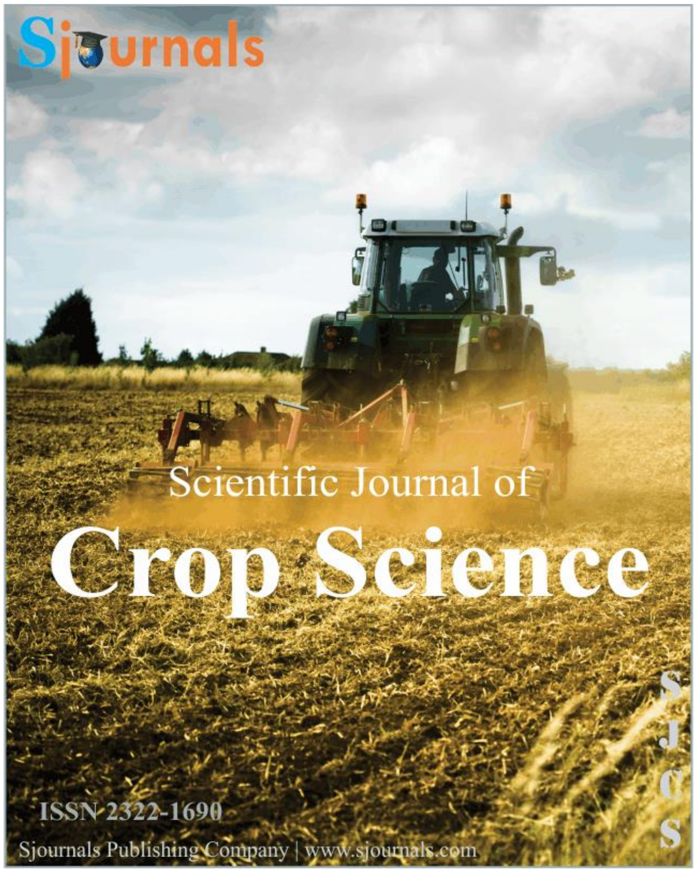
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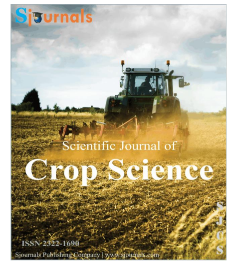

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Original article

Weed control in strip planted wheat under conservation agriculture practice is more effective than conventional tillage

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ABSTRACT

Smallholder farms in South Asia are rapidly adopting herbicides for labour saving weed control in crops but effective weed management technologies have not been well developed. Weed management technologies are especially in demand for the emerging Conservation Agriculture practices involving minimum soil disturbance planting and retention of crop residues. The present study was undertaken to determine the effectiveness of crop reesidue retention relative to herbicides and hand weeding for weed control and yield of strip-planted, irrigated wheat on the Eastern Gangetic Plain of Bangladesh. Wheat (cv. *BARI Wheat 26)* was grown during the winter season (November-March) in 2014-15 (first year) and 2015-16 (second year) after monsoon rice, with strip planting (SP) and conventional tillage (CT) combined with the six weed control practices [T_1: CT + three hand weedings (HW) (Control), T_2: pre-plant herbicide (PRE) + SP + one HW, T_3: PRE + SP + pre-emergence herbicide (PE), T_4: PRE + SP + post-emergence herbicide (PO), T_5: PRE + SP + PE + PO, T_6: PRE + SP + weed-free (WF)], and two levels of retained rice straw *viz.,* M_0: no-mulch and M_{50}: 50% standing mulch. The PRE herbicide (glyphosate), PE herbicide (pendimethalin) and PO herbicide (carfentrazone-ethyl) were applied at recommended dose and time. The combination of applied PRE, SP, 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 24% higher yield and 40% higher economic returns relative to the control treatment. Hence, the study concluded that the SP integrated with effective herbicides and residue mulching-based weed control options was more profitable than manual weeding in CT while also saving labour for wheat production.

1. Introduction

Minimum soil disturbance planting requires less total labour and energy to achieve approximately the same crop production as CT making this technology more profitable with lower production costs. For this reason, CA is becoming increasingly attractive to farmers worldwide (Friedrich et al., 2012). Bangladeshi farmers can also adopt MT technology for more profitable crop production than conventional tillage (Bell et al., 2019). Minimum tillage (MT) methods also offer significant environmental benefits through fuel energy savings and reduction in greenhouse gas emissions (Alam et al., 2019).

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 (Farmer et al., 2017). 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 (Adhikary and Ghosh, 2014). Moreover, massive weed infestation may limit the adoption of minimum tillage system if weeds are not successfully controlled (Eager et al., 2013).

In Bangladesh, traditionally, weeds are managed manually or by tillage. However, decreased labour availability and increased wages, especially during peak demand periods, are decreasing the capacity for timely manual weeding on farms (Krishna et al., 2016). 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 cohorts and provided better yield over manual weeding even under strip planting practice (Rahman et al., 2012). However, the repeated long-term use of herbicide with the same mode of action may lead to the development of herbicide resistance in weeds, making weed control more difficult (Busi and Powels, 2017).

On the other hand, the persistence of herbicides in the soil and its detrimental effects on succeeding crops is a significant issue. Furthermore, shifts in weed populations due to continuous use of a particular herbicide, less availability of appropriate herbicide 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 reduced tillage. Agronomic options like mulch of the previous crops have been reported to suppress weeds including in this system of crop cultivation (Nichols et al., 2015).

