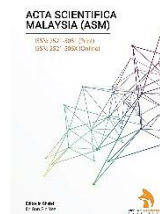


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RESEARCH ARTICLE

MINIMUM TILLAGE NON-PUDDLED TRANSPLANTED RICE (*ORYZA SATIVA* L.): WEED CONTROL AND ECONOMICS UNDER CONSERVATION AGRICULTURE PRACTICE IN BANGLADESHMohammad Mobarak Hossain^a, Mahfuza Begum^b, Abul Hashem^c, Md. Moshir Rahman^b, Richard W. Bell^d^a *Rice Breeding Innovation Platform, International Rice Research Institute, Metro Manila 1301, Philippines.*^b *Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202 Bangladesh.*^c *Department of Agriculture and Food, 75 York Road, Northam, WA 483, Australia.*^d *Agricultural Sciences, Murdoch University, South St, Murdoch WA 6150, Australia.**Corresponding Author Email: mm.hossain@irri.org

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ABSTRACT

Crisis of agricultural laborers in South Asia's rural zones is pushing to pursue a labor-saving conservation agriculture strategy for crop production and weed control. Non-puddled transplanting and mulching residues of the previous crop are being developed for rice-based cropping systems in Bangladesh to address this issue. Hence, the present study was undertaken to determine the effectiveness of strip tillage vs. conventional tillage combined with previous rice residues relative to herbicides and hand weeding on weed control and grain yield of winter rice during January-May in 2015 and 2016. Rice cv. *BRR1 dhan28* was transplanted with a combination of six treatments: puddled conventional tillage (CT)+3 hand weeding (HW) (Control); Pre-plant (PRE) herbicide (glyphosate)+non-puddled strip tillage (ST)+1HW; PRE+ST+pre-emergence (PE) herbicide (pendimethalin); PRE+ST+post-emergence (PO) herbicide (ethoxysulfuron-ethyl); PRE+ST+PE+PO; PRE+ST+weed-free (WF); and two levels of rice residues: no-residue (R₀) vs. 50% standing residue (R₅₀). The CT had done using a two-wheel tractor (2WT) by four ploughings and cross ploughings followed by levelling. A Versatile Multi-Crop Planter (VMP) was used for ST in a single pass operation. Over the two years, PRE+ST+PE+PO reduced weed density by 40% in the first year and 50% in the second year and weed biomass by 70% than CT+3HW in both years. Retention of 50% residue reduced weed density by 20% and biomass by 34%. The highest grain yield (12% higher than CT+3HW without residue) was obtained from PRE+ST+WF with 50% residue, while the highest BCR (47% higher over CT+3HW without residue) was obtained from PRE+ST+PE+PO with 50% residue.

KEYWORDS

Crop residues, herbicides, non-puddled, strip tillage, weed control

1. INTRODUCTION

Most rice (*Oryza sativa* L.) farmers in the Asian continent establish seedlings by transplanting in puddled soil, usually for easy crop establishment and weed control (Bell et al., 2019). However, rice can be grown successfully by transplanting into non-puddled soils as an alternative to the conventional puddled transplanting method without any yield penalty with additional economic benefits of savings in labour, fuel, and irrigation water (Hossain et al., 2015; Gathala et al., 2015). Compared to conventional tillage (CT), 31-76% of the energy and 25-26% water could be saved by bed planting and minimum tillage (MT) under non-puddled transplanting (Townsend et al., 2016). But heavy weed infestation occurs in about 80% of the undisturbed soil areas or minimum tillage that has been characterized against the wide-spread adoption of MT (Sims et al., 2018; Nicholas et al., 2015; Rahman, 2016).

In conventional puddled transplanting systems, live weeds are controlled by burying them and their viable seeds into the saturated and flooded soil

resulting in the less early emergence of weeds (Soni et al., 2020; Raj et al., 2019). But in the non-puddled transplanting, the emergence of those viable seeds during the early crop growth period results in a higher infestation of weeds and the proliferation of annual and perennial weeds such as *Richardia scabra* L., and *Cynodon dactylon* L. identified as one of the most significant constraints to produce the crop in non-puddled transplanting, and have been identified as the most vulnerable factor against the sustainable acceptance of this practice worldwide (Baker et al., 2018; Eager et al., 2013; Jeyarajan et al., 2017; Brown et al., 2017).

Crop yields in non-puddled soils can be similar or even higher than CT if weeds are controlled successfully (Busaria et al., 2015). Conversely, grain yield in the non-puddled systems may decline sharply if weeds were not controlled effectively (Zahan et al., 2018). Therefore, farmers are recommended to do manual weeding up to six times during the rice cropping season to reduce weed pressure (Farooq et al., 2011). But the acute shortage of labor during peak periods can delay weeding, causing drastic losses in rice grain yield (Sunyob et al., 2015; Dilipkumar et al.,

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2017). With the view to meeting up the demands of workforces needed for hand weeding, herbicides are being rapidly adopted in countries that face a scarcity of labor for weeding and improving crop yields significantly (Dahal and Karki, 2014; Rashid et al., 2012). The recent development of broad-spectrum herbicides could provide an opportunity to control weeds in the non-puddled transplanting system more effectively (Jikun et al., 2017). However, the repeated use of these chemicals may lead to the development of herbicide resistance in weeds (Beckie et al., 2019; Lu et al., 2019). Off-label use of herbicides is also reported to compromise 11% of production costs compared with 2-5% in manual systems (Price and Kelton, 2011). But other agronomic options like crop residue mulching may help reduce weed infestations and minimize the demand for herbicide in CA systems (Jabran, 2019).

