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RESEARCH ARTICLE

Effect of Herbicidal Weed Control Method on the Yield of T. *Aman* Rice Varieties

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ABSTRACT

Weed competition is a major factor limiting the productivity of transplanted *aman* rice, particularly where labor shortages limit timely manual weeding. An experiment was carried out at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh, from July to November 2022 to study the effect of variety and herbicidal weed control method on the yield performance of T. *aman* rice varieties. Two rice varieties, BR11 and BRRI dhan49, were included in the experimental treatments, along with six weeding treatments: T_1 (no weeding), T_2 (hand weeding at 25 DAT), T_3 (pre-emergence herbicide Superhit 500 EC), T_4 (pre-emergence herbicide with one hand weeding at 35 DAT), T_5 (post-emergence herbicide Livina 18 WP), and T_6 (post-emergence herbicide with one hand weeding at 35 DAT). The experiment was designed using Randomized Complete Block Design (RCBD) with three replications. Weed pressure was highest under no weeding (T1), resulting in the lowest grain yield (4.88 t ha^{-1}). In contrast, the integrated treatment of pre-emergence herbicide followed by one hand weeding at 35 days after transplanting (T4) proved most effective, reducing weed density (5.51 m^{-2}) and increasing grain yield (5.88 t ha^{-1}). Among the varieties, BR11 consistently produced higher yield (5.65 t ha^{-1}) than BRRI dhan49 due to better yield components. The interaction effect revealed that BR11 combined with integrated weed management (pre-emergence herbicide + hand weeding) produced the highest grain yield (6.19 t ha^{-1}), highlighting the importance of genotype × management synergy. The finding indicates that combining pre-emergence herbicide with one hand weeding is an effective, sustainable strategy for improving *aman* rice yield.

Keywords: *Weed dynamics, Integrated weed management, Pre-emergence herbicide, Post-emergence herbicide, Multivariate analysis, T. Aman rice*

INTRODUCTION

Rice (*Oryza sativa* L.) is the most extensively cultivated crop and the staple food in Bangladesh. Annual rice production is 37.6 million tons from 11.7 million ha of land, which contributes 11.5% of total GDP (BBS, 2022). However, despite its pivotal role, rice cultivation, particularly the *aman* rice varieties, frequently faces considerable yield reductions due to weed proliferation (Ali *et al*., 2022). In Bangladesh, where rice is a staple, weed infestation is a leading problem in rice cultivation (Islam *et al*., 2017). These

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weeds compete with rice plants for essential resources such as nutrients, water, and sunlight, leading to significant yield losses estimated at 15% to 60% (Paul *et al*., 2025; Humaira *et al*., 2025). Furthermore, uncontrolled weed growth can also reduce grain quality and interfere with harvesting operations, thereby diminishing overall agricultural productivity and economic returns for farmers (Ferdous *et al*., 2016; Fiza *et al*., 2024). To mitigate these substantial losses, effective weed management strategies are imperative for sustainable rice production (Sultana *et al*., 2025; Islam *et al*., 2025). Various weed control methods, including manual weeding, chemical control with herbicides, and integrated approaches, have been developed to address this persistent challenge (Ferdous *et al*., 2016; Mia *et al*., 2024). Among these, chemical control utilizing herbicides has gained prominence due to its efficiency in managing diverse weed populations and reducing labor requirements, particularly in direct-seeded rice systems where weeds present a major hindrance (Janghel *et al*., 2025).

However, the singular application of herbicides often falls short of achieving complete weed eradication, necessitating integrated approaches that combine pre-emergence and post-emergence herbicide applications, sometimes supplemented by manual weeding (Ali *et al*., 2022; Shahabuddin *et al*., 2016). For instance, sequential applications of pendimethalin as a pre-emergence herbicide followed by bispyribac sodium 10 SC as a post-emergence treatment have demonstrated significant inhibition of diverse weed types, leading to higher paddy yields (Chandra and Walia, 2025). Similarly, research has shown that applying bispyribac acid 40% SC at 70 g a.i ha^{-1} at 10 DAT, followed by two hand weedings at 20 and 40 DAT, significantly enhances plant height, leaf area index, and dry matter production, ultimately resulting in increased grain and straw yields (Suseendran *et al*., 2017). This multi-faceted approach underscores the necessity of integrating various control mechanisms to achieve optimal weed suppression and maximize agricultural output in rice cultivation (Choudhary *et al*., 2025). Despite the advancements in herbicidal weed control, exclusive reliance on chemical methods is often insufficient and can lead to the evolution of herbicide-resistant weed biotypes, thereby necessitating a broader integrated weed management framework (Butts *et al*., 2022; Matloob *et al*., 2014). This issue is particularly pronounced in regions heavily reliant on chemical controls, where intensive herbicide use has driven the selection for resistant weed populations and altered weed community structures (Kumar *et al*., 2021). Therefore, a comprehensive integrated weed management strategy, incorporating cultural, mechanical, and chemical methods, is crucial for sustainable rice production (Ali *et al*., 2024). Such an integrated approach optimizes control efficacy, minimizes environmental impact, and mitigates the development of herbicide resistance, thereby ensuring long-term agricultural viability (Dhakal and Poudel, 2020; Singh, 2018).

The continuous use of pre-emergence herbicides at high doses can lead to a shift in weed flora and the development of herbicide resistance, necessitating the incorporation of post-emergence herbicides for broader-spectrum control (Rathika *et al*., 2020). This emphasizes the importance of tank-mixing different herbicides to target a wider array of weed species and reduce the selection pressure for resistance (Ashraf *et al*., 2018). Integrated weed management strategies, incorporating both pre-emergence and post-emergence herbicides alongside other control methods, are essential for effective, broad-spectrum weed control in transplanted rice (Ahmed *et al*., 2021; Chaudhary and Dhakal, 2023). Therefore, this experiment was conducted to evaluate how different herbicidal weed control and hand weeding methods affect weed dynamics and yield of transplanted *aman* rice. The study focused on weed composition, density, and dry weight, as well as comparing the efficiency of different control methods on crop growth and yield. The findings aim to support practical and effective weed management strategies for improving rice productivity.

MATERIALS AND METHODS

Experimental Location

The field experiment was carried out at the Agronomy Field Laboratory of Bangladesh Agricultural University, Mymensingh (24.75° N latitude and 90.50° E longitude, 18 m above sea level) from July to November 2022.

Experimental Soil and Climate

The soil of the experimental field belongs to the Old Brahmaputra Alluvium under AEZ-9. The land was medium-high, with a silt loam texture and a pH of 6.8. The area experiences a subtropical climate, characterized by hot, humid, and rainy conditions from April to September, and cooler, drier weather from October to March. Detailed soil physicochemical properties and weather data are presented in Table 1 and Figure 1.

