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Research articles

Research notes

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RESEARCH ARTICLE

Efficacy of a new post-emergent herbicide bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl (pre-mix) in managing mixed weed flora and improving productivity of transplanted rice

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Prevention of weed competition during the critical period of rice necessitates the identification of effective and economic options to manage weeds to enhance the rice productivity. Hence, an experiment was conducted to study the efficacy of a new post-emergent herbicide bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl (pre-mix) in managing mixed weed flora and improving transplanted rice productivity. Ten treatments were evaluated, during the *kharif* seasons of 2019 and 2020, at the Research Farm of Department of Agronomy, Punjab Agricultural University, Ludhiana, using a randomized complete block design replicated thrice. The post-emergence application (PoE) of bispyribac-sodium 38% plus metsulfuron-methyl 2.5% plus chlorimuron-ethyl 2.5% (bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl) (pre-mix) 43 g/ha recorded 42.3% and 19.8%; 63.3% and 56.6% and 75.0% and 83.6% reduction in biomass of grasses, broad-leaved weeds and sedges, at 42 days after application (DAA) during 2019 and 2020, respectively, over control. Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl at 43 g/ha also resulted in 52.8% and 47.0% higher rice grain yield in 2019 and 2020, respectively, over control, there by demonstrating its ability to efficiently control the mixed weed flora and improve the productivity of transplanted rice.

Keywords: Bispyribac-sodium, Chlorimuron-ethyl, Premix herbicide, Metsulfuron-methyl, Transplanted rice, Weed management

INTRODUCTION

Weeds are major contributor to yield loss in rice, along with other biotic and abiotic stresses (Jabran *et al.* 2019). Gharde *et al.* (2018) reported 4420 million USD annual economic losses due to weeds in India. The range of loss in productivity is estimated by the duration and intensity of crop-weed competition (Sardana *et al.* 2017). In Indian rice cultivation, hand weeding twice is commonly practiced, mostly at three and six weeks after transplanting. However, manual weed control is increasingly becoming unaffordable to farmers due to limited labor availability, rising labor costs, the difficulty of distinguishing rice plants from *Echinochloa* spp. during early growth (Rao 2021). To address these challenges, farmers also rely on herbicides for weed management, owing to their effectiveness, affordability and widespread use (Wang *et al.* 2018). Some of the grasses, broad-leaved weeds and sedges are not effectively controlled by application of narrow spectrum herbicides. Premix of herbicides provided broad-spectrum weed control as compared to application of narrow spectrum herbicide (Choudary and Dixit 2024).

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Bispyribac-sodium is a systemic, post-emergent herbicide in the pyrimidinyl oxybenzoic acid group. Bispyribac-sodium translocate within plant tissues and primarily functions by inhibiting acetolactate synthase (ALS), a critical enzyme involved in the biosynthesis of essential branched-chain amino acids necessary for plant growth (Osuna *et al.* 2002). Several studies have confirmed its efficacy in controlling weeds in rice ecosystems, but limited research was done on its performance in combination with other herbicides, particularly in transplanted rice. Another herbicide from the sulfonylurea class, is metsulfuron-methyl, recognized for its ability to manage over 60 weed species, especially effective against broad-leaved weeds in rice fields (Boutin *et al.* 2012). Similarly, chlorimuron-ethyl also a sulfonylurea compound, acts by inhibiting ALS, thereby blocking the biosynthesis of vital amino acids such as valine, leucine, and isoleucine, ultimately causing plant death.

The mixture of bispyribac-sodium, metsulfuron-methyl and chlorimuron-ethyl provides an opportunity to effectively manage diverse weed flora during the critical period of crop-weed competition in transplanted rice with its single application after 15-25 days of transplanting (DAT). The pre-mix formulation