Previous crop residues have been reported to suppress weeds' emergence and growth by suppressing germination and establishing weeds (Mwendwa et al., 2018; Latif et al., 2019). Apart from allelochemicals effects on weed seed germination, decreased soil temperature fluctuations and light penetration also inhibit weed germination (Tursun et al., 2018). Residues are reported to reduce perennial weed density and biomass by 35 and 75%, respectively, and annual weeds by around 80% than no

residue (Utami et al., 2020). These results indicate that crop residues can be a promising tool for suppressing weeds in the non-puddled transplanting system. The non-puddled rice transplanting technology and residue retention are the components of conservation agriculture being developed in Bangladesh. But the optimum weed control for crops is still not well defined. Limited research data are available on weed control for non-puddled rice transplanting. Hence, the present on-farm experiment aimed to determine increased residue's effectiveness compared to PRE, PE and PO herbicides on the weed control and grain yield of winter rice transplanted under minimum tillage in the form of strip tillage in Bangladesh.

2. MATERIALS AND METHODS

2.1 Experimental site and season

The experiment was conducted on a farmers' field located at the Bhangnamari area of Gouripur sub-district under Mymensingh district of Bangladesh (24.75° N and 90.50° E at 18 m altitude) during January-May in 2015 and 2016 (Figure 1).



Figure 1: Map of Bangladesh showing the site of the on-farm experiment at Gouripur, Mymensingh, Bangladesh.

The field was a medium-high land under the Old Brahmaputra Floodplain of predominantly dark grey non-calcareous alluvium soils. The soil properties have been presented in Table 1.

Table 1: The physico-chemical properties of soil (0-15 cm) of the experimental field at Gouripur, Mymensingh, Bangladesh		
Sand (%)	:	50
Silt (%)	:	23
Clay (%)	:	27
Textural class	:	Sandy Clay Loam
pH	:	7.20
Organic matter (%)	:	0.93
Total nitrogen (%)	:	0.13
Available sulfur (mg kg ⁻¹)	:	13.9
Available phosphorus (mg kg ⁻¹)	:	16.3
Exchangeable potassium (mg kg ⁻¹)	:	0.28

In the first year, the highest maximum (33.5°C) and minimum (24.3°C) temperatures were recorded in April and May, respectively. In the second year, the highest maximum and minimum temperature (32.2 and 24.0°C, respectively) was recorded in May. January was the coldest month, and temperature increased towards May. Rainfall started at the maturity before harvesting the crop. The highest rainfall was recorded in April (203.2 mm in the first year and 206.5 mm in the second year (Figure 2).

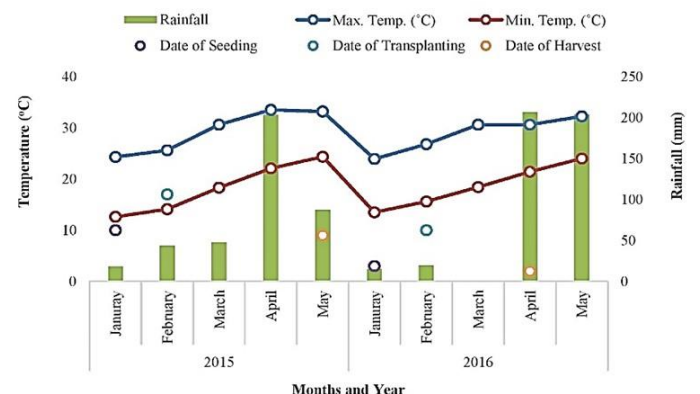


Figure 2: Monthly average temperature and total rainfall distribution pattern in 2015 and 2016 at Gouripur, Mymensingh, Bangladesh.

2.2 Experimental treatments

This study comprised two tillage types combined with six weed control practices viz., i. Puddled conventional tillage (CT)+3 hand weeding (HW) (Control); ii. Pre-plant herbicide (PRE)+Non-puddled strip tillage (ST)+1HW; iii. PRE+ST+pre-emergence herbicide (PE); iv. PRE+ST+post-emergence herbicide (PO); v. PRE+ST+PE+PO; and vi. PRE+ST+weed-free (WF)] and two levels of previous monsoon rice crop residue [R₀: no-residue and R₅₀: 50% standing residue.

2.3 Seedling raising and transplanting

In the first year, seeding was done in the nursery bed on January 10, and 35 days of seedlings were transplanted on February 17. But in the second year, the seeding and transplanting did one week earlier than that of first-year to avoid rainfall before harvest. Seedlings were always transplanted at a row distance of 25 cm × 15 cm between hills at 2-3 seedlings hill⁻¹ in the same plot in both years. In both years, 20 kg of seeds was used.

2.4 Tillage operation

The CT was done by a two-wheel tractor (2WT). The land was prepared by four plowings and cross plowings followed by sun-drying for two days and laddering. The ST was done by a Versatile Multi-Crop Planter (VMP) in a single pass operation. Each strip had 4 rows, each 6 cm wide and 5 cm deep. Row distance was adjusted at 25 cm with 15 cm hill to hill distance. Three days before ST operation, PRE (glyphosate) was applied @ 3.7 L ha⁻¹. After ST, the land was flooded with 3-5 cm standing water one day before

transplanting to allow the strips to soften enough for transplanting seedlings (Haque et al., 2016).

2.5 Residue retention

In no-residue treatment, rice was transplanted without retaining any residues of previous monsoon rice while in 50% residue treatment previous rice was harvested at 50% of height standing in the respective plots.