Several minimum soil disturbance planting options could be used, and the strip planting (SP) is one of them (Johansen et al., 2012). 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 mulch retention has been developing in Bangladesh (Haque et al., 2019), 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 crop 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. Materials and methods

2.1. Experimental site and season

Wheat crop was grown for consecutive years in an crop sequence of Rice-Wheat-Mungbean on a farmers' field located at Gouripur Upazila in Mymensingh district of Bangladesh during mid November-March in 2014-15 first year 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).

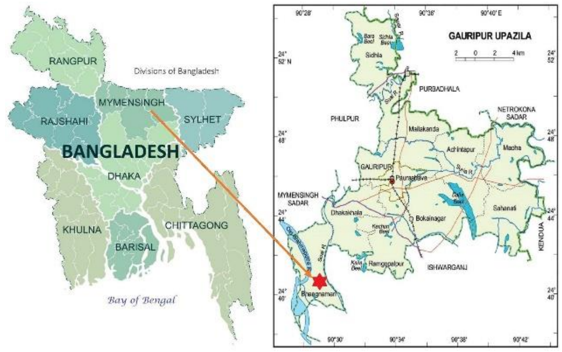

Fig. 1. Map of Bangladesh showing the site of on farm experiment.

2.2. Edaphic and climatic condition

The experimental site is situated on the Old Brahmaputra Floodplain of predominantly dark grey non-calcareous alluvium soils under the *Sonatala* series. It is on medium-high land with the characteristics as presented in Table 1.

Table 1
The physical and chemical properties of soil (0-15 cm) of the experimental field.

Properties	Proportion
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

During the study period, March was the warmest month when the highest maximum temperatures were 30.6 and 31.1 ℃ and the highest minimum temperatures were 18.4 and 20.2℃ in first and second year, respectively (Figure 2). Temperature declined gradually from November to January. January was the coldest month. November in 2014 and December 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.

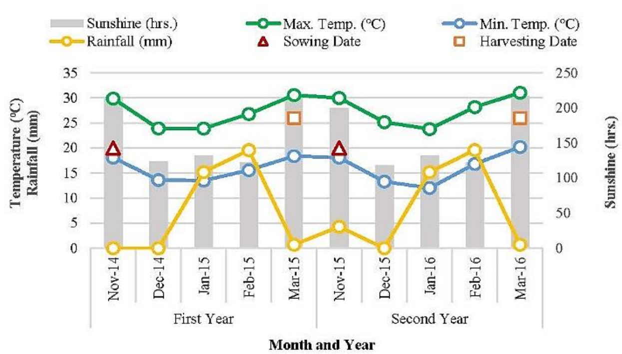

Fig. 2. Monthly temperature and rainfall distribution pattern in the first and second year (2014-15 and 2015-16).

2.3. Experimental treatments

Wheat was grown in consecutive years on the same plots with treatments comprising a combination of six planting and weed control practices *viz*., T_1: conventional tillage (CT) + three hand weeding (HW) (Control), T_2: Pre-plant herbicide (PRE) + strip planting (SP) + one HW, T_3: PRE + SP + pre-emergence (PE) herbicide, T_4: PRE + SP + post-emergence (PO) herbicide, T_5: PRE + SP + PE + PO, T_6: PRE + SP + weed-free (WF) were combined with and two levels of retained rice straw as M_0: no-mulch and M_{50}: 50% standing mulch.

2.4. Planting operations

In each 9 m × 5 m plot, CT was done using a two-wheel tractor (2WT). The land was prepared by four plowing and cross plowing operations followed by sun-drying for two days and levelling. The SP was done by a Versatile Multi-crop Planter (VMP) in a single pass operation (Haque et al., 2017). Strips were prepared to accommodate four rows, each 6 cm wide and 5 cm deep. Three days before SP operation, glyphosate was applied @ 3.7 L ha^{-1}.

In CT, wheat 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.

In no-mulch practice, seeding was done without retaining rice straw while in 50% retention practice, previous rice was harvested at 50% height from the ground in the respective plots.

2.5. Weed control practices

In CT, 3 HW were done at 25, 45, and 65 days after sowing (DAS). In SP, one 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 at field capacity condition are presented in Table 2.

Table 2
Herbicides and rates of application used in the experiment[1]

Group	Name	HARC class	Dose* (ha^{-1})	Applied at
Pre-plant (PRE)	Glyphosate	Group G	3.7 L	3 DBS
Pre-emergence (PE)	Pendimethalin	Group K1	2.5 L	3 DAS
Post-emergence (PO)	Carfentrazone-ethyl	Group E	1.25 Kg	25 DAS

[1]DBS = Days before sowing, DAS = Days after sowing, HARC = Herbicide Resistance Action Committee, *Dose of product.

2.6. Cultural operations and measurements

The recommended dose of nitrogen (N), phosphorus (P), potassium (K) and sulfur (S) was applied. The N as urea, phosphorus as triple super phosphate, potassium as muriate of potash and sulfur as gypsum was applied @ 100, 26, 33, and 20 kg ha^{-1}, respectively. The entire amount of PKS was broadcast before seeding and mulching. Two-thirds of the N was applied at final plowing and one-third at crown root initiation stage.

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

Weed densities were recorded in a 0.50 m × 0.50 m quadrat at 25, 45 and 65, and 120 DAS. 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. Weed control efficacy (WCE) had calculated as follows (Mani et al., 1973). Phyto-toxicity of herbicides in wheat was assessed visually following the rating (IRRI, 1965) presented in the Table 3.

$$\mathrm{W}CE\ (\%) = \frac{WDC - WDT}{WDC} \times 100$$

Where, WDC and WDT are weed dry matter in control and treatment, respectively.

Table 3
Phyto-toxicity ratings of herbicides.

