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ON-FARM EVALUATION OF CONSERVATION AGRICULTURE PRACTICE ON WEED CONTROL AND YIELD OF WHEAT IN NORTHERN BANGLADESH

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ABSTRACT

On account of rural labour shortages, smallholder farms in South Asia are seeking labour saving strategies for planting and weed control. To overcome this challenge, conservation agriculture practices involving mechanized planting and crop residue retention together with the application of herbicides are being developed. But their effectiveness for weed control is still uncertain. The present study was undertaken to determine the effectiveness of residue retention relative to herbicides and hand weeding for weed control and yield of wheat in strip planted soil in northern Bangladesh. The on-farm experiment was conducted during November-March in 2014-2016, with wheat cv. *BARI Wheat 26* grown after monsoon rice under two tillage types combined with the six weed control practices [P_1: conventional tillage (CT)+three hand weedings (HW) (Control), P_2: Glyphosate (Gly)+strip planting (SP)+one HW, P_3: Gly+SP+pre-emergence (PE) herbicide, P_4: Gly+SP+post-emergence (PO) herbicide, P_5: Gly+SP+PE+PO, P_6: Gly+SP+weed-free (WF); and two levels of rice residue retention, R_0: no-residue and R_{50}: 50% residue (by height). The CT consisted of two primary tillage operations by a two-wheel tractor, anwhiled SP had done by a Versatile Multi-crop Planter in a single-pass process. A pre-plant herbicide (glyphosate), a PE herbicide (pendimethalin) and PO herbicide (carfentrazon-ethyl) was applied at recommended doses. The combination of applied glyphosate, SP, followed by sequential application of PE and PO herbicides and the retention of 50% of rice straw achieved the highest weed control efficacy. Furthermore, this practice produced the 24% higher yield and 40% higher economic returns relative to control without exerting any phyto-toxicity in wheat.

Contribution/Originality: This study is one of the very few studies in Bangladesh which have investigated the effect of conservation agriculture principles on weed and crops. Results highlighted the impact of herbicides together with crop residue mulching on weed control and yield of wheat in strip planted soil.

1. INTRODUCTION

Conservation agriculture (CA) includes diverse forms of crop management practices involving use of herbicide for weed control but is based on minimum soil tillage, retention of residues on soil surface, and crop rotation [1]. Tillage has been an essential component of traditional agricultural systems. It is the mechanical manipulation of soil and plant residues facilitating crop planting. It kills weeds, regulates the circulation of water and air within the soil and mobilizes nutrients from the soil for crop growth [2]. However, conventional tillage (CT) causes a decrease in soil fertility by accelerated erosion, soil water loss while delaying sowing of crops and consuming labour [3]. The CA, by avoiding tillage and saving labour is a promising approach in Bangladeshi agriculture for optimizing crop yields, with economic and environmental benefits [4].

The CA is a set of minimum soil disturbance practices that leave crop residues on the soil surface. This practice can slow the breakdown of plant residues and reduce the release of mineralized inorganic forms of plant nutrients in soil through preserving optimum soil moisture content [5]. Minimum tillage (MT) also offer significant environmental benefits through fuel energy savings and decreased greenhouse gas emissions [6]. Effective energy use is one of the conditions for sustainable agricultural production, since it provides financial savings, conserves fossil fuel resources, and decreases air pollution [7].

Increased labour scarcity for agriculture owing to migration from rural to urban areas within and outside the country [8] is impacting on crop production worldwide. The MT requires less total labour requirements to achieve approximately the same crop production as of CT making MT more profitable over CT with lower production costs [9]. For this reason, MT is becoming increasingly attractive to farmers worldwide. Bangladeshi farmers can also adopt this technology for more profitable crop production than CT [10].

The conventional mechanized tillage systems control the existing weeds by burying them and their seeds into the soil, resulting in less early emergence of weeds [11]. By contrast, to achieve a similar low weed competition at crop establishment, pre-planting non-selective herbicides must be used to kill the existing weeds on the untilled field. Subsequently, pre-emergence herbicide followed by a post-emergence may be needed to control remaining viable weed seeds near the surface of the less disturbed soil [12]. Moreover, massive weed infestation may limit the adoption of MT system if weeds are not successfully was controlled [13].

In Bangladesh, traditionally, weeds are managed manually or by tillage. However, decreased labour availability and high wages, especially during peak demand periods, are decreasing the capacity for timely manual weeding on farms [14]. To overcome this constraint, farmers are switching to herbicidal weed control as it is a quick, effective, and low-cost weed control method. Previous studies confirmed the application of pre-emergence and post-emergence herbicides ensured continuous effective control of weed species that emerged in several flushes and provided better yield over manual weeding even under minimum tillage practice [15]. However, the repeated use of herbicide with the same mode of action may lead to the development of herbicide resistance in weeds, making weed control more difficult [16].

On the other hand, the persistence of herbicides in the soil and its detrimental effects on succeeding crops is a significant issue [17]. Furthermore, shifts in weed populations due to continuous use of a particular herbicide, less availability of appropriate herbicide modes of action, high prices, and environmental pollution-related issues underpin the need to adopt integrated weed management strategies to increase the sustainability of crop production with MT. Agronomic options like residue mulching of the previous crops have been reported to suppress weeds including in this system of crops cultivation [18].

Several minimum soil disturbing options could be used, and the strip planting (SP) is one of them [19]. The SP involves disturbance of a slot up to 6 cm deep and 4-6 cm wide, covering the equivalent to 15-25 % of the soil surface. Strip planted wheat cultivation technology based on straw residue retention has been developing in Bangladesh [20], but the optimum weed control for crops is still not well defined. There are still limited research data available on weed control for SP wheat cultivation. In this study, we tested the effect of rice straw residue retention relative to pre-plant, pre-emergence, and post-emergence herbicides on weed control and yield of wheat in Bangladesh established by SP.

