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# MULCHING AND WEED MANAGEMENT EFFECTS ON THE PERFORMANCE OF RICE (ORYZA SATIVA L.) TRANSPLANTED IN NON-PUDDLED SOIL

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#### ARTICLE DETAILS

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## ABSTRACT

Labour shortage is pushing the smallholder farms to seek for labour saving strategies for planting and weed control. With this point of view, this study was undertaken to determine the effectiveness of mulching from previous crop relative to herbicides and hand weeding on weed control and grain yield of rice transplanted in non-puddled soil after mustard in the northern Bangladesh during January to May in 2014 and 2015. Rice cv. BRRI dhan28 was transplanted with a combination of six weed control practices [Conventional tillage (CT)+3 hand weeding (HW) (Control); Glyphosate (Gly)+strip tillage (ST)+1HW; Gly+ST+pre-emergence (PE) herbicide (pendimethalin); Gly+ST+post-emergence (PO) herbicide (Ethoxysulfuron-ethyl); Gly+ST+PE+PO; and Gly+ST+weed-free (WF)], and two levels mulch of previous mustard [Mo: no mulch and M<sub>50</sub>: 50% mulch (875 kg ha<sup>-1</sup>). Over the two years, CT produced 30% higher weed density and 40% higher weed biomass than ST. Spraying herbicides at PE followed by at PO in ST reduced weed density by 45% and weed biomass by 70%. Retention of 50% mulch reduced weed density by 20% and biomass by 34%. The combination of applied glyphosate, ST, followed by sequential application of PE and PO herbicides and the retention of 50% mulch achieved the highest weed control efficacy. Furthermore, this practice produced the 12% higher yield and 47% higher economic returns relative to manual weed control in conventional tillage. These results demonstrate the value of mulch integrated with pre-plant, PE and PO herbicides in controlling weeds and improving grain yield and return of rice transplanted in a non-puddled soil.

## **KEYWORDS**

Herbicides, mulch, non-puddled, strip tillage, grain yield.

# 1. Introduction

Farmers in Bangladesh, like other tropics and subtropics of Asia, traditionally transplant rice (Oryza sativa L.) seedlings in puddled soil, usually for comfortable crop establishment and weed control (Bell et al., 2019). However, rice can be grown successfully by transplanting into nonpuddled soils as an alternative to the conventional method of puddled transplanting (Mvumi et al., 2017). Additionally, rice established by nonpuddled transplanting gives similar or higher yield than puddled transplanted rice with additional economic benefits due to 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; Alam et al., 2020). Heavy weed infestation occurs about 80% of the undisturbed soil area (Basir et al., 2019; Sims et al., 2018). Hence, the non-puddled technique has been characterized by greater weed densities than CT (Nichols 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 (Baker et al., 2018; Eager et al., 2013). 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 yield in non-puddled transplanting, have also been identified as the most vulnerable factor against the sustainable acceptance of this practice worldwide (Kumar and Ladha, 2011; 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 (Farooq et al., 2011; 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 (Pandey et al., 2012).

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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., 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 labour for weeding to improve crop yields significantly (Dahal and Karki, 2014; Rashid et al., 2012; Jikun et al., 2017). The recent development of broad-spectrum herbicides such as pre-plant (PRE), PE and PO 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 in conservation agriculture (CA) compared with 2-5% in CT systems (Price and Kelton, 2011). But other agronomic options like crop mulching may help reduce weed infestations and minimize the demand for herbicide in CA systems (Jabran, 2019).

Mulching of previous crop has been reported to suppress the emergence and growth of weeds through suppressing germination and the establishment of 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). Mulches are reported to reduce perennial weed density and biomass by 35 and 75%, respectively, and annual weeds by around 80% compared to no mulch (Utami et al., 2020). These results indicate that crop mulching can be a promising tool for suppressing weeds in the non-puddled transplanting system. The nonpuddled rice transplanting technology based on mulch retention is 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 the effectiveness of increased mulching compared to PRE, PE and PO herbicides on the weed control and grain yield of boro rice (winter rice) in Bangladesh.