Scale	Degree of toxicity
1	Non-Toxic
2	Slightly Toxic
3	Moderately Toxic
4	Sever Toxic
5	Toxic (Plant Kill)

The crop was harvested at maturity (when 80% of spikelets turned brown) in 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} were recorded from ten randomly selected hills before harvest. The weight of 1000-grains, and grain and straw yields was recorded. Grain yield was adjusted at 14% moisture content.

The economics of crop production was estimated following the partial budgeting system. The variable costs were calculated based on labor requirement for 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 dividing the gross return by total cost of production.

2.7. Statistical design and analysis

All the trials were conducted in a complete block design with the weeding and mulch treatments randomized. In the second year, weeding and mulch treatments were assigned to the same plots as in 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 analyses were performed between weed biomass and rice yield. The statistical package program STAR (IRRI, 2014) was used to analyze all data.

3. Results and discussion

3.1. Weed species composition

Among the treatment combinaions of this study, we present the weed data for CT + 3 HW and PRE + SP + PE + PO treatments under no-mulch and 50% mulch levels. During the first and second year of experimentation, 39 weed species were identified from 13 families (Table 4). The most common families were Cyperaceae (8 species), Poaceae (7), Amaranthaceae (4), Asteraceae (4), Linderniaceae (2), Rubiaceae (2) and Solanaceae (2).

After two seasons of wheat cultivation, CT produced 44 % more weeds compared to SP (Table 4). In the second year, CT had 12 % more weeds (37 species) than first year (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 the second year were absent in the first year. In the second year, SP produced 33 % fewer weeds (22 species) than in the 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 sepecies of CT, *Chenopodium album* L. and *Dentella repens* L. were absent in SP in either season. CT produced 91% homogenous weeds in the second year while SP produced 82% homogenous weeds in two consecutive years. In the first year, CT and SP had 57% common species, and in the second year there were 45% common weed species between CT and SP (Table 3). These results imply that, over time SP increases weed species diverstiy in the soil weed seed bank. Retention of 50% mulch was more suppressive to weed in SP than CT and in the second year than the first year.

Table 4
Weed species composition in conventional tillage plus three hand weeding (CT + 3 HW) and strip planting (SP) together with pre-plant, pre-emergent and post-emergence herbicides (PRE + SP + PE + PO)[2].

Weed		First year		Second year		First year		Second year	
		CT + 3 HW				PRE + SP + PE + PO			
Type	Species	M_0	M_{50}	M_0	M_{50}	M_0	M_{50}	M_0	M_{50}
Broad leaf	*Ageratum conyzoides* L.	P	P	P	P	P	P	P	A
	Amaranthus viridis L.	P	P	P	P	A	A	P	P
	A. spinosus L.	A	P	P	P	P	P	P	P
	Alternanthera sessilis L.	P	P	P	P	P	P	P	P
	A. philoxeroides L.	P	P	P	P	P	P	P	A
	Brassica kaber L.	P	P	P	P	A	A	P	P
	Centipeda minima Lour.	A	A	P	P	P	P	A	A
	Chenopodium album L.	P	P	P	P	A	A	A	A
	Cyanotis axillaris Roem.	P	P	P	P	P	P	P	P
	Dentella repens L.	P	P	P	P	A	A	A	A
	Desmodium triflorum L.	P	P	P	P	P	P	A	A
	Eichhornia crassipes Mart.	P	P	P	P	P	P	P	P
	Eclipta alba L.	P	P	P	P	P	P	P	P
	Euphorbia parviflora L.	A	P	P	P	P	P	A	A
	Gnaphalium luteoAalbum L.	P	P	A	A	P	P	A	A
	Hedyotis corymbosa L.	P	P	P	P	P	P	P	P
	Jussia decurrence Walt.	P	P	P	P	P	A	P	P
	Lindernia antipoda L.	P	P	P	A	A	P	P	P
	L. hyssopifolia L.	P	P	P	A	P	P	P	P
	Nicotina plumbaginifolia L.	P	P	P	P	P	P	P	P
	Physalis heterophylla Nees.	A	A	P	P	P	P	P	P
	Pistia stratiotes L.	P	P	P	P	P	P	A	A
	Polygonum coccineum L.	A	A	P	P	P	P	A	A
	Rotala ramosior L.	P	A	P	P	P	P	A	A
	Solanum torvum L.	A	A	P	P	P	P	P	A
	Spilanthes acmella L.	P	A	P	P	A	A	P	A
Sub-Total		20	20	25	23	20	20	17	13
Grass	*Cynodon dactylon* L.	P	P	A	A	P	P	A	A
	Digitaria sanguinalis L.	P	P	P	P	P	P	A	A
	Echinochloa crusgalli L.	P	P	P	P	P	P	P	P
	E. colonum L.	A	A	P	P	P	A	A	A
	Eleusine indica L.	P	P	P	P	P	P	P	P
	Leersia hexandra L.	P	P	P	P	P	P	A	A
	Panicum distichum L.	P	P	A	A	P	P	A	A
Sub-Total		6	6	5	5	7	6	2	2
Sedges	*Cyperus difformis* L.	P	P	P	P	P	P	P	P
	C. rotundus L.	P	P	P	P	P	P	P	A
	C. iria L.	P	P	P	A	P	P	A	A
	Eleocharis atropurpurea Ret.	P	P	P	A	P	P	A	A
	Fimbristylis miliacea L.	P	P	P	P	P	P	P	P
	Scirpus mucronatus L.	A	P	A	P	P	A	A	A
	S. juncoides L.	A	A	P	P	A	A	A	A
	S. supinus L.	A	A	P	P	A	A	A	A
Sub-Total		5	6	7	6	6	5	3	2
Grand Total		31	32	37	34	33	31	22	17

[2]CT = Conventional tillage, HW = Hand weeding, PRE = Pre-plant herbicide, SP = Strip-planting, PE = Pre-emergence herbicide, PO = Post-emergence herbicide, M_0 = no-mulch, M_{50} = 50% mulch, P = Present, A = Absent.