2. MATERIAL AND METHODS

2.1. Experimental Site and Season

A two-year crop sequence (Rice-Wheat-Mungbean) experiment was conducted on a farmers' field located at

Durbachara village of Bhangnamari union, situated at Gouripur sub-district in Mymensingh district of Bangladesh. Wheat was grown during mid November-March in 2014-15 and 2015-16 in the cool dry season. The site was located at latitude 24.75° N and longitude 90.50° E) at 18 m altitude Figure 1.

Figure-1. Map of Bangladesh showing the site of on farm experiment.
Source: Department of Soil Science, Faculty of Agriculture, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh.

2.2. Edaphic and Climatic Condition

The experiment site is situated on the Old Brahmaputra Floodplain of predominantly dark grey non-calcareous alluvium soils under the *Sonatala* series. It was on flood free medium-high land. Soil characteristics have been presented in Table 1.

Table-1. Soil properties at 0-15 cm depth of the experimental field.

A. Physical characteristics of soil			
i.	Sand (2.00-0.50 mm)	:	50%
ii.	Silt (0.5-0.002 mm)	:	23%
iii.	Clay (< 0.002 mm)	:	27%
iv.	Textural class	:	Sandy Clay Loam
B. Chemical characteristics of soil			
i.	pH	:	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

Source: Department of Soil Science, Faculty of Agriculture, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh.

During the study period, March was the warmest month when the highest maximum temperatures were 30.6 and 31.06 ℃ and the highest minimum temperatures were 18.4 and 20.2 ℃ in 2014-15 and 2015-16, respectively followed by February. Temperature declined gradually from November to January. January was the coldest month. November in 2014, and Dcember and March in both years were the driest months when no rainfall was recorded.

The highest rainfall event comprising about 20 mm was recorded in February during both years. November and March enjoyed the highest sunshine hours while the December had least sunshine hours during both years Figure 2.

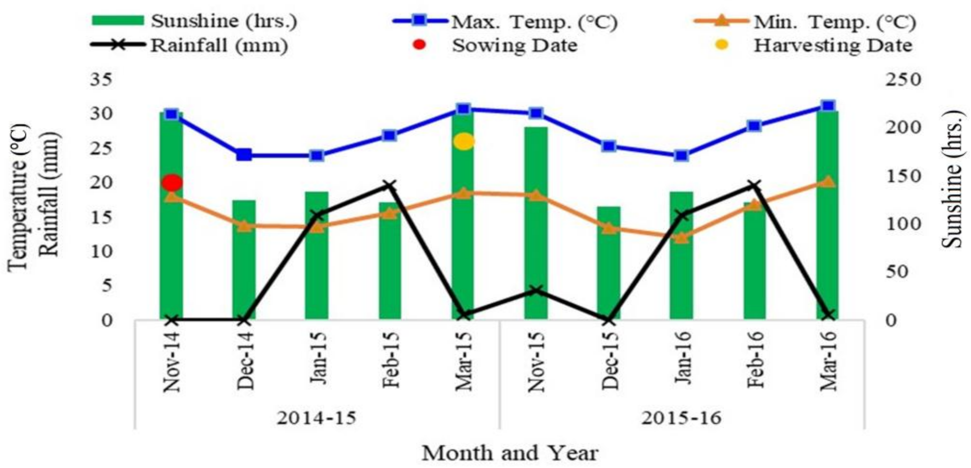

Figure-2. Monthly average temperature and total rainfall distribution pattern in 2014-15 and 2015-16.
Source: Department of Irrigation & Water Management, Faculty of Agricultural Engineering & Technology, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh.

2.3. Experimental Treatments and Design

The present study deals with wheat cv. *BARI Wheat 26* in two consecutive years on the same plots with treatments comprising a combination of six tillage and weed control practices *viz.* (i) Conventional tillage (CT)+3 hand weeding (HW) (Control); (ii) Glyphosate (Gly)+strip planting (SP)+1HW; (iii) Gly+SP+pre-emergence (PE) herbicide, (iv) Gly+SP+post-emergence (PO) herbicide), (v) Gly+SP+PE+PO, and (vi) Gly+SP+weed-free (WF); and two levels of rice straw as (i) R_0: no-residue and (ii) R_{50}: 50% residue. Treatments were arranged in randomized complete block design, replicated three times, with plots split for residue levels.

2.4. Tillage Operation

In each 9 m × 5 m plot, conventional tillage (CT) was done using a two-wheel tractor (2WT). The land was prepared by four plowings and cross plowing followed by sun-drying for two days and levelling. Strip planting (SP) was done by a Versatile Multi-crop Planter (VMP) in a single pass operation [21]. Strips had prepared for 4 rows, each 6 cm wide and 5 cm deep. Three days before SP operation, glyphosate had applied @ 3.7 L ha^{-1}.

2.5. Seed Sowing

In CT, seeds were sown manually in rows 20 cm apart. In SP, continuous line sowing was done using the VMP at 20 cm apart. Seeds were covered with soil just after sowing. In both CT and SP, 120 kg seeds ha^{-1} were sown on November 20 in both years.

2.6. Residue Retention Practice

Two levels of straw residues of monsoon rice were used in this study. In no-residue practice, seeding was done without retaining rice straw while in 50% residue practice, 50% residue (height basis) of previously harvested rice was used. This amount of residue was spread over the plots after seeding of wheat seeds.

