMP.

Weed control using herbicides provided higher net-benefits in ST over manual three times hand weeding in CT in this study. This finding agrees with the previous study, where 37.1 - 73.4% savings were calculated from herbicidal weed control over manual weeding [30]. Previous research also reported higher weeding costs in manual weeding are economically non-profitable over herbicidal weed control and the application of appropriate herbicide can replace hand weeding successfully [31].

About 7% higher profit in 50% residue might be occurred solely from about 5-9% higher grain yield than no-residue in all crops of summer rice-mustard-winter rice system. Therefore, the study claimed that, crop cultivation using

Table 5: Effect of tillage practices on inputs requirements in summer rice, mustard and winter rice

Crops	Treatments	Tillage operation		Weed control		Labor requirement	
		Costs	Savings (%)	Costs	Savings (%)	Man-days	Savings (%)
Summer rice	CT + 3 HW	81.2	-	124.0	-	167	-
	PRE + ST + PE + PO	35.3	56	97.2	21	125	25
Mustard	CT + 3 HW	65.0	-	80.0	-	150	-
	PRE + ST + PE + PO	35.3	45	48.0	40	106	29
Winter rice	CT + 3 HW	108.2	-	309.0	-	175	-
	PRE + ST + PE + PO	35.3	67	131.0	58	136	22

Notes: CT: Conventional Tillage; HW: Hand Weeding; PRE: Pre-Plant Herbicide; ST: Strip Tillage; PE: Pre-Emergence Herbicide; PO: Post-Emergence Herbicide; Costs are in US\$

strip tillage, applied a pre-plant, pre-emergence, and post-emergence herbicide in sequence; with the retention of 50% crop residue could achieve the higher profit compared to the existing conventional practice of crop cultivation.

Total pattern productivity of summer rice -mustard-rice pattern

The tillage options, weed control practices and residue mulching had influenced the productivity in terms of rice equivalent yield (REY) of the pattern (Table 6). Results revealed that PRE + ST + PE + PO and 50% residue increased productivity by 21 and 4% than CT + 3 HW and no-residue, respectively. It was found that the incorporation of mustard had increased the productivity of the R-M-R system by 41% than the R-R system.

The total pattern productivity of the summer rice-mustard-winter rice pattern was about 41% higher than the summer rice-fallow-winter rice pattern. The incorporation of mustard with an average yield of 1.57 t ha⁻¹ might have benefited such benefit in the summer rice-fallow-winter rice pattern. This



Table 6: Effect of treatments on total pattern productivity of summer rice -mustard-winter rice pattern.

Treatments	Yield (t ha ⁻¹) of			REY of rice-mustard-rice system	
	Summer rice	Mustard	Winter rice		
CT + 3 HW	M ₀	7.41 ^c	1.33 ^{cd}	5.37 ^c	13.80 ^d
	M ₅₀	7.59 ^b	1.41 ^c	5.50 ^b	14.30 ^c
PRE + ST + PE + PO	M ₀	8.34 ^{ab}	1.73 ^b	6.05 ^{ab}	16.60 ^{ab}
	M ₅₀	8.55 ^a	1.82 ^a	6.20 ^a	17.50 ^a
LSD _(0.05)	0.23	0.21	0.17	0.88	

Notes: CT: Conventional Tillage; HW: Hand Weeding; PRE: Pre-Plant Herbicide; ST: Strip Tillage; PE: Pre-Emergence Herbicide; PO: Post-Emergence Herbicide; M₀: no-mulch; M₅₀: 50% mulch; LSD: Least Significant Difference. The market price of summer rice, mustard, and winter rice @ 194.58, 588.23 and 205.89 US\$ ha⁻¹, respectively. 1 US\$ = 84.75 BDT on January 09, 2021.

finding agrees with earlier studies reveal that including one or more short duration crop(s) in existing cropping patterns increases system productivity [32].

Conclusions

Resource conserving technology is a novel crop management approach for intensive rice-based cropping systems in Bangladesh. The study concluded that the strip tillage integrated with effective herbicides and residue mulching was a profitable alternative to manual weeding in conventional tillage. This approach also saves labor for crop cultivation and sustainable intensification of the summer rice-mustard-winter rice cropping system in Bangladesh under resource conserving technology practice.

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