3.2. Effect of treatments on weed density, biomass, weed control efficacy and phyto-toxicity

The combined impact of tillage types weed control practices and mulch levels was significant (p<0.05) on both weed density and biomass at all dates of sampling except (p>0.05) at 120 DAS (Figure 3) in both years. In the first year, at 25 DAS, PRE + SP + 1 HW produced the highest weed density and biomass, followed by CT + 3 HW and PRE + SP + PE. At 45 and 65 DAS, CT + 3 HW and PRE + SP + 1 HW had the highest weed density and biomass, followed by the PRE + SP + PE and PRE + SP + PO. Treatment PRE + SP + PE + PO produced the lowest weed density and biomass. Among the treatment combinations, retention of 50% mulch reduced both density and biomass significantly relative to no-mulch. Among the different assessment dates, the highest weed density and biomass were found at 25 DAS, followed by 45 , 65 and 120 DAS. The trend of both weed density and biomass response to the treatments was more or less similar in the second year.

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 in the first and the second year, respectively, while weed biomass was depressed by 70% in both years. Retention of 50% mulch reduced weed density by 16-20% and biomass by 27-34%. The most effective suppression by 50% of mulch was found when combined with PRE + SP + PE + PO.

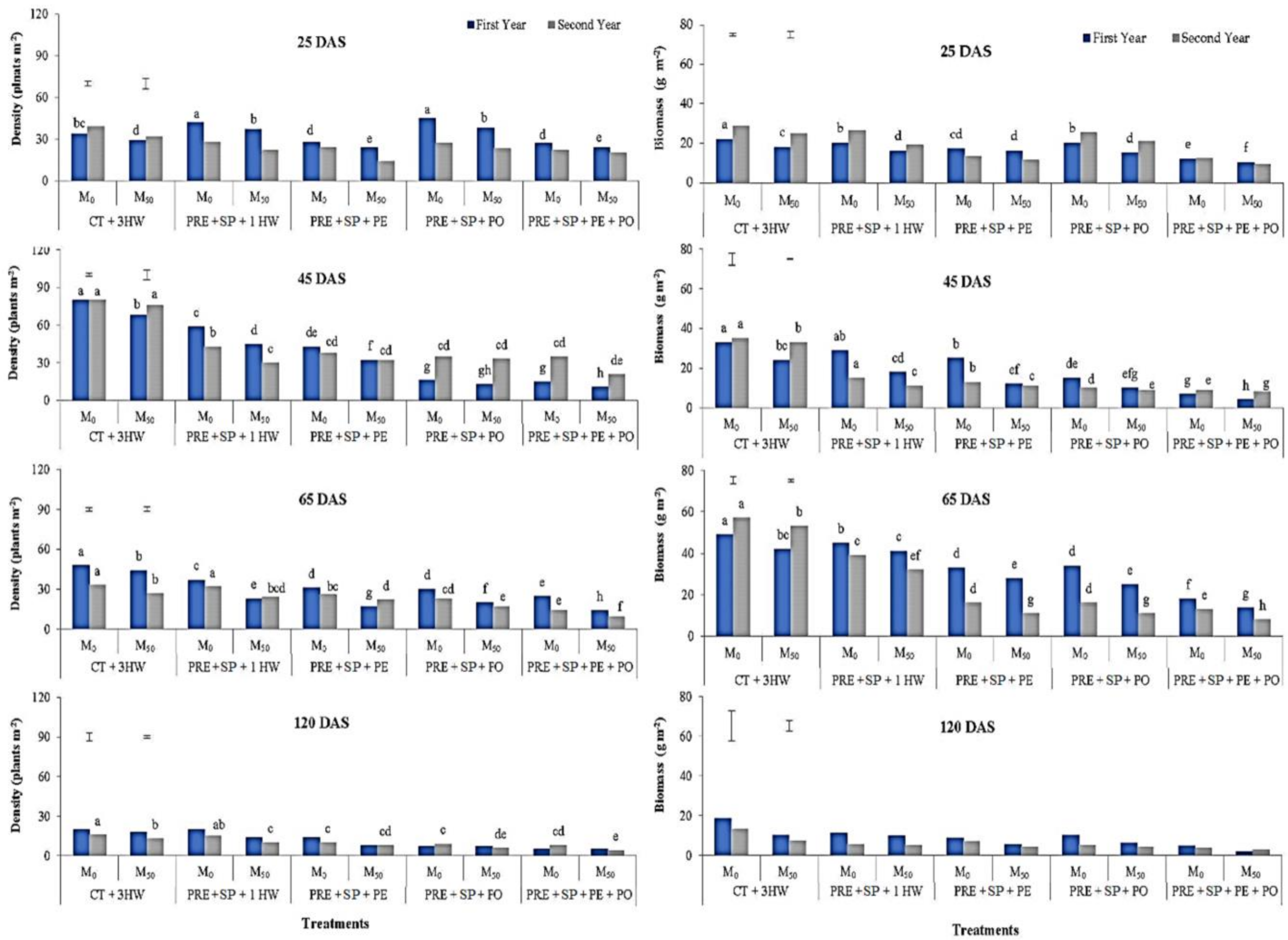

Fig. 3. Effect of treatments on the weed density and biomass at different dates for first year and second year. For each year, means followed by the same letter did not differ significantly at P < 0.05.