2.7. Weed Control Practices

In CT, 3 HWs were done at 25, 45, and 65 DAS. In SP, 1 HW was done at 25 DAS. In the weed-free (WF) treatment, six HWs were done at 15, 25, 45, 65, 75, and 90 DAS. Herbicides were applied by hand-operated knapsack sprayer fitted with a flat-fan nozzle at a spray volume of 300 L ha^{-1}. Herbicides used in different treatments are presented in Table 2.

Table-2. Herbicides and rates of application used in the experiment.

Herbicides			Dose	Time of	Field
Group	**Name**	**HARC class**	**(ha^{-1})**	**application**	**condition**
Pre-plant	Glyphosate	Group G	3.7 L	3 DBS	Field capacity
Pre-emergence	Pendimethalin	Group K1	2.5 L	3 DAS	
Post-emergence	Carfentrazon-ethyl	Group E	1.25 g	25 DAS	

Note: DBS= Days before sowing, DAS= Days after sowing, HARC= Herbicide Resistance Action Committee.

2.8. Cultural Operations

The nitrogen in the form of urea, phosphorus from triple super phosphate, potassium from muriate of potash and sulfur from gypsum was applied @ 100, 26, 33, and 20 kg ha^{-1}, respectively. The entire amount of PKS was broadcast before seeding and residue retention. Two-thirds of the N was applied at final ploughing and one-third at crown root initiation (CRI) stage.

Irrigations were applied at 20, 55 and 80 DAS. First and third irrigation was very light and excess water was drained out to prevent wilt and lodging. Cutworm was controlled by Tricosale® 20EC @ 500 ml ha^{-1}. *Bipolaris* leaf blight was controlled by Tilt® 250 EC @ 0.5 ml L^{-1} of water. Bird was kept away for 10 DAS and rat was controlled using zinc phosphide poison.

2.9. Data Recording

Weed densities (plants m^{-2}) were recorded in a 0.50 m × 0.50 m quadrat at 25, 45 and 65 DAS, and at crop harvest. The quadrat was placed randomly at four places in each plot. The weed density was counted in plants m^{-2}, and the weed biomass was recorded in g m^{-2} after oven drying the samples at 70 ℃ for 72 hrs. The similarity among weed species between CT and SP in two consecutive years was calculated using the following formula [22].

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

Where,
nc = number of common species between two communities
n1 = number of individuals of community 1
n2 = number of individuals of community 2

Weed control efficacy (WCE) was calculated as using the formula follows [23] :

$$\text{WCE} = \frac{\text{weed dry weight in the control plot} - \text{weed dry weight in the treated plot}}{\text{weed dry weight in the control plot}} \times 100$$

Phyto-toxicity of herbicides in wheat was assessed visually following the grading [24] as below:

Table-3. Qualitative description of treatment effects on crop in the visual scoring scale of 0 to 10.

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

Source: Rao [24].

The crop was harvested at maturity (when 80% of spikelets turned brown) on March 26 in both years, from three randomly selected patches of 3 m × 1 m in each plot. Plant population and number of tillers and spikes m^{-2} and number of grains $spikes^{-1}$ were recorded from randomly selected ten hills before harvest. The weight of 1000-grains, and grain and straw yields was recorded. Grain yield was adjusted at 14% moisture content [25], and percent yield increase over control (YOC) was calculated as described below [26].

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

The economics of crop production was estimated following the partial budgeting system. The variable costs were calculated based on labour requirement for seeds sowing, weeding, harvesting and threshing, irrigation, fertilization, and all other input costs like seed, fertilizer, irrigation, etc. The gross return was calculated based on the yield and market price of grain and 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 [27] as follows:

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

2.10. Statistical Analysis

Data were subjected to two-way analysis of variance, and Duncans' Multiple Range Test compared means at P<0.05, using the statistical package program *STAR* [28].

3. RESULTS AND DISCUSSION

3.1. Weed Flora Composition

Among the treatment combinaions of this study, we present the weed data for CT+3HW and Gly+SP+PE+PO treatments under no-residue and 50% residue levels. Over two years wheat cultivation during 2014-15 and 2015-16, total 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).

After two seasons of wheat cultivation, compared to SP, CT produced 44% more weeds Table 4. In 2015-16, CT had 12% more weeds (37 species) than 2014-15 (31 species). Seven species *viz. Centipeda minima* Lour. *Physalis heterophylla* Nees. *Polygonum coccineum* L. *Solanum torvum* L. *Echinochloa colonum* L. *Scirpus juncoides* L. and *S. supinus* L. recorded in 2015-16 were absent in 2014-15. In 2015-16, SP produced 33% fewer weeds (22 species) than in 2014-15 (33 species). Among the 17 weed species of SP in 2015-16, three species (*Amaranthus viridis* L, *Brassica kaber* L. and *Spilanthes acmella* L.) were absent after being present in 2014-15.

Among the 37 sepecies of CT, *Chenopodium album* L. and *Dentella repens* L. were absent in SP in either season. CT produced 91% homogenous weeds in 2015-16 and 2014-16 and while SP produced 82% common weeds in two consecutive years. In 2014-15, CT and SP had 57% common species, and in 2015-16 there were 45% common weed species between CT and SP Table 4. This result inclined that, over time SP increases weed species diverstiy in the soil weed seed bank. Retention of 50% residue was more suppressive to weed in SP than CT and in the second year than the first year.