Experimental treatment and design

The experimental treatments included two varieties, viz. BR11 (V_1), BRRI dhan49 (V_2) and six herbicidal weed control methods viz. control (T_1), hand weeding at 25DAT (T_2), application pre-emergence herbicide (Superhit 500 EC) (T_3), application pre-emergence herbicide with one hand weeding at 35 DAT (T_4), application post emergence herbicide (Livina 18 WP) (T_5), application post emergence herbicide with one hand weeding at 35 DAT (T_6). The trial followed the RCBD method and was replicated thrice. 36 plots in all, each measuring 2.5 m by 2.0 m and spaced 0.5 m within units and 1.0 m between blocks, were set up in a 2 × 6 × 3 configuration. The treatments were randomly allocated to each plot.

Crop Husbandry

Rice seeds were collected from the Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur. The land was prepared with two power-tiller ploughings 15 days before transplanting, followed by additional plowing, cross-plowing, and ladder leveling. Experimental plots were then laid out according to the design and treatments. Recommended fertilizers: urea (150 kg ha^{-1}), TSP (100 kg ha^{-1}), MoP, gypsum (70 kg ha^{-1}), and zinc sulfate (10 kg ha^{-1}) were applied, with TSP, MoP, and gypsum incorporated during final land preparation. Urea was applied in three splits at 15, 30, and 45 DAT. Sprouted seeds were sown on July 1, 2022, in a well-prepared seedbed. Thirty-one-day-old seedlings were transplanted on August 1, 2022, using two seedlings per hill in well-puddled soil. Intercultural operations such as gap filling, weeding, irrigation, and drainage were carried out as needed to ensure normal crop growth. Missing hills were replanted within seven days. Pest infestation was minimal; however, Basudin

Table 1. Physiochemical composition of the initial soil (0-15 cm depth) at the research area

Physical properties		Chemical composition	
Constituents	Results	Constituents	Results
Particle size analysis	2.57	Soil pH	6.8
Bulk density (g/ce)	1.42	Organic matter (%)	1.30
Porosity (%)	44.7	Total nitrogen (%)	0.101
Sand (%) (0.0-0.02 mm)	21.75	Available phosphorus (ppm)	27
Silt (1%) (0.02-0.002 mm)	66.60	Exchangeable potassium (me%)	0.12
Soil textural class	Silt loam		

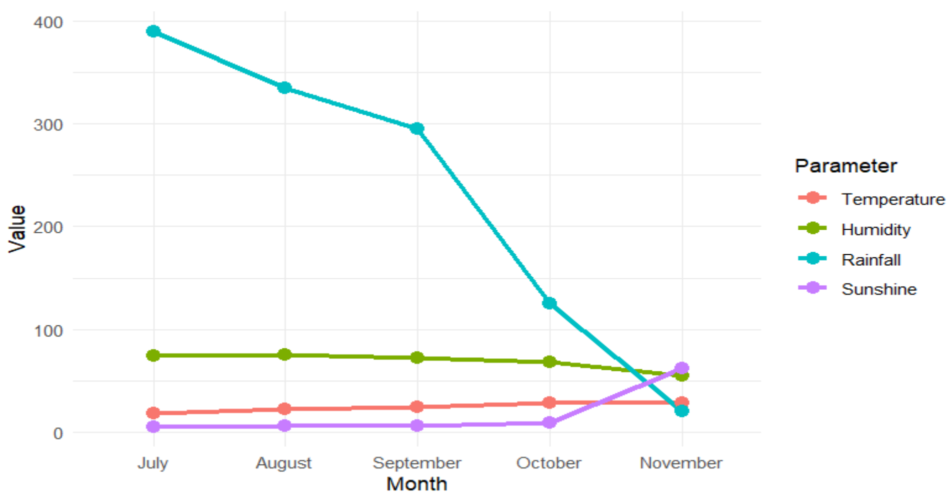

Figure 1. Monthly average temperature (°C), humidity (%), rainfall(mm) and sunshine (hrs) during July to November 2022.

was applied at 17 kg ha^{-1} during the tillering stage, and Diazinon 60 EC at 850 ml ha^{-1} to control rice bugs and stem borers. The crop was harvested on November 15, 2022, when about 90% of the grains turned golden yellow. Plants from each plot were harvested, bundled, tagged, and sun-dried to constant weight before recording grain and straw yields.

Collection and Calculation of Data

Weed data were recorded at 50 DAT using two 1 m^2 quadrats per plot, leaving the central area untouched for yield measurement. Weeds inside each quadrat were identified, counted, and expressed per m^2. They were then uprooted, cleaned, sun-dried, oven-dried at 60°C for 72 hours, and weighed to determine dry biomass (g m^{-2}). Data on rice growth (plant height, number of total tillers $hill^{-1}$, number of effective tillers $hill^{-1}$, number of non-effective tillers $hill^{-1}$), yield, and yield components (grains $panicle^{-1}$, sterile spikelets $panicle^{-1}$, grain yield, straw yield, biological yield, harvest index) were collected from sample plots. Yield-related data were recorded from randomly selected plants in each plot. The following formula calculates harvest index:

Harvest index = Grain yield/ Biological yield× 100

Statistical analysis

The analysis of variance (ANOVA) technique was used to examine all of the data that was gathered, and Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984) was used to determine the mean differences using MSTAT-C and R.

RESULTS AND DISCUSSION

Infested Weed Species

Weed density and dry weight

Effect of variety

The total number of weeds varied significantly due to varietal treatments (Table 3). It was observed that the total number of weeds (19.54) was higher in V_2 at 50 DAT. However, the total number of weeds (14.58) was lower in V_1 at 50 DAT. The maximum dry weight (3.49 g m^{-2}) was found in V_2, while the minimum (2.99 g m^{-2}) was in V_1.

Effect of herbicidal weed control method

The total number of weeds varied significantly due to various weed control treatments. The highest number of weeds (30.56) was recorded in T_1 (No Weeding), and the lowest number of weeds (5.513) was recorded in T_4 (Table 4). The total number of weeds was highest in unweeded treatments, and the lowest weed population was recorded in pre-emergence herbicide with one hand weeding treatment. There was a significant effect of weeding treatment on total weed dry weight (g m^{-2}) at 50 DAT. At 50 DAT, the highest weed dry weight (5.06 gm^{-2}) was observed in the T_1 (no weeding) treatment. The lowest dry weight (1.12 g m^{-2}) was observed in the T_4 (Application of pre-emergence herbicide with 1 hand weeding at 35 DAT) treatment.