Treatment PRE + SP + WF with or without mulch achieved the highest weed control efficacy (WCE) in both years (Figure 4). Apart from PRE + SP + WF, at 25 DAS, the highest WCE had found from PRE + SP + PE + PO, followed by PRE + SP + PO and CT + 3 HW with 50% mulch, respectively. PRE + SP + 1 HW without mulch was the least efficient. At 45 DAS, the highest WCE was recorded from PRE + SP + PE + PO with 50% mulch followed by PRE

+ SP + PO, PRE + SP + PE, and PRE + SP + 1 HW with 50% mulch, respectively. The lowest WCE was recorded from CT + 3 HW without mulch. This trend was similar at 65 and 120 DAS. In the second year, the relative WCE among treatments was similar to that of the first year. During the experimentation period, none of the herbicides exerted any visual phyto-toxicity on wheat (data not shown).

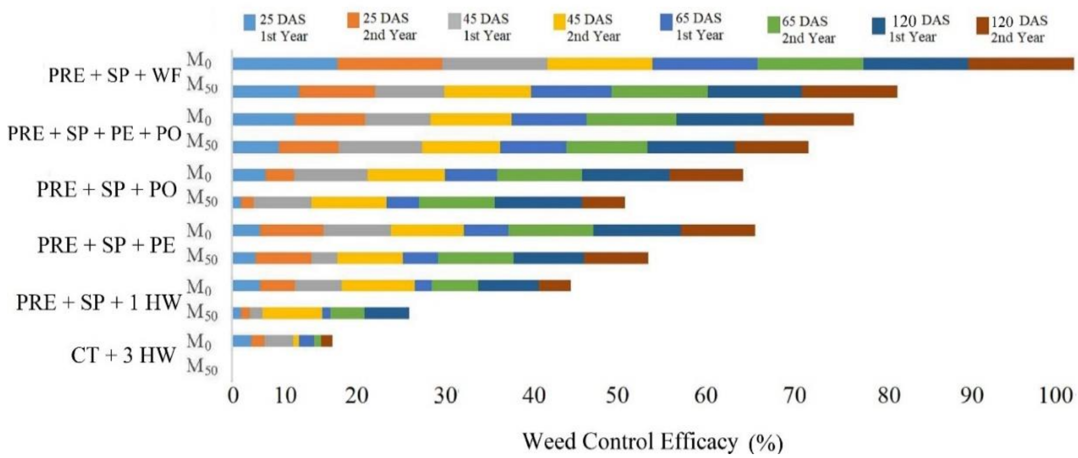

Fig. 4. Weed control efficacy (%) of different treatments for the first year and the second year.

In this study, CT + 3 HW without mulch produced the highest weed density and biomass. At the same time, the lowest weed density and biomass occurred in PRE + SP + PE + PO with 50% mulch 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 (Haque et al., 2016). Tilled soils also provide germination stimulus for weeds requiring scarification, exposure to light, ambient CO_2 concentrations, higher nitrate concentrations, and greater temperature fluctuations to break dormancy, leading to higher weed density in CT (Zahan et al., 2020).

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 (Chauhan et al., 2012). 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 (Anderson, 2015). 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 (Malik et al., 2014). Consequently, the growth, development, and seed setting of the weed plant is affected. CT also allows vigorous weed seedlings with greater seed setting ability (Kumar et al., 2019) 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 by increasing the availability of seeds to predators and minimizing predators' mortality in minimally-disturbed soil (Chhokar et al., 2018). Thus, a greater reduction in weed density as well as weed biomass is likely to occur in SP than CT is likely over time.

In the present study, treatment CT + 3 HW 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 carfentrazone-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 in CT (Figure 4). The broad-spectrum activity and higher phyto-toxic effects of herbicides (Islam et al., 2018) 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.

Retention of 50% rice straw mulch produced 16-20% less weed density and 27-34% less biomass than no mulch. The beneficial effect of mulch mulching on weed suppression is attributed to smothering of weeds, suppressing weed seed germination and weed growth, lowering soil temperatures, changing allelo-chemicals released from decaying plant tissues, and temporary immobilization of nutrients (Kanissery et al., 2019). Release of nutrients and organic matter upon decomposition of mulches 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% mulch. Moreover, decreased soil temperature fluctuations with mulch retention (Alam et al., 2018) and reduced light penetration facilitate cooler average soil temperatures that reduce weed seed germination and cause delayed germination in mulched field relative to no-mulch.

Furthermore, increased microbial populations which can be aided by decomposition of the mulch and soil moisture conservation accelerate weed seed decay and loss of seed viability (Lemessa, 2015). The high amounts of mulch may delay the emergence of weeds, and such late emerged weeds are less competitive and can produce fewer seeds than with earlier emergence (Chauhan et al., 2012). Collectively, these factors may have reduced weed pressure in SP relative to CT in this study. Thus, the combined effect of herbicides and mulches in SP suppressed weed density and biomass more effectively than no-mulch in CT in this study.

In soil weed seed bank, weed emerges in several cohorts. Generally, weed emergence occurs within three weeks of planting crops (Sangeetha et al., 2011). The pre-emergence herbicide at 3 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 (2012) found PE alone can control the weeds of the first cohort but fail to handle some escaped problematic weeds and weeds of the second cohort, which could be controlled PO. Awan et al. (2015) also reported the sequential application of two or three herbicides can manage all types of weed more efficiently at the later stage of crop growth than the earlier stage when they used a single herbicide.

3.3. Effect of treatments on the yield of wheat

In the first year, the highest grain yield was recorded from PRE + SP + WF and PRE + SP + PE + PO, followed by CT + 3 HW (Figure 5). Treatments such as PRE + SP + 1 HW, PRE + SP + PE and PRE + SP + PO produced the lowest yields in the first year. In second year, the grain yield response to the treatments was like to that of the first year. The highest grain yield in PRE + SP + WF and PRE + SP + PE + PO was associated with the highest number of tillers and spikes m^{-2}. Among the treatment combinations, retention of 50% mulch produced a 5-6% more tillers and spikes, and about 4% higher wheat yield over no-mulch.

