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EFFECT OF SUNFLOWER RESIDUES AND HERBICIDE ON WEED SUPPRESSION, GRAIN YIELD AND ECONOMICS OF TRANSPLANTED AMAN RICE

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Abstract

A field experiment was conducted at Agronomy Field Laboratory, Patuakhali Science and Technology University, Dumki, Patuakhali from July 2018 to November 2018 to evaluate the effect of sunflower residues and herbicides on the yield and economic performance of transplanted *Aman* rice. Weed control methods tested were T_1 = weedy check (Unweeded control), T_2 = Weed-free check by hand weeding twice, T_3 = Pendimethalin, T_4 = Pretilachlor, T_5 = Butachlor, T_6 = Pyrazosulfuron ethyl, T_7 = Bensulfuron methyl + Acetachlor, T_8 = Bispyriback sodium, T_9 = 2,4-D amine, T_{10} = MCPA, T_{11} = Sunflower residues, T_{12} = Sunflower residues + 100% Pyrazosulfuron ethyl, T_{13} = Sunflower residues + 75% Pyrazosulfuron ethyl, T_{14} = Sunflower residues + 50% Pyrazosulfuron ethyl. The experiment was laid out in a randomized complete block design with fourteen treatments replicated thrice. Weedy check registered significantly the highest total weed density (354.67 m^{-2}) and total weed dry matter (51.81 g^{-2}) while weed-free treatment by hand weeding twice recorded significantly the lowest total weed density (6.67 m^{-2}) and total weed dry matter 0.49 g^{-2}) . Weedy check produced the highest weed index (34.24%) and hand weeding produced the lowest. Among different herbicides applied alone, butachlor had the lowest total weed density (15 m^{-2}) and total weed dry matter (6.43 g^{-2}) after hand weeding. Hand weeding recorded the highest grain yield (5.14 t ha^{-1}) which was statistically similar to pendimethalin, pretilachlor, butachlor, bensulfuron methyl + acetachlor and sunflower residues + 100% pyrazosulfuron ethyl. Higher grain yield was attributed to a higher number of panicle m^{-2}, number of filled grains $panicle^{-1}$ and 1000-grain weight. The highest gross margin (22955 Tk. ha^{-1}) and benefit-cost ratio (1.32) were obtained from butachlor. Integration of sunflower residues with pyrazosulfuron ethyl produced effective weed suppression and satisfactory yield comparable to butachlor. Although the integration is less profitable than butachlor the farmers can use this technology as a feasible and environmentally sound approach in transplanted *Aman* rice field.

Introduction

Weeds are a major cause of yield reduction in rice and its control is labor intensive. Hand weeding and other traditional control methods are time consuming and involve high labor costs. The climate as well as the edaphic condition of Bangladesh is favorable for the growth of weeds. So, the rice crop is usually infested heavily with weeds resulting in grain yield reduction by 70-80% for direct seeded *Aus* rice (early summer), 30-40% for transplanted *Aman* rice (late summer), and 22-36% for modern *Boro* rice (winter) (BRRI, 2008). Weeds not only cause huge reductions in rice yields but also increase the cost of cultivation, reduce input efficiency, interfere with agricultural operations, impair quality, act as alternate hosts for several insect pests, diseases, affect the aesthetic look of the ecosystem as well as native biodiversity, affect human and cattle health (Bhuiyan *et al.*, 2017). Weeds compete for nutrient, space, sunlight and moisture with rice resulting in crop yield loss. Thus, weed is a serious threat for sustaining rice production in Bangladesh and necessitates proper weed management for rice production. Herbicidal weed control methods offer an advantage to save labor and money, as a result, regarded as cost-effective. Chemical weed control is becoming popular in Bangladesh mainly due to scarcity of labor during peak growing season and lower weeding cost. The early crop growth stage (up to 45–60 days of transplanting) is the most competitive for weeds and hence the crop growth is affected negatively (Barua *et al.*, 2008). Therefore, both pre-emergence and post emergence herbicide works well in transplanted rice.