Interaction effect of variety and herbicidal weed control method

The interaction effect of variety and weed control treatments had a significant effect on the total number

Table 2. Weed species found in the experimental plots in transplanted *aman* rice

SL	Local Name	Scientific Name	Family	Lifecycle	Type
01	Jhilmorich	*Sphenoclea zeylanica*	Sphenocleaceae	Annual	Broad leaf
02	Keshuti	*Eclipta alba*	Asteraceae	Annual	Broad leaf
03	Panilong	*Ludwigia octovalvis*	Onagraceae	Annual	Broad leaf
05	Jaina	*Fimbristylis miliacea*	Cyperaceae	Annual	Sedge
06	Holde Mutha	*Cyperus difformis*	Cyperaceae	Perennial	Sedge
07	Pani Kachu	*Monochoria vaginalis*	Pontederiaceae	Perennial	Broad leaf
08	Chechra	*Scirpus maritimus*	Cyperaceae	Perennial	Sedge
04	Khude Shama	*Echinochloa colona*	Poaceae	Annual	Grass
09	Shama	*Echinochloa crussgalli*	Poaceae	Annual	Grass
10	Kakpaya	*Dactyloctenium aegyptium*	Poaceae	Annual	Grass
11	Angata	*Paspalum scrobiculatum*	Poaceae	Perennial	Grass
12	Arail	*Leersia hexandra*	Poaceae	Perennial	Grass

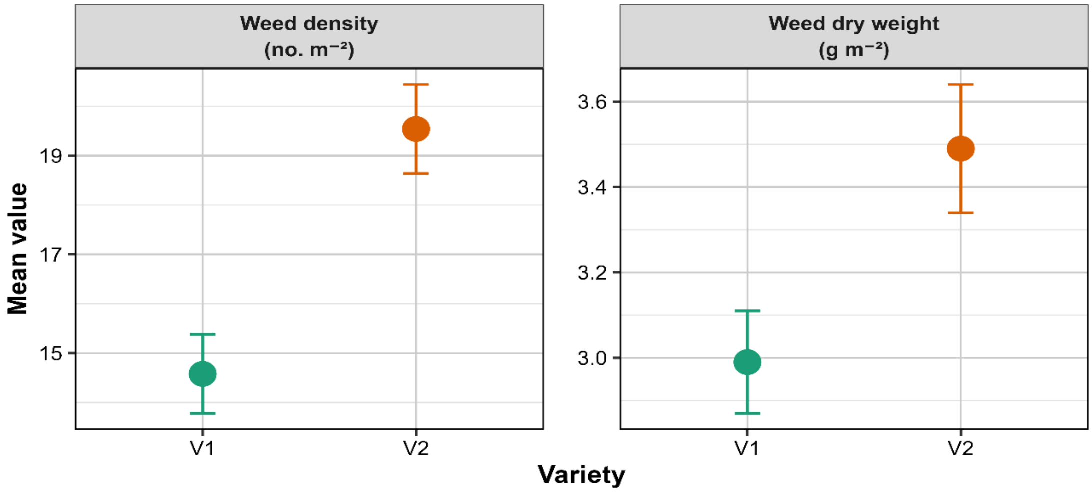

Figure 2. Effect of variety on weed density and weed dry weight of T. aman rice. V1 = BR11, V2 = BRRI dhan49

Table 3. Effect of variety on weed density and weed dry weight

Variety	Weed density (no. m^{-2})	Weed dry weight (g m^{-2})
BR11	14.58b	2.99
BRRI dhan49	19.54a	3.49
$S\bar{x}$	0.96	0.36
Level of significance	**	NS
CV (%)	16.85	32.94

** = Significant at 1% level of probability, NS = Not significant

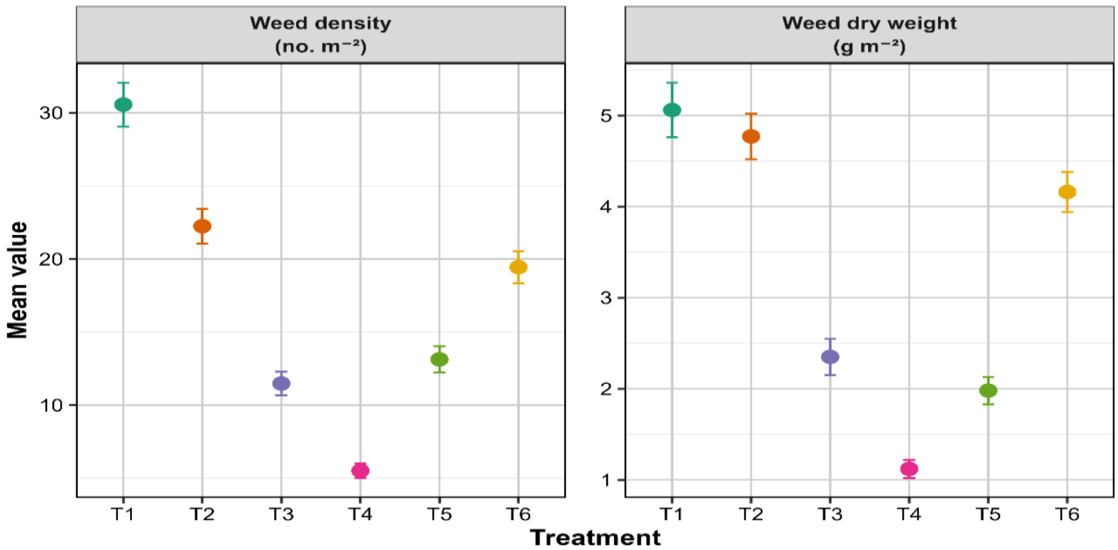

Figure 3. Effect of different treatments on weed density and weed dry weight. Where, T_1 = No weeding, T_2 = Hand weeding at 25 DAT, T_3 = Application of pre-emergence herbicide (Superhit 500 EC), T_4 = Application of pre-emergence herbicide with 1 hand weeding at 35 DAT, T_5 = Application of post-emergence herbicide (Livina 18 WP), T_6 = Application of post-emergence herbicide with 1 hand weeding at 35 DAT

Table 4. Effect of herbicidal weed control method on weed density and weed dry weight of T. *aman* rice

Herbicidal weed control method	Weed density (no. m^{-2})	Weed dry weight (g m^{-2})
T_1	30.56a	5.06a
T_2	22.24b	4.77a
T_3	11.48 c	2.35 bc
T_4	5.513 d	1.12 c
T_5	13.13 c	1.98 c
T_6	19.44b	4.16ab
$S\bar{x}$	1.66	0.62
Level of significance	**	**
CV (%)	16.85	32.94

** = Significant at 1% level of probability. *All other details are as described in Figure 3.*

of weeds in T. *aman* rice fields. It was observed that the treatment combination V_1T_1 (BR11 × No Weeding) resulted in the highest (27.62) total number of weeds, which was statistically similar to V_2T_6 (BRRI dhan49 × Application of post-emergence herbicide with 1 hand weeding at 35 DAT). However, the combination of V_1T_4 (BR11 ×Application of pre-emergence herbicide with 1 hand weeding at 35 DAT) showed the lowest (4.48) total number of weeds, which was statistically similar to V_1T_3 (BR11 × Application of pre-emergence herbicide), V_2T_4 (BRRI dhan49 × Application of pre-emergence herbicide with 1 hand weeding at 35 DAT) (Table 5).