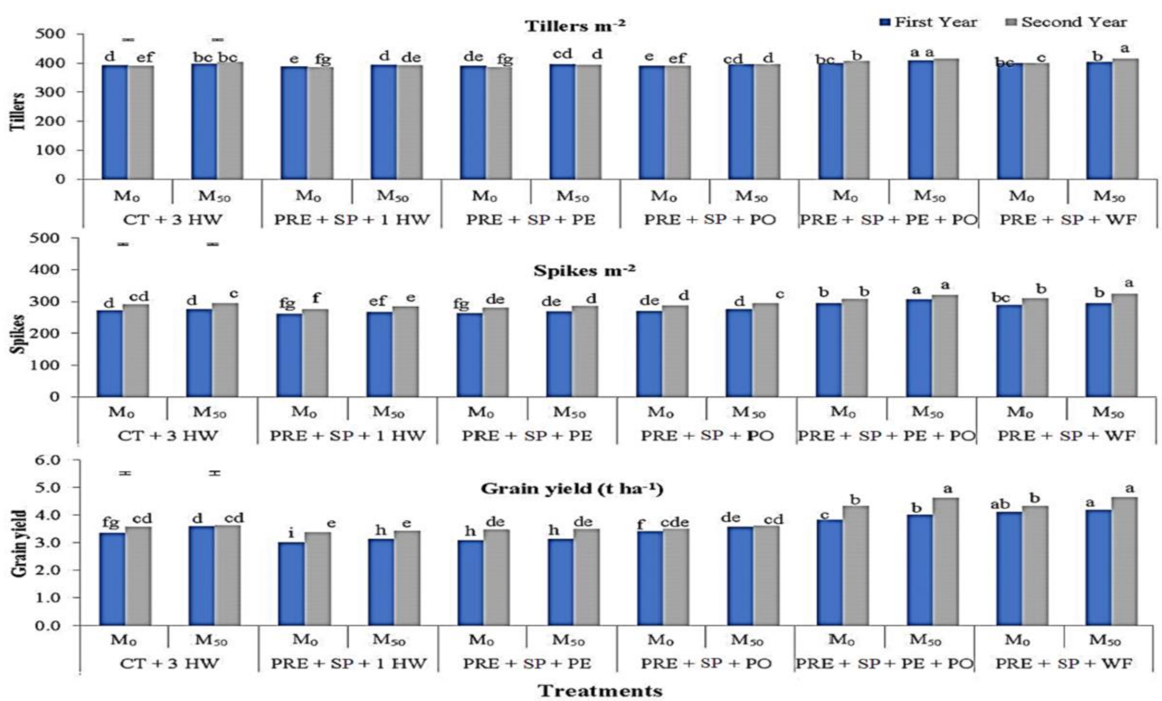

Fig. 5. Effect of treatments on the yield attributes and yield of wheat for first year and second year. For each year, means followed by the same letter did not differ significantly at P < 0.05.

In the present study, better yield in SP over CT might be due to a reduction in weed density and weed biomass. As the weed pressure and grain yield are inversely related (Sangeetha et al., 2011) and it was previously reported that crop yield in the strip tillage system is greater than in the traditional system when weeds are controlled successfully (Mishra and Singh, 2012). 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 (Martin and Weiner, 2014) 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 (Shahzad et al., 2016). There was a strong negative correlation between grain yield and weed biomass (Table 5), indicating that increasing each 1 kg weed biomass at 25, 45, and 65 DAS resulted wheat yield by loss by 4.73, 2.95 and 2.12 kg ha^{-1}, respectively in the first year and 3.81, 1.47 and 1.48 kg ha^{-1}, respectively in the second year.

Table 5
Regression relationships between wheat yield (kg ha^{-1}) and weed biomass (kg ha^{-1}) at different dates in first and second year[3].

			First year		Second year	
Y-axis	**X-axis**		**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

[3]DAS = Date after sowing, RE = Regression equation, R^2 = Coefficient of determination, y = Estimated grain yield, x = Weed biomass.

In this study, mulching increased the grain yield by 4% over no-mulch. Mulch releases mineralized nutrients that influence crop growth. Simultaneously, it suppresses weed growth and supplies organic matter for heterotrophic N fixing microorganisms (Alam et al., 2014; Shrivastav et al., 2015), which could be utilized by the crops, resulting in higher yield. 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 planting, and crop mulch mulching on the yield contributing characters of wheat might directly affect the wheat yield. In this study, the highest numbers of tillers m^{-2} and spikes m^{-2}, respectively, might have led to a better outcome in SP over manual weeding in CT.

3.4. Economics of wheat cultivation

Over the two years, highest profit calculated from PRE + SP + PE + PO with 50% mulch (Table 6) followed PRE + SP + WF with 50% mulch, the same treatments without mulch, PRE + SP + PE, PRE + SP + PO with 50% and without mulch, respectively and PRE + SP + 1 HW with 50%. Treatment CT + 3 HW and PRE + SP + 1 HW without mulch, respectively incurred financial losses. In the second year, treatments followed the similar trend of BCR. PRE + SP + PE + PO with 50% mulch earned 7% higher BCR than no-mulch, which was 43% higher than PRE + SP + WF, with 50% mulch and 47% higher than CT + 3 HW without mulch. Mulch alone increases BCR by 9% over no-mulch.

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 (2019) 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. (2014) 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 weeding 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$ 42.49 and 47.02 ha^{-1}, respectively. Thus, herbicidal weed control saved 57% cost over manual weeding in CT and 67% over six hand weeding of weed-free treatment in SP. Previous research also reported higher costs in manual weeding were not profitable relative to herbicidal weed control (Muoni et al., 2014).