2.6 Weed control treatments

In CT, 3 HWs were performed at 25, 45, and 65 days after transplanting (DAT). In ST of treatment (ii), 1 HW did at 25 DAT. In the weed-free (WF) treatment, 6 HWs at 15, 25, 45, 65, 75, and 90 DAT have completed. Herbicides were applied by a hand-operated knapsack sprayer fitted with a flat-fan nozzle to deliver a spray volume of 300 L ha⁻¹. Herbicides used in different treatments have presented in Table 2.

Table 2: Different herbicides used in the experiment at Gouripur, Mymensingh, Bangladesh¹

Table 2: Different herbicides used in the experiment at Gouripur, Mymensingh, Bangladesh ¹					
Herbicide			Dose (ha ⁻¹)	Time of application	Field condition
Group	Name	HARC class			
Pre-plant	Glyphosate	Group G	3.7 L	3 DBT	Field capacity
Pre-emergence	Pendimethalin	Group K1	2.5 L	3 DAT	
Post-emergence	Ethoxysulfuron-ethyl	Group B	100 g	25 DAT	Standing water

¹DBT = Days before transplanting, DAT = Days after transplanting, HARC= Herbicide Resistance Action Committee

2.7 Fertilizer application and crop protection

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 zinc sulfate at final tillage. Nitrogen was applied @ 80 kg 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. Standard crop protection measures have followed throughout the study period.

2.8 Measurements

Densities of different weed species were recorded randomly from four locations per plot using a quadrat of 0.50 m × 0.50 m at 25, 45, 65 (flowering stage), and 115 DAT (crop maturity). The weed density (plants m⁻²), and the weed dry biomass (g m⁻²) was recorded. Fresh weed biomass was dried in the oven at 70°C for 72 hours, and dry weight was recorded. Phyto-toxicity of herbicides in rice was assessed visually using the rating presented in Table 3 (Rao, 1983).

Table 3: Phyto-toxicity rating of herbicides in rice

Effect	Rating	Injury Level
None	0	No injury, normal
Slight	1	Slight stunting, injury or discolouration
	2	Some stand loss, stunting or discolouration
	3	Injury more pronounced but not persistent
Moderate	4	Moderate injury, recovery possible
	5	Injury more persistent, recovery doubtful
	6	Near severe injury no recovery possible
Severe	7	Severe injury stand loss
	8	Almost destroyed a few plants surviving
	9	Very few plants alive
Complete	10	Complete destruction

The crop was harvested at maturity (when 80% of rice grain became golden yellow) on May 9 in the first year and May 2 in the second year, from randomly selected three quadrats 3 m × 1 m area in each) per plot. The number of panicles m⁻², number of grains and sterile spikelets panicle⁻¹ were recorded from randomly selected ten hills before harvest. The weight of 1000-grains, and grain and straw yield was recorded per plot and expressed as t ha⁻¹. Grain yield was adjusted at 14% moisture content, and per cent yield increase over control (YOC) was calculated using the following formula (Devasenpathy et al., 2008).

$$YOC(\%) = \frac{YT - YC}{YC} \times 100$$

Where, YT and YC are yield in the treatment and in control, respectively.

The economics of crop production was estimated following the partial budgeting system. The variable costs were calculated based on labour requirement for seeding, transplanting, weeding, harvesting and threshing, irrigation, fertilization, residues and all other variable input costs like seed, fertilizer, irrigation, and residue etc. Finally, the benefit-cost ratio (BCR) was calculated by using the formula (Price, 1985).

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

2.9 Statistical design and analysis

All the trials were conducted in a randomized complete block design with the weeding and residue treatments combined. Weeding and residue retaining plots of the second year received the same plots of weeding and the residue treatments as of the first year. The treatments were replicated four times (four blocks) each season. Data were subjected to analysis of variance; treatment means were separated by the Duncans' Multiple Range Test at P<0.05. Regression analysis was done between weed biomass and rice yield. The statistical package program STAR was used to analyze all data.

3. RESULTS AND DISCUSSION

3.1 Weeds species composition

We present the weed data for CT+3HW and Gly+SP+PE+PO treatments under no-residue and 50% residue levels among the treatment combinations of this study. Over two years of rice cultivation in the first year (2015) and the second year (2016), total of 39 weed species were identified from 16 families (Table 4). The most common families were Cyperaceae (8), Poaceae (7), Amaranthaceae (4), Asteraceae (4), Linderniaceae (2), Rubiaceae (2) and Solanaceae (2). Compared to SP, after two seasons of wheat cultivation, CT produced 44 % more weeds (Table 4). In the second year, CT had 12% more weeds (37 species) than the first year (31 species). Seven species viz., *Centipeda minima* Lour., *Physalis heterophylla* Nees., *Polygonum coccineum* L., *Solanum torvum* L., *Echinochloa colonum* L., *Scirpus juncooides* L., and *S. supinus* L. recorded in second year were absent in the first year. In the second year, SP produced 33% fewer weeds (22 species) than in first year (33 species). Among the 17 weed species of SP in the second year, three species (*Amaranthus viridis* L., *Brassica kaber* L., and *Spilanthes acmella* L.) were absent after being present in the first year. Among the 37 species of CT, *Chenopodium*

album L. and *Dentella repens* L. were absent in ST in either season. CT produced 91% homogenous weeds in the second year and second year 4-16 and while ST grew 82% common weeds in two consecutive years.