3.2. Effect of Treatments on Weed Density and Biomass, Weed Control Efficacy, and Phyto-Toxicity

The combined impact of weed control practices and residue levels was significant (p≤0.05) on both weed density Figure 3 and biomass Figure 4 at all dates of sampling except at crop harvest (p>0.05) in both years. In 2014-15, at 25 DAS, Gly+SP+1HW produced the highest weed density and biomass, followed by CT+3HW and Gly+SP+PE. At 45 and 65 DAS, CT+3HW and Gly+SP+1HW had the highest weed density and biomass, followed by Gly+SP+PE and Gly+SP+PO. Treatment Gly+SP+PE+PO produced the lowest weed density and biomass.

Table-4. Weed flora composition in different treatments

Weed type	Scientific name	LC	2014-15		2015-16		2014-15		2015-16	
			CT+3HW				Gly+SP+PE+PO			
			R_0	R_{50}	R_0	R_{50}	R_0	R_{50}	R_0	R_{50}
Broad leaf	*Ageratum conyzoides* L.	P	+	+	+	+	+	+	+	-
	Amaranthus viridis L.	A	+	+	+	+	-	-	+	+
	A. spinosus L.	A	-	+	+	+	+	+	+	+
	Alternanthera sessilis L.	P	+	+	+	+	+	+	+	+
	A. philoxeroides L.	P	+	+	+	+	+	+	+	-
	Brassica kaber L.	A	+	+	+	+	-	-	+	+
	Centipeda minima Lour.	P	-	-	+	+	+	+	-	-
	Chenopodium album L.	A	+	+	+	+	-	-	-	-
	Cyanotis axillaris Roem.	A	+	+	+	+	+	+	+	+
	Dentella repens L.	P	+	+	+	+	-	-	-	-
	Desmodium triflorum L.	P	+	+	+	+	+	+	-	-
	Eichhornia crassipes Mart.	P	+	+	+	+	+	+	+	+
	Eclipta alba L.	A	+	+	+	+	+	+	+	+
	Euphorbia parviflora L.	A	-	+	+	+	+	+	-	-
	Gnaphalium luteo-album L.	A	+	+	-	-	+	+	-	-
	Hedyotis corymbosa L.	A	+	+	+	+	+	+	+	+
	Jussia decurrence Walt.	A	+	+	+	+	+	-	+	+
	Lindernia antipoda L.	A	+	+	+	-	-	+	+	+
	L. hyssopifolia L.	A	+	+	+	-	+	+	+	+
	Nicotina plumbaginifolia L.	A	+	+	+	+	+	+	+	+
	Physalis heterophylla Nees.	A	-	-	+	+	+	+	+	+
	Pistia stratiotes L.	P	+	+	+	+	+	+	-	-
	Polygonum coccineum L.	A	-	-	+	+	+	+	-	-
	Rotala ramosior L.	A	+	-	+	+	+	+	-	-
	Solanum torvum L.	P	-	-	+	+	+	+	+	-
	Spilanthes acmella L.	A	+	-	+	+	-	-	+	-
Sub-Total			20	20	25	23	20	20	17	13
Grass	*Cynodon dactylon* L.	P	+	+	-	-	+	+	-	-
	Digitaria sanguinalis L.	A	+	+	+	+	+	+	-	-
	Echinochloa crusgalli L.	A	+	+	+	+	+	+	+	+
	E. colonum L.	A	-	-	+	+	+	-	-	-
	Eleusine indica L.	A	+	+	+	+	+	+	+	+
	Leersia hexandra L.	P	+	+	+	+	+	+	-	-
	Panicum distichum L.	P	+	+	-	-	+	+	-	-
Sub-Total			6	6	5	5	7	6	2	2
Sedge	*Cyperus difformis* L.	A	+	+	+	+	+	+	+	+
	C. rotundus L.	P	+	+	+	+	+	+	+	-
	C. iria L.	A	+	+	+	-	+	+	-	-
	Eleocharis atropurpurea Ret.	A	+	+	+	-	+	+	-	-
	Fimbristylis miliacea L.	A	+	+	+	+	+	+	+	+
	Scirpus mucronatus L.	P	-	+	-	+	+	-	-	-
	S. juncoides L.	P	-	-	+	+	-	-	-	-
	S. supinus L.	P	-	-	+	+	-	-	-	-
Sub-Total			5	6	7	6	6	5	3	2
Grand Total			31	32	37	34	33	31	22	17

Note: LC= Life Cycle, CT=Conventional tillage, HW= Hand weeding, Gly= Glyphosate, SP= Strip planting, PE=Pre-emergence herbicide, Post-emergence herbicide, R_0= no-residue, R_{50}= 50% residue, A=Annual, P=Perennial, + Present, - Absent.

Among the treatment combinations, retention of 50% residue reduced both density and biomass significantly relative to no-residue. Among the different dates of assessment, the highest weed density and biomass were found at 25 DAS, followed by 45 and 65 DAS, and crop harvest. The trend of both weed density and biomass response to the treatments was more or less similar in 2015-16.

Over the two years, CT produced about 30% higher weed density and 40% higher weed biomass than SP. Spraying PE followed by PO reduced weed density by 40% and 50% in 2014-15 and 2015-16, respectively, while weed biomass was depressed by 70% in both years. Retention of 50% residue reduced weed density by 16-20% and biomass by 27-34%. The most effective suppression by 50% of residue had found while combined with Gly+SP+PE+PO.