A significant effect was observed on weed dry weight at 50 DAT due to the interaction effect of variety and the herbicidal weed control method. At 50 DAT, the highest weed dry weight (5.38g m^{-2}) was observed in V_2T_1 (BRRI dhan49 × no weeding) treatment, and the

Table 5: Combined effects of variety and herbicidal weed control method on weed density and weed dry weight of T. aman rice

Treatment combination	Weed density (no. m^{-2})	Weed dry weight (g m^{-2})
V_1T_1	27.62 ab	4.74 ab
V_1T_2	20.88 bc	4.66 ab
V_1T_3	9.333 de	2.18 bc
V_1T_4	4.480 e	0.84 c
V_1T_5	12.81 cde	1.93 bc
V_1T_6	12.40 cde	3.60 abc
V_2T_1	33.50 a	5.38 a
V_2T_2	23.61 b	4.88 ab
V_2T_3	13.64 cd	2.52 abc
V_2T_4	6.547 de	1.41 c
V_2T_5	13.45 cd	2.02 bc
V_2T_6	26.48 ab	4.73 ab
$S\bar{x}$	2.35	0.87
Level of significance	**	**
CV (%)	16.85	32.94

All other details are as described in Figures 2 and 3.

lowest weed dry weight (0.84 g m^{-2}) was observed in V_1T_4 (BR11 × Application of pre-emergence herbicide with 1 hand weeding at 35 DAT) treatment (Table 5).

Yield and Yield Contributing Character at Harvest

Effect of variety

Plant height varied significantly due to varietal treatments. The higher plant height (106.91 cm) was observed in V_1, and the lower plant height (99.59 cm) was observed in V_2. The varietal treatment significantly influenced the number of total tillers $hill^{-1}$. The higher number of total tillers $hill^{-1}$ (10.42) was observed in V_1, and the lower number of total tillers $hill^{-1}$ (9.94) was observed in V_2. The varietal treatment significantly influenced the number of effective tillers $hill^{-1}$. The higher number of effective tillers $hill^{-1}$ (9.01) was recorded in V_1, and the lower number of effective tillers $hill^{-1}$ (8.7) was recorded in V_2. The number of non-effective tillers $hill^{-1}$ was not significantly influenced by variety (Table 6).

The varietal treatment significantly influenced the number of grains $panicle^{-1}$. The higher number of grains $panicle^{-1}$ (107.27) was observed in V_1, and the lower number of grains $panicle^{-1}$ (90.61) was observed in V_2. The varietal treatment significantly influenced the number of sterile spikelets $panicle^{-1}$. The higher number of sterile spikelets $panicle^{-1}$ (15.22) was observed in V_1. The lower number of sterile spikelets $panicle^{-1}$ (8.77) was observed in V_2 (Table 6). The varietal treatment significantly influenced the weight of 1000 grains. The higher weight of 1000 grains (26.27 gm) were observed in V_1, and the lower weight of 1000 grains (19.62 gm) was observed in V_2. The varietal treatment significantly influenced the grain yield. The higher (5.65 t ha^{-1}) grain weight obtained from V_1 was mainly due to the favorable effect of the highest number of grains $panicle^{-1}$ (107.27) and other yield attributes, and the lower (5.22 t ha^{-1}) grain weight obtained from V_2. This difference was observed due to different rice plant cultivar characteristics. The varietal treatment significantly influenced the straw yield. The higher (7.45 t ha^{-1}) straw yield was observed in V_1, and the lower (6.63 t ha^{-1}) straw yield was observed in V_2. The varietal treatments significantly influenced the biological yield. The higher (13.11 t ha^{-1}) biological yield was observed in V_1, and the lower (11.86 t ha^{-1}) yield was observed in V_2. The varietal treatment significantly influenced the harvest index. The higher (45.06%) harvest index was observed in V_1,

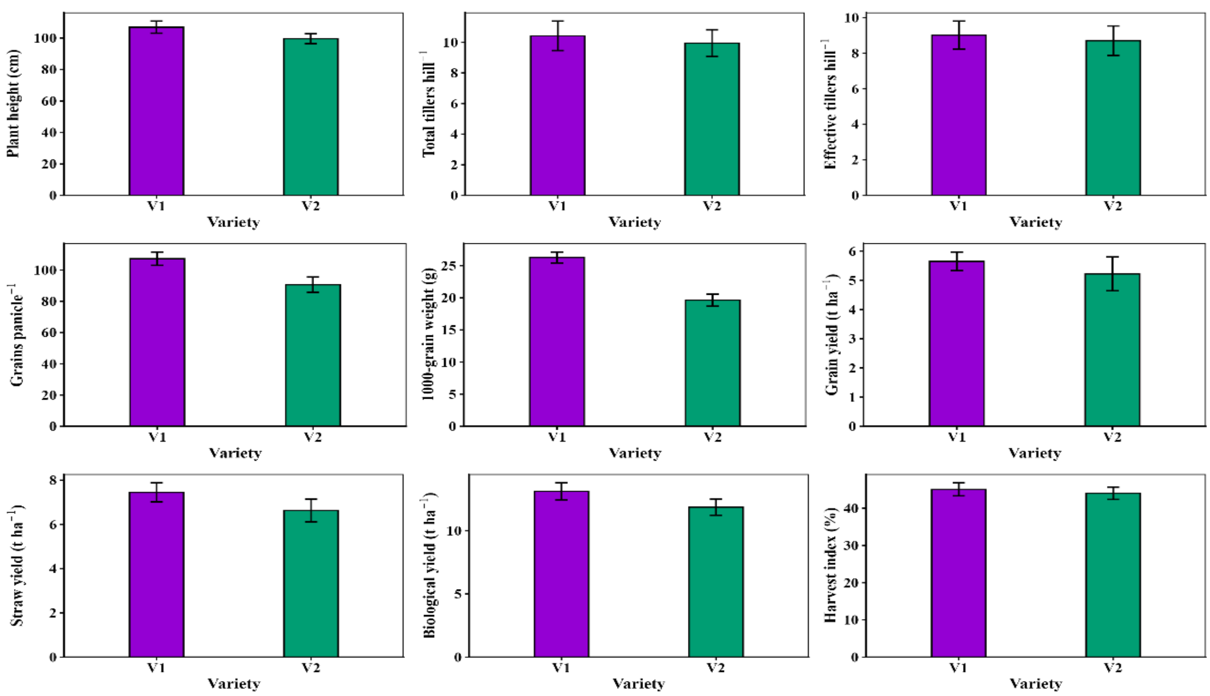

Figure 5. Effect of variety on yield and yield-contributing characters of T. aman rice at harvest. All other details are as described in Figure 2.

and the lower (44.02%) harvest index was observed in V_2.