Table 6
Economics (US$ ha^{-1}) of wheat cultivation for the first year (2014-15) and the second year (2015-16)[4].

Treatments		Production cost		Total income		BCR	
		First year	Second year	First year	Second year	First year	Second year
CT + 3 HW	M_0	1104.7	1104.7	1059.7	1124.5	0.96	1.02
	M_{50}	1104.7	1104.7	1131.7	1145.8	1.02	1.04
PRE + SP + 1 HW	M_0	968.5	968.5	967.9	1055.9	0.98	1.09
	M_{50}	968.5	968.5	1002.8	1080.1	1.04	1.12
PRE + SP + PE	M_0	930.3	930.3	986.9	1091.5	1.06	1.17
	M_{50}	930.3	930.3	1001.3	1102.9	1.08	1.19
PRE + SP + PO	M_0	930.3	930.3	1079.4	1102.4	1.16	1.18
	M_{50}	930.3	930.3	1124.8	1137.1	1.21	1.22
PRE + SP + PE + PO	M_0	974.4	974.4	1194.6	1355.4	1.23	1.39
	M_{50}	974.4	974.4	1246.8	1446.5	1.28	1.48
PRE + SP + WF	M_0	1089.1	1089.1	1263.8	1343.6	1.16	1.23
	M_{50}	1089.1	1089.1	1291.1	1432.3	1.19	1.32

[4]CT = Conventional tillage, HW = Hand weeding, PRE = Pre-plant herbicide, SP = Strip planting, PE = Pre-emergence herbicide, PO = Post-emergence herbicide, WF = Weed free, M_0 = no-mulch, M_{50}= 50% mulch, BCR = Benefit-cost ratio, 1 US$=84.74 BDT in December 2020.

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 the results of consecutive years, economical weed control was achieved by spraying a knockdown pre-plant herbicide sprayed ahead of strip planting of wheat, followed by a pre-emergence and a post-emergence herbicide and the retention of 50% standing residue of the previous rice crop. Strip planting of wheat was a more profitable alternative to the conventional tillage.

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References

Adhikary, P., Ghosh, R.K., 2014. Effects of cropping sequence and weed management on density and vertical distribution of weed seeds in alluvial soil. J. Crop Weed, 10(2), 504-507.

Alam, M.K., Bell, R.W, Biswas, W.K., 2019. Increases in soil sequestered carbon under conservation agriculture cropping decrease the estimated greenhouse gas emissions of wetland rice using Life Cycle Assessment. J. Clean. Prod., 224, 72-87.

Alam, M.K., Bell, R.W., Haque, M.E., Kader, M.A., 2018. Minimal soil disturbance and increased mulch retention increase soil carbon in rice-based cropping systems on the Eastern Gangetic Plain. Soil Tillage Res., 183, 28-41.

Alam, M.K., Islam, M.M., Salahin, N., Hasanuzzaman, M., 2014. Effect of tillage practices on soil properties and crop productivity in wheat-mungbean-rice cropping system under subtropical climatic conditions. Sci. World J., 437283.

Anderson, R.L., 2015. Integrating a complex rotation with no-till improves weed management in organic farming: A review. Agron. Sustain. Dev., 35, 3, 967-974.

Awan, T.H., Cruz, P.C.S., Chauhan, B.S., 2015. Agronomic indices, growth, yield contributing traits and yield of dry-seeded rice under varying herbicides. Field Crops Res., 177, 15-25.

Bell, R.W., Haque, M.E., Jahiruddin, M., Rahman, M.M., Begum, M., Miah, M.A.M., Islam, M.A., Hossen, M.A., Salahin, N., Zahan, T., Hossain, M.M., Alam, M.K., Mahmud, M.N.H., 2019. Conservation agriculture for rice-based intensive cropping by smallholders in the Eastern Gangetic Plain. Agr., 9, 5.

Belz, R.G., Duke S.O., 2014. Herbicides and plant hormesis. Pest Manag. Sci., 70(5), 698-707.

Brito, I.P., Tropaldi, L., Carbonari, C.A., Velini, E.D., 2018. Hormetic effects of glyphosate on plants. Pest Manag. Sci., 74(5), 1064-1070.

Busi, R., Powles, S.B., 2017. Inheritance of 2,4-D resistance traits in multiple herbicide resistant *Raphanus raphanistrum* populations. Plant Sci., 257, 1-8.

Chauhan, B.S., Singh, R.G., Mahajan, G., 2012. Ecology and management of weeds under conservation agriculture. Crop Protect., 38, 57-65.

Chhokar, R.S., Sharma, R.K., Gill, S.C., Singh, R.K., Kajla, V.J.M., Chaudhary, A., 2018. Suitable wheat cultivars and seeding machines for conservations agriculture in rice-wheat and sugarcane-wheat cropping system. J. Cereal Res., 10(2), 78-88.

Eager, E.A., Haridas, C.V., Pilson, D., Rebarber, R., Tenhumberg, B., 2013. Disturbance frequency and vertical distribution of seeds affect long-term population dynamics: A mechanistic seed bank model. Am. Nat., 182, 180-190.

Farmer, J.A., Bradley, K.W., Young, B.G., Steckel, L.E., Johnson, W.G., Jason, K.N., Davis, V.M., Loux, M.M., 2017. Influence of tillage method on management of Amaranthus species in soybean. Weed Technol., 31, 10-20.

Friedrich, T., Derpsch, R., Kassam, A., 2012. Overview of the global spread of conservation agriculture. Field Action Sci. Rep., 6(1), 1-9.