During both the years, CT plots showed a greater number of weed species than ST. Heavy soil pulverization in CT may bring up dormant weed seeds from the sub-soil layers to the upper soil layers, where conditions are more favorable for weed seeds' germination. By contrast, in ST, only 20% of the soil surface was disturbed by tillage. The placement of viable seed close to the soil surface was more restricted in ST. as such fewer weed seed was brought up to the surface (the favorable zone for germination of weed seed) by ST. Reduced weed density in ST might also minimize the soil weed seed bank (Chauhan et al., 2012; Ruisi et al., 2015). In the CT treatment, no herbicide was applied, resulting in greater weed pressure. On the other hand, ST received a PRE (glyphosate), a PE (pendimethalin), a PO (Ethoxysulfuron-ethyl), and the combination of PE and PO. These herbicides are very effective in controlling weeds from the very beginnings of crop growth. Thus, these treatments of ST had fewer weeds compared to CT. Undisturbed soils in ST may also cause most seeds to remain dormant in the subsoil. Hence, it reduced weed pressure, perhaps,

by increasing the weed seed predation by rodents and other granivores (Chauhan and Mahajan, 2012; Barre et al., 2018).

3.2 Effect on weed density and biomass

The effect of residue and weed control practices on weed density was significant ($p < 0.01$) at all dates except the time of crop harvest in the first year, and at 65 and 115 DAT in the second year ($p > 0.05$) (Figure 3). In the first year, at 25 DAT, PRE+ST+1HW without residue produced the highest number of weeds m^{-2} , followed by the same treatment with 50% residue, and CT+3HW without residue. PRE+ST+PE with or without 50% residue, PRE+ST+PO with or without 50% residue, and PRE+ST+PE+PO with 50% residue produced the lowest weeds. At 45 DAT, CT+3HW without residue had the highest number of weeds m^{-2} , and the lowest was recorded from PRE+ST+PE+PO with 50% residue. PRE+ST with PE or PO, without or with residue, produced a statistically similar number of weeds. At 65 DAT, CT+3HW and PRE+ST+1HW without residue showed the highest weed density followed by both of them with 50% residue, PRE+ST+PE without residue.

Table 4: Weed species composition in CT+3HW and PRE+ST+PE+PO treatments²

Weed type	Scientific name	First Year		Second Year		First Year		Second Year	
		CT+3HW				PRE+ST+PE+PO			
		R ₀	R ₅₀	R ₀	R ₅₀	R ₀	R ₅₀	R ₀	R ₅₀
Broad leaf	<i>Ageratum conyzoides</i> L.	+	+	+	+	+	+	+	-
	<i>Amaranthus viridis</i> L.	+	+	+	+	-	-	+	+
	<i>A. spinosus</i> L.	-	+	+	+	+	+	+	+
	<i>Alternanthera sessilis</i> L.	+	+	+	+	+	+	+	+
	<i>A. philoxeroides</i> L.	+	+	+	+	+	+	+	-
	<i>Brassica kaber</i> L.	+	+	+	+	-	-	+	+
	<i>Centipeda minima</i> Lour.	-	-	+	+	+	+	-	-
	<i>Chenopodium album</i> L.	+	+	+	+	-	-	-	-
	<i>Cyanotis axillaris</i> Roem.	+	+	+	+	+	+	+	+
	<i>Dentella repens</i> L.	+	+	+	+	-	-	-	-
	<i>Desmodium triflorum</i> L.	+	+	+	+	+	+	-	-
	<i>Eichhornia crassipes</i> Mart.	+	+	+	+	+	+	+	+
	<i>Eclipta alba</i> L.	+	+	+	+	+	+	+	+
	<i>Euphorbia parviflora</i> L.	-	+	+	+	+	+	-	-
	<i>Gnaphalium luteo-album</i> L.	+	+	-	-	+	+	-	-
	<i>Hedyotis corymbosa</i> L.	+	+	+	+	+	+	+	+
	<i>Jussia decurrense</i> Walt.	+	+	+	+	+	-	+	+
	<i>Lindernia antipoda</i> L.	+	+	+	-	-	+	+	+
	<i>L. hyssopifolia</i> L.	+	+	+	-	+	+	+	+
	<i>Nicotina plumbaginifolia</i> L.	+	+	+	+	+	+	+	+
<i>Physalis heterophylla</i> Nees.	-	-	+	+	+	+	+	+	
<i>Pistia stratiotes</i> L.	+	+	+	+	+	+	-	-	
<i>Polygonum coccineum</i> L.	-	-	+	+	+	+	-	-	
<i>Rotala ramosior</i> L.	+	-	+	+	+	+	-	-	
<i>Solanum torvum</i> L.	-	-	+	+	+	+	+	-	
<i>Spilanthes acmella</i> L.	+	-	+	+	-	-	+	-	
Sub-Total		20	20	25	23	20	20	17	13
Grass	<i>Cynodon dactylon</i> L.	+	+	-	-	+	+	-	-
	<i>Digitaria sanguinalis</i> L.	+	+	+	+	+	+	-	-
	<i>Echinochloa crusgalli</i> L.	+	+	+	+	+	+	+	+
	<i>E. colonum</i> L.	-	-	+	+	+	-	-	-
	<i>Eleusine indica</i> L.	+	+	+	+	+	+	+	+
	<i>Leersia hexandra</i> L.	+	+	+	+	+	+	-	-
	<i>Panicum distichum</i> L.	+	+	-	-	+	+	-	-
Sub-Total		6	6	5	5	7	6	2	2
Sedge	<i>Cyperus difformis</i> L.	+	+	+	+	+	+	+	+
	<i>C. rotundus</i> L.	+	+	+	+	+	+	+	-
	<i>C. iria</i> L.	+	+	+	-	+	+	-	-
	<i>Eleocharis atropurpurea</i> Ret.	+	+	+	-	+	+	-	-
	<i>Fimbristylis miliacea</i> L.	+	+	+	+	+	+	+	+
	<i>Scirpus mucronatus</i> L.	-	+	-	+	+	-	-	-
	<i>S. juncooides</i> L.	-	-	+	+	-	-	-	-
<i>S. supinus</i> L.	-	-	+	+	-	-	-	-	
Sub-Total		5	6	7	6	6	5	3	2
Grand Total		31	32	37	34	33	31	22	17