## 2. MATERIAL AND METHODS

#### 2.1 Experimental site, edaphic and climatic conditions

The experiment was conducted on a farmers' field located at Durbachara village of Gouripur Upazila in the Mymensingh district of Bangladesh ( $24.75^{\circ}$  N and  $90.50^{\circ}$  E at 18 m altitude) during January-May in 2014 and 2015 (Figure 1).

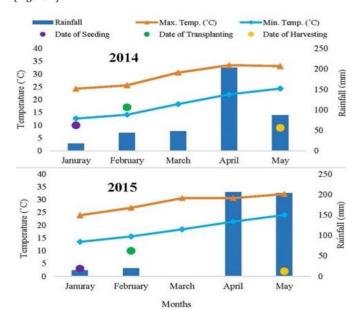


**Figure 1:** Map of Bangladesh showing the site of the on-farm experiment at Gouripur, Mymensingh, Bangladesh

The experiment site is situated on the Old Brahmaputra Floodplain of predominantly dark grey non-calcareous alluvium soils under the *Sonatala* series (Brammer, 1996). It was a medium-high land of sandy clay loam texture having pH 7.2. Soil characteristics are presented in Table 1.

<b>Table 1:</b> The physical, and chemical properties of soil (0-15 cm) of									
the experimental field at Gouripur, Mymensingh, Bangladesh									
A. Physical characteristics of soil									
i.	Sand (0.50- 2.00 mm)	:	50 %						
ii.	Silt (0.002- 0.5 mm)	:	23 %						
iii.	Clay (< 0.002 mm)	:	27 %						
iv.	Textural class	:	Sandy Clay Loam						
B. Chemical characteristics of soil									
i.	рН	:	7.20						
ii.	Organic matter (%)	:	0.93						
iii.	Total nitrogen (%)	:	0.13						
iv.	Available sulfur (ppm)	:	13.9						
v.	Available phosphorus (ppm)	:	16.3						
vi.	Exchangeable potassium (ppm)	:	0.28						

During the study period, in 2014, the highest maximum (33.5°C) and minimum (24.3°C) temperatures were recorded in April and May, respectively. In 2015, the highest maximum and minimum temperature (32.2 and 24.0°C, respectively) had recorded in May. January was the coldest month, and temperature increased towards May. Insufficient rainfall occurred throughout the growing season of rice in both years. Rainfall started at the maturity before harvesting of the crop. The highest rainfall was recorded in April (203.2 mm in 2014 and 206.5 mm in 2015 (Figure 2).



**Figure 2:** Monthly average temperature and total rainfall distribution pattern in 2014 and 2015 at Gouripur, Mymensingh, Bangladesh

### 2.2 Experimental treatments

This study comprised of a combination of six tillage and weed control practices viz., (i) Conventional tillage (CT)+3 hand weeding (HW) (Control); (ii) Glyphosate (Gly)+strip tillage (ST)+1HW; (iii) Gly+ST+pre-emergence (PE) herbicide, (iv) Gly+ST+post-emergence (PO) herbicide), (v) Gly+ST+PE+PO, and (vi) Gly+ST+weed-free (WF); and two levels of mustard crop residue mulches such as (i)  $M_0$ : no mulch and (ii)  $M_{50}$ : 50% mulch.

## 2.3 Seedling raising and transplanting

In 2014, seeds of winter rice cv. *BRRI dhan28* was sown in the nursery seed bed on 10 January, and 35-day-old seedlings were transplanted in

conventional tillage and non-puddled strip tillage on 17 February 2014. But in 2015, the seed was sown in the nursery seed bed on 03 January and transplanted on 10 February (one week earlier than 2014) to avoid rainfall before harvest. Seedlings were always transplanted at a row distance of 25 cm with 15 cm distance between hills at 2-3 seedlings hill-1.

#### 2.4 Tillage operation

Conventional tillage (CT) was done by a two-wheel tractor (2WT). The land was prepared by four plowings and cross plowing followed by sundrying for two days and laddering. The strip tillage (ST) was done by a Versatile Multi-crop Planter (VMP) in a single pass operation. Each strip had four 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, 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 Mulching treatments

Two levels of mulch were applied in this study. In no-mulch treatment, rice was transplanted without retaining mulch of previous mustard crop while in 50% mulch treatment  $875~kg~ha^{-1}$  of dried mulch of the previous mustard crop was used. This amount of mulch was evenly spread over the plot after tillage operation but before transplanting.