Haque, M.E., Bell, R.W., 2019. Partially mechanized non-puddled rice establishment: on-farm performance and farmers' perceptions. Plant Prod. Sci., 22(1), 23-45.

Haque, M.E., Bell, R.W., Islam, A.K.M.S., Sayre, K.D., Hossain, M.M., 2017. An innovative versatile multi-crop planter for crop establishment using two-wheel tractors. Agr. Mech. Asia Afr. Latin Am., 48, 33-37.

Haque, M.E., Bell, R.W., Islam, M.A., Rahman, M.A., 2016. Minimum tillage unpuddled transplanting: An alternative crop establishment strategy for rice in conservation agriculture cropping systems. Field Crop Res., 185, 31-39.

Hossain, M.I., Hossain, M.I., Ohab, M.A., Sheikh, M.H.R., Nag, B.L., 2019. Effect of different tillage options and mulch retention for sustainable crop production in wheat-mungbean-rice cropping pattern in dry areas. Bangladesh Agr. J., 22(2), 67-75.

IRRI, 1965. International Rice Research Institute, Annual Report for 1963. IRRI, Los Baños, Laguna, The Philippines.

IRRI, 2014. International Rice Research Institute, Statistical Tool for Agricultural Research (STAR), Biometrics and Breeding Informatics, PBGB Division. IRRI, Los Baños, Laguna, The Philippines.

Islam, A.K.M.M., Hia, M.A.H., Sarkar, S.K., Anwar, M.P., 2018. Herbicide based weed management in aromatic rice of Bangladesh. J. Bangladesh Agr. Univ., 16(1), 31-40.

Islam, A.K.M.S., Hossain, M.M., Saleque, M.A., 2014. Effect of unpuddled transplanting on the growth and yield of dry season rice (*Oryza sativa* L.) in High Barind Tract. Agr., 12(2), 91-97.

Johansen, C., Haque, M.E., Bell, R.W., Thierfelder, C., Esdaile, R.J., 2012. Conservation agriculture for small holder rainfed farming: Opportunities and constraints of new mechanized seeding systems. Field Crop Res., 132, 18-32.

Kanissery, R., Gairhe, B., Kadyampakeni, D., Batuman, O., Alferez F., 2019. Glyphosate: Its environmental persistence and impact on crop health and nutrition. Plants, 8(11), 499-509.

Krishna, V., Keil, A., Aravindakshan, S., Meena, M., 2016. Conservation tillage for sustainable wheat intensification: the example of South Asia. In: Langridge, P. editor. Achieving Sustainable Cultivation of Wheat. Burleigh Dodds Science Publishing Limited. 1-21.

Kumar, R., Singh, U.P., Mahajan, G., 2019. Performance of zero-till wheat (*Triticum aestivum* L.) and weed species as influenced by mulch and weed management techniques in rice based cropping system. Int. J. Curr. Microbiol. Appl. Sci., 8(4), 270-277.

Lemessa, F., 2015. Cover crops as a means of ecological weed management in agroecosystems. J. Crop Sci. Biotechnol., 18(2), 133-145.

Malik, R.K., Virender, K., Ashok, Y., Andrew, M., 2014. Conservation agriculture and weed management in south Asia: perspective and development. Indian J. Weed Sci., 46, 31-35.

Mani, V.S., Malla, M.L., Gautam, K.C., Bhagwndas, 1973. Weed killing chemicals in potato cultivation. Indian Farm, 23(8), 17-18.

Martin, C., Weiner, J., 2014. Effect of density and sowing pattern on weed suppression and grain yield in three varieties of maize under high weed pressure. Weed Res., 54(5), 467-474.

Mishra, J.S., Singh, V.P., 2012. Tillage and weed control effects on productivity of a dry seeded rice-wheat system on a vertisol in Central India. Soil Tillage Res., 123, 11-20.

Muoni, T., Rusinamhodzi, L., Rugare, J.T., Mabasa, S., Mangosho, E., Mupangwa, W., Thierfelder, C., 2014. Effect of herbicide application on weed flora under conservation agriculture in Zimbabwe. Crop Protect., 66, 1-7.

Nichols, V., Verhulst, N., Cox, R., Govaerts, B., 2015. Weed dynamics and conservation agriculture principles: A review. Field Crop Res., 183, 56-68.

Rahman, M., Juraimi, A.S., Suriya, A.S.M.J., Azmi, B.M., Anwar, P., 2012. Response of weed flora to different herbicides in aerobic rice system. Sci. Res. Essay, 7(1), 12-23.

Sahu, G., Mohanty, S., Das, S., 2020. Conservation agriculture-a way to improve soil health. J. Exp. Biol. Agr. Sci., 8, 355-368.

Sangeetha, C., Chinnusamy, C., Prabhakaran, N.K., 2011. Performance of early post emergence herbicide in irrigated soybean (*Glycine max* (L.) Merill). Madras Agr. J., 98(4-6), 144-146.

Shahzad, M., Farooq, M., Hussain, M., 2016. Weed spectrum in different wheat-based cropping systems under conservation and conventional tillage practices in Punjab, Pakistan. Soil Tillage Res., 163, 71-79.

Shrivastav, N., Basnet, K., Amgain, L., Karki, T., Khatri, N., 2015. Weed dynamics and productivity of spring maize under different tillage and weed management methods. Azarian J. Agr., 2, 118-122.

Zahan, T., Rahman, Md.M., Begum, M., Bell, R.W., 2020. Weed control strategies for wheat (*Triticum aestivum* L.) in a cereal-legume cropping system on the Old Brahmaputra Floodplain, Bangladesh. Weed J. Asian Pac. Weed Sci. Soc., 2, 35-50.

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