²CT = Conventional tillage, HW = Hand weeding, PRE = Pre-plant herbicide, ST = Strip tillage, PE=Pre-emergence herbicide, PO = Post-emergence herbicide, R₀ = no-residue, R₅₀ = 50% residue, + Present, - Absent

The effect of residue and weed control practices on weed density was significant ($p \leq 0.01$) at all dates except the time of crop harvest in the first year, and at 65 and 115 DAT in the second year ($p > 0.05$) (Figure 3). In the first year, at 25 DAT, PRE+ST+1HW without residue produced the highest number of weeds m^{-2} , followed by the same treatment with 50% residue, and CT+3HW without residue. PRE+ST+PE with or without 50% residue, PRE+ST+PO with or without 50% residue, and PRE+ST+PE+PO with 50% residue produced the lowest weeds. At 45 DAT, CT+3HW without residue had the highest number of weeds m^{-2} , and the lowest was recorded from PRE+ST+PE+PO with 50% residue. PRE+ST with PE or PO, without or with residue, produced a statistically similar number of weeds. At 65 DAT, CT+3HW and PRE+ST+1HW without residue showed the highest weed density followed by both of them with 50% residue, PRE+ST+PE without residue.

PRE+ST+PE with 50% residue, PRE+ST+PO without residue, PRE+ST+PO with 50% residue, and PRE+ST+PE+PO without residue. PRE+ST+PE+PO with 50% residue produced the lowest weed density. At 115 DAT, weed density response to treatments was non-significant. In the second year, at 25 and 45 DAT, the treatment effect was significant but at 65 and 115 DAT non-significant. The weed biomass was also influenced significantly ($p \leq 0.01$) by residue and weed control practices at all dates of assessment in both years but non-significant ($p > 0.05$) at 115 DAT in the second year (Figure 3). In the first year, at 25 DAT, the highest weed biomass was recorded from PRE+ST+1HW without residue followed by the same treatment with 50% residue, which was identical to CT+3HW without residue and PRE+ST+PO with or without 50% crop residue. The treatment PRE+ST+PE with 50% residue produced the lowest weed biomass. At 45 DAT, CT+3HW without residue produced the highest weed biomass followed by the same treatment with 50% residue, while PRE+ST+1HW without residue. The treatment PRE+ST+PE and PRE+ST+PO without residue ranked the third, followed by both the treatments with 50% residue and PRE+ST+PE+PO without residue. PRE+ST+PE+PO with 50% residue produced the lowest biomass.

At 65 DAT, similar trends in weed response were observed. At 25 and 45 DAT of the second year, the interaction effect was like that of the first year. At 65 DAT, CT+3HW without residue produced the highest weed biomass followed by the same treatment without residue, PRE+ST+1HW, PRE+ST+PE, and PRE+ST+PO and PRE+ST+PE+PO with or without 50% residue. Overall, among the treatment combinations, 50% residue combined with PRE+ST+PE+PO was more effective in suppressing weed density and biomass in second year than in the first year. The weed density and biomass declined with time onwards from 25 DAT to maturity of rice. The results revealed that, over the two years, solely CT produced about 30% higher weed density and 40% higher weed biomass than ST. Spraying PE followed by PO reduced weed density by 40% in the first year and 50% in the second year while weed biomass by 70% in both years. Among the treatment combinations, 50% residue reduced weed density by 20% and biomass by 34%.

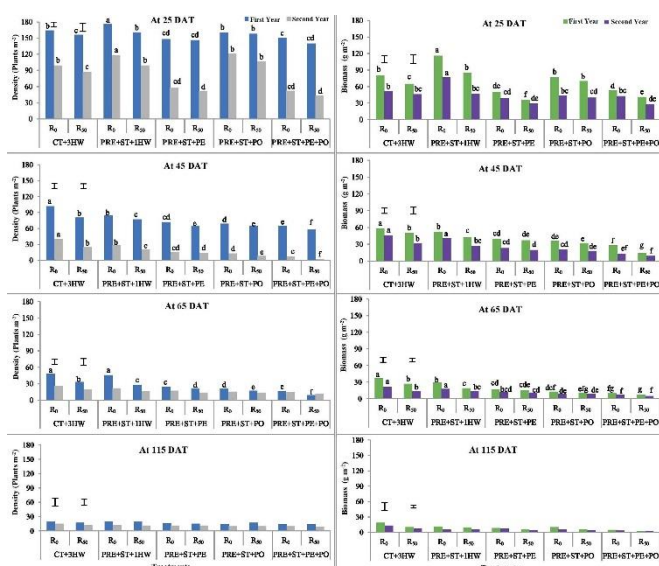


Figure 3: Effect of treatments on the weed density and biomass at different dates of assessment for the first and second year at Gouripur, Mymensingh, Bangladesh. For each year, means followed by the same letter did not differ significantly at $P < 0.05$.