Effect of herbicidal weed control method

Plant height was significantly influenced by different weed control methods. It was observed that T_2 treatment produced the tallest plant (104.22 cm), which was statistically identical to T_5 and T_6. The lowest plant height (101.34 cm) was observed in T_1. Among the different weed control methods, the highest number of total tillers hill^{-1} (11.4) was observed in T_4, which was statistically similar to T_3. The T_1 treatment gave the lowest number of total tillers hill^{-1} (8.83). No weeding treatment failed to produce more tillers due to severe weed infestation in the experimental plots. The highest (9.72) number of effective tillers hill^{-1} was obtained in T_4 treatment, which was statistically similar to T_3, and T_1 treatment produced the lowest (8.22) number of effective tillers hill^{-1}. The highest number of non-effective tillers (1.72) was obtained by the treatment, which was statistically similar to T_2 and T_3, and the lowest number of non-effective tillers (0.61) was obtained from the T_1 treatment (Table 7). The highest number of grains panicle^{-1} (105.91) was obtained in the T_4 treatment, which was statistically similar to T_2, and the lowest number of grains panicle^{-1} (92.87) was observed in the T_1 treatment. The highest number of sterile spikelets panicle^{-1} (12.73) was obtained from the T_2 treatment. The lowest number of sterile spikelets panicle^{-1} (11.19) was observed in the T_6 treatment (Table 7). The 1000-grain weight was highest (23.1 g) in the T_4 treatment and lowest (22.72 g) in the T_6 treatment. The highest (5.88 t ha^{-1}) grain yield was obtained from the treatment, which was statistically similar to T_6. The lowest (4.88 t ha^{-1}) grain yield was obtained from the T_1 treatment. The highest (8.25 t ha^{-1}) straw yield was obtained from the T_4 treatment. Significantly, the lowest straw yield (6.22 t ha^{-1}) was obtained from the T_1 treatment. Straw yield increased with weed-free conditions, as weed-free conditions increased plant growth. The highest (14.13 t ha^{-1}) biological yield was observed in the T_4 treatment. The T_1 treatment produced the lowest (11.11 t ha^{-1}). The highest (47.45%) harvest index was observed in the T_1 treatment. The lowest harvest index (41.45%) was observed in treatment T_4.

Interaction effect of variety and herbicidal weed control method

The highest plant height (108.33cm) was observed in the V_1T_6 treatment, which was significantly similar to V_1T_1, V_1T_2, V_1T_3, and V_1T_5. The lowest plant height (95.67) was observed in the V_2T_1 treatment. The highest number of total tillers hill^{-1} (11.7) was observed in V_1T_4, and the lowest number of total tillers hill^{-1} (8.66) was observed in V_2T_1. The highest number of effective tillers hill^{-1} (9.99)

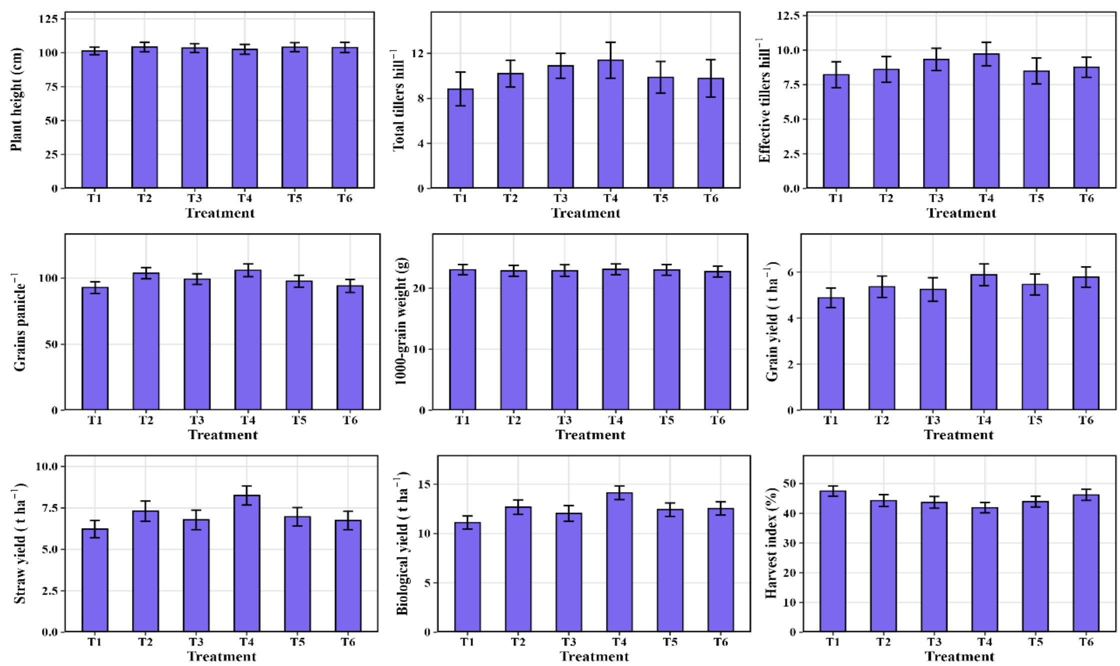

Figure 6. Effect of herbicidal weed control method on yield and yield-contributing characters of T. aman rice at harvest. All other details are as described in Figure 3.

Table 6: Effect of variety on yield and yield-contributing characters of *T. aman* rice at harvest.

Variety	Plant height (cm)	Total tillers hill^{-1} (no.)	Effective tillers hill^{-1} (no.)	Non-effective tillers hill^{-1} (no.)	Grains panicle^{-1} (no.)	Sterile spikelets panicle^{-1} (no.)	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
BR11	106.91a	10.42a	9.01a	1.4	107.27a	15.22a	26.27a	5.65a	7.45a	13.11a	45.06a
BRRI dhan49	99.59b	9.944 b	8.70b	1.24	90.61 b	8.77b	19.62b	5.22 b	6.63 b	11.86 b	44.02 b
Sx	0.61	0.23	0.15	0.25	0.73	0.26	0.1	0.07	0.06	0.09	0.29
Level of significance	**	*	*	NS	**	**	**	**	**	**	**
CV (%)	1.78	6.68	5.1	55.73	2.22	6.47	1.26	3.84	2.85	2.18	1.98

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant

Table 7: Effect of herbicidal weed control method on yield and yield contributing characters of *T. aman* rice at harvest.

Herbicidal weed control method	Plant height (cm)	Total tillers hill^{-1} (no.)	Effective tillers hill^{-1} (no.)	Non-effective tillers hill^{-1} (no.)	Grains panicle^{-1} (no.)	Sterile spikelets panicle^{-1} (no.)	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
T_1	101.34 b	8.83 d	8.22 c	0.61 b	92.87 c	11.66 bc	23.05ab	4.88 c	6.22 d	11.11 d	47.45a
T_2	104.22a	10.2 bc	8.61 bc	1.61a	103.76a	12.73a	22.86ab	5.36 b	7.30 b	12.67 b	44.24c
T_3	103.50ab	10.9ab	9.33a	1.61a	99.29 b	12.28ab	22.89ab	5.25 b	6.78 c	12.04 c	43.64c
T_4	102.50ab	11.4a	9.72a	1.72a	105.91a	12.18ab	23.10a	5.88a	8.25a	14.13a	41.85d
T_5	104.06a	9.88 c	8.49 bc	1.38ab	97.69b	11.91abc	23.01ab	5.46 b	6.96 c	12.42 b	43.91c
T_6	103.89a	9.77 c	8.77 b	0.99ab	94.11c	11.19 c	22.72 b	5.78a	6.74 c	12.53 b	46.15b
Sx	1.06	0.39	0.26	0.43	1.27	0.45	0.17	0.12	0.11	0.16	0.51
Level of significance	**	**	**	**	**	*	**	**	**	**	**
CV (%)	1.78	6.68	5.10	55.73	2.22	6.47	1.26	3.84	2.85	2.18	1.98

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant. All other details are as described in Figure 3 was recorded in V_1T_4, which was statistically identical to V_1T_3, and the lowest number of effective tillers hill^{-1} (7.88) was recorded in V_2T_1. The highest number of non-effective tillers hill^{-1} (2.22) was observed in V_1T_5. The lowest number of non-effective tillers hill^{-1} (0.44) was observed in V_1T_1 (Table 8). The highest number of grains panicle^{-1} (115.07) was observed in the V_1T_2 treatment, which was statistically similar to V_1T_4. The lowest number of grains panicle^{-1} (85.32) was observed in the V_2T_1 treatment, which was statistically similar to V_2T_3 and V_2T_6. The highest number of sterile spikelets panicle^{-1} (17.13) was observed in V_1T_2. The lowest number of sterile spikelets panicle^{-1} (8.33) was observed in the V_2T_2 treatment (Table 8). The highest weight of 1000 grains (26.42 gm) were observed in the V_1T_5 (BR11 × Application of post-emergence herbicide Livina 18 WP) treatment. The lowest weight of 1000 grains (19.42 g) was observed in V_2T_6 treatment.