Due to high labor and huge time requirement for manual weeding, farmers of the coastal areas, particularly in Kalapara Upazila are forced to opt for other alternative measures like chemical weed control. Phyrazosulfuron ethyl (an early post-emergence herbicide), pendimethalin (pre-emergenceherbicide), and butachlor (pre-emergence herbicide)are being used for weed control in rice in this area. However, the indiscriminate use of herbicides poses serious problems, such as environmental pollution, human health hazards, developing weed resistance, depletion of crop diversity, and reduction of crop productivity (Khanh *et al.*, 2005). Allelopathy is suggested to be a potentially safer method for weed control compared to the use of synthetic herbicides. Jabran *et al.* (2015) reported that allelopathy has a pertinent significance for ecological, sustainable, and integrated weed management systems. Many researchers reported that the incorporation of sunflower residues alone or in combination with lower doses of herbicides into field soil significantly reduced the weed population and dry weight over control (Alsaadawi *et al.*, 2011; Saif *et al.*, 2016; Rawat *et al.*, 2017). However, little information is available on the use of crop residues and herbicides for weed control in transplanted *Aman* rice in Bangladesh. Therefore, this study was undertaken to investigate the effect of sunflower residues and herbicides on weed growth, yield, and economics of transplanted *Aman* rice.

Materials and Methods

The experiment was conducted at the Agronomy Field Laboratory of Patuakhali Science and Technology University (PSTU), Dumki, Patuakhali in high land during the period from July to November, 2018. The experimental site lies at 22°27' N latitude and 90°23' E longitude at an altitude of three-meter above the sea level. The experimental field belongs to the Agro-Ecological Zone-13; Ganges Tidal Floodplain. The texture of the soil was clay loam having pH 6.0, organic matter 1.38%, total N 0.09%, available P 6.30 ppm, exchangeable K 0.11 me/100g, available S 15.25 ppm, and available Zn 0.46 ppm. There were fourteen weed control treatments included in the study. These were as follows:

T_1 = Weedy check (Unweeded control), T_2 = Weed-free check by hand weeding twice (at 20 and 40 DAT), T_3 = Pendimethalin (PE), T_4 = Pretilachlor (PE), T_5 = Butachlor (PE), T_6 = Pyrazosulfuron ethyl (Early post-emergence), T_7 = Bensulfuron methyl + Acetachlor (PE), T_8 = Bispyriback sodium ((Post-emergence), T_9 = 2, 4-D amine (PoE), T_{10} = MCPA (PoE), T_{11} = Sunflower residues (PE), T_{12} = Sunflower residues (PE) + 100% Pyrazosulfuron ethyl (Early post-emergence), T_{13} = Sunflower residues (PE) + 75% Pyrazosulfuron ethyl (Early post-emergence) and T_{14} = Sunflower residues (PE) + 50% Pyrazosulfuron ethyl (Early post-emergence). Sunflower residues were studied in combination with Pyrazosulfuron ethyl only because many of the farmers of this region use this herbicide for weed control in rice.

The experiment was laid out in a randomized complete block design with three replications. The layout was completed one day before transplanting. Spaces of 1m and 0.5 m were maintained in between replication and unit plots, respectively. The individual plot size was 4 m × 2.5 m (10 m^2). The variety BRRI dhan49 was used as planting material. Fertilizer was applied @ 90-15-51-9-1 kg N, P, K, S, and Zn ha^{-1}, respectively through urea, triple super phosphate, muriate of potash, gypsum and zinc sulphate on a soil test basis. Urea was applied in three equal splits; 1st at 15 days after transplanting (DAT), 2nd at 30 DAT and 3rd at 45 DAT. The total amount of triple super phosphate, muriate of potash, gypsum and zinc sulphate was applied during final land preparation. Thirty-two days old uniform seedlings were transplanted on 9 August 2018 at the rate of 2-3 seedlings $hill^{-1}$ at a spacing of 20 × 20 cm. The herbicides used in this experiment are available in paddy growing area and their description with the rate and time of application is as follows:

Table 1. Details of the herbicides used in the study

Trade name	Common name	Chemical family	Rate of application	Time of application
Panida 33EC	Pendimethalin	Dinitroaniline	2.50 L ha^{-1}	5 DAT
Super Heat 500 EC	Pretilachlor	Chloroacetamide	1.0 L ha^{-1}	5 DAT
Amchlor 5G	Butachlor	Chloroacetamide	25 kg ha^{-1}	5 DAT
Super power 10WP	Pyrazosulfuron ethyl	Sulfonylurea	150 g ha^{-1}	7 DAT
Super Mix 18 WP	Bensulfuran methyl+ Acetachlor	Chloroacetamide + Sulfonylurea	0.74 kg ha^{-1}	5 DAT
Extra power 20WP	Bispyribac sodium	Pyrimidinylthiob-enzoates	148 g ha^{-1}	7 DAT
Fielder	2, 4-D Amine	Phenoxy-carboxylic acid	2.25 L ha^{-1}	28 DAT
MCPA 500	MCPA	Phenoxy-carboxylic acid	988 ml ha^{-1}	28 DAT