In this study, the conventional tillage with three times hand weeding (CT+3HW) without residue produced the highest weed density and

biomass. By contrast, the lowest was recorded from non-selective pre-plant (PRE) herbicide applied before strip tillage (ST) operation followed by PE and then the PO herbicide (PRE+ST+PE+PO) with 50% residue over two successive years. The higher weed density and biomass in CT might have occurred from continuous heavy soil crushing. Such soils are more aerated, warmer, and experienced greater temperature fluctuations. These conditions offer better germination environments for most weed seeds, even dormant weed seeds, which may be brought up to the upper soil layers from the sub-soil layers in CT (Batlla et al., 2020). Tilled soils also provide germination stimulus for weeds requiring scarification, ambient CO_2 concentrations, and higher nitrate concentrations to break dormancy (Maqsood et al., 2018). Moreover, the higher rate of weed seed burial in CT reduced seed mortality; hence, the higher rate of seed viability (Vivek et al., 2020).

The emergence of vigorous weed seedlings from the deeper soil of CT facilitates the better seed sets and seed rains on the ground (Singh et al., 2015). Consequently, a dense combination of different weed species might lead to higher weed density and biomass in CT in this study. By contrast, in a non-puddled ST system, seed banks are concentrated in the soil's top layer. Weed seeds on or close to the soil surface can lose viability due to desiccation and harsh weather (Anderson, 2015). Such conditions trigger lethal germination as the radicle of germinated weed seeds remaining near the soil surface (Sneha et al., 2018). Furthermore, the higher rate of weed seed predation by ants, rodents, granivores, pathogens, and birds by increasing the availability of seeds to predators and by minimizing mortality of these predators in minimal disturbed soil of non-puddled ST might have attributed to lower weed densities over CT (Baraibar et al., 2017).

In the present study, the control treatment (CT+3HW) did not receive any herbicide. The escaped seedlings of problematic and persistent weeds from hand weeding may have resulted in the higher weed density and biomass. On the other hand, ST received a combination of pre-plant, pre-emergence, and post-emergence herbicides. These chemicals are very effective in controlling weeds and reduced weed density in ST. Compared to a single application of pre-emergence and post-emergence herbicide, a combination of them exerted 70% higher weed control efficacy than hand weeding, which attributed to their broad-spectrum activity and higher phytotoxic effects against both grass and broad-leaved even narrow-leaved weeds compared to a single application of each (Umair et al., 2018; Usman et al., 2010). In this study, the sequential application of these herbicides exerted the best weed control ability. Pre-emergence herbicide alone can control the weeds of the first cohort but fail to prevent some escaped problematic weeds and weeds of the second cohort controlled by the post-emergence herbicide.

Plots that retained 50% residue showed around 22% fewer weeds than no-residue (13% less in the first year than the second year) among different treatment combinations. Here, the beneficial effect of the residue is to defeat weeds by creating physical barriers by smothering weeds, suppressing weed seed germination and growth, lowering soil temperatures, and exerting the effect of allelochemicals released from decaying plant tissues in association with temporary immobilization of nutrients (Sondhia, 2014). Probably, moisture conservation by residues may have enhanced the weed seed decay, losing seed viability, and failure of seed germination hence, reducing the weed emergence in 50% residue over no-residue (Mashavakure et al., 2020). The delayed emergence of weaker weeds in the 50% residue due to less space and light has a lower ability to produce and shed fewer seeds in the soil, resulting in the lower weed density (Dahal and Karki, 2014). In this study, the most significant relative suppression of weed density and biomass by 50% residue was with PRE+ST+PE+PO, which might have occurred from the combined effect of ST having the adverse impact of PRE, PE, and PO herbicides.

These effects of residue may cause to reduce the weed pressure with residue practices over no-residue. The less weed biomass in ST only due to lesser densities of etiolated, weaker, and smaller weed plants with lower weed dry weight in the subsequent seasons (Mesquita et al., 2016). The weed density and biomass reduced to a great extent in the first year compared with the second year, which might be attributed to the crop rotation. In this study, the winter rice was the third crop in the first year and the sixth crop in the second year, which was rotated with monsoon rice and mustard. Crop rotations can lead to more significant weed mortalities than sequential mono-cropping due to greater variability in the type and timing of soil, crop, and weed management (Sandra et al., 2015). Dissimilar planting dates of monsoon rice, mustard, and winter rice (in the present study) having different growth patterns might have disrupted weed life cycles in non-puddled ST than puddled CT (Brainard et al., 2013).

In this study, the highest weed density was recorded at 25 DAT, followed by 45, 65, and 115 DAT. In soil, weed emerges in several cohorts. Generally, the emergence of the first cohort of weed occurred within three weeks of planting (Sangeetha et al., 2011). At 25 DAT, pre-emergence herbicide application offered better control of weed or before, reducing seed sets and seed rains to the soil compared to hand weeding in both CT and ST. Persistent weeds remain uncontrolled and escape during this time, and many new weeds consisting of a complex mixture of species emerge simultaneously with crops up to 45 DAT. During this time, sequential application of PE and PO herbicides provided better weed control by effectively killing almost all broadleaves, grasses, and sedges that emerged at this time. Even the weeds escaped the treatments at 25 DAT and might lead to lower weeds at 65 DAT than 45 DAT. After 65 DAT, there is very little chance to emerge new weeds from the soil might be due to the highest crop weed competition offered by crops on weeds and the life cycle of weeds to be completed. That may cause to produce the lowest weed density and biomass at 115 DAT in this study.