#### 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 was performed at 25 DAT. In the weedfree (WF) treatment, 6 HWs were performed at 15, 25, 45, 65, 75, and 90 DAT. Herbicides were applied by a hand-operated knapsack sprayer fitted with a flat-fan nozzle to deliver a spray volume of 300 L ha $^{\rm -1}$ . Herbicides used in different treatments are presented in Table 2.

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

 $^1\mathrm{DBT}\text{=}\ \mathrm{Days}$  before 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<sup>-1</sup> as triple superphosphate, muriate of potash, gypsum, and zinc sulfate at final tillage. Nitrogen was applied @ 80 kg ha<sup>-1</sup> as urea in three equal splits at 25, 45, and 60 DAT. Rice was irrigated four times at 20, 35, 50, and 65 DAT due to scare rainfall throughout the crop growing season. Adequate crop protection measures were taken as per the recommendation of the BRRI (BRRI, 2014).

## 2.8 Measurements

Densities of different weed species were recorded randomly from four locations per plot using a quadrat of 0.50 m  $\times$  0.50 m at 25, 45, 65 (flowering stage), and 115 DAT (crop maturity). The weed density (plants  $\rm m^{-2}$ ), and the weed dry biomass (g  $\rm m^{-2}$ ) was recorded. Fresh weed biomass was dried in the oven at 70°C for 72 hours and dry weight was recorded. The similarity among weed species between CT and ST in two consecutive years was calculated using the following formula (Habich, 2001).

Similarity (%) = 
$$\frac{2\Sigma nc}{\Sigma n1 + \Sigma n2} \times 100$$
 Where,

nc = number of common species between two communities

n1 = number of individual of community 1

n2 = number of individual of community 2

The crop was harvested at maturity (when 80% of rice grain became golden yellow) on 9 May in 2014 and 2 May in 2015, from randomly selected three quadrats 3 m  $\times$  1 m area in each) per lot plot. Plant height, number of panicles m<sup>-2</sup>, number of grains and sterile spikelets panicle<sup>-1</sup> were recorded from randomly selected ten hills before harvest. The weight of 1000-grains, grain yield and straw yield was recorded per plot and expressed as t ha<sup>-1</sup>. Grain yield was adjusted at 14% moisture content, and percent yield increase over control (YOC) was calculated using the following formula (USDA, 1979; Devasenpathy et al., 2008).

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

$$YOC(\%) = \frac{\text{yield in treatment - yield in control}}{\text{yield in control}} \times 100$$

The economics of crop production was estimated following the partial budgeting system (Perrin et al., 2008). The variable costs were calculated based on labor requirement for sowing/transplanting, weeding, harvesting and threshing, irrigation, fertilization, mulching and all other variable input costs like seed, fertilizer, irrigation, and mulch etc. The gross return was calculated based on the market price of grain and the byproducts. The gross benefit was calculated by deducting the variable cost from the gross return. The benefit-cost ratio (BCR) was calculated by using the formula as follows (Price, 1985):

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

#### 2.9 Statistical design and analysis

All the trials were conducted in a randomized complete block design with the weeding and mulching treatments combined. Weeding and mulching plots of 2014 received the weeding and the mulching treatments 2015 were assigned in the same plots as 2014. 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 between weed biomass and rice yield. The statistical package program *STAR* [43] was used to analyze all data (IRRI, 2014).

# 3. RESULTS AND DISCUSSION

### 3.1 Composition of weed flora

Over two rice growing seasons in 2014 and 2015, a total of 21 weed species were identified under nine families (Table 3). The most common families were Poaceae (6 species), Cyperaceae (5), Asteraceae (3), and Amaranthaceae (2), with one each of Commelinaceae, Convolvulaceae, Polygonaceae, Onagraceae, and Oxalidaceae. Compared to ST, CT produced 15% more weed species in 2014 and 64% more weeds species in 2015 (Table 3). In 2015, CT had 20% more weeds (18 species) than 2014 (15 species). Three species viz., Jussiaea decurrens DC., Ipomoea aquatica Forssk., and Scirpus mucronatus L. of 2015 were absent in 2014. In 2015, ST produced 31% fewer weeds (nine species) than 2014 (13 species). Among the 13 weed species recorded in ST in 2014, three weed species (Cyperus nemoralis Cherm., Mikania micrantha Kunth., and Sphilanthes acmella A.) were not found in CT in either season. Among the nine species of ST in 2015, four species (Cyanotis axillaris L., Echinochloa colona (L.) Link, Jussiaea decurrens (Walter), and Scirpus mucronatus L.) were absent after being present in 2014. CT produced 91% homogenous weeds in 2014 and 2015 while ST produced 82% common weeds in two consecutive years. In 2014, CT and ST had 57% common weed species, and in 2015 there were 45% common weed species between CT and ST (Table