DAT= Days after transplanting

Liquid/powdery herbicides were sprayed uniformly with the spray volume of 500 L ha^{-1} for pre-emergence spray and 350 L ha^{-1} for post-emergence spray using a knapsack sprayer with a flat fan nozzle. The pre-emergence application was made on the soil surface with 5 cm water depth uniformly with minimum trampling. Granular herbicide was broadcast uniformly on the soil surface by mixing with sand. Hand weeding was carried on bund side and paths whenever the weeds emerged in order to keep the experimental site clean. In the weed-free treatment, the plots were kept weed free up to 40 DAT by two hand weeding at 20 and 40 days after transplanting. Weedy plots allowed season long weed infestation. At physiological maturity, heads of sunflower plants were removed and the plants were harvested, air-dried for several days under sun light and chopped into 2-3 cm pieces. Sunflower plants were collected from the farmers' field of Sreerampur village of Dumki Upazila, Patuakhali. Chopped material was kept under room condition until use. The air-dried and chopped residues were incorporated in soil 3 days after transplanting of *Aman* rice @ 5 t ha^{-1}. Data on weed density and dry weight were recorded at 45 DAT randomly from 0.25 m^2 (0.5 x 0.5 m) area and then converted to per square meter. Dry weights of weeds were taken by drying them in an electric oven at 70°C until the constant weight was recorded.

Phyto-toxicity of herbicides on rice plants was determined visually (yellowing leaves, burning leaf tips, stunting growth etc.) according to the scale suggested by IRRI (1999). The rating of toxicity was done within a week (2nd, 4th, and 6th days) of herbicides application from 10 samples of each plot. The mean rate was calculated from 10 sample plants of a unit field plot. The day of recovery from the toxicity was also recorded visually. The degree of toxicity on the rice plants was measured by the following scale.

Rating	Visual symptom	Effect
1	No effect	No toxicity
2	Yellowing leaves	Slightly toxicity
3	Yellowing leaves and stunting	Moderate toxicity
4	Burning leaves and leaf tips	Severe toxicity
5	Burning plant, plant killed	Highly Toxicity (plant killed)

Yield components were recorded from 10 random hills except for the harvest and border area. An area of 5.12 m^2 (3.2 m x 1.6 m) was harvested from the centre of each plot to estimate grain and straw yields. After threshing and cleaning, the fresh weight of grain was recorded and adjusted to 14 % moisture content. Straw yield was recorded after proper sun drying.

Weed index (WI) was calculated by using the following formula (Misra and Misra, 1997)

Weed index (%) $= \frac{x-y}{x} 100$

Where, x = Yield from weed free plots, y = Yield from treated plots

The cost of cultivation of each treatment was worked out. Further the economic evaluation of each treatment was done by estimating the gross returns, net returns and benefit cost ratio. The price of the inputs at the time of their use and the prevailing market price of the products obtained were considered for working out the cost of cultivation, returns, and benefit-cost ratio. The collected data were statistically analyzed using the F-test. Data on weed count and weed dry weight have shown a high degree of variation. Therefore, the data on weed count and weed dry weight were subjected to square-root $[(x + 0.5)^{0.5}]$ transformation to make an analysis of variance more valid as suggested by Chandel (1984). Data were analyzed with STAR 2.0.1 software for analysis of variance and means were compared based on the least significant difference (LSD) test at the 0.05 probability level (Gomez and Gomez, 1984).

Results and Discussion

Phytotoxicity of herbicides on rice plant

The degree of toxicity of the herbicide to rice plants and the symptoms produced on the plant are presented in Table 2.All the pre-emergence and early post-emergence herbicides showed no toxicity. Angiras and Kumar (2005) also found that the application of pyrazosulfuron ethyl showed no phytotoxic effect on rice plants. Bhuiyan *et al.* (2018) reported no phytotoxic symptoms on rice with the application of combined herbicide like Metolachlor + bensulfuron methyl. Zahan *et al.* (2014) found a non-hazardous effect of pretilachlor on transplanted *Aman* rice crop production. Post-emergence herbicides 2, 4-D amine and MCPA showed burning of the lower leaves that recovered within 15 days. Similar results were also reported by Shibayama (1980) who observed the yellowing and burning of lower leaves of rice plants treated with phenoxy acetic acid herbicides.

