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EFFICACY OF HERBICIDE MIXTURES FOR TRANSPLANTED *AMAN* RICE IN SILTY CLAY LOAM SOIL OF BANGLADESH

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Abstract

Weed management plays an important role in obtaining target yield. A field experiment was carried out at the Agronomy field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, from July to December 2019 to get the most effective weed control strategy for transplanted *Aman* rice. The soil of the study field was silty clay loam in nature. The study consisted of two factors *i.e.*, variety (4: Chinigura, BR11(Mukta), BRRI dhan56, and BRRI hybrid dhan6) and herbicide (4) *viz.*, Bispyribac-sodium WP @ 150 g ha^{-1}, Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1}, Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}, and weedy check as a control. The experiment was laid out in a split-plot design with three replications. Thirteen weed species were found in the experimental plots, mostly broadleaf and sedge. *Monochoria vaginalis* was the most dominant weed species. The study noticed that the application of mixed herbicides offered better weed control over single herbicide application. Application of Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} significantly reduced weed density and biomass and was the best way of controlling complex weed flora. The study marked out BR11 (Mukta) as the most potential *aman* rice variety to produce the highest yields at applying Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1}. This treatment gave the highest gross return (Tk. 1,46,010), net return (Tk. 88,699), and benefit-cost ratio (2.55). Therefore, the study suggests the application of mixed herbicides and BR11 (Mukta) to get the optimum yield of transplanted *Aman* rice and maximum economic benefit.

Introduction

Rice (*Oryza sativa* L.) is Bangladesh's major growing crop, mostly grown in three seasons *viz. Aus* (Pre-monsoon), *Aman* (Monsoon or rainy season) and *Boro* (Dry season) rice. Among the three growing seasons, the area coverage *of Aman* rice is the highest (67% of the cropped area of 85.77 hectares). In 2020, the amount of land used for HYV varieties was 44.47 lakh (4.44 million) hectares, hybrid 2.40 lakh (0.24 million) hectares, local varieties 7.15 lakh (0.75 million) hectares, and for broadcast *Aman* 3.12 lakh (0.31 million) hectares of cultivable land. The total land under the *Aman* rice was 57.14 lakh (5.71 million) hectares (Magzter, 2021). In 2019–20, about 88% was planted to modern varieties, with traditional landrace varieties covering 12% (BBS, 2019). The average rice yield of Bangladesh is almost 50% less than the world's average yield (Rahman *et al.*, 2023). Therefore, to boost rice yield and production, attempts must be made to increase the yield per unit area by adopting modern rice varieties and applying improved technology and management practices (such as irrigation, spacing, weed, insect, etc.)

Weed is the most important threat to the upland or aerobic rice systems, resulting in yield losses between 30 and 98% (Ramana *et al.*, 2014). The high competitive ability of weeds exerts a serious negative effect on crop production. Among the harmful pest, weeds contribute to maximum losses in crop production, potentially reducing crop production by 34%, followed by animal pests (18%) and pathogens by 16% (Abbas *et al.*, 2018). Although hand weeding is a popular weed control method, the unavailability of labour during the peak period discourages farmers from choosing this method. Mechanical weeding and chemical weed control are the alternatives to hand weeding. In the last few years, chemical weed control has increased (Ahmed *et al.*, 2014) because of getting quick and site-specific weed control at a low cost compared to traditional control methods (Zahan *et al.*, 2018). Using herbicides is a promising alternative for controlling weeds (Rahman, 2016). However, continuous and indiscriminate use of herbicides may alter their degradation and pose persistence problems due to residual effects beyond harvest, threatening health and ecology. The use of herbicides with different modes of action and chemistry is desirable to reduce the problem of residue build-up, a shift in weed flora (Rajkhowa *et al.*, 2006), and the development of herbicide resistance in weeds (Rao *et al.*, 2007).

Herbicide mixture may be one option for managing or delaying cross-resistance development in weeds against herbicides (Dhawan *et al.*, 2009). Different pre-mix and tank-mix combinations are being tried to control mixed types of weeds in one go (Yadav *et al.*, 2008), reducing the total volume of herbicide and easing and economizing its application. Zahan *et al.* (2021) found that sole dependence on herbicides having a single mode of action is not advisable. It can contribute to weed species shifting towards difficulty to control and the rapid evolution of multiple herbicide resistance, which threatens wheat production. Bharat and Kachroo (2007) reported that tank mix application of fenoxaprop+ metribuzin (120+100 g ha^{-1}, sulfosulfuron + 2, 4-D (25 + 500 g ha^{-1}), clodinafop + metsulfuron methyl (60+2 g ha^{-1}, isoproturon + 2, 4-D (1000 + 500 g ha^{-1}) and metribuzin (175 or 200 g ha^{-1}) significantly reduced both grass and broadleaf weeds. Applying two or more herbicides simultaneously, using pre-package mixtures, or mixing different herbicide products before the applications, is a prevalent approach in chemical weed control. Some mixed herbicides are usually available in our country and worldwide, such as bensulfuron methyl + acetachlor, bensulfuron methyl + pretilachlor, bensulfuron methyl + butachlor, bensulfuron methyl + mefenacet, bensulfuron methyl + quinclorac, bensulfuron methyl + cyhalofop-butyl + fecoxaprop-p-ethyl, bispyribac sodium, butachlor + propanil, carfentrazone-ethyl + isoproturon, ethoxysulfuron + fluazifop-p-ethyl, fenoxaprop-p-ethyl + ethoxysulfuron, etc (BCPA, 2020). Currently, the use of mixed herbicides against weeds in transplanted *Aman* rice has increased its effectiveness daily.

Rice varieties colossally affect the development and pervasion of weeds in the field. Typically short-height varieties face more weed infestation than taller ones (Tshewang *et al.*, 2016). Thus, an appropriate variety ought to be chosen to keep away from the weed rivalry and get the greatest yield from rice. High-yielding rice varieties are now more available than conventional ones (Shew *et al.*, 2019). Even the growth process of rice plants under different agro-climatic conditions differs with rice varieties (Alam *et al.*, 2012). Moreover, Zahan *et al.* (2017) reported that the response of transplanted *Aman* rice varieties differs with herbicides. Therefore, the performance of herbicides also could vary with the *Aman* rice varieties.

Some herbicide mixtures have been launched in Bangladesh for wide-spectrum weed control in transplanted rice. But the information on their efficacy against weeds in transplanted rice varieties is very meager in the literature. Therefore, the study evaluated the performance of transplanted Aman rice varieties and found the most efficient mixed herbicide(s) with the best yield providing *Aman* rice varieties.

Materials and Methods

The study was done at the Agronomy field of Sher-e-Bangla Agricultural University (SAU), Dhaka, Bangladesh. The experimental site is geographically situated at 23 77′ N latitude and 90 33′ E longitude at an altitude of 8.6 meters above sea level. The experimental field belongs to the Agro-Ecological Zone (AEZ) of “The Modhupur Tract”, AEZ-28. The land was fairly leveled highland. The soil of the experimental site was silty clay loam in texture belonging to the Tejgaon series having pH 5.8–6.5 and ECE 25–28 at 0-15 cm soil depths. The experiment was conducted in the rainy (*Aman*) season from July to December 2019. Usually, the experimental site was under the subtropical climate and was characterized by high temperature, high humidity, and heavy precipitation with occasional gusty winds from March to August; however, scanty rainfall was associated with moderately low temperature. The detailed meteorological data of monthly averaged maximum and minimum temperature, relative humidity, and total rainfall during the experimentation period are given in Table 1.

Table 1. Monthly average of maximum and minimum temperature and the monthly total rainfall during the study period (July to December 2019)

	Air temperature (˚C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
July'19	32.6	26.8	81	114
August'19	32.6	26.5	80	106
September'19	32.4	25.7	80	86
October'19	31.2	23.9	76	52
November'19	29.6	19.8	53	00
December'19	28.8	19.1	47	00

Source: Metrological Centre, (Climate Division), Bangladesh Meteorological Department, Agargaon, Dhaka

The study considered two factors as treatments, *i.e.*, variety 4: Chinigura, BR11(Mukta), BRRI dhan56, and BRRI hybrid dhan6 and herbicide 4: Bispyribac-sodium WP @ 150 g ha^{-1}, Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1}, Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}, and weedy check as a control. The experiment was laid out in a split-plot design with three replications. In the main plot, there was herbicide treatment, and variety was in the subplot. There were 16 treatment combinations and 48 unit plots. The unit plot size was 5.04 m^2 (2.8 m and 1.8 m). The blocks and unit plots were separated by 1.0 m and 0.50 m spacing, respectively. Herbicides were applied to each plot at par with the treatment requirement by a knapsack hand sprayer. In the case of weedy check plots, weeds were allowed to grow along with the crop throughout the crop season and no control measures were adopted to check the weeds. The weed flora present in the weedy check plots was noted.

The tested varieties' healthy and disease-free seeds were collected from Bangladesh Rice Research Institute (BRRI). Before raising seedlings, sprouted seeds of all the rainy season (*Aman*) rice varieties were planted in the seedbeds, and 25-day old seedlings were transplanted in the main field on July 8, 2019 following the standard procedures. Detailed information on the tested herbicides is given in Table 2.

Table 2. Details of the tested herbicides in *aman* rice

Herbicide	Trade name with registered company	Mode of action	Rate of application	Time of application (DAT)
Bispyribac-sodium	Xtrapower 20WP; ACI Crop Care Ltd.	Inhibits plant amino acid synthesis – Acetohydroxyacid synthase (AHAS)	150 g ha^{-1}	20
Acetochlor 14% + Bensulfuron methyl 14%	Ayna plus-18WP; Jass Agro Ltd.	Inhibits cell division in the shoots and roots of the plant	750 g ha^{-1}	12
Pretilachlor 6% + Pyrazosulfuron 0.15%	UPLEROS; ACI Crop Care Ltd.	Inhibits acetolactate synthase	9.88 kg ha^{-1}	3

The experimental land was fertilized with N, P, K, S, and Zn at 69, 20, 35, 11, and 2 kg ha^{-1} in the forms of urea, triple super phosphate, muriate of potash, gypsum, and zinc sulphate, respectively. All of the fertilizers except urea were applied as basal doses at the time of final land preparation. Urea was applied in three equal splits: the first split at 21 days after transplanting (DAT), the second split was top dressed at 45 DAT (active vegetative stage), and the third split was applied at 60 DAT (panicle initiation stage). Irrigation was provided up to 5 cm in each plot according to the critical stages of rainy season rice. Regular observations were made to see the growth and visual differences of the crops due to the treatments applied in the experimental field.

Weed density and dry matter were recorded from 1 m^2 of the area at 30 and 60 days after transplanting of rainy season rice. After counting the numbers, fresh weeds were oven dried at 80° C until a constant weight was obtained. The sample was then transferred into desiccators and allowed to cool down to room temperature, and the final weight of the sample was taken. Relative weed density, weed control efficiency (WCE), weed control index (WCI), crop growth rate (CGR; mg cm^{-2} day^{-1}), relative growth rate (RGR; mg g^{-1} day^{-1}), and net assimilation rate (NAR; mg cm^{-2} day^{-1}) were calculated following the below-mentioned formula.

(i) $\text{Relative weed density (\%)} = \frac{\text{Number of individuals of same species}}{\text{Number of individual of all species}} \times 100$ (Mishra, 1968)

(ii) $\text{WCE} = \frac{\text{Weed population in control} - \text{weed population in treated plot}}{\text{Weed population in control}} \times 100$ (Mani *et al.*, 1973)

(iii) $\text{WCI} = \frac{\text{Weed dry weight in control} - \text{weed dry weight in treated plot}}{\text{Weed dry weight in control}} \times 100$ (Mishra and Tosh, 1979)

(iv) Crop growth rate (CGR) = $\frac{W2-W1}{P(t2-t1)}$ (Watson, 1956)

Where, P = ground area (cm^{-2}), W_1 = dry weight per unit area at t_1, W_2 = dry weight per unit area, at t_2, t_1 = time of first sampling, t_2 = time of second sampling

(v) Relative growth rate (RGR) = $\frac{Ln(W2)-\text{Ln}(W1)}{(t2-t1)}$ (Beadle, 1985)

Where, Ln = natural log values, W_1 = dry weight per unit area at t_1, W_2 = dry weight per unit Area, at t_2, t_1 = time of first sampling, t_2 = time of second sampling

(vi) Net assimilation rate (NAR) = $\frac{(W2-W1)(\text{LnLA2}-\text{LnLA1})}{(t2-t1)(\text{LnLA2}-\text{LnLA1})}$ (Gregory, 1926)

Where, LA_1 = leaf area of first sampling, LA_2 = leaf area of second sampling, W_1 = dry weight per unit area at t_1, W_2 = dry weight per unit area at t_2, t_1 = time of first sampling, t_2 = time of second sampling, Ln = natural log values

Dry matter accumulation in rice plant (g) was recorded at 30, 45, 60, and 90 DAT. The sample plants were oven-dried for 72 hours at 70°C, and then data were recorded from randomly selected plant samples $plant^{-1}$ $plot^{-1}$. The crop was manually harvested at the maturity of grains (when 80–90% of the grains were golden yellow). The harvesting dates of Chinigura, BR11, BRRI dhan56, and BRRI hybrid dhan-6 were November 29, 2019, November 22, 2019, November 08, 2019, and November 15, 2019, respectively. Data on yield contributing characters were collected from ten (10) pre-selected hills $plot^{-1}$ before harvesting the whole plot crop. Grain and straw yields were recorded from the central area of 1 m^2 of each plot and finally converted to t ha^{-1} after adjusting grain moisture content at 12%. The straw yield was recorded after sun-drying the straws properly.

For cost and return analysis, input costs, overhead costs, and some common costs were considered (Mian and Bhuiya, 1977). In the input costs, all material costs and non-material costs were taken into consideration. In a day 8 working hours was considered for labour as a man's day with 400 Tk. wage $labour^{-1}$ day^{-1}. The mechanical labour came from the tractor. A period of eight working hours for a tractor was taken to be tractor day. In the case of overhead cost, the value of land was taken Tk. 200000 ha^{-1}. The interest on this cost was calculated for 6 months @ Tk. 12.5% per year based on the interest rate of the bank. The common cost was 5% of the total cost. The total cost of production, gross return, net return, and benefit-cost ratio was calculated from the following formula.

Total cost of production (Tk. ha^{-1}) = Input costs (Tk. ha^{-1}) + Overhead costs (Tk. ha^{-1}) + Common cost (Tk. ha^{-1})

Gross return from rice (Tk. ha^{-1}) = Value of grain yield (Tk. ha^{-1}) + Value of straw (Tk. ha^{-1})

Net return (Tk. ha^{-1}) = Gross return (Tk. ha^{-1}) – Total cost of production (Tk. ha^{-1})

$$\text{Benefit cost ratio (BCR)} = \frac{\text{Grossreturn (Tk/ha)}}{\text{Cost of production (Tk/ha)}}$$

The collected data were compiled and analysed statistically using the analysis of variance (ANOVA) technique with the help of a computer package program named Statistix 10 Data analysis software and the mean differences were adjusted by the Least Significant Difference (LSD) test at 5% level of probability.

Results and Discussion

The experimental field was infested by thirteen weed species with three grasses, three sedges, and seven broadleaf weed species and the most dominating species were broadleaf and sedge weeds (Table 3). These weed species were belonging to the nine families of Alismataceae, Menyanthaceae, Asteraceae, Sphenocleaceae, Pontederiaceae, Onagraceae, Papayeraceae, Cyperaceae, and Poaceae. The grasses were *E. cruss-galli*, *Eleusine indica*, and *E. colona*, sedges were *Scirpus maritimus, Cyperus diformis* and *C. rotundus*, and broadleaved were, *Sagittaria guayansis, Nymphoides cristatum, Enydra fluctuans, Sphenoclea zeylanica, Monochoria vaginalis, Ludwigia octovalvis*, *and Marsilea quadrifolia*. Bhuiyan, and Mahbub (2020) reported infestation of two types of grass, two sedges, and four broadleaves in the rice field belonging to the families of Poaceae, Cyperaceae, Pontederiaceae, Marsileaceae, Sphenocleaceae, and Asteraceae. The broadleaf weed species were *M. vaginalis, Marsilea minuta*, *S. zeylanica*, and *Eclipta alba*, grasses were *E. crus-galli, Cynodon dactylon*, and sedges were *C. difformis*, and *Scirpus maritimus.* Yadav *et al.* (2008) also reported that the major associated weeds in rice field were *E. glabrescens*, and *E. colona* (L.) among grasses, *Ammannia baccifera* L. and *Euphorbia* sp. among broad-leaved weeds, and *Fimbristylis miliacea* (L.) Vahl*, Cyperus iria* L.*, C. rotundus* L., and *C. difformis* L. among sedges. Bari *et al.* (1995) reported that the three important weeds of transplanted *aman* rice fields were *F. miliacea*, *Paspalum scrobiculatum*, and *Lyperus rotundus*. Mamun *et al.* (1993) also reported that *F. miliacea*, *Lindernia antipola*, and *Eriocaulen cenerseem* were important weeds in transplant *Aman* rice fields.

Table 3. Weed flora of the experimental field in *Aman* season during 2019

Local name	English name	Scientific name	Family	Habitat	Weed type
Chapra	Goose grass	*Eleusine indica*	*Poaceae*	Annual	Grass
Choto shama	Jungle rice	*Echinochloa colona*	*Poaceae*	Perennial	Grass
Boro shama	Barnyard grass	*Echinochloa crus-galli*	*Poaceae*	Annual	Grass
Holde mutha	Yellow nutsedge	*Cyperus diformis*	*Cyperaceae*	Perennial	Sedge
Mutha	Nutsedge	*Cyperus rotundus*	*Cyperaceae*	Perennial	Sedge
Cechra	Dwarf Club-rush	*Scirpus maritimus*	*Cyperaceae*	Perennial	Sedge
Shusni shak	European water clover	*Marsilea quadrifolia*	*Papayeraceae*	Perennial	Broadleaf
Chadmala	Duck weed	*Sagittaria guayansis*	*Menyanthaceae*	Perennial	Broadleaf
Helenca	Buffalo spinach	*Enydra fluctuans*	*Asteraceae*	Annual	Broadleaf
Jheel-morich	Gooseweed	*Sphenoclea zeylanica*	*Sphenocleaceae*	Annual	Broadleaf
Choto Pani kochu	Pickerel weed	*Monochoria vaginalis*	*Pontederiaceae*	Perennial	Broadleaf
Pani Long	Mexican Primrose Willow	*Ludwigia octovalvis*	*Onagraceae*	Perennial	Broadleaf

Species-wise weed population (No. m^{-2}) and relative weed density (%) at 30 DAT and 60 DAT showed that there was a predominance of broadleaf and sedge weeds in weedy check plots (Table 4). *M. vaginalis* was the most dominant weed (36 or 18 m^{-2} and 15.93, 16.98 %) at 30 and 60 DAT followed by *S. guayansis and C. rotundus* weed species at 30 and 60 DAT. While the dominancy of *S. maritimus* at least at 30 DAT and *M. quadrifolia* at 60 DAT was the least among all the weed species.

Table 4. Species wise weed population (No. m^{-2}) and relative weeds density (%) in weedy check plots at 30 and 60 DAT

Scientific name	Weed population (No. m^{-2})		Relative weeds density (%)	
	30 DAT	60 DAT	30 DAT	60 DAT
Sagittaria guayansis	31	12	13.72	11.32
Enydra fluctuans	18	8	7.96	7.55
Sphenoclea zeylanica	22	9	9.73	8.49
Monochoria vaginalis	36	18	15.93	16.98
Ludwigia octovalvis	17	9	7.52	8.49
Marsilea quadrifolia	7	2	3.10	1.89
Scirpus maritimus	5	4	2.21	3.77
Eleusine indica	10	6	4.43	5.66
Echinochloa colona	13	9	5.75	8.49
Cyperus diformis	23	9	10.18	8.49
Cyperus rotundus	27	12	11.95	11.32
Echinochloa crus-galli	7	3	3.10	2.83

Weed density and dry matter

Effect of herbicides was significant on weed density and dry matter at 30 and 60 DAT of rainy (*Aman*) season rice (Figure 1). Results revealed that the highest weed density (26 and 14 m^{-2} at 30 and 60 DAT) and maximum weed dry matter (8.02 and 5.36 g m^{-2} at 30 and 60 DAT) was recorded in weedy check plot. On the other hand, acetochlor 14% + bensulfuron methyl 4% WP treated plot had the lowest weed density (2.33 and 1.78 m^{-2} at 30 and 60 DAT) and minimum weed dry matter (1.78 and 1.00 g m^{-2} at 30 and 60 DAT). This was due to the application of acetochlor 14% + bensulfuron methyl 4% WP @ 750 g ha^{-1} mix herbicide which might have prevented the germination of susceptible weed species and also reduced the growth of germinated weeds by inhibiting the process of photosynthesis comparable to other herbicide treatments. Earlier studies also reported maximum weed density and dry matter in untreated weedy checks (Mishra, 2019; Suryakala *et al.*, 2019). Application of a mixture of herbicides offered 80% or even more control of annual and perennial weeds comparable to a single application of herbicide in the previous studies (Mahbub and Bhuiyan, 2018).

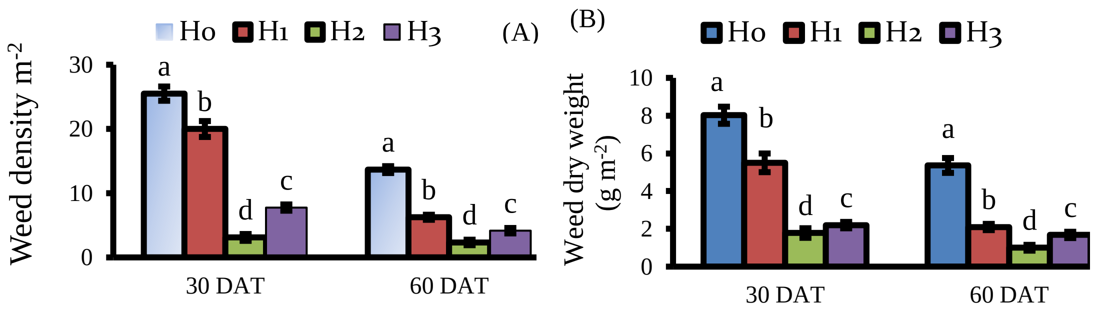

Fig. 1. Effect of herbicide on (A) weed density and (B) weed dry matter at 30 and 60 days after transplanting of rainy (*aman*) season rice (Here, H_0=Weedy check, H_1=Bispyribac sodium WP @ 150 g ha^{-1}, H_2=Acetochlor 14%+ Bensulfuron methyl 4% WP @ 750 g ha^{-1} and H_3=Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1})

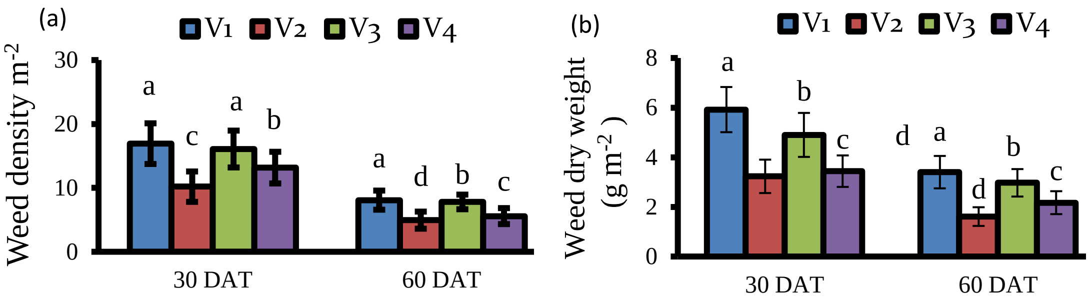

Fig. 2. Effect of variety on weed density and weed dry matter at 30 and 60 days after transplanting of rainy (*aman*) season rice (Here, V_1 = Chinigura, V_2 = BR11, V_3 = BRRI dhan56 and V_4 = BRRI hybrid dhan6)

The variety had a significant effect on weed density and weed dry matter at 30 DAT and 60 DAT of rainy season rice (Fig.2). The highest weed density m^{-2} (16.92 and 8.08 m^{-2} at 30 and 60 DAT) and maximum weed dry matter (5.92 and 3.40 g m^{-2} at 30 and 60 DAT) was counted from the Chinigura rice variety. Minimum weed density (10.19 and 4.95 m^{-2} at 30 and 60 DAT) and dry matter (3.22 and 1.61 g m^{-2} at 30 and 60 DAT) were observed in BR 11 rice variety. The reason for getting a lower number of weeds in the high-yielding cultivar might be due to the vigorous growth of the cultivar helping to suppress weeds. Afrin *et al.* (2015) also reported that competitive rice varieties *viz.*, hybrids, usually have better vigour than inbreeds and effectively suppress the infestation of weed populations or density.

The interaction effect of herbicide and variety was significant on weed density and dry matter at 30 and 60 DAT (Table 5).

Table 5. Combined effect of herbicide and rice variety on weed density and weed dry weight m^{-2} of T. *Aman* rice at 30 and 60 DAT

Treatment	Weed density (m^{-2})		Weed dry weight (g m^{-2})	
	30 DAT	60 DAT	30 DAT	60 DAT
H_0V_1	29.67±1.19a	16.34± 0.82a	9.70±0.39a	7.08±0.35a
H_0V_2	20.00±0.8d	12.13±0.61c	6.51 ±0.26d	3.68±0.18d
H_0V_3	27.33±1.09b	13.87±0.69b	9.27±0.37b	5.97±0.3b
H_0V_4	25.00 ±1 c	12.3 ±0.62c	6.580±0.26d	4.71±0.24b
H_1V_1	24.66±0.99c	7.33±0.37d	8.03±0.32c	2.73 ±0.14e
H_1V_2	15.33 ± 0.61e	4.67±0.23g	4.01±0.16f	1.35±0.07h
H_1V_3	23.33 ±0.93c	7.67±0.38d	5.83±0.23e	2.48±0.12ef
H_1V_4	16.67 ± 0.67e	5.33±0.27f	4.12±0.16f	1.85±0.09g
H_2V_1	4.33 ± 0.17h	3.66±0.18h	3.10±0.12g	1.79±0.09g
H_2V_2	0.11 ± 0.01i	0.33±0.02k	0.81±0.03g	0.39±0.02j
H_2V_3	4.33 ± 0.17h	3.67±0.18h	1.86 ± 0.07i	1.02±0.051i
H_2V_4	3.67 ± 0.15h	1.66±0.08j	1.31±0.05k	0.81±0.04i
H_3V_1	9.01 ±0.36fg	4.99±0.25fg	2.85±0.11h	1.98±0.1g
H_3V_2	5.33 ± 0.21h	2.66±0.13i	1.54±0.06jk	1.01±0.05i
H_3V_3	9.34 ± 0.37f	6.00±0.3e	2.64±0.11h	2.40±0.12f
H_3V_4	7.34 ±0.29g	2.99±0.15i	1.77±0.07ij	1.31±0.07h
SE	0.88	0.23	0.11	0.13
CV (%)	7.67	4.36	3.18	6.15

In a column means having a similar letter(s) are statistically similar and those having a dissimilar letter(s) differ significantly at a 0.05 level of probability. Here, H_0 = Weedy check, H_1= Bispyribac sodium WP @ 150 g ha^{-1}, H_2 = Acetochlor 14%+ Bensulfuron methyl 4% WP @ 750 g ha^{-1} and H_3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}; V_1 = Chinigura, V_2 = BR 11, V_3 = BRRI dhan56 and V_4 = BRRI hybrid dhan6

The results revealed that Chinigura variety had the highest weed density (29.67 and 16.34 m^{-2} at 30 and 60 DAT) and maximum dry matter (9.70 and 7.08 g m^{-2} at 30 and 60 DAT) in the weedy check plots. While application of mixed herbicide, *i.e.,* acetochlor 14% + bensulfuron methyl 4% WP @ 750 g ha^{-1} in BR11 variety had the lowest weeds density (0.11 and 0.33 m^{-2} at 30 and 60 DAT) and minimum weed dry weight (0.86 and 0.39 g m^{-2} at 30 and 60 DAT). The variation in weed density and dry matter was due to the effective weed control offered by mixing herbicides and high-yielding rice cultivars compared to application of single herbicide with low-yielding rice varieties.

Weed control efficiency and Weed control index

Application of herbicides significantly affects the weed control efficiency (WCE) and weed control index (WCI) of T. *Aman* rice at 30 and 60 DAT (Figure 3). Due to herbicide treatments, WCE ranged from 22.1 to 88.9% and WCI ranged from 32.4 to 82.5% over the weedy check plots. Application of acetochlor 14% + bensulfuron methyl 4% WP @ 750 g ha^{-1} offered higher WCE and WCI than the other treatments. However, all the herbicide treatments suppressed weeds, but the magnitude of suppression was higher in acetochlor 14% + bensulfuron methyl 4% WP @ 750 g ha^{-1} treated plots (WCE: 88.9 and 83.7 % and WCI: 78.7 and 82.5% at 30 and 60 DAT, respectively). The weedy check plot obtained the minimum WCE and WCI (0.0 % at both 30 and 60 DAT). The differences in WCE and WCI of the herbicide treatments were due to the variations in weed density in treated plots that directly reflected the effect of herbicides on weeds. Herbicides deteriorate the physiological and morphological features of weeds, help to reduce weed density and biomass, and increase weed control efficiency (Bhuiyan and Mahbub, 2020) and weed control index (Suryakala *et al.*, 2019). In the earlier study, Mishra (2019) found that the weed control efficiency was higher with the application of Bensulfuron methyl 60g ha^{-1} + Pretilachlor 600 g ha^{-1} at 3 DAT than hand weeding, which varies from 74% at 30 DAT to 42.9% at 90 DAT. This might be due to the effect of weeds during the initial stages of crop growth with herbicide application. Priya and Kubsad (2013) also reported higher weed control efficiency and lower weed index in herbicide treatments than weedy check owing to lower weed dry weight, higher weed control efficiency, and lower weed index due to effective control of complex weed flora.

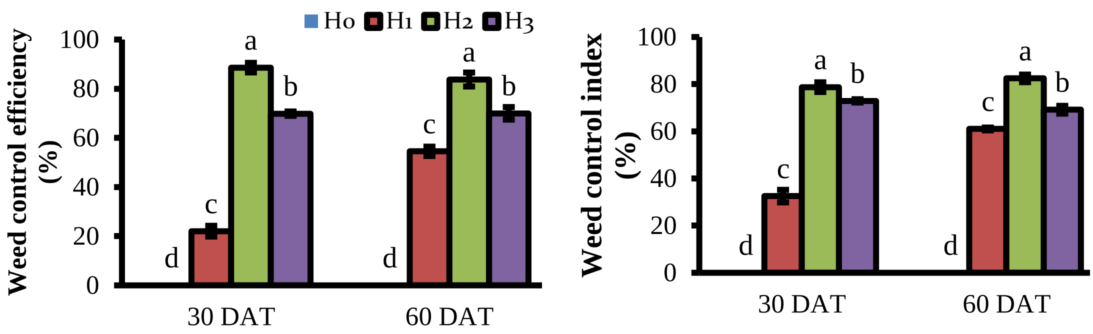

Fig. 3. Effect of herbicide on weed control efficiency and weed control index of T. *Aman* rice at 30 and 60 days after transplanting (Here, H0 =Weedy check, H1= Bispyribac sodium WP @ 150 g ha^{-1}, H2 =Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} and H3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}).

Rice varieties significantly affected WCE and WCI of T. *Aman* rice at 30 and 60 DAT (Figure 4). WCE ranged from 41.2 to 59.2%, and WCI ranged from 39.0 to 56.3% with the varieties. Experiment results revealed that cultivation of BR11 rice variety cultivation recorded the maximum WCE (49.0 and 59.2%) and WCI (50.4 and 56.3%) at 30 and 60 DAT while the cultivation of

BRRI dhan56 rice variety cultivation recorded minimum WCE (41.2 and 43.8 %) and WCI (39.0 and 50.3%) at 30 and 60 DAT. Afrin *et al.* (2015) also found a similar result, who reported that different rice varieties significantly influenced weed control efficiency and index. Chauhan and Johnson (2011) reported that the weed control index could be attributed to less weed biomass due to the highly competitive variety's ability to suppress weeds.

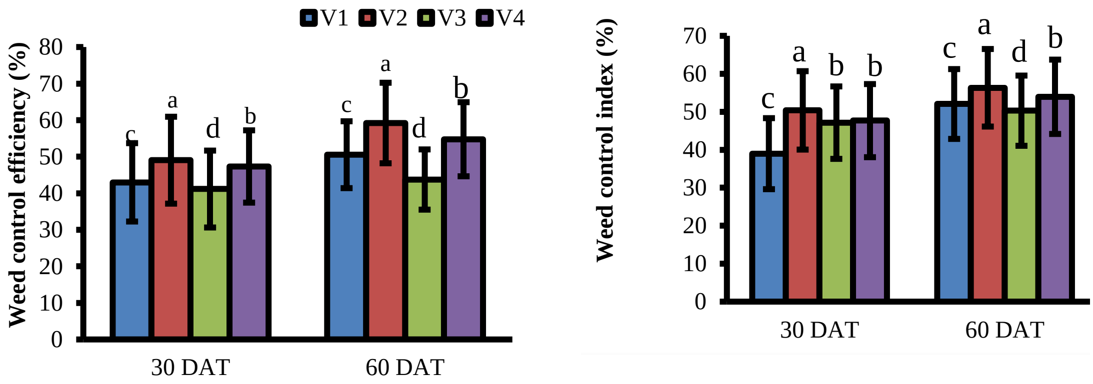

Fig. 4. Effect of variety on weed control efficiency and weed control index of T. *Aman* rice at 30 and 60 days after transplanting (Here, V_1 = Chinigura, V_2 = BR11, V_3 = BRRI dhan56 and V_4 = BRRI hybrid dhan)

The combined effect of herbicide and rice variety significantly affected WCE and WCI at 30 and 60 DAT (Table 6).

Table 6. Combined effect of herbicide and rice variety on weed control efficiency (%) and weed control index (%) of T. *aman* rice at 30 and 60 DAT

Treatment	Weed control efficiency (%)		Weed control index (%)	
Combinations	30 DAT	60 DAT	30 DAT	60 DAT
H_0V_1	-	-	-	-
H_0V_2	-	-	-	-
H_0V_3	-	-	-	-
H_0V_4	-	-	-	-
H_1V_1	16.89±0.35h	55.12±1.84g	17.22±0.29h	61.44±1.23de
H_1V_2	23.35±0.49g	61.50±2.05f	38.35±0.64g	63.32±1.27d
H_1V_3	14.64±0.3h	44.73±1.49h	37.11±0.62g	58.46±1.17e
H_1V_4	33.32±0.69f	56.81±1.89g	37.39±0.63g	60.79 ±1.22de
H_2V_1	85.41±1.78b	77.60 ±2.59c	68.04±1f	74.72±1.49c
H_2V_2	99.45±2.07a	97.28±3.24a	86.79±1.28a	89.31±1.79a
H_2V_3	84.16±1.75b	73.54±2.45d	79.94±1.18b	82.92±1.66b
H_2V_4	85.32±1.78b	86.55±2.88b	80.14±1.18b	82.87±1.66b
H_3V_1	69.64±1.45d	69.44±2.31e	70.62±1.04e	72.03±1.44c
H_3V_2	73.35±1.53c	78.04±2.6c	76.34±1.13c	72.65±1.45c
H_3V_3	65.81±1.37e	56.74±1.89g	71.52±1.05de	59.80±1.2e
H_3V_4	70.64±1.47cd	75.7±2.52cd	73.15±1.08d	72.12±1.44c
SE	1.39	1.72	1.17	1.56
CV (%)	3.78	4.05	3.14	3.61

In a column means having a similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at a 0.05 level of probabilit

Here, H_0 = Weedy check, H_1= Bispyribac sodium WP @ 150 g ha^{-1}, H_2= Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} and H_3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}, V_1 = Chinigura, V_2 = BR 11, V_3 = BRRI dhan56 and V_4 = BRRI hybrid dhan6

Due to the combined effect of herbicide and rice variety, the WCE ranged from 14.64 to 99.45% and WCI ranged from 17.22 to 89.31% over the weedy check plot. Application of acetochlor 14% + bensulfuron methyl 4% WP @ 750 g ha^{-1} mixed herbicide along with BR 11 rice variety recorded the maximum WCE (99.5 and 97.3%) and WCI (86.8 and 89.3%) at 30 and 60 DAT. The reason might be related to the effect of the application of acetochlor 14% + bensulfuron methyl 4% WP @ 750 g ha^{-1} in BR11 that hampered weed growth and reduced weed number and biomass, and boosted up weed control efficiency and weed control index of this combined treatment. While the minimum WCE and WCI (0.0 and 0.0 %) at 30 and 60 DAT was recorded in weedy check plots along with Chinigura rice, and statistically similar results were also found in the weedy check plots along with BR11, BRRI dhan56, and BRRI hybrid dhan6 rice cultivation.

Plant height

Plant height is an important morphological character that acts as a potential indicator of the availability of growth resources in its approach. The study results expressed that rice plant heights significantly varied with herbicide treatments (Figure 5). The maximum plant height (40.1 cm) was recorded from acetochlor 14% + bensulfuron methyl 4% WP @ 750 g ha^{-1} (H_2) mixed herbicide treatment at 15 DAT which was statistically similar with bispyribac sodium (40.0 cm) and significantly superior over remaining treatments. At 30 DAT the maximum plant height (80.0 cm) was recorded from pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}which was statistically similar with (79.3 cm) acetochlor 14% + bensulfuron methyl 4% WP @ 750 g ha^{-1}. The tallest plants (99.8, 117.3, 136.1, and 138.8 cm at 45, 60, and 90 DAT, and at harvest, respectively) were recorded from acetochlor 14% + bensulfuron methyl 4% WP @ 750 g ha^{-1} treated plots and statistically similar results were also obtained from bispyribac sodium treated plots, pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1} treated plots, and also from bispyribac-sodium treated plots. On the other side, acetochlor 14% + bensulfuron methyl 4% WP treated plots had the shortest plants (37.34 cm) at 15 DAT which was statistically similar with pretilachlor 6% + pyrazosulfuron 0.15% WP treated plots. However, the weedy check plots had the shortest plants at 15, 45, 60, and 90 DAT, and even at harvest (72.8, 92.7, 113.3, 130.7, and 132.9 cm, respectively). At the earlier growth stage, spraying mixed herbicide in plants may produce a thin layer in the leaf surface area that might hamper photosynthesis, and as a result, dry matter accumulation and plant height get affected for a while comparable to the plants of no herbicide sprayed plots or weedy check plots. In the earlier study, Das *et al.* (2017) reported that the application of herbicides did not show any phytotoxic symptoms on rice plants. However, Teja *et al.* (2017) reported that the plant height of rice varied significantly with herbicide treatments.

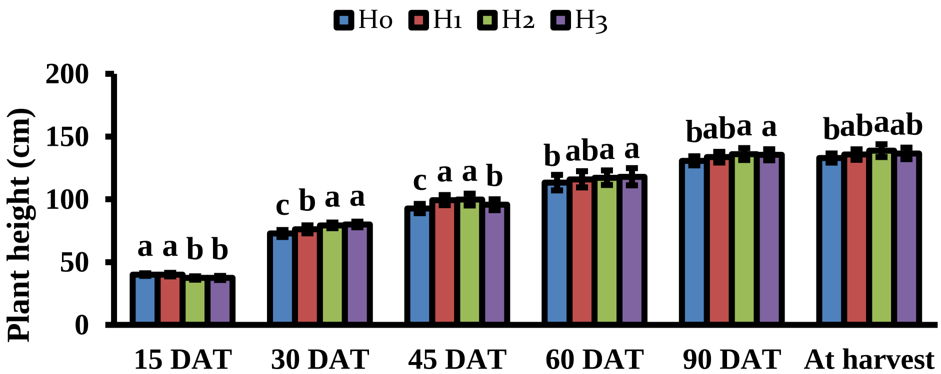

Fig. 5. Effect of herbicide on plant height of T. *Aman* rice at different days after transplanting. Here, Weedy check, H_1= Bispyribac sodium WP @ 150 g ha^{-1}, H_2 = Acetochlor 14%+ bensulfuron methyl 4% WP @ 75 g ha^{-1} and H_3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}.

Rice plant height was significantly differed with the varieties at different days after transplanting (Figure 6). The results expressed that Chinigura had the maximum plant height (45.60, 87.67, 107.99, 130.97, 155.24, and 158.18 cm at 15, 30, 45, 60, 90 DAT, and, at harvest, respectively) while BR11 had the minimum plant height (34.31, 64.58, 74.77, 80.61, 117.76, and 119.86 cm at 15, 30, 45, 60, 90 DAT, and at harvest, respectively). The variation in plant height is probably due to the genetic makeup of the variety. Salam *et al.* (2020) also observed a similar result and reported that the varieties significantly influenced plant height.

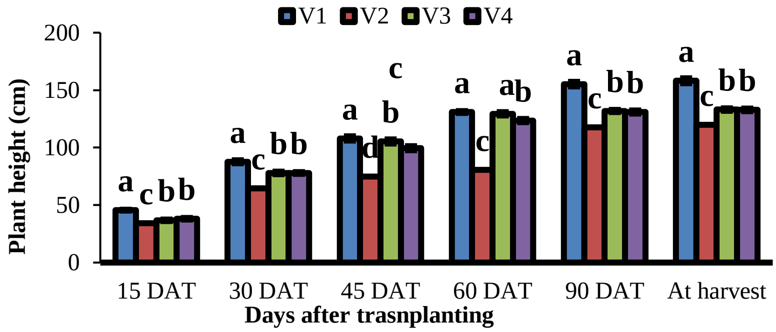

Fig. 6. Effect of variety on plant height of T. *Aman* rice at different days after transplanting

Rice plant height was significantly varied with the combined effect of herbicide and variety (Table 7).

Table 7. Combined effect of herbicide and variety on plant height at different after transplanting of A*man* rice

Treatments	Days after transplanting (DAT)					At harvest
	15	30	45	60	90	
H_0V_1	45 59±1.3 a	82.43±4.54 b	100.53±3.01 d	128.80±2.51 c-e	147.53± 9.31 b	149.33±6.67 c
H_0V_2	38.30±1.09 b-d	58.53±2.12 i	72.73±2.7 h	78.67±0.7 i	116.29±3.5 g	117.07±4.26 f
H_0V_3	37.24±1.06 c-e	73.90± 1.39 fg	101.01±6.26 d	126.87±2.7 c-f	129.58±2.7 de	134.2±2.37 de
H_0V_4	39.16±1.12 bc	76.30±3.64 d-f	96.40±5.24 ef	118.93± 4.24 g	129.33±2.9 de	130.93±2.8 e
H_1V_1	46.16±1.32 a	89.05± 4.16 a	109.97±4.05 ab	130.53±1.56 bc	156.30±5.19 a	157.23±5.76 b
H_1V_2	33.33±0.95 fg	60.67± 2.75 i	78.30±2.79 g	79.27±0.89 i	120.54±3.87 fg	121.53± 5.4 f
H_1V_3	39.59±1.13 bc	75.33± 2.27 e-g	109.23±7.66 ab	130.07±0.06 bc	131.42±3.03 c-e	133.50± 4.91 de
H_1V_4	41.07±1.17 b	79.43±1.22 b-d	100.08±1.17 de	123.97±3.25 e-g	126.10±3.61 ef	130.40±3.64 e
H_2V_1	44.50±1.27 a	89.83 ±3.33 a	111.83±5.93 a	130.56±1.91 bc	158.78±4.57 a	164.33±5 a
H_2V_2	32.89±0.94 g	69.57±0.86 h	74.23±2.32 h	84.45±1.77 h	116.42±6.47 g	119.37±6.62 f
H_2V_3	36.32±1.04 c-e	80.27±1.14 bc	106.27±6.65 bc	124.67±4.6 d-f	132.72 ±5.04 cd	133.70±5.87 de
H_2V_4	35.65±1.02 d-g	77.40± 2.62 c-e	106.97±5.8 bc	129.31±1.46 b-d	136.43±4.1 c	137.83±4.1 d
H_3V_1	46.17±1.32 a	89.37±2.93 a	109.62±6.96 ab	134.00±3.03 ab	158.37±0.87 a	161.81±1.92 ab
H_3V_2	32.71±0.93 g	69.53±2.73 h	73.83±3.54 h	80.03±1.57 hi	117.79±0.51 g	121.47±1.03 f
H_3V_3	33.97±0.97 e-g	82.50±0.75 b	104.36±4.05 c	136.07±0.37 a	133.80±0.46 cd	130.93±0.64 e
H_3V_4	36.66±1.05 c-e	78.59±2.54 c-e	94.46 ±4.49 f	121.93±4.58 fg	132.07±0.57 cd	132.23±0.64 de
SE	1.59	1.60	1.83	2.45	2.82	3.16
CV(%)	5.04	2.54	2.32	2.59	2.58	2.85

In a column means having a similar letter(s) are statistically similar and those having a dissimilar letter(s) differ significantly at a 0.05 level of probability Here, H_0 = Weedy check, H_1= Bispyribac sodium WP @ 150 g ha^{-1}, H_2 = Acetochlor 14% + bensulfuron methyl 4% WP @ 750 g ha^{-1} and H_3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}; V_1 = Chinigura, V_2 = BR11, V_3 = BRRI dhan56 and V_4 = BRRI hybrid dhan6

Chinigura variety had the tallest plants (46.2 cm) at 15 DAT in Pretilachlor 6% + pyrazosulfuron 0.15% WP treated plots and statistically similar height was found in bispyribac sodium treated plots (46.2 cm), weedy check plots (45.6 cm), and acetochlor 14% + Bensulfuron methyl 4% WP treated plots (44.5 cm) with the same variety. At 30, 45, 60 DAT, and even at harvest, the tallest plants were found from Chinigura variety in acetochlor 14% + Bensulfuron methyl 4% WP treated plots and also from pretilachlor 6% + pyrazosulfuron 0.15% WP treated plots and bispyribac-sodium WP treated plots. However, at 60 DAT, BRRI dhan56 had the tallest plants in pretilachlor 6% + pyrazosulfuron 0.15% WP treated plots and also from Chinigura variety in the pretilachlor 6% + pyrazosulfuron 0.15% WP treated plots. BR11 recorded the shortest plants from pretilachlor 6% + pyrazosulfuron 0.15% WP treated plots at 15 DAT. At 30, 45, 60, and 90 DAT, and at harvest the shortest plants (58.5, 72.7, 78.7, 116.3 and 117.1 cm, respectively) were in the weedy check plots of Chinigura variety.

Dry matter accumulation (DMA), Crop growth rate (CGR), and Net assimilation rate (NAR)

Application of herbicides significantly affected DMA, CGR, and NAR of T. *Aman* rice at 30, 45, 60 and 90 DAT (Fig. 8). The maximum DMAs (9.2, 27.5, 63.8 and 108.1 g plant^{-1} at 30, 45, 60 and 90 DAT, respectively), CGR (3.94 mg cm^{-2} day^{-1}), and NAR (7.46 mg cm^{-2} day^{-1}) were recorded in acetochlor 14% + bensulfuron methyl 4% WP treated plots. The minimum DMAs (5.7, 20.9, 49.5, and 90.3 g plant^{-1} at 30, 45, 60, and 90 DAT respectively) and CGR (3.63 mg cm^{-2} day^{-1}) were found in weedy check plots. The minimum NAR (6.20 mg cm^{-2} day^{-1}) was recorded in Bispyribac-sodium WP treated plots. The DMA and CGR differences in herbicide-treated plots over weedy check plots were due to the reduction of weeds which ultimately helped in undisturbed plant growth by utilizing its surrounded resources. Similar result was also observed by Lodhi (2016) who reported that weed control treatments caused remarkable variations in the quantity of dry matter accumulation and crop growth rate of rice.

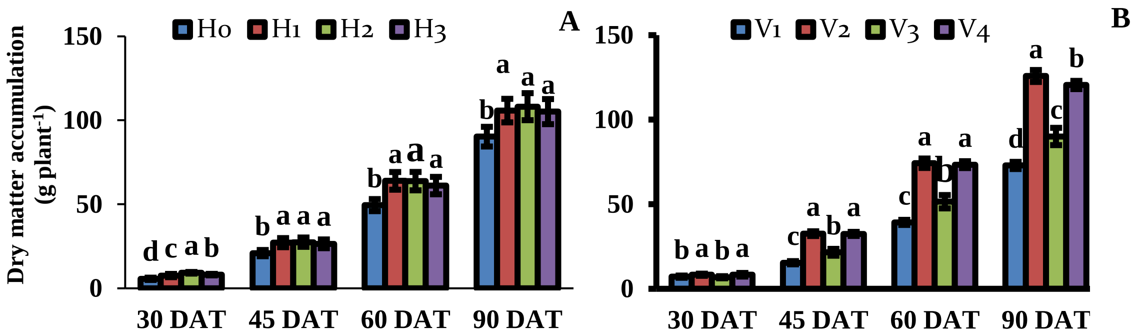

Fig. 8. Effect of herbicide(A) and variety (B) on dry matter accumulation plant^{-1} of T. *aman* rice at 30, 45, 60 and 90 days after transplanting Here, H0 = Weedy check, H1= Bispyribac sodium WP @ 150 g ha^{-1}, H2 = Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} and H3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}, V1 = Chinigura, V2 = BR 11, V3 = BRRI dhan56 and V4 = BRRI hybrid dhan6

The dry matter accumulation (DMA) differs with the varieties due to the differences in leaf area, growth stage, and resources utilization ability of the varieties. In this study, varieties had significant effect on DMAs of T. *Aman* rice at 30, 45, 60 and 90 DAT and also on CGR (Fig. 8 and Figure 9). BR11 had the maximum DMAs (8.32, 32.61, 74.26 and 125.85 g plant^{-1}, respectively) at 30, 40, 60 and 90 DAT and the maximum CGR (4.59 mg cm^{-2} day^{-1}). While Chinigura rice had the minimum DMAs (7.18, 15.42, 39.27, and 72.95g plant^{-1} at 30, 40, 60 and 90 DAT, respectively) and the minimum CGR (2.99 mg cm^{-2} day^{-1}). Usually, high yielding or hybrid varieties have competition, weed suppression, and resource utilization ability greater than the local varieties that influence dry matter accumulation. The results of this study are aligned with Nahida *et al.* (2013), who reported that dry matter (DM) accumulation over time considerably varied with the varieties, and also with the study of Mia and Shamsuddin (2011), who reported that the higher CGR is related to higher leaf area index and net assimilation rate.

The combined effect of herbicide and rice variety was significant on DMA (Table 8) and (Table 9) CGR. The maximum dry matter accumulations (10.3, 37.5, 84.4, and 138.8 g plant^{-1}, at 30, 45, 60, and 90 DAT, respectively) and CGR (4.83 mg cm^{-2} day^{-1}) were recorded in Acetochlor 14% + Bensulfuron methyl 4% WP treated plots of BR11. In weedy check plots, Chinigura rice had the minimum CGR (2.76mg cm^{-2} day^{-1}) and minimum dry matter accumulation at 30 DAT (5.32 g $plant^{-1}$). DMAs at 45 and 60 DAT were minimum (12.2 and 33.9 g $plant^{-1}$) in Bispyribac- sodium treated plots of Chinigura rice.

Table 8. Combined effect of herbicide and rice variety on dry matter accumulation at 30, 45, 60, and 90 days after transplanting of T. *Aman* rice

Treatment	Dry matter accumulation (g $plant^{-1}$)			
	30 DAT	45 DAT	60 DAT	90 DAT
H_0V_1	5.32±2.2 i	13.80±1.2 g	34.99±0.6 g	66.00±0.8 h
H_0V_2	6.14±1.3 gh	26.11±0.4 e	60.05±1 d	108.07±1.2 f
H_0V_3	5.58±0.5 hi	16.70±2.1 f	40.74±0.7 f	76.51±0.9 gh
H_0V_4	5.58±4.8 hi	27.16±4.1 e	62.34±1.2 d	110.55±1.3 e
H_1V_1	7.24±3.1 f	12.20±3.7 g	33.89±0.6 g	66.00±0.8 h
H_1V_2	8.14±2.9 e	31.28±3.3 d	72.61±1.2 c	123.43±1.2 bd
H_1V_3	6.71±3.9 fg	3237±4.3 cd	73.82±1.3 c	119.1±1.4 ce
H_1V_4	8.29±5.1 d	32.88±1.9 cd	75.57±1.3 bc	114.69±1.5 de
H_2V_1	8.91±1.3 cd	18.13±2.1 f	45.33±0.8 ef	80.78±0.9 g
H_2V_2	10.26±1.9 a	37.45±1.4 a	84.40±1.4 a	138.76±1.5 a
H_2V_3	8.27±2.2 d	18.72±1.7 f	46.23±0.8 e	82.57±0.9 g
H_2V_4	9.48±1.4 bc	35.56±1.5 ab	79.28±1.3 ab	130.4±1.5 ab
H_3V_1	7.24±1.8 f	17.55±2.4 f	42.93±0.7 ef	79.04±0.9 g
H_3V_2	8.74±0.4 cd	35.58±0.8 ab	79.97±1.3 ab	133.1±1.5 ab
H_3V_3	6.78±0.5 fg	18.58±2.5 f	45.19±0.8 ef	82.15±0.9 g
H_3V_4	9.84±0.7 abg	34.24± 2.6 bc	76.5±1.3 bc	126.44±1.4 bc
SE	0.35	1.21	2.54	5.09
CV (%)	5.73	5.84	5.21	6.10

In a column means having a similar letter(s) are statistically similar and those having a dissimilar letter(s) differ significantly at a 0.05 level of probability Here, H_0 = Weedy check, H_1= Bispyribac sodium WP @ 150 g ha^{-1}, H_2 = Acitachlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} and H_3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}; V_1 = Chinigura, V_2 = BR11, V_3 = BRRI dhan56 and V_4 = BRRI hybrid dhan6

Table 9. Combined effect of herbicide and rice variety on crop growth rate and net assimilation rate of T. *aman* rice

Treatments	Crop growth rate (mg cm^{-2} day^{-1})	Net assimilation rate (mg cm^{-2} day^{-1})
H_0V_1	2.76±0.11g	6.04±0.4fg
H_0V_2	4.27±0.17c	6.44±0.43de
H_0V_3	3.18±0.13f	5.83± 0.39g
H_0V_4	4.29±0.17c	7.19±0.48b
H_1V_1	2.85±0.11g	6.15±0.41e-g
H_1V_2	4.52±0.18b	6.25±0.42ef
H_1V_3	4.03±0.16d	7.19±0.48b
H_1V_4	3.48±0.14e	5.22±0.39h
H_2V_1	3.15±0.13f	7.19±0.48b
H_2V_2	4.83±0.19a	7.93±0.53a
H_2V_3	3.23±0.13f	6.91±0.46bc
H_2V_4	4.55±0.18b	7.82±0.52a
H_3V_1	3.21±0.13f	7.76±0.52a
H_3V_2	4.73±0.19a	6.74±0.45cd
H_3V_3	3.29±0.13f	6.05±0.4fg
H_3V_4	4.44±0.18b	6.96±0.46bc
SE	0.06	0.17
CV (%)	2.17	3.26

In a column means having a similar letter(s) are statistically similar and those having a dissimilar letter(s) differ significantly at a 0.05 level of probability Here, H_0 = Weedy check, H_1= Bispyribac sodium WP @ 150 g ha^{-1}, H_2 = Acitachlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} and H_3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}; V_1 = Chinigura, V_2 = BR11, V_3 = BRRI dhan56 and V_4 = BRRI hybrid dhan6

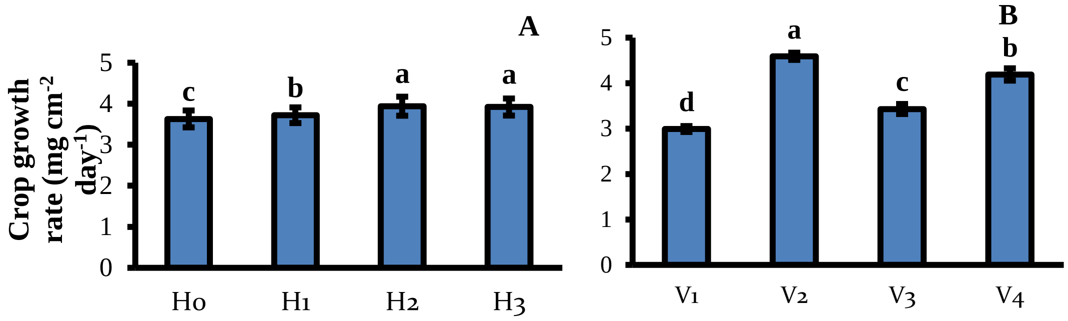

Fig. 9. Effect of herbicide (A) and variety (B) on crop growth rate of T. *Aman* rice Here, H0 = Weedy check, H1= Bispyribac sodium WP @ 150 g ha^{-1}, H2 = Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} and H3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}, V1 = Chinigura, V2 = BR11, V3 = BRRI dhan56 and V4 = BRRI hybrid dhan6

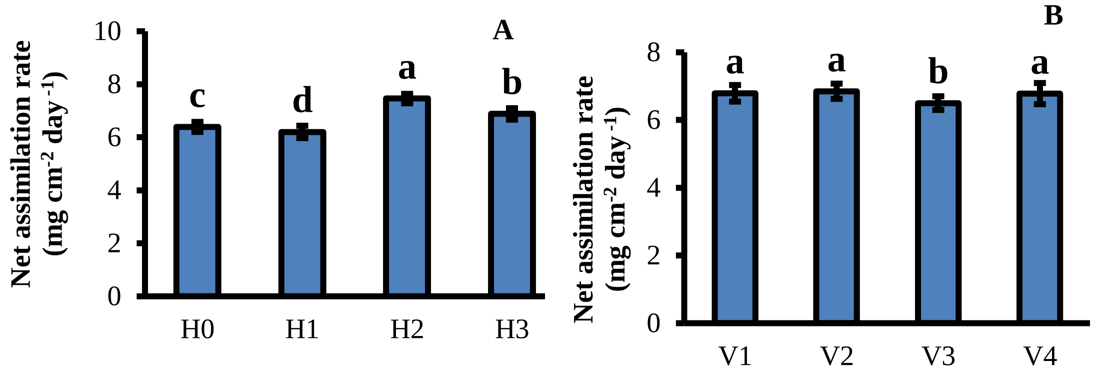

Fig. 10. Effect of herbicide (A) and variety (B) on net assimilation rate at 30, 45, 60, and 90 days after transplanting of T. *Aman* rice

In a column means having a similar letter(s) are statistically similar and those having a dissimilar letter(s) differ significantly at a 0.05 level of probability Here, H0 = Weedy check, H1= Bispyribac sodium WP @ 150 g ha^{-1}, H2 = Acitachlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} and H3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}; V1 = Chinigura, V2 = BR11, V3 = BRRI dhan56 and V4 = BRRI hybrid dhan6

Grain yield, Straw yield, and harvest index

The grain and straw yields (t ha^{-1}) and harvest index (%) of T. *aman* rice were significantly influenced by herbicide application, and grain yield significantly varied with the herbicide treatments (Figure 11, Fig. 12 and Figure 13). The grain and straw yields (3.25 t ha^{-1} and 2.26 t ha^{-1}, respectively) and harvest index (36.0%) were the lowest in weedy check plots where weeds were allowed to grow throughout the crop growing season. The highest grain and straw yields (4.49 t ha^{-1} and 6.38 t ha^{-1}, respectively) and harvest index (42.0%) were obtained from acetochlor 14% + bensulfuron methyl 4% WP, and it provided superior weed control over all other herbicide treatments. Effective mix herbicides can affect a wide range of weed species causing a reduction of weed density comparable to single or other low-effective mix herbicide applications. The similar result reported by Suryakala *et al.* (2019) showed that grain yield production was lower in un-weeded control, respectively indicating the importance of weed management in the critical growth period of the crop by herbicide application, which facilitated the efficient use of resources. Hossain and Mondal (2014) also reported that tank-mix application of bispyribac + ethoxysulfuron, pretilachlor fb metsulfuron-methyl + chlorimuron-ethyl and pretilachlor + bensulfuron resulted in more rice grain yield than their sole application. Mishra (2019) reported better performance of herbicide combinations in controlling weeds and increasing yield in transplanted rice.

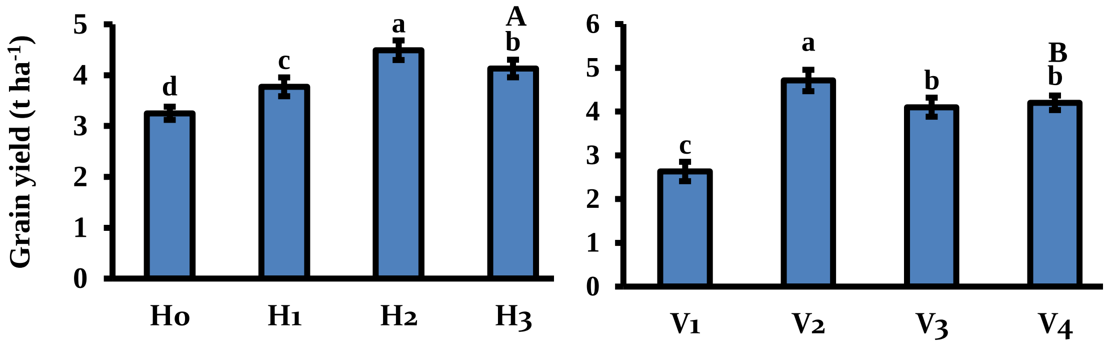

Fig. 11. Effects of herbicide and variety on grain yield of T. *aman* rice Here, H0 = Weedy check, H1 = Bispyribac sodium WP @ 150 g ha^{-1}, H2 = Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} and H3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1} V1 = Chinigura, V2 = B 11, V3 = BRRI dhan56 and V4 = BRRI hybrid dhan6

Grain and straw yields and harvest index were significantly varied with rice varieties (Figure 11, Figure 12, and Figure 13). The maximum grain and straw yields (4.71 t ha^{-1} and 6.40 t ha^{-1}, respectively) and harvest index (42.2%) were recorded from BR11 because of producing the maximum number of filled grains per panicle along with a maximum 1000-seed weight that collectively contributed to higher grain yield. While Chinigura rice had the minimum grain and straw yields (2.63 t ha^{-1} and 5.13 t ha^{-1}, respectively) and harvest index (34.3%). The similar finding was reported by Islam *et al.* (2013) that the varieties which produced a higher number of effective tillers hill^{-1} and a higher number of filled grains panicle^{-1} also showed higher grain yield ha^{-1}. Dutta (2002) also reported that the genotypes, which produced more effective tillers hill^{-1} and a higher number of grains per panicle also showed higher grain yield in rice.

Grain yield was significantly influenced by the combined effect of herbicide and rice variety (Table 10). BR11 had the maximum grain and straw yields (5.57 t ha^{-1} and 6.76 t ha^{-1}, respectively) and harvest index (45.1%) in acetochlor 14% + bensulfuron methyl 4% WP applied plots while Chinigura rice produced the minimum grain and straw yields (2.26 t ha^{-1} and 4.21 t ha^{-1}, respectively) and harvest index (30.8%) in the weedy check plots.

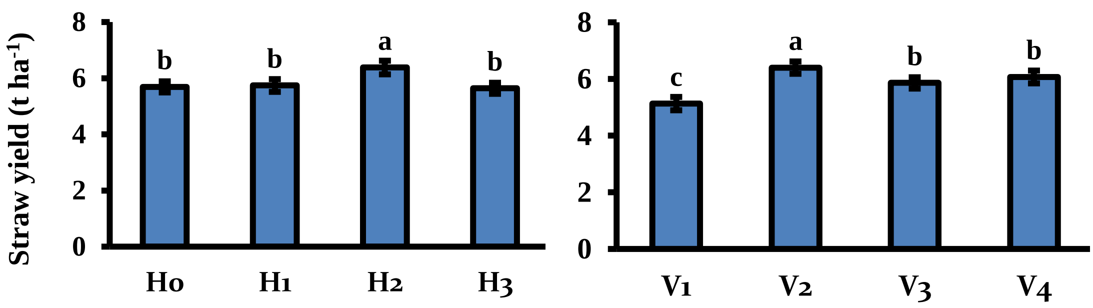

Fig. 12. Effect of herbicide and variety on straw yield of T. *aman* rice Here, H0 = Weedy check, H1= Bispyribac sodium WP @ 150 g ha-1, H2 = Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} and H3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1} V1 = Chinigura, V2 = BR11, V3 = BRRI dhan56 and V4 = BRRI hybrid dhan6

Table 10. Combined effect of herbicide and rice variety on grain and straw yields (t ha^{-1}) and harvest index (%) of T. *aman* rice

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
H_0V_1	2.26±0.41g	4.79±0.72e	32.00±0.86f
H_0V_2	3.78±0.47e	5.94±0.74b-d	38.89±0.93de
H_0V_3	3.26±0.41f	5.70±0.71cd	36.38±0.87e
H_0V_4	3.68±0.46e	6.34±0.79a-c	36.73±0.87e
H_1V_1	2.32±0.42g	4.21±0.74e	36.35±0.86e
H_1V_2	4.55±0.57c	6.58±0.82ab	40.8 ±0.97b-d
H_1V_3	3.98±0.5de	5.63±0.7d	41.42±0.97b-d
H_1V_4	4.24±0.53cd	6.52±0.82ab	39.41±0.94 c-e
H_2V_1	2.98±0.6f	6.71±0.86a	30.75±0.98f
H_2V_2	5.57±0.7a	6.76±0.85a	45.09±1.07a
H_2V_3	4.88±0.61b	6.34±0.79a-c	43.49±1.04ab
H_2V_4	4.52±0.57c	5.72±0.72cd	44.14±1.05ab
H_3V_1	2.94±0.49f	4.80±0.73e	37.98±0.96de
H_3V_2	4.93±0.62b	6.32±0.79a-c	43.82±1.04ab
H_3V_3	4.28±0.53cd	5.76±0.72cd	42.63±1.01 a-c
H_3V_4	4.36± 0.54c	5.69±0.72cd	43.63±1.04ab
SE	0.11	0.31	0.45
CV (%)	4.84	6.61	5.31

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Here, H_0 = Weedy check, H_1= Bispyribac sodium WP @ 150 g ha^{-1}, H_2 = Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} and H_3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}. V_1 = Chinigura, V_2 = BR11, V_3 = BRRI dhan56 and V_4 = BRRI hybrid dhan6

Economic viability of different treatments combination

The economic performance of treatment combinations was determined ha^{-1} area basis, including total cost of production, gross returns, net returns, and benefit cost ratio (profit over per taka investment) under treatments imposed (Table 11). Cost of production varied due to different herbicide applications and rice variety cultivation. The cost of production varied mainly for the herbicide application. In the case of a weedy check, there was no involvement of cost for herbicide application. In this experiment, the highest total production cost occurred in Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1} mixed herbicide application along different rice variety cultivation and lowest in weed check fields along with different rice variety cultivation. Gross return was influenced by different herbicide treatments along with different rice variety. The highest gross return (146010 taka) was recorded under Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} mixed herbicide along with BR11 while the minimum (61290 taka) in weedy check plot along with Chinigura. Net return was varied by different herbicide treatments along with different rice variety. The highest net return (88699 taka) was recorded under Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} mixed herbicide along with BR11 while the minimum (4849 taka) in Bispyribac sodium WP @ 150 g ha^{-1} herbicide along with Chinigura.

Benefit cost ratio (BCR)

The benefit cost ratio varied in different herbicide treatments along with different rice variety. The highest benefit cost ratio (2.55) was recorded under Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} mixed herbicide along with BR11 due to reason that higher grain yield (5.57 t ha^{-1}), straw yield (6.76 t ha^{-1}) and lower weed density (0.11) and weed biomass (0.33) per meter square were recorded under this treatment combination while the minimum (1.08) in Bispyribac-sodium WP @ 150 g ha^{-1} herbicide along with Chinigura. Due to reason that effective mixed herbicide reduces wide density weed population while helping the plant to higher production due to fewer weeds competition. On the other hand, single herbicides reduce weed density of one or two species, which helps to grow others weeds, and they grow vigorously and consume more resources, resulting in poor crop plant growth. This result supports the findings of Salam *et al.* (2020), who reported that benefit cost ratio varied among different rice varieties. Sunil *et al.* (2010) also reported that pre-emergence application of bensulfuron methyl + pretilachlor (6.6 GR) @ 0.06 + 0.6 kg ha^{-1} + one inter cultivation at 40 DAS recorded significantly higher grain and straw yields (4425 and 5020 kg ha^{-1}), lower weed population and dry weight (17 and 2.32 g m^{-2}). This treatment also resulted in higher net returns and B:C ratio.

Table 11. Cost of production, return and Benefit cost ratio (BCR) of T. *aman* rice varieties *i.e,* Chinigura, BR11, BRRI dhan56 and BRRI hybrid dhan6 under different treatments

Treatment Combinations	Fixed variable cost	Herbicide application cost	Total cost of production	Gross return (Tk)	Net return (Tk)	BCR
H_0V_1	55865	0	55865	61290	5425	1.10
H_0V_2	55865	0	55865	100440	44575	1.80
H_0V_3	55865	0	55865	87200	31335	1.56
H_0V_4	55865	0	55865	98340	42475	1.76
H_1V_1	56016	1345	57361	62210	4849	1.08
H_1V_2	56016	1345	57361	120330	62969	2.10
H_1V_3	56016	1345	57361	105130	47769	1.83
H_1V_4	56016	1345	57361	112520	55159	1.96
H_2V_1	56011	1300	57311	81210	23899	1.42
H_2V_2	56011	1300	57311	146010	88699	2.55
H_2V_3	56011	1300	57311	128340	71029	2.24
H_2V_4	56011	1300	57311	118720	61409	2.07
H_3V_1	56243	3364	59607	78300	18693	1.31
H_3V_2	56243	3364	59607	129570	69963	2.17
H_3V_3	56243	3364	59607	112760	53153	1.89
H_3V_4	56243	3364	59607	114690	55083	1.92

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. Here, H_0 = Weedy check, H_1= Bispyribac sodium WP @ 150 g ha^{-1}, H_2 = Acitachlor 14%+ Bensulfuron methyl 4% WP @ 750 g ha^{-1} and H_3 = Pretilachlor 6% + pyrazosulfuron 0.15% WP @ 9.88 kg ha^{-1}. V_1 = Chinigura, V_2 = BR 11, V_3 = BRRI dhan56 and V_4 = BRRI hybrid dhan6

Conclusion

The study suggests that the application of Acetochlor 14% + Bensulfuron methyl 4% WP @ 750 g ha^{-1} mixed herbicide combination with BR11(Mukta) gave the maximum grain and straw yields offering the highest gross return, net return, and benefit cost ratio. However, further investigation is necessary for the other soil types under different AEZs in Bangladesh.

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