Table 3: Weed species present in conventional and strip tillage in								
2014 and 2015 at Gouripur, Mymensingh, Bangladesh <sup>2</sup>								
	Conven		Strip					
Weed species	tilla	<del>-</del>	tillage					
	2014	2015	2014	2015				
1. Alternanthera sessilis L.	Y	Y	Y	Y				
2. A. philoxeroides Griseb.	Y	Y	N	N				
3. Cyanotis axillaris L.	Y	Y	Y	N				
4. Cyperus difformis L.	Y	Y	Y	Y				
5. C. compressus L.	Y	Y	Y	Y				
6. C. nemoralis Cherm.	N	N	Y	Y				
7. Cynodon dactylon L.	Y	Y	N	N				
8. Eclipta alba L.	Y	Y	Y	Y				
9. Echinochloa crussgalli L.	Y	Y	Y	Y				
10. E. colona (L.) Link	Y	Y	Y	N				
11. Fimbristylis miliaceae (L.) Vahl	Y	Y	Y	Y				
12. Jussiaea decurrens DC.	N	Y	Y	N				
13. Ipomoea aquatica Forssk.	N	Y	N	N				
14. Leersia hexandra Sw.	Y	Y	N	N				
15. Leptochloa chinensis L.	Y	Y	N	N				
16. Mikania micrantha Kunth.	N	N	Y	Y				
17. Oxalis europea Jord.	Y	Y	N	N				
18. Parapholis strigosa Dumort.	Y	Y	N	N				
19. Polygonum coccineum Muhl.	Y	Y	N	N				
20. Scirpus mucronatus L.	N	Y	Y	N				
21. Sphilanthes acmella A.	N	N	Y	Y				
Total number of weed species	15	18	13	9				
<sup>2</sup> Y = Present, N = Absent		•						

During both the years, CT plots showed 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 be due to minimizing the soil weed seed bank (Chauhan et al., 2012; Ruisi et al., 2015). In the CT treatment, no herbicide was applied, which might have resulted in a greater weed pressure. On the other hand, ST received a pre-plant (glyphosate), a pre-emergence herbicide (pendimethalin), postemergence herbicides (Ethoxysulfuron-ethyl), and the combination of both. 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).

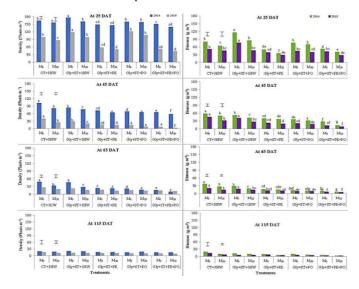
## 3.2 Effect on weed density and biomass

The effect of mulch and weed control practices on weed density was significant (p $\leq$ 0.01) at all dates except the time of crop harvest in 2014, and at 65 and 115 DAT in 2015 (p>0.05) (Figure 3). In 2014, at 25 DAT, Gly+ST+1HW without mulch produced the highest number of weeds m $^{-2}$ , followed by the same treatment with 50% mulch, and CT+3HW without mulch. Gly+ST+PE with or without 50% mulch, Gly+ST+PO with or without 50% mulch, and Gly+ST+PE+PO with 50% mulch produced the lowest weeds. At 45 DAT, CT+3HW without mulch had the highest number of weeds m $^{-2}$ , and the lowest was recorded from Gly+ST+PE+PO with 50% mulch. Gly+ST with PE or PO, without or with mulch, produced a statistically similar number of weeds.