Table 2. Toxicity level of different herbicidal treatments on transplanted *Aman* rice plants

Treatments	Rating	Symptoms observed on rice crop	Toxicity level
Pendimethalin (PE)	1.0	No effect	No toxicity
Pretilachlor (PE)	1.0	No effect	No toxicity
Butachlor (PE)	1.0	No effect	No toxicity
Pyrazosulfuron ethyl (Early post-emergence)	1.0	No effect	No toxicity
Bensulfuron methyl + Acetachlor (PE)	1.0	No effect	No toxicity
Bispyriback sodium (Post- emergence)	1.0	No effect	No toxicity
2, 4-D amine (PoE)	3.67	Burning of lower leaves	Toxicity
MCPA (PoE)	3.67	Burning of lower leaves	Toxicity
Sunflower residues (PE) + 100% pyrazosulfuron ethyl (Early post-emergence)	1.0	No effect	No toxicity
Sunflower residues (PE) + 75% pyrazosulfuron ethyl (Early-post emergence)	1.0	No effect	No toxicity
Sunflower residues (PE) + 50% pyrazosulfuron ethyl (Early-post emergence)	1.0	No effect	No toxicity

PE = Pre-emergence, PoE = Post-emergence

Effect of weed control methods

Weed density

All the weed control methods reduced the mean density of total weeds as compared to the weedy check (Table 3). Non-treated weedy check recorded the highest total mean weed density (354.67 plants m^{-2}) and weed-free treatment by hand weeding recorded the lowest density (6.67 plants m^{-2}). Akbar *et al.* (2011) reported that hand pulling resulted in higher weed suppression than in chemical weed control.

Table 3. Effect of weed control methods on weed prevalence at 45 days after transplanting of transplanted *Aman* rice

Treatments	Weed density (no. m^{-2})	Weed dry weight (gm^{-2})
T_1	18.81 a (354.67)	7.22 a (51.81)
T_2	2.67 i (6.67)	0.97 h (0.49)
T_3	6.34 fg (40.00)	3.05 b-d (8.83)
T_4	5.92 g (34.67)	2.98 c-e (8.37)
T_5	3.90 h (15.00)	2.63 ef (6.43)
T_6	7.80 de (60.34)	3.22 bc (9.91)
T_7	3.95 h (15.33)	2.68 d-f (6.78)
T_8	7.24 ef (52.00)	3.20 bc (9.80)
T_9	9.35 bc (87.00)	3.39 b (10.98)
T_{10}	8.40 cd (70.67)	3.26 bc (10.15)
T_{11}	9.75 b(94.66)	3.44 b (11.34)
T_{12}	5.80 g (33.33)	1.97 g (3.39)
T_{13}	7.33 ef (53.67)	2.58 f (6.14)
T_{14}	8.58 cd (73.35)	2.94 c-f (8.16)
LS	**	**
LSD$_{(0.05)}$	1.0174	0.3952
CV (%)	8.02	7.57

T_1 = Weedy check, T_2 = Weed-free check by hand weeding twice, T_3 = Pendimethalin, T_4 = Pretilachlor, T_5 = Butachlor,T_6 = Pyrazosulfuron ethyl, T_7 = Bensulfuron methyl + Acetachlor, T_8 = Bispyriback sodium, T_9 = 2, 4-D amine, T_{10} = MCPA, T_{11} = Sunflower residues, T_{12} = Sunflower residues + 100% pyrazosulfuron ethyl, T_{13} = Sunflower residues + 75% pyrazosulfuron ethyl, T_{14} = Sunflower residues +

50% pyrazosulfuron ethyl, LS = level of significance. Figures in parentheses are original values. Figures in a column followed by different letters differ significantly, but with common letter (s) do not differ significantly at 5% level of probability.

Butachlor and bensulfuron methyl + acetachlor were similar in controlling total weed density and significantly reduced the total weed density over a weedy check and other herbicides tested alone or in combination with sunflower residues. Application of butachlor at 1.25 kg a.i. ha^{-1} gave efficient weed control in rice as reported by Hasanuzzaman *et al.* (2008). Singh *et al.* (2005) observed that bensulfuron methyl (Londax) at different doses (40 g a. i. ha^{-1} and 50 g a.i. ha^{-1}) applied alone or as tank mixture with butachlor @ 1000 g a.i. ha^{-1} reduced the density of all the sedges and broad-leaved weeds. The lower weed density was due to their higher efficacy to control weeds in rice. Both the herbicides reduced the total mean weed density by about 96% as compared to the weedy check. The herbicides 2, 4-D amine and MCPA were the worst regarding weed control. 2, 4-D amine and MCPA being broad leaf killer, they only picked broad-leaved weeds, while the grasses escaped its control. Hence their overall effect was lesser as compared to other herbicides. Sunflower residue incorporated alone resulted in 73.31% control of the total weed population. Sunflower residue along with 100%, 75% and 50% pyrazosulfuron ethyl resulted in 90.60%, 84.87% and 79.32% reduction of total weed density, respectively over weedy check. However, the use of 50% of the recommended dose of pyrazosulfuron ethyl coupled with sunflower residue scored statistically similar suppression of total weed density to that achieved with the recommended dose (100%) of the same herbicide used alone.