Treatment Gly+SP+WF with or without residue achieved the highest WCE in both years Table 5. Apart from Gly+SP+WF, at 25 DAS, the highest WCE had found from Gly+SP+PE+PO, followed by Gly+SP+PO and CT+3HW with 50% residue, respectively. Gly+SP+1HW without residue was the least efficient. At 45 DAS, the highest WCE had recorded from Gly+SP+PE+PO with 50% residue followed by Gly+ST+PO, Gly+SP+PE, and Gly+SP+1HW with 50% residue, respectively. The lowest has recorded from CT+3HW without residue. This trend was more or less similar at 65 DAS and crop harvest. In 2015-16, the relative WCE among treatments was identical to that of 2014-15. During the experimentation period, except for the very slight toxic effect of pendimethalin (PE) at 25 DAS in 2014-15, none of the herbicides exerted any visual phyto-toxicity on wheat (data not shown). The very slight toxicity symptoms after PE application recovered three days after application.

In this study, CT+3HW without residue retention produced the highest weed density and biomass. At the same time, the lowest weed density and biomass occurred in Gly+SP+PE+PO with 50% residue in two successive years. CT offers a better germination environment for most of the weed seeds due to a more aerated and warmer soil created by massive soil pulverization, equivalent to about 80% of soil disturbance [29]. Tilled soils also provide germination stimulus for weeds requiring scarification, ambient CO_2 concentrations, higher nitrate concentrations, and larger temperature fluctuations to break dormancy, leading to higher weed density in CT [30].

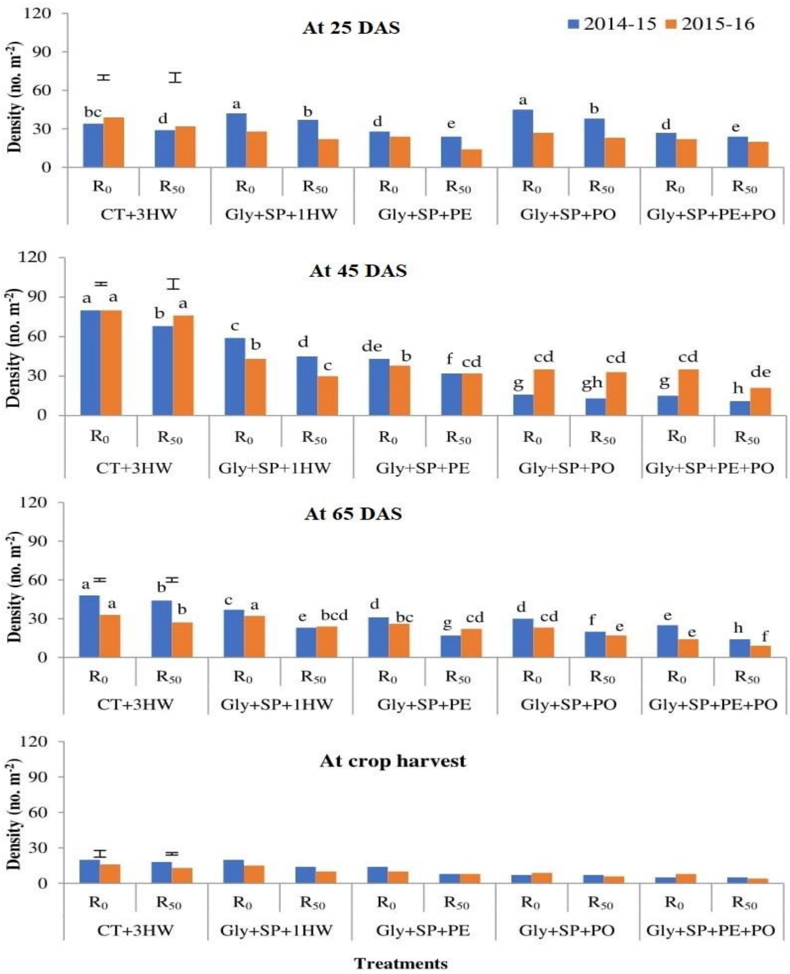

Figure-3. Effect of treatments on the weed density at different dates during 2014-15 and 2015-16. For each year, means followed by the same letter did not differ significantly (P> 0.05).

In SP, more than 75% of the weed seeds are retained in the top 1 cm soil layer, whereas in CT soil, there are only 11% of weed seeds in the surface 1 cm of soil [31]. Many weed seeds on or close to the soil surface can lose viability due to desiccation and harsh weather, leading to increases in non-viable weed seeds in the seed bank that might lead to reduced weed density in SP than CT [32]. Moreover, the lower weed density in SP might have attributed to weed seeds' lethal germination, as the radicle of germinated weeds remaining near the soil surface in SP that may have difficulty penetrating the soil [33]. Consequently, the growth, development, and seed setting of the weed plant is hampered. CT also allows vigorous weed seedlings with greater seed setting ability [34] to emerge from deeper in the soil than undisturbed soils in SP which might lead over time to lower weed density and biomass in SP than CT. Lower weed density in SP might also be associated with weed seed predation by ants, rodents, other granivores, pathogens, and birds [35] by increasing the availability of seeds to predators and minimizing predators' mortality in minimally-disturbed soil [36]. Thus, reducing weed density as well as weed biomass in SP than in CT is likely over time.