At 65 DAT, CT+3HW and Gly+ST+1HW without mulch showed the highest weed density followed by CT+3HW and Gly+ST+1HW with 50% mulch, Gly+ST+PE without mulch. Gly+ST+PE with 50% mulch, Gly+ST+PO without mulch, Gly+ST+PO with 50% mulch, and Gly+ST+PE+PO without mulch. Gly+ST+PE+PO with 50% mulch produced the lowest weed density. At 115 DAT, weed density response to treatments was non-significant. The trend in the weed density of the treatments at 25 and 45

DAT in 2016 was similar to that of 2014, while the trend at 65 and 115 DAT was non-significant. The weed biomass was also influenced significantly (p≤0.01) by mulching and weed control practices at all dates of assessment in both years but non-significant (p>0.05) at 115 DAT in 2014 (Figure 3).

In 2014, at 25 DAT, the highest weed biomass was recorded from Gly+ST+1HW without mulch followed by the same treatment with 50% mulch, which was identical to CT+3HW without mulch and Gly+ST+PO with or without 50% crop mulch. The treatment Gly+ST+PE with 50% mulch produced the lowest weed biomass. At 45 DAT, CT+3HW without mulch produced the highest weed biomass followed by the same treatment with 50% mulch, which was similar to Gly+ST+1HW without mulch followed by the Gly+ST+1HW with 50% mulch. The treatment Gly+ST+PE and Gly+ST+PO without mulch ranked the third, followed by both the treatments with 50% mulch and Gly+ST+PE+PO without mulch. Gly+ST+PE+PO with 50% mulch produced the lowest biomass. At 65 DAT, similar trends in weed response were observed.



**Figure 3:** Effect of weed control practices and mulching on the weed density and biomass at different dates of assessment during 2014 and 2015 at Gouripur, Mymensingh, Bangladesh

At 25 and 45 DAT of 2015, the interaction effect was similar to that of 2014. At 65 DAT, CT+3HW without mulch produced the highest weed biomass followed by the same treatment without mulch, Gly+ST+1HW, Gly+ST+PE, and Gly+ST+PO and Gly+ST+PE+PO with or without 50% mulch. Overall, among the treatment combinations, 50% mulch combined with Gly+ST+PE+PO was more effective in suppressing weed density and biomass in 2015 than in 2014. 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 2014 and 50% in 2015 while weed biomass by 70% in both years. Among the treatment combinations, 50% mulch reduced weed density by 16-20% and biomass by 27-34%.

In this study, the conventional tillage with three times hand weeding (CT+3HW) without mulch ( $M_0$ ) produced the highest weed density and biomass. By contrast, the lowest was recorded from non-selective preplant (PE) herbicide applied before strip tillage (ST) operation followed by PE and then the PO herbicide (Gly+ST+PE+PO) with 50% mulch ( $M_{50}$ ) 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 be attributed to having 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, preemergence, 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 narrowleaved 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% mulch showed around 22% fewer weeds than nomulch (13% less in 2015 than 2014) among different treatment combinations. Here, beneficial effect of the of mulching 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 mulches may have enhanced the weed seed decay, losing seed viability, and failure of seed germination hence, reducing the weed emergence in mulched plots over no-mulch (Mashavakure et al., 2020). In addition, the delayed emergence of weaker weeds in the mulched field due to less space and light has a lower ability to produce and shed fewer seeds in the soil that might result in the lower weed density (Dahal and Karki, 2014). In this study, the most significant relative suppression of weed density and biomass by 50% mulch was with Gly+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 mulching may cause to reduce the weed pressure with mulched practices over no-mulching. The less weed biomass in ST simply 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 2015 compared with 2014, which might be attributed to the crop rotation. In this study, the *boro* (winter season) rice was the third crop in 2014 and the sixth crop in 2015, which was rotated with T. *Aman* (summer season) 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 different crops (*viz.* summer rice, mustard, and winter rice in the present study) having different growth patterns are more likely to result in disruption of weed life cycles due to changing management practices might be a key in reducing the weed density and biomass in non-puddled ST than puddled CT (Brainard et al., 2013).