3.5 Effect on rice grain yield

In this study, PRE+ST+WF with 50% residue produced the highest grain yield (Figure 4), followed by PRE+ST+PE+PO with 50% residue, PRE+ST+WF without residue, PRE+ST+PE+PO without residue, CT+3HW with or without residue, and PRE+ST+PO with 50% residue. The lowest yield was recorded from PRE+ST+1HW without residue, followed by PRE+ST+1HW and PRE+ST+PE with 50% residue, and PRE+ST+PO without residue. In the second year, PRE+ST+WF with 50% or without residue and PRE+ST+PE+PO with 50% residue produced the statistically similar highest yield followed by PRE+ST+PE+PO without residue, CT+3HW with or without 50% residue. The lowest grain yield was recorded from PRE+ST+1HW without residue, followed by PRE+ST+1HW with 50% residue, PRE+ST+PE, or PRE+ST+PO with 50% or without residue.

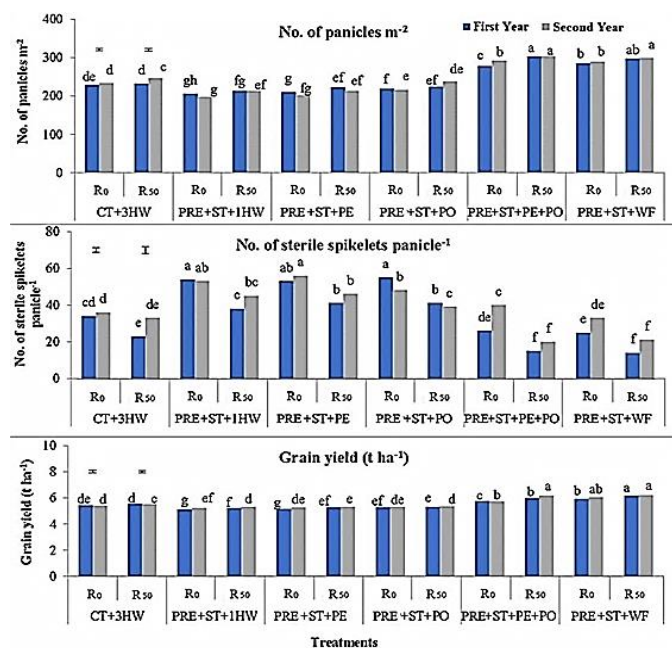


Figure 4: Effect of treatments on yield attributes and yield of rice for first and second year at Gouripur, Mymensingh, Bangladesh. For each year, means followed by the same letter did not differ significantly at $P < 0.05$.

The CT+3HW produced about 6% higher grain yield than PRE+ST+1HW

during both years. The addition of a PE or PO treatment instead of hand weeding had an almost similar yield to CT+3HW. However, the application of PE, followed by the PO, yielded about 10% more than CT and 3HW. An increase in yield may be attributed to the increases in the number of panicles m^{-2} , grains panicle $^{-2}$, and sterile spikelets panicle $^{-2}$. None of the herbicide treatments, together with ST, produced as much grain yield as in the 6HW (weed-free) to ensure a weed-free condition. Compared to CT+3HW, PRE+ST+1HW, PRE+ST+PE, and PRE+ST+PO reduced grain yield by 2-5%, while PRE+ST+PE+PO increased grain yield by 10% and PRE+ST+WF increased grain yield by about 12% in both years. Retention of 50% residue increased grain yield by 4% only in the first year; however, residue's effect varied with weed control practices. During this time, among the treatment combinations, 50% residue produced 5% higher number of panicles and grains, and 13% lower sterile spikelets over no-residue.

In the present study, greater ST than CT yield might be due to the reduced weed density and weed biomass as the weed pressure and grain yield are inversely related (Martin and Weiner, 2014). It was previously reported that crop yield in the non-puddled system is likely to be more than the puddled transplanting when weeds are controlled successfully (Shahzad et al., 2016). The higher weeds in CT may reduce crop yield due to the higher crop weed competition. Weeds compete with the crops for nutrients, available moisture, and light with crop plants and may exude allelochemicals, which reduce the yield in CT with manual hand weeding (Clarence et al., 2015). Plots treated herbicides in ST infested was with fewer weeds and produced higher yield by producing more panicles $^{-2}$ and filled grains panicles $^{-2}$ (Awan et al., 2015; Islam et al., 2018). That is why in this study, regression analysis showed a strong negative correlation between grain yield and weed biomass (Table 5), indicating that an increase in the weed biomass by 10 kg at 25, 45, or 65 DAT resulted in a 1% decrease in the grain yield of rice in each year.

In addition to weed control, some herbicides may promote crops' growth (Brito et al., 2018; Belz and Duke, 2014). The better crop growth and development may have contributed to greater grain yields in ST over CT. Manual hand weeding in CT may exert some sorts of physical disturbance to crops and thus may lead to reducing the crop yield. In this study, 50% residue increased the grain yield by 4% over no-residue, which might be attributed to the residue's beneficial effects. Residue converts to mineralized nutrients that promote crop growth. Simultaneously, it prevents weed growth and supplies organic matter for heterotrophic N fixing microorganisms, which could be utilized by the crops, resulting in higher yield (Shrivastav et al., 2015; Alam et al., 2014). Fewer weeds in 50% residue may reduce the crop weed competition for nutrients and other resources and give the crop plant advantages for better growth and crop yield. The beneficial effect of herbicides, strip tillage, and crop residue on the yield contributing characters of rice might directly affect rice yield. In this study, the highest numbers of panicles m^{-2} , and the lowest numbers of sterile spikelets panicle $^{-1}$ might have led to an improved effect of weed management and residue levels in ST over manual weeding in CT.