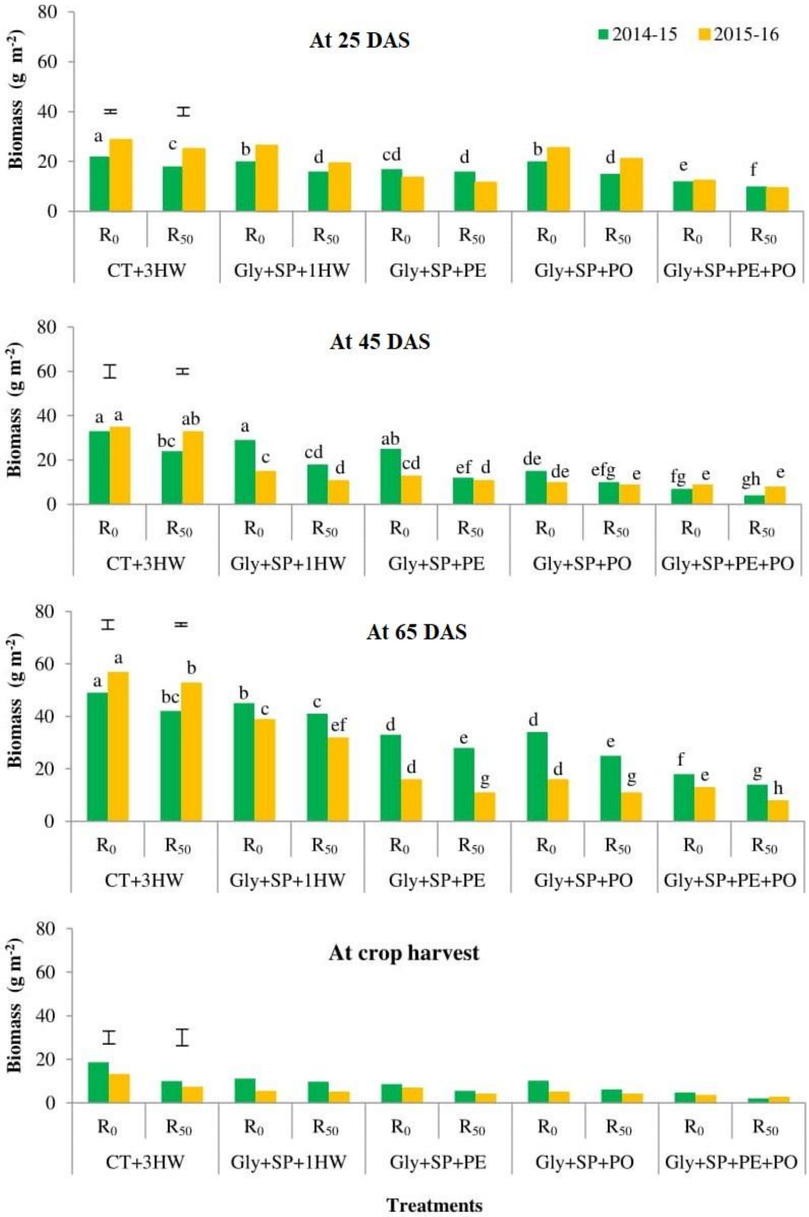

Figure-4. Effect of treatments on the weed biomass at different dates during 2014-15 and 2015-16. For each year, means followed by the same letter did not differ significantly (P > 0.05).

In the present study, control treatment (CT+3HW) did not receive any herbicide which may have resulted in the higher weed density here. Some weeds escaped the three hand weeding operations, leading to higher density in CT than SP. On the other hand, SP received glyphosate followed by pendimethalin and carfentrazon-ethyl herbicides. These herbicides were very effective for controlling weeds from before sowing resulting in less weed density in SP than CT. Compared to the single application of pre- and post-emergence herbicide, the combination of them exerted 70% higher WCE than hand weeding of CT Table 5. The broad-spectrum activity and higher phytotoxic effects of herbicides [37]; [38] against both grass, broad-leaved, and even narrow-leaved weeds compared to a single application of each may explain the higher WCE in SP than CT.

Table-5. Effect of different treatments on the weed control efficacy.

Treatments		Weed control efficacy at							
		25 DAS		45 DAS		65 DAS		crop harvest	
		2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
CT+3HW	R_0	0	0	0	0	0	0	0	0
	R_{50}	18	13	27	6	14	7	0	10
Gly+SP+1HW	R_0	9	8	12	57	8	32	42	0
	R_{50}	27	33	45	69	16	44	58	30
Gly+ST+SP+PE	R_0	23	53	24	63	33	72	67	60
	R_{50}	27	60	64	69	43	81	83	70
Gly+SP+PO	R_0	9	12	55	71	31	72	83	40
	R_{50}	32	27	70	74	49	81	83	70
Gly+SP+PE+PO	R_0	45	57	79	74	63	77	83	70
	R_{50}	55	67	88	77	71	86	83	90
Gly+SP+WF	R_0	100	100	100	100	100	100	100	100
	R_{50}	100	100	100	100	100	100	100	100

Note: CT= conventional tillage, HW= hand weeding, Gly= Glyphosate, SP= Strip planting, PE= pre-emergence herbicide, PO= post-emergence herbicide, WF= weed free, R_0= no-residue, R_{50}= 50% residue, DAS= Days after sowing.

Retention of 50% rice straw residue produced lesser weed density and biomass than no-residue. The beneficial effect of residues on weed suppression is attributed to smothering of weeds, suppressing weed seed germination and growth, lowering soil temperatures, changing allelo-chemicals released from decaying plant tissues, and temporary immobilization of nutrients [39]. Release of nutrients and organic matter upon decomposition of residues can stimulate the vigorous root and shoot growth of crops. The robust crop is more competitive than weeds to absorb nutrients, reducing weed pressure with 50% residue retention. Moreover, decreased soil temperature fluctuations with residue retention [40] and reduced light penetration facilitate cooler average soil temperatures that reduce weed seed germination and cause delayed germination in residue retained field relative to no-residue.