Weed dry weight

The observation on weed dry matter recorded from different weed control treatments at 45 DAT is presented in Table 3. In general, all weed control treatments significantly reduced the total weed dry weight compared with non-treated plots. The minimum weed dry weight of weeds was recorded from manual weeding (0.49 g m^{-2}) and the maximum weed dry weight was recorded in weedy check (51.81 g m^{-2}). Among the sole herbicide treatments, butachlor registered the lowest weed dry weight (6.43 g m^{-2}) and 2, 4-D amine the highest (10.98 g m^{-2}). None of the treatments were compared to manual weeding in reducing total weed dry weight. However, sole application of sunflower residue and sole application of pyrazosulfuron ethyl at the recommended dose recorded statistically similar total weed dry weight indicating the allelopathic properties of sunflower. Sunflower residues + 50% pyrazosulfuron ethyl, sunflower residues + 75% pyrazosulfuron ethyl, butachlor, and bensulfuron methyl + acetachlor were statistically similar and better than all other herbicides tested in reducing total weed dry weight. Raj *et al.* (2016) reported that total weed dry biomass at the harvesting of rice was significantly reduced by pre-emergence application of pendimethalin, butachlor and bispyriback sodium over weedy check.

Yield attributes

Data pertaining to yield components are presented in Table 4. Plant height was significantly affected by different weed control treatments. Among weed control treatments, manual weeding recorded the highest plant height (101.34 cm) which was similar to sunflower residues + 100% pyrazosulfuron ethyl (95.97 cm). Butachlor recorded plant height of 94.89 cm, next to sunflower residues + 100% pyrazosulfuron ethyl. Weedy check recorded the lowest plant height (88.66 cm). All weed control treatments except 2, 4-D amine, and MCPA recorded a significantly higher number of panicles m^{-2} over the weedy check. The highest number of panicles m^{-2} (305.00) was recorded from weed free plots by manual weeding which was statistically similar to sunflower residues + 100% pyrazosulfuron ethyl (271.75), butachlor (270.25), bensulfuron methyl + acetachlor (265.00), pretilachlor (263.25) and pendimethalin

(262.75). In general, pre-emergence and early post-emergence herbicides performed better than post-emergence herbicides. The post-emergence herbicides 2, 4-D amine and MCPA produced the lowest no. of panicles m^{-2} among the herbicides used alone or in combination with sunflower residues and were similar to weedy check. Gopinath *et al.* (2012) observed a higher number of panicles m^{-2} in butachlor treated plots in rice.

All the herbicides except 2, 4-D amine and MCPA resulted in a significantly higher number of grains panicle^{-1} than the weedy check. Of the weed control treatments, the highest number of grains panicle^{-1} (120.78) was recorded in weed-free treatment, being similar to sunflower residues + 100% pyrazosulfuron ethyl (109.80) and butachlor (108.11). These results are the substantiating with the results of Acharya and Bhattacharya (2013). The reason for higher plant height, more number of panicles m^{-2} and grains panicle^{-1} in the treatments might be due to the fact that there was lower weed-crop competition in terms of dry matter production of weeds as well as good source sink relationship which allowed the crop to absorb the required amount of nutrient, water and sunlight for its growth, production of panicles m^{-2} and grains panicle^{-1}. All the pre-emergence herbicides, pyrazosulfuron ethyl (early post-emergence) and bispyriback sodium (post-emergence) tested alone, sunflower residues used alone or in combination with pyrazosulfuron ethyl (75 and 50%) produced similar no. of grains panicle^{-1}. Weedy check treatment gave the lowest no. of grains panicle^{-1} (78.85). Weedy check treatment produced significantly the highest number of sterile spikelets panicle^{-1} (29.53). Weed-free treatment by hand weeding twice produced the lowest number of sterile spikelets panicle^{-1} (9.15) which was similar to sunflower residues + 100% pyrazosulfuron ethyl (12.53). 1000-grain weight was not significantly influenced by different weed control treatments.