The highest grain weight (6.19 t ha^{-1}) was observed in V_1T_4. The lowest grain weight (4.77 t ha^{-1}) was observed in V_2T_1 (BRRI dhan49 × No weeding), which was statistically similar to V_1T_1 and V_2T_5. The interaction of variety and different weed control methods had a significant influence on straw yield. The highest straw yield (9.43 t ha^{-1}) was observed in V_1T_4. The lowest straw yield (5.98 t ha^{-1}) was observed in V_2T_1. The interaction of variety and different weed control methods had a significant influence on biological yield. The highest (15.62 t ha^{-1}) biological yield was observed in V_1T_4, and the lowest (10.75 t ha^{-1}) biological yield was observed in V_2T_1. The interaction of variety and different weed control methods had a significant influence on harvest index. The highest harvest index (50.54%) was observed in V_1T_1, and the lowest harvest index (39.64%) was observed in V_1T_4.

PCA, Heatmap and Correlation analysis

The PCA biplot (Figure 7) explained 78.5% of total variation (Dim1 = 56.1%, Dim2 = 22.4%), clearly separating weed management treatments and their effects. Treatments under no weeding (T_1) clustered with higher weed density (WD) and weed dry weight (WDW), indicating strong weed pressure. In contrast, integrated approaches, especially pre-emergence herbicide combined with hand weeding (T_4) and post-emergence herbicide plus hand weeding (T_6), were positioned opposite weed traits and aligned with yield-related variables (GY, BY, SY), suggesting better crop performance. T_3 and T_5 showed moderate effects, lying between extremes. The strong vector alignment of yield traits confirms their positive association. Overall, integrated weed management significantly improves productivity by effectively suppressing weeds.

The correlation matrix reveals clear agronomic patterns among weed traits and yield components (Figure 8). Weed density (WD) and weed dry weight (WDW) show a strong positive association, indicating consistent weed pressure buildup. Both WD and WDW are negatively correlated with key productivity traits (TT, ET, GY, SY, BY), confirming that higher weed burden suppresses crop performance. Growth parameters such as GP, PH, and SSP exhibit strong positive interrelationships and are positively linked with yield traits, suggesting their combined contribution to productivity. Notably, TT and ET show significant positive correlations with grain and biological yield, highlighting their importance in yield formation. Overall, effective weed management treatments (e.g., integrated herbicide + hand weeding) likely enhance growth traits, thereby improving yield outcomes.

The clustered heatmap highlights distinct treatment-driven patterns in weed suppression and crop performance (Figure 9). Treatments combining herbicides with hand weeding (T_4 and T_6) group closely and show strong positive associations (green) with growth and yield traits (GP, PH, TGW, GY, SY, BY), indicating superior crop performance. In contrast, the no-weeding treatment (T_1) clusters separately and is strongly associated with higher weed density (WD) and weed dry weight (WDW), while showing negative relationships with yield attributes. Sole herbicide applications (T_3 and T_5) are moderately effective but remain inferior to integrated approaches. The clustering pattern clearly demonstrates that integrated weed management enhances yield-linked traits while minimizing weed pressure, supporting its adoption for sustainable productivity improvement.

This study clearly demonstrates that weed management practices and rice variety choices are pivotal in determining weed populations and yield outcomes in transplanted *aman* rice. The markedly higher weed density and dry biomass in the no-weeding treatment highlight the intense competitive effects from a wide range of weed species in rice fields. This intense competition for resources light, water, and nutrients directly translates into reduced growth and development for the rice crop, ultimately leading to significant yield

Table 8: Combined effects of variety and herbicidal weed control method on yield and yield contributing characters of T. *aman* rice

Interaction	Plant height (cm)	Total tillers $hill^{-1}$ (no.)	Effective tillers $hill^{-1}$ (no.)	Non-effective tillers $hill^{-1}$ (no.)	Grains $panicle^{-1}$ (no.)	Sterile spikelets $panicle^{-1}$ (no.)	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
V_1T_1	107.00a	9.00 ef	8.55 def	0.44 c	100.43d	14.45bc	26.35a	5.00 fg	6.47f	11.47g	50.54a
V_1T_2	108.11a	10.6abc	9.00 bcd	1.66abc	115.07a	17.13a	26.27a	5.57 cd	7.75b	13.32b	45.58bcd
V_1T_3	107.67a	11.2ab	9.66ab	1.55abc	109.98b	15.56b	26.20a	5.29 def	6.97cd	12.27de	43.16f
V_1T_4	103.44b	11.7a	9.99a	1.77ab	111.45ab	15.26bc	26.31a	6.19a	9.43a	15.62a	39.64g
V_1T_5	106.89a	10.4 bcd	8.22 ef	2.22a	104.48c	14.96bc	26.42a	5.80 bc	7.15c	12.95bc	44.76cde
V_1T_6	108.33a	9.44 def	8.66 de	0.77 bc	102.20cd	13.96c	26.02a	6.07ab	6.94cd	13.02bc	46.64b
V_2T_1	95.67d	8.66 f	7.88 f	0.77 bc	85.32g	8.86d	19.76b	4.77 g	5.98g	10.75h	44.37cdef
V_2T_2	100.33c	9.77 cdef	8.22 ef	1.55abc	92.45e	8.33d	19.44b	5.15 ef	6.86cde	12.02ef	42.89f
V_2T_3	99.33c	10.6abc	9.00 bcd	1.66abc	88.60fg	9.00d	19.58b	5.21 ef	6.60ef	11.81fg	44.12def
V_2T_4	101.56bc	11.1ab	9.44abc	1.66abc	100.37d	9.10d	19.88b	5.57 cd	7.07cd	12.64cd	44.05ef
V_2T_5	101.22bc	9.33 def	8.77 cde	0.55 bc	90.89ef	8.87d	19.60b	5.12 fg	6.77def	11.89efg	43.05f
V_2T_6	99.44c	10.1 bcde	8.88 cde	1.22abc	86.02g	8.42d	19.42b	5.50 cde	6.54ef	12.04ef	45.66bc
Sx	1.5	0.56	0.37	0.6	1.79	0.63	0.24	0.16	0.16	0.22	0.72
Level of significance	**	**	**	**	**	**	**	**	**	**	**
CV (%)	1.78	6.68	5.1	55.73	2.22	6.47	1.26	3.84	2.85	2.18	1.98