Furthermore, increased microbial populations which can be aided by decomposition of the residue and soil moisture conservation accelerate weed seed decay and loss of seed viability [41]. The high amounts of residue may delay the emergence of weeds, and such late emerged weeds can produce fewer seeds than with earlier emergence [42]. Collectively, these factors may have reduced weed pressure in SP relative to CT in this study. Thus, the combined effect of herbicides and residues in SP suppressed weed density and biomass more effectively than no-residue in CT in this study. In soil weed seed bank, weed emerges in several flushes. Generally, weed emergence occurs within three weeks of planting crops [43]. The pre-emergence herbicide at three DAS offered better control of weed compared to hand weeding in both CT and SP. Surviving and newly emerging weeds were suppressed by post-emergence herbicide application at 25 DAS. The combined effect of pre- and post-emergence herbicides killed almost all broadleaves, grasses, and sedges weeds. After 45 DAS, weed plants reached near maturity and completion of their life cycle. It is important to prevent seed set of weed and seed replenishment of the soil weed seed bank. Mishra and Singh [44] found pre-emergence herbicide alone can control the weeds of the first batch but fail to handle some escaped problematic weeds and weeds of the second batch, which could be controlled by post-emergence herbicides. Awan, et al. [45] also reported the sequential application of two or three herbicides can manage all types of weed efficiently at the later stage of crop growth than the earlier stage when they used a single herbicide.

33. Effect of Treatments on the Yield

In 2014-15, the highest grain yield had recorded from Gly+SP+WF and Gly+SP+PE+PO, followed by CT+3HW Figure 5. Treatment Gly+SP+1HW, Gly+SP+PE and Gly+SP+PO produced the lowest yields. In 2015-16, the trends in grain yield production were more or less identical to that of 2014-15. The highest grain yield in Gly+SP+WF and Gly+SP+PE+PO was associated with the highest number of tillers and spikes m^{-2} and grains $spikes^{-1}$. Among the treatment combinations, retention of 50% residue produced a 6% more spikes, 14% more grains $spikes^{-1}$ and about 4% higher seed yield over no-residue. Gly+SP+PE+PO with 50% residue produced 24% yield advances compared to CT+3HW without residue. In the present study, better yield in SP over CT might reduce weed density and weed biomass. As the weed pressure and grain yield are inversely related and it was previously reported that crop yield in SP than CT when weeds are controlled successfully [44]. The higher weeds in CT may reduce crop yield due to the higher crop weed competition. Weeds compete for the crops by using the available moisture, and nutrients; compete for space and light with crop plants and excrete allelo-chemicals [45] which results in yield reduction in CT with manual hand weeding. Herbicide (3 types) treated plots in SP were infested with fewer weeds offer higher yield advantages by producing more panicles and filled grains [46]; [47]. There was a strong negative correlation between grain yield and weed biomass Table 6 indicating that increasing each 1 kg weed biomass at 25, 45, and 65 DAS resulted in a considerable amount of yield decrease of wheat.

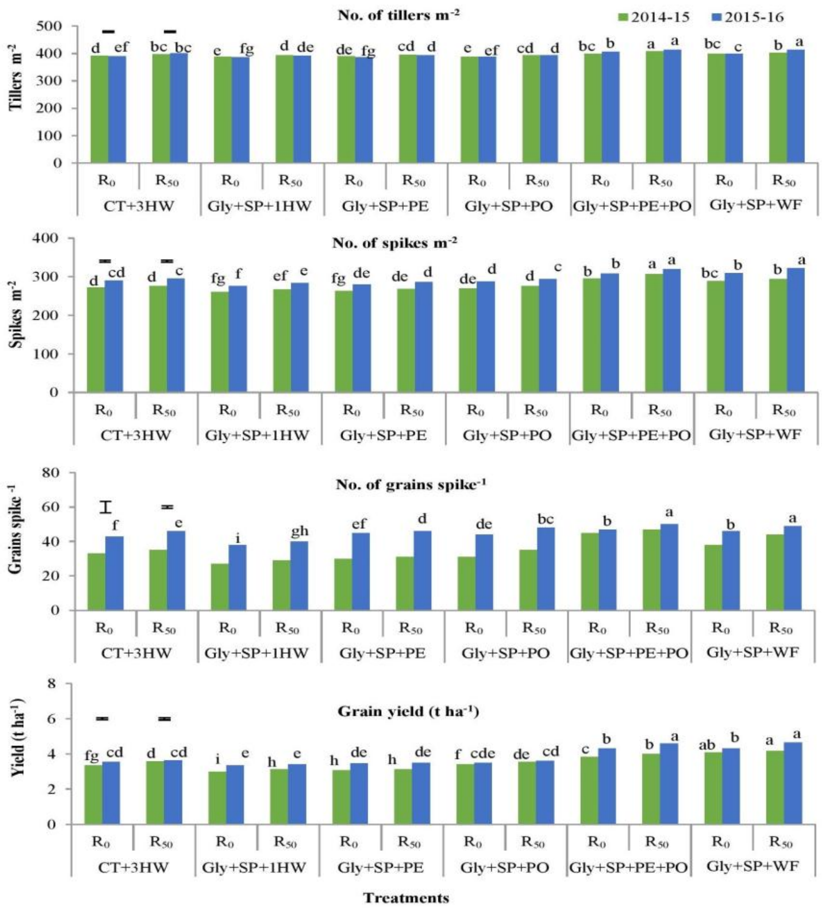

Figure-5. Effect of treatments on the yield attributes and yield of wheat during 2014-15 and 2015-16. For each year, means followed by the same letter did not differ significantly (P > 0.05).