Table 4. Effect of weed control methods on yield attributes of transplanted *Aman* rice

Treatments	Plant height (cm)	Panicle m^{-2} (No.)	Grains panicle^{-1} (No.)	Sterile spikelets panicle^{-1} (No.)	1000-grain weight (g)
T_1	88.66 d	209.50 d	78.85 d	29.53 a	17.49
T_2	101.34 a	305.00 a	120.78 a	9.15 g	19.15
T_3	94.15 b-d	262.75 ab	105.42 b	16.47 c-f	18.79
T_4	94.40 bc	263.25 ab	105.89 b	16.27 c-f	18.94
T_5	94.89 bc	270.25 ab	108.11 ab	14.47 ef	19.01
T_6	90.31b-d	252.50 bc	100.25 bc	19.93 bc	18.25
T_7	94.47 bc	265.00 ab	106.76 b	15.80 d-f	18.97
T_8	93.43b-d	261.75 b	105.38 b	16.80 c-e	18.78
T_9	89.43 cd	215.75 cd	85.02 d	21.27 b	18.05
T_{10}	90.19 cd	217.00 cd	87.53 cd	21.13 b	18.22
T_{11}	92.14 b-d	253.25 bc	101.02 b	18.87 b-d	18.46
T_{12}	95.97 ab	271.75 ab	109.80 ab	12.53 fg	19.12
T_{13}	93.32 b-d	260.50 b	101.77 b	17.87 b-e	18.67
T_{14}	92.49 b-d	260.25 b	101.38 b	18.60 b-d	18.66
LS	**	**	**	**	NS
$LSD_{(0.05)}$	5.68	42.54	13.24	4.08	-
CV (%)	3.63	9.95	7.79	13.68	7.58

T_1 = Weedy check, T_2 = Weed-free check by hand weeding twice, T_3 = Pendimethalin, T_4 = Pretilachlor, T_5 = Butachlor, T_6 = Pyrazosulfuron ethyl, T_7 = Bensulfuron methyl + Acetachlor, T_8 = Bispyriback sodium, T_9 = 2, 4-D amine, T_{10} = MCPA, T_{11} = Sunflower residues, T_{12} = Sunflower residues + 100% pyrazosulfuron ethyl, T_{13} = Sunflower residues + 75% pyrazosulfuron ethyl, T_{14} = Sunflower residues + 50% pyrazosulfuron ethyl, LS = level of significance. Figures in a column followed by different letters differ significantly, but with common letter (s) do not differ significantly at 5% level of probability.

Grain yield, straw yield, harvest index and weed index

Grain yield was significantly influenced by weed control treatments (Table 5). The weed-free plots by hand weeding recorded the highest grain yield (5.14 t ha^{-1}), being comparable to pendimethalin, pretilachlor, butachlor, bensulfuron methyl + acetachlor, and sunflower residues + 100% pyrazosulfuron ethyl. Singh *et al.* (2008) reported that the application of different herbicide treatments gave similar yield to that of weed-free plots. The weedy check treatment produced significantly the lowest grain yield (3.38 t ha^{-1}). Among different herbicides, butachlor gave the maximum yield (4.81 t ha^{-1}). BhanuRekha *et al.* (2004) observed that pre-emergence application of butachlor @ 1.5 kg a.i. ha^{-1} recorded the highest rice grain yield among different herbicides. Pre-emergence application of butachlor @ 1.25 kg a.i. ha^{-1} recorded a significantly higher grain yield of 6084 kg ha^{-1} in transplanted rice (Jayadeva *et al.*, 2009). Singh *et al.* (2005) observed that bensulfuron methyl (Londax) at different doses (40 g a.i. ha^{-1} and 50 g a.i. ha^{-1}) applied alone or as tank mixture with butachlor @ 1000 g a.i. ha^{-1} increased the grain yield. All these results support our findings of the experiment.2, 4-D amine and MCPA recorded the lowest grain yields (4.01 and 4.11 t ha^{-1}, respectively) among the herbicides treatments. The pre-emergence and early post-emergence herbicides (sole) treated plots, contributed to yield increase ranging from 30.47% to 42.31% with an average value of 38.34% over the weedy check, while the respective increase in yields for 2, 4-D amine and MCPA were only 18.64% and 21.60%, respectively. However, the post emergence herbicide bispyriback sodium recorded a 33.43% yield increase over the weedy check. From the data presented, it might reasonably be argued that early application of herbicides offered early season weed control up to the period of full canopy cover by rice plants, which might also contribute to higher grain yield. Application of post-emergence herbicides at 28 DAT (as recommended) could not bring the desired benefits as weeds grew luxuriantly and competed with the crop for resources like nutrients, solar radiation, water, and space. Moreover, they have shown phytotoxicity symptoms (burning of lower leaves) as shown in Table 2 which might have resulted in decreased nutrient uptake and photosynthetic efficiency and thereby ultimately reduced the grain yield. It is noticeable here that grain yields produced by sunflower residue alone and sunflower residue + pyrazosulfuron ethyl at 75 and 50% of recommended dose were comparable to pyrazosulfuron ethyl used alone. In indicates that a reduced rate of pyrazosulfuron ethyl may be feasible for providing satisfactory grain yield when it is applied simultaneously with sunflower residue. These findings are in agreement with Alsaadawi and Sarbout (2015) who found that a combination of a lower rate of trifluralin and sunflower residues at 6 t ha^{-1} significantly reduced weed density and weed biomass by 79 and 90%, respectively over control. Straw yield followed a similar trend as the grain yield.