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant. All other details are as described in Figures 2 and 3

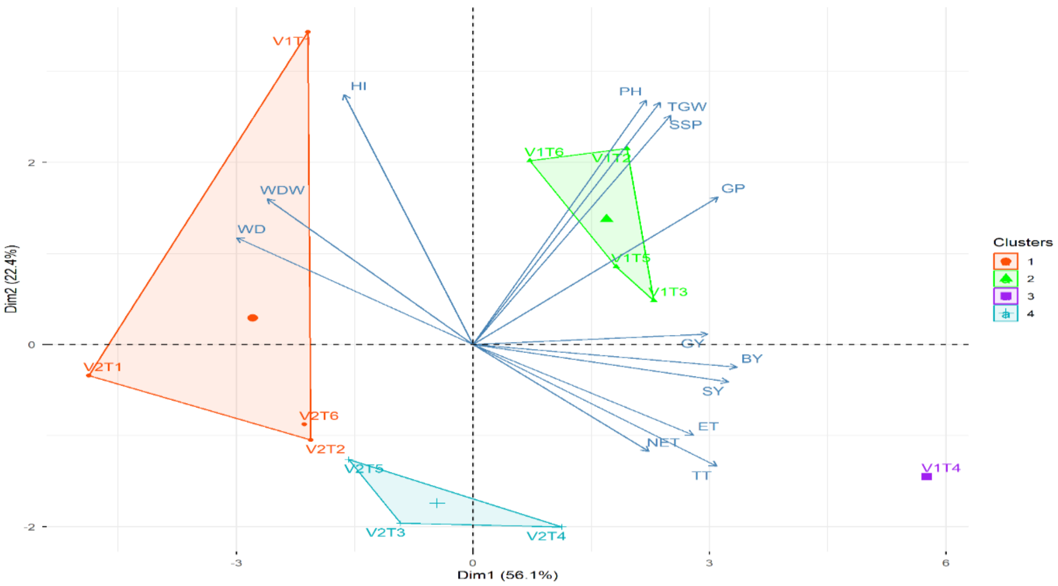

Figure 7. Principal Component Analysis illustrating the combined influence of rice variety and herbicide-based weed management on weed dynamics and yield-attributing traits in T. *aman* rice.

Where, WD=Weed density, WDW= Weed dr weight, PH= Plant height, TT=Total tiller, ET= Effective tiller, NET= Noneffective tiller, GP= Grain panicle^{-1}, SSP= Sterile spikelet panicle^{-1}, TGW= 1000 grain wight, GY= Grain yield, SY= Straw yield, BY= Biological yield, HI= Harvest index. All other details are as described in Figures 2 and 3.

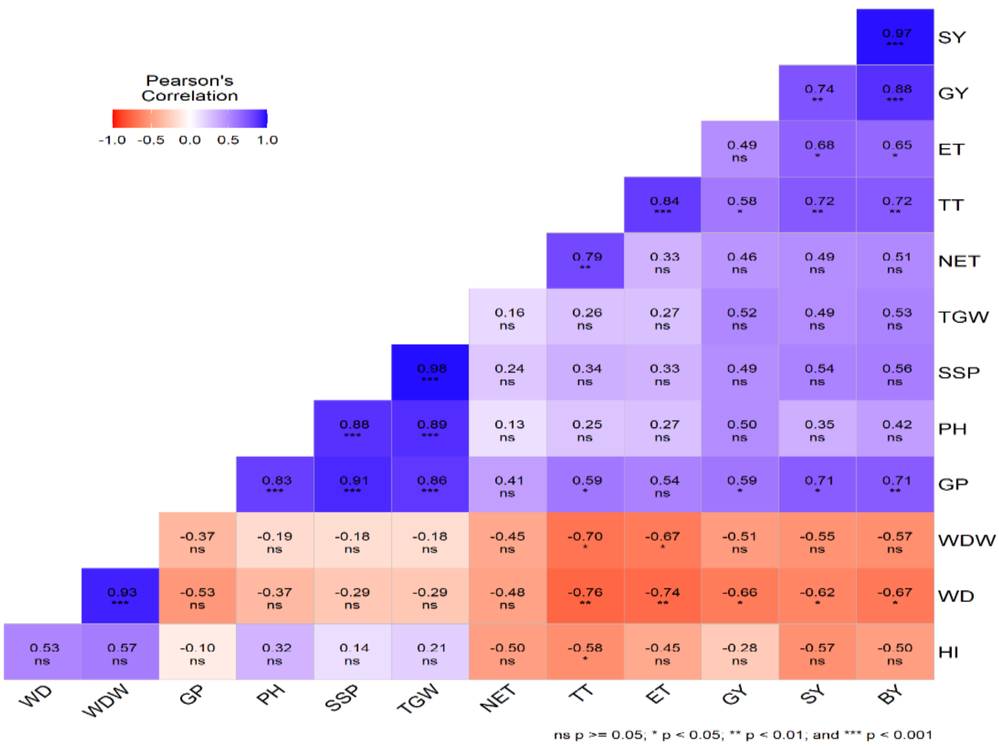

Figure 8. Correlation matrix depicting relationships among weed parameters and yield-contributing traits under different varietal and herbicidal weed control treatments in T. *aman* rice.

All other details are as described in Figures 2, 3 and 7.