In this study, 50% residue increased the grain yield by 4% over no-residue. Upon decomposition, residue releases mineralized nutrients that influence crop growth. Simultaneously, it suppresses weed growth and supplies organic matter for heterotrophic N fixing microorganisms [48]; [49], which could be utilized by the crops, resulting in higher yield. 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, SP, and crop residues on the yield contributing characters of wheat might directly affect the wheat yield. In this study, the highest numbers of tillers m^{-2}, spikes m^{-2} and grains $spike^{-1}$, respectively, might have led to a better outcome in SP over manual weeding in CT.

Table-6. Regression relationships between wheat yield (kg ha^{-1}) and weed biomass (kg ha^{-1}).

Y-axis	X-axis		2014-15		2015-16	
			RE	R^2	RE	R^2
Yield	Weed biomass at	25 DAS	y=4183.5-4.74x	0.67	y=4435.3-3.81x	0.59
		45 DAS	y=3961.1-2.95x	0.62	y=4121.1-2.31x	0.63
		65 DAS	y=4107.7-2.12x	0.70	y=4139.0-1.47x	0.84

Note: DAS= Date after sowing, y= grain yield of wheat, x = biomass of weeds, RE=Regression equation, R^2=Regression co-efficient.

3.4. Economics of Wheat Cultivation

Over the two years, highest profit had calculated from Gly+SP+PE+PO with 50% residue Table 7 followed by the same treatment without residue and Gly+SP+PE, Gly+SP+PO, and Gly+SP+1HW with 50% and without residue, respectively. Treatment CT+3HW without residue incurred financial losses in 2014-15. In the second year, Gly+SP+PE or Gly+SP+PO with or without residue earned the identical BCR which was around 13% higher than CT+3HW. Among the treatment combinations, retention of 50% residue earned 9% higher BCR than no-residue. Gly+SP+PE+PO with 50% residue earned about 40% higher profit than CT+3HW without residue.

Table-7. Economics of wheat cultivation (values in US$ ha^{-1}).

Treatments		Production cost		Total income		Profit/loss		BCR	
		2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
CT+3HW	R_0	1104.7	1104.7	1059.7	1124.5	-45.0	19.8	0.96	1.02
	R_{50}	1104.7	1104.7	1131.7	1145.8	27.0	41.1	1.02	1.04
Gly+SP+1HW	R_0	968.5	968.5	967.9	1055.9	-0.6	87.4	1.00	1.09
	R_{50}	968.5	968.5	1002.8	1080.1	34.2	111.6	1.04	1.12
Gly+SP+PE	R_0	930.3	930.3	986.9	1091.5	56.6	161.2	1.06	1.17
	R_{50}	930.3	930.3	1001.3	1102.9	71.0	172.6	1.08	1.19
Gly+SP+PO	R_0	930.3	930.3	1079.4	1102.4	149.1	172.1	1.16	1.18
	R_{50}	930.3	930.3	1124.8	1137.1	194.5	206.8	1.21	1.22
Gly+SP+PE+PO	R_0	974.4	974.4	1194.6	1355.4	220.2	380.9	1.23	1.39
	R_{50}	974.4	974.4	1246.8	1446.5	272.4	472.1	1.28	1.48
Gly+SP+WF	R_0	1089.1	1089.1	1263.8	1343.6	174.6	254.5	1.16	1.23
	R_{50}	1089.1	1089.1	1291.1	1432.3	201.9	343.2	1.19	1.32

Note: CT= conventional tillage, HW= hand weeding, Gly= Glyphosate, SP= strip planting, PE= pre-emergence herbicide, PO= post-emergence herbicide, WF= weed free, R_0= no-residue, R_{50}= 50% residue, BCR= Benefit-cost ratio, 1 US$=85 BDT.

In the present study, the variation in BCR can be attributed to the variation in grain yield and cost required for cultivation in CT and SP. Land preparation in CT required US$ 190.80 ha^{-1}, but SP required only US$ 35.80 ha^{-1}. Thus, SP saved around 68% cost for land preparation due to fewer tillage passes and lower fuel consumption than for CT land preparation. In one previous study, Haque and Bell [50] estimated 70% savings in land preparation for SP over CT, due to the lower land preparation cost in SP which ranged from US$ 32.54 - 33.25 ha^{-1}; while the land preparation cost in the case of CT corresponded to US$88.24 - 110.29 ha^{-1}. In another study, Islam, et al. [51] computed 49% of savings from the land preparation in SP over CT.

Moreover, weed control using herbicides provided higher net benefits over three hand weeding operations in CT, or the six hand weeding operations for the weed-free condition under SP. In CT, three times hand weeding required US$ 313.28 ha^{-1}. On the other hand, one and six hand weedings in SP required US$ 104.43 and US$ 417.71 ha^{-1}, respectively. By contrast, application of glyphosate cost US$ 44.75 ha^{-1}, while one pre-emergence and post-emergence application required US$ 89.51 ha^{-1}, respectively. Thus, herbicidal weed control saved 57% cost over manual weeding in CT and 67% over six hand weedings of weed-free treatment in SP. Previous research also reported higher costs in manual weeding were not profitable relative to herbicidal weed control [52].

4. CONCLUSION

Conservation agriculture is a novel crop management approach for rice-based cropping systems in Bangladesh for which effective weed control strategies need to be developed. From two years results, economical weed control was achieved by spraying a knockdown pre-plant herbicide ahead of strip planting of wheat, followed by a pre-emergence and a post-emergence herbicide and the retention of 50% residue (by height) of the previous rice crop. Strip planting of wheat was a more profitable alternative to the conventional tillage.

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