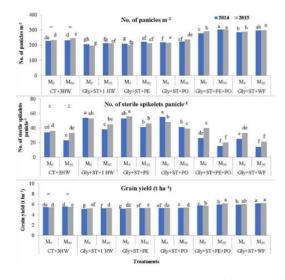
In this study, the highest weed density was recorded at 25 DAT, followed

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 at 25 DAT 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 and 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, Gly+ST+WF with 50% mulch produced the highest grain yield (Figure 4), followed by Gly+ST+PE+PO with 50% mulch, Gly+ST+WF without mulch, Gly+ST+PE+PO without mulch, CT+3HW with or without mulch, and Gly+ST+PO with 50% mulch. The lowest yield was recorded from Gly+ST+1HW without mulch, followed by Gly+ST+1HW and Gly+ST+PE with 50% mulch, and Gly+ST+PO without mulch. In 2014, Gly+ST+WF with 50% or without mulch and Gly+ST+PE+PO with 50% mulch produced the statistically similar highest yield followed by Gly+ST+PE+PO without mulch, CT+3HW with or without 50% mulch. The lowest grain yield was recorded from Gly+ST+1HW without mulch, followed by Gly+ST+1HW with 50% mulch, Gly+ST+PE, or Gly+ST+PO with 50% or without mulch. No significant yield variation was found during consecutive years.

The result reveals that, the control treatment (CT+3HW) produced about 6 % higher grain yield than Gly+ST+1 HW 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<sup>-2</sup>, grains panicle<sup>-2</sup>, 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, Gly+ST+1HW, Gly+ST+PE, and Gly+ST+PO reduced grain yield by 2-5%, while Gly+ST+PE+PO increased grain yield by 10% and Gly+ST+WF increased grain yield by about 12% in both years. Mulching increased grain yield by 4% only in 2015; however, mulch's effect varied with weed control practices. During this time, among the treatment combinations, 50% mulch produced 5% higher number of panicles and grains, and 13% lower sterile spikelets over no-mulch.



**Figure 4:** Effect of weed control practice and mulching on yield attributes and yield of rice in 2014 and 2015 at Gouripur, Mymensingh, Bangladesh

In the present study, greater yield in ST than CT 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 exudate allelochemicals, which may result in yield reduction 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's why in this study, regression analysis showed a strong negative correlation between grain yield and weed biomass (Table 4), 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.

**Table 4:** Correlation and regression between rice yield (kg ha-¹) and weed biomass (kg ha-¹) at different dates in 2014 and 2015 at Gouripur, Mymensingh, Bangladesh³

Y-Axis	X-Axis		2014		2015		
			RE	R <sup>2</sup>	RE	R <sup>2</sup>	
Yield	Weed biomass at	25 DAT	y=5938.8- 0.8111x	0.63	y=6056.2- 1.3375x	0.58	
		45DAT	y=5984.9- 1.5040x	0.65	y=5975.3- 1.9865x	0.60	
		65 DAT	y=5825.4- 2.1343x	0.73	y=6032.1- 4.7262x	0.66	

<sup>3</sup>DAT= Days after transplanting, RE= Regression equation y= grain yield of rice, x = biomass of weeds, R<sup>2</sup> = coefficient of determination

In addition to weed control, some herbicides may promote the growth of crops (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, mulching increased the grain yield by 4% over no-mulch, which might be attributed to the beneficial effects of mulches. Mulch converts to mineralized nutrients that promotes 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 (Shrivastay et al., 2015; Alam et al., 2014). Fewer weeds in 50% mulch 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 mulching on the yield contributing characters of rice might directly affect rice yield. In this study, the highest numbers of panicles m<sup>-2</sup>, and the lowest numbers of sterile spikelets panicle-1might have led to an improved effect of weed management and mulching in ST over manual weeding in CT.

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

Data revealed that during the experimentation, the highest profit was obtained from Gly+ST+PE+PO with 50% mulch (Table 4) followed by the same treatment without mulch and, Gly+ST+PE, Gly+ST+PO, and Gly+ST+1HW with or without 50% mulch. Treatment CT+3HW and Gly+ST+WF with and without mulch incurred economic losses. Among them, CT+3HW without mulch incurred the maximum loss in both the years. In this study, more profit was calculated in 2015 than in 2014. In the second year, Gly+ST+PE or Gly+ST+PO with or without mulch earned the similar BCR but around 13% higher than CT+3HW. Gly+ST+PE+PO with 50% mulch earned 7% higher BCR than no-mulch, which was 43% higher than Gly+ST+WF with 50% mulch and 47% higher than CT+3HW without mulch. Mulch alone increases BCR by 9% over no-mulch