The harvest index was not significantly affected by weed control treatments. All the weed control methods showed a lower weed index (3.31-21.98%) than the weedy check (34.24%) (Table 5). Singh *et al.* (2008) reported that the application of different herbicide treatments recorded a lower weed index. Similar results were also reported by Bhuiyan *et al.* (2017). The highest weed index in weedy check was due to the lowest grain yield associated with unchecked weed growth throughout the crop growth period. Pre-emergence and early post-emergence herbicides exhibited lower weed index as compared to post-emergence herbicides (2, 4-D amine, and MCPA). However, the lowest weed index was noticed in the application of sunflower residues along with 100% pyrazosulfuron ethyl (3.31%) followed by butachlor (6.42%), as a result of satisfactory control of weeds.

Table 5. Effect of weed control methods on grain yield, straw yield, harvest index and weed index of transplanted *Aman* rice

Treatments	Grain yield (t ha^{-1})	% increase yield over control	Straw yield (t ha^{-1})	Harvest index (%)	Weed index (%)
T_1	3.38 d	-	5.01 e	40.29	34.24
T_2	5.14 a	52.07	7.39 a	41.02	0.00
T_3	4.71 ab	39.35	6.41 b-d	42.36	8.37
T_4	4.72 ab	39.64	6.43 b-d	42.33	8.17
T_5	4.81 ab	42.31	6.86 a-c	41.22	6.42
T_6	4.41 bc	30.47	5.95 d	42.57	14.20
T_7	4.73 ab	39.94	6.60 a-d	41.75	7.98
T_8	4.51 bc	33.43	6.36 b-d	41.49	12.26
T_9	4.01 c	18.64	5.85 de	40.67	21.98
T_{10}	4.11 c	21.60	5.89 d	41.10	20.04
T_{11}	4.40 bc	30.18	6.12 cd	41.83	14.40
T_{12}	4.97 ab	47.04	6.99 ab	41.56	3.31
T_{13}	4.46 bc	31.95	6.35 b-d	41.26	13.23
T_{14}	4.45 bc	31.66	6.24 b-d	41.63	13.42
LS	**	-	**	NS	-
$LSD_{(0.05)}$	0.58	-	0.86	-	-
CV (%)	7.74	-	8.09	5.20	-

T_1 = Weedy check, T_2 = Weed-free check by hand weeding twice, T_3 = Pendimethalin, T_4 = Pretilachlor, T_5 = Butachlor, T_6 = Pyrazosulfuron ethyl, T_7 = Bensulfuron methyl + Acetachlor, T_8 = Bispyriback sodium, T_9 = 2, 4-D amine, T_{10} = MCPA, T_{11} = Sunflower residues, T_{12} = Sunflower residues + 100% pyrazosulfuron ethyl, T_{13} = Sunflower residues + 75% pyrazosulfuron ethyl, T_{14} = Sunflower residues + 50% pyrazosulfuron ethyl, LS = level of significance

Figures in a column followed by different letters differ significantly, but with common letter (s) do not differ significantly at 5% level of probability.

Economic analysis

The acceptance of generated technology by the farmers ultimately depends on the economics involved in the production. The data on a total variable cost, gross return, gross margin and benefit-cost ratio of rice as influenced by weed control treatments are presented in Table 6. The maximum variable cost (Tk.82235.00 ha^{-1}) was involved in the case of hand weeding. The treatment with sunflower residues (5 t ha^{-1}) + 100% pyrazosulfuron ethyl needed the second highest cost (Tk.81345.00 ha^{-1}) followed by sunflower residues (Tk.80985.00 ha^{-1}). The lowest cost of production (Tk.70985.00 ha^{-1}) was involved in the weedy check. The cost varied due to differences in the cost of weed control methods. Weed-free treatment by hand weeding realized the highest gross return of Tk.102160.00 ha^{-1} followed by the application of butachlor (Tk.95490.00 ha^{-1}) and bensulfuron methyl + acetachlor (Tk.93610.00 ha^{-1}). This can be attributed to better weed control in these treatments resulting in increased grain yield and thereby increased gross return. Weedy check realized the lowest (Tk. 67480.00 ha^{-1}) gross return. The highest gross margin of Tk. 22955.00 ha^{-1} was earned from the application of butachlor followed by bensulfuron methyl + acetachlor (Tk. 21959.00 ha^{-1}).