3.6 Effect of treatments on Benefit-Cost Ratio (BCR)

Data revealed that PRE+ST+PE+PO plus 50% residue fetched the highest profit (Table 6) followed by the same treatment without residue and, PRE+ST+PE, PRE+ST+PO, and PRE+ST+1HW with or without 50% residue. Treatment CT+3HW and PRE+ST+WF with and without residue incurred economic losses. Among them, CT+3HW without residue, incurred the maximum loss in both the years. PRE+ST+PE or PRE+ST+PO with or without residue earned the similar BCR but around 13% higher than CT+3HW. PRE+ST+PE+PO with 50% residue earned 7% higher BCR than no-residue, which was 43% higher than PRE+ST+WF with 50% residue and 47% higher than CT+3HW without residue. Residue alone increases BCR by 9% over no-residue.

Table 5: Regression analysis between rice yield ($kg\ ha^{-1}$) and weed biomass ($kg\ ha^{-1}$) at different dates for the first and second year at Gouripur, Mymensingh, Bangladesh³

Y-Axis	X-Axis	First Year		Second Year		
		RE	R ²	RE	R ²	
Yield	Weed biomass at	25 DAT	$y=5938.8-0.81x$	0.63	$y=6056.2-1.33x$	0.58
		45 DAT	$y=5984.9-1.50x$	0.65	$y=5975.3-1.98x$	0.60
		65 DAT	$y=5825.4-2.13x$	0.73	$y=6032.1-4.72x$	0.66

³DAT = Days after transplanting, y = grain yield of rice, x = biomass of weeds, RE = Regression equation, R² = Coefficient of determination

Table 6: Economics (US\$ ha⁻¹) of rice cultivation for first and second year⁴

Treatments		Total cost		Total income		BCR	
		First Year	Second Year	First Year	Second Year	First Year	Second Year
CT+3HW	R ₀	1477.3	1381.7	1451.8	1307.5	0.98	0.95
	R ₅₀	1477.3	1381.7	1474.1	1338.0	0.99	0.97
PRE+ST+1HW	R ₀	1166.1	1188.2	1261.5	1396.1	1.08	1.17
	R ₅₀	1166.1	1188.2	1294.2	1413.4	1.11	1.19
PRE+ST+PE	R ₀	1107.3	1107.3	1268.6	1399.6	1.15	1.26
	R ₅₀	1085.2	1107.3	1300.6	1408.8	1.20	1.27
PRE+ST+PO	R ₀	1085.2	1107.3	1293.6	1410.6	1.19	1.27
	R ₅₀	1085.2	1107.3	1300.6	1422.6	1.20	1.28
PRE+ST+PE+PO	R ₀	1129.4	1151.4	1418.6	1495.4	1.26	1.30
	R ₅₀	1129.4	1151.4	1467.2	1592.5	1.30	1.38
PRE+ST+WF	R ₀	1526.4	1548.5	1456.1	1451.2	0.95	0.94
	R ₅₀	1526.4	1548.5	1510.9	1500.0	0.99	0.97

⁴CT= conventional tillage, HW= hand weeding, PRE= Pre-plant herbicide, ST= Strip tillage, PE= Pre-emergence herbicide, PO= Post-emergence herbicide, WF= Weed free, R₀= no-residue, R₅₀= 50% residue, 1US\$=84.75 BDT (in December 2020).

In the present study, the variation in BCR might be attributed to increased grain yield and reduced cost in ST. One hectare land preparation in CT required US\$ 190.80 ha⁻¹, but ST required only US\$ 35.80. Thus, ST saved around 68% cost for land preparation in this study. Cost savings due to a reduction in tillage, fuel, and labour might have reduced the total variable cost in ST than CT. One previous study estimated 70% savings in land preparation in ST over CT, where the ST needed the lowest land preparation cost (US\$ 32.54 - 33.25 ha⁻¹), and the CT required the cost (US\$88.24 - 110.29 ha⁻¹) (Haque and Bell, 2019). Another study estimated 49% savings for land preparation cost in ST over CT (Islam et al., 2014).

Moreover, herbicidal weed control was more profitable than 3HW in CT, and 6HW (weed-free) in ST. In CT, 3HW incurred US\$ 313.28 ha⁻¹. On the other hand, 6HW in ST incurred US\$ 417.71 ha⁻¹, while 1HW incurred US\$104.43. By contrast, application of glyphosate at pre-plant required US\$ 44.75 ha⁻¹, one pre-emergence application and post-emergence application required US\$ 43.92 and 45.59 ha⁻¹, respectively. Thus, herbicidal weed control required US\$ 134.26 ha⁻¹ and ultimately saved 57% cost over manual weeding in CT and 67% over six hand weeding of weed-free treatment in ST. Previous research also reported that higher weeding costs in manual weeding were economically non-profitable over herbicidal weed control (Tatenda and Stanford, 2013; Hossain et al., 2016). The application of appropriate herbicide can replace hand weeding successfully with additional savings for weed controlling. Variation in BCR due to 50% residue practice might have attributed to the higher grain yield with 50% residue than no-residue.

4. CONCLUSION

Minimum tillage non-puddled transplanting in the form of strip tillage is a noble practice for rice cultivation. Under this system, spraying a pre-plant herbicide followed by a pre- and post-emergence herbicide with the retention of 50% of the previous rice straw residue could control weeds more effectively than manual practice of conventional tillage. This practice also fetched the highest economic benefits.

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