Table 4: Cost and return analyses of rice production using different practices of tillage, weed control and mulching (values in US\$ ha-1) at Gouripur,					
Mymensingh, Bangladesh⁴					

Mymensingn, Bangladesn									
Treatments		Total cost		Total income		Profit/loss		BCR	
		2013	2014	2013	2014	2013	2014	2013	2014
CT+3HW	$M_0$	1477.3	1381.7	1451.8	1307.5	-25.5	-116.4	1.0	0.9
C1+3HW	M <sub>50</sub>	1477.3	1381.7	1474.1	1338.0	-3.2	-87.7	1.0	1.0
Gly+ST+1HW	$M_0$	1166.1	1188.2	1261.5	1396.1	95.4	47.2	1.1	1.2
Giy+31+111W	M <sub>50</sub>	1166.1	1188.2	1294.2	1413.4	128.1	63.1	1.1	1.2
Gly+ST+PE	$M_0$	1107.3	1107.3	1268.6	1399.6	161.3	134.0	1.1	1.3
GIY+31+FE	M <sub>50</sub>	1085.2	1107.3	1300.6	1408.8	215.4	142.7	1.2	1.3
Gly+ST+PO	$M_0$	1085.2	1107.3	1293.6	1410.6	208.4	145.6	1.2	1.3
diy+31+FO	M <sub>50</sub>	1085.2	1107.3	1300.6	1422.6	215.4	155.8	1.2	1.3
Gly+ST+PE+PO	M <sub>0</sub>	1129.4	1151.4	1418.6	1495.4	289.3	183.1	1.3	1.3
GIYTSITFETFO	M <sub>50</sub>	1129.4	1151.4	1467.2	1592.5	337.8	278.9	1.3	1.4
Gly+ST+WF	$M_0$	1526.4	1548.5	1456.1	1451.2	47.4	-23.6	1.0	0.9
	M <sub>50</sub>	1526.4	1548.5	1510.9	1500.0	102.1	16.2	1.0	1.0

 $^4$ CT= conventional tillage, HW= hand weeding, Gly= Glyphosate, ST= strip tillage, PE= pre-emergence herbicide, PO= post-emergence herbicide, WF= weed free,  $M_0$ = no-mulch,  $M_{50}$ = 50% mulch

In the present study, the variation in BCR might be attributed to the increased in grain yield and reduced cost in ST. One hector land preparation in CT required US\$ 190.80 ha<sup>-1</sup> but ST required only US\$ 35.80. Thus, ST saved around 68% cost for land preparation in this study. Cost savings due to reduction in tillage, fuel, and labour might have reduced the total variable cost in ST compared to CT. One previous study estimated 70% savings in land preparation in ST over CT, where the lowest land preparation cost (US\$ 32.54 - 33.25 ha<sup>-1</sup>) was recorded in ST; and the maximum land preparation cost (US\$88.24 - 110.29 ha<sup>-1</sup>) was incurred in the CT (Haque and Bell., 2019). In another study, 49% savings from land preparation in ST over CT were estimated (Islam et al., 2014). Moreover, herbicidal weed control was more profitable relative to 3HW in CT, and 6HW (weed-free) in ST.

In CT, 3HW incurred US\$ 313.28 ha<sup>-1</sup>. On the other hand, 6HW in ST incurred US\$ 417.71 ha<sup>-1</sup>, while 1HW incurred US\$104.43. By contrast,

application of glyphosate at pre-plant required US\$ 44.75 ha<sup>-1</sup>, one preemergence application and post-emergence application required US\$ 43.92 and 45.59 ha<sup>-1</sup>, respectively. Thus, herbicidal weed control required US\$ 134.26 ha<sup>-1</sup> 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% mulch practice might have attributed to the higher grain yield with 50% mulch than no-mulch.

## 4. CONCLUSION

Under strip tillage non-puddled system, spraying a pre-plant herbicide followed by a pre- and post-emergence herbicide with the retention of 50% of the previous crop mulch could control weeds more effectively over

manual weeding in conventional tillage and fetches the highest economic benefits.

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