Table 6. Effect of different weed control methods on the cost of production, gross return, gross margin and benefit-cost ratio of transplanted *Aman* rice

Treatments	Total variable cost (Tk. ha^{-1})	Gross return (Tk. ha^{-1})	Gross margin (Tk. ha^{-1})	Benefit-cost ratio
T_1	70985	67480	-3505	-
T_2	82235	102160	19925	1.24
T_3	73723	92890	19167	1.26
T_4	72135	93100	20965	1.29
T_5	72535	95490	22955	1.32
T_6	71345	86150	14805	1.21
T_7	71651	93610	21959	1.31
T_8	71873	89390	17517	1.24
T_9	73235	79870	6635	1.09
T_{10}	71973	81650	9677	1.13
T_{11}	80985	87040	6055	1.07
T_{12}	81345	98470	17125	1.21
T_{13}	81255	88520	7265	1.09
T_{14}	81165	88130	6965	1.09

T_1 = Weedy check, T_2 = Weed-free check by hand weeding twice, T_3 = Pendimethalin, T_4 = Pretilachlor, T_5 = Butachlor, T_6 = Pyrazosulfuron ethyl, T_7 = Bensulfuron methyl + Acetachlor, T_8 = Bispyriback sodium, T_9 = 2, 4-D amine, T_{10} = MCPA, T_{11} = Sunflower residues, T_{12} = Sunflower residues + 100% pyrazosulfuron ethyl, T_{13} = Sunflower residues + 75% pyrazosulfuron ethyl, T_{14} = Sunflower residues + 50% pyrazosulfuron ethyl

Note:

Price of input and output

Urea = 20.00 (Tk. kg^{-1}), TSP = 28.00 (Tk. kg^{-1}), MoP = 20.00 (Tk. kg^{-1}), Gypsum = 20.00 (Tk. kg^{-1}), Zinc sulphate = 180.00 (Tk. kg^{-1}), Labor = 450.00 (Tk. day^{-1}), Rice seed = 22.00 (Tk. kg^{-1}), Pendimethalin = 1095 Tk. L^{-1}, Pretilachlor = 1150 Tk. L^{-1}, Butachlor = 62.00 (Tk. kg^{-1}), Pyrazosulfuron ethyl = 60.00 (Tk. 25 g^{-1}), Bensulfuran methyl+ Acetachlor = 45.00 (Tk. 50 g^{-1}), Bispyribac Na = 120.00 (Tk.20 g^{-1}), 2,4-D Amine = 100.00 (100 ml^{-1}), MCPA = 100.00 (100 ml^{-1}).

However, the gross margin recorded in butachlor was around 15.21% higher than weed free treatment. Higher gross margin was the result of higher grain and straw yields due to better control of weeds throughout the crop growth. The highest gross margin and benefit-cost ratio were recorded in bensulfuronmethyl as reported by Saha and Rao (2009). A negative gross margin was recorded in the weedy check (-Tk. 3505 ha^{-1}). The highest BCR of 1.32 was realized with the application of butachlor which was close to bensulfuron methyl + acetachlor (1.31). This was due to the lower cost of herbicides and no labor use for weeding. Hand weeding recorded a lower BCR (1.24) which could be due to the higher cost involved in engaging human labor for weeding. The lowest BCR was due to lowest grain and straw yields caused by heavy weed infestation. Hasanuzzaman *et al.* (2008) and Singh *et al.* (2017) reported that herbicidal treatments were more profitable than hand weeding. Maiti and Mukharjee (2003) also obtained lower gross margin and BCR in farmers' practice of hand weeding. Among the weed control treatments, although hand weeding rendered effective weed control and highest grain yield, pre-emergence application of butachlor rendered the highest gross margin and benefit cost ratio of transplanted *Aman* rice. The use of butachlor reduces the drudgery on labors and saves scarce and costly labor thus resulting in a lower cost of cultivation.

Conclusion

From this study, it is observed that the use of butachlorand bensulfuron methyl+ acetachlor were most profitable among different weed control methods. The use of herbicide may be an alternative in controlling weeds more easily and cheaply when there is a labor crisis. It may therefore be concluded that the herbicide butachlorand bensulfuron methyl+ acetachlor can be used as an alternative for greater profitability when labor is a limiting factor in producing transplanted *Aman* rice. Application of sunflower residues along with pyrazosulfuron ethyl is another option for an eco-friendly approach in minimizing reliance upon synthetic herbicides in sustainable agriculture.

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