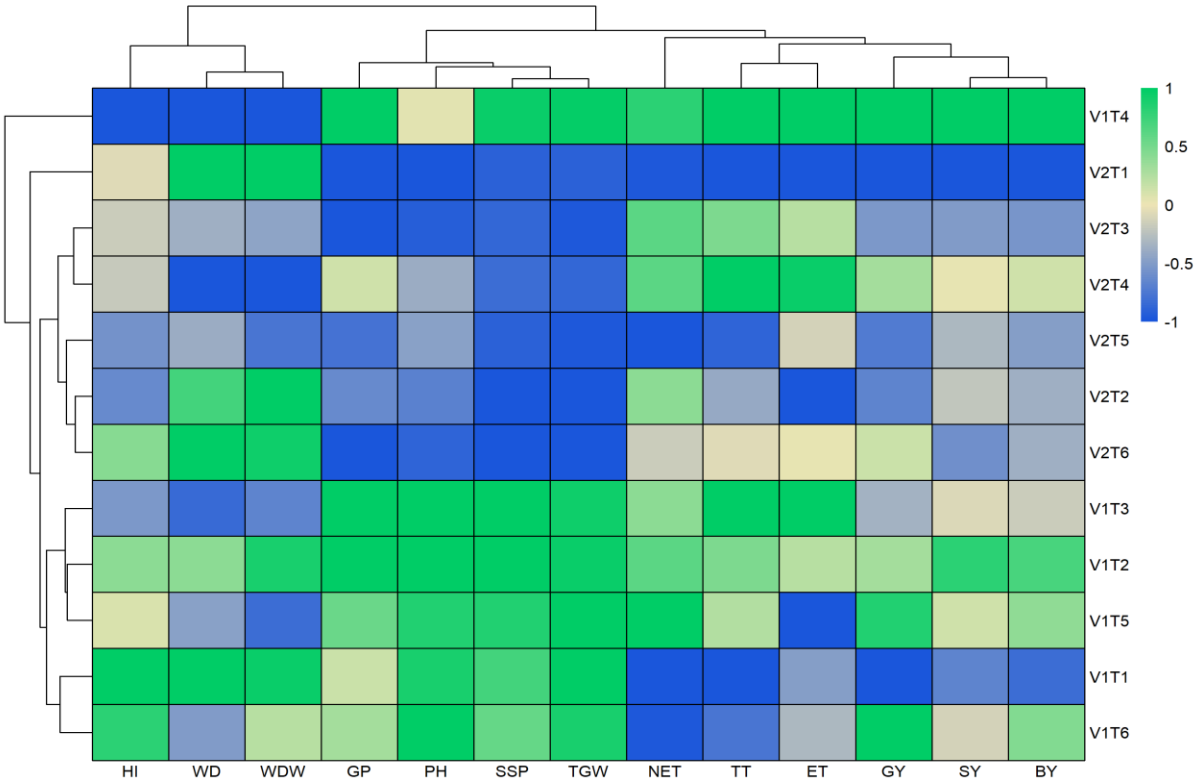

Figure 9. Heatmap visualization of treatment-wise interactions between rice varieties and herbicide strategies affecting weed dynamics and yield-related attributes in T. *aman* rice.

All other details are as described in Figures 2, 3 and 7.

penalties (Verma *et al*., 2023). Among the weed control strategies tested, the integrated approach combining pre-emergence herbicide with hand weeding was most effective at reducing weed density and biomass. This efficacy is attributed to the herbicide's initial suppression of weed germination and early growth, complemented by hand weeding that addresses escaped weeds and later-emerging flushes, thereby minimizing competition throughout critical growth stages (Roy *et al*., 2017). In particular, treatments combining pre-emergence herbicide application with hand weeding, such as pretilachlor followed by one manual weeding, consistently produced the highest grain, straw, and biological yields while minimizing weed biomass, in direct contrast to unweeded controls that exhibited the lowest productivity across these parameters (Shahabuddin *et al*., 2016).

Although sole herbicide applications exhibited moderate efficacy in weed suppression, they proved inadequate for providing season-long control, resulting in elevated weed densities and diminished yields relative to integrated management approaches. This outcome suggests that while herbicides offer an initial advantage, the prolonged weed-free period critical for optimal rice development necessitates a multifaceted strategy (Sahu *et al*., 2020). This integrated strategy optimizes resource allocation for the rice crop, leading to enhanced physiological processes and ultimately greater yield potential (Arthanari, 2023; Popy *et al*., 2017). This finding corroborates previous research indicating that a single herbicide application often falls short in fully managing weed infestations throughout the entire cropping cycle, underscoring the need for supplemental control measures (Akter *et al*., 2020; Parthipan and Ravi, 2014).

Significant varietal differences influenced weed infestation and yield performance. Compared to BRRI dhan49, BR11 exhibited lower weed density and superior yields, owing to its enhanced competitive ability, taller stature, and greater tillering. BR11's higher yields stemmed primarily from increased grains per panicle and elevated 1000-grain weight, highlighting its strong genetic potential under effective weed management. These findings are consistent with earlier reports demonstrating that cultivar selection significantly modulates crop-weed interference and yield stability in varied agricultural contexts (Afroz *et al*., 2019; Hossen, 2020). Significant variety × weed management interactions were observed. BR11 with integrated control (T_4) produced the highest grain yield (6.19 t ha^{-1}) from the V_1T_4 interaction, reflecting strong synergy that minimized weed competition and maximized yield traits. In contrast, BRRI dhan49 without weeding (V_2T_1) gave the lowest yield, due to poor competitive ability against weeds. This synergistic effect underscores the importance of matching appropriate weed management practices with high-performing cultivars to optimize agricultural productivity and resource use efficiency (Ferdous *et al*., 2016). This observation underscores the necessity of considering genotypic traits in conjunction with specific weed control interventions to achieve maximal agronomic benefits.

Multivariate analyses demonstrated that elevated weed density and dry weight markedly suppress yield, whereas enhanced crop growth traits boost productivity (Acharya *et al*., 2026). The clustering patterns validated that integrated treatments excel in weed suppression and overall crop performance enhancement. Specifically, treatments combining pre-emergence herbicides with subsequent mechanical or manual weeding consistently exhibited superior yield parameters, which is congruent with findings from similar studies (Dolie *et al*., 2023; Negalur and Halepyati, 2016). This is further supported by observations that integrated approaches incorporating both pre-emergence and post-emergence herbicides, especially when supplemented with hand-weeding, achieve superior broad-spectrum weed control compared to single-application strategies (Verma *et al*., 2025).

The integration of pre-emergence herbicide application and hand weeding, particularly when combined with the BR11 rice variety, substantially improves yield attributes and promotes sustainable weed suppression. This comprehensive approach optimizes resource allocation for the rice crop, leading to enhanced physiological processes and ultimately greater yield potential. Such integrated management practices not only mitigate the immediate impact of weed competition but also contribute to long-term agricultural sustainability by reducing reliance on single-tactic interventions and fostering healthier agroecosystems (Joshi *et al*., 2016).

Conclusion.

The findings demonstrate that effective weed management is essential for sustaining transplanted *aman* rice productivity under field conditions. The treatment T_4 (pre-emergence herbicide + one hand weeding at 35 DAT) was the most effective, producing the highest grain yield (5.88 t ha^{-1}) with the lowest weed density (5.51 m^{-2}). In contrast, T_1 (no weeding) resulted in severe yield loss (4.88 t ha^{-1}) due to intense weed competition. Among varieties, BR11 performed better than BRRI dhan49, and the interaction V_1T_4 (BR11 × T4) achieved the maximum yield (6.19 t ha^{-1}). Therefore, adopting such integrated strategies can enhance yield stability, reduce labor constraints, and support sustainable rice production in Bangladesh and similar agro-ecological regions.

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The authors certify that this manuscript is original and has not been previously published. Appropriate citations have been provided for all referenced works, and the manuscript has been thoroughly checked to ensure the absence of plagiarism.

Consent for Publication:

All authors have reviewed and approved the final version of the manuscript and consent to its publication in this journal.

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Data Availability:

The data supporting the findings of this study are presented within the manuscript and are available in the tables and figures provided.

Author Contributions:

Md. Ariful Islam conducted the experiment, analyzed the data, and prepared the first draft of the manuscript. Md. Shafiqul Islam assisted in the experimental design and supervised the research work. Bejoy Chandra Sarkar and Zeba Humaira contributed to the analysis and interpretation of data, assisted with field data collection, and contributed to the preparation of the manuscript. Mahfuza Begum critically revised the manuscript and approved the final version for publication. All authors reviewed and approved the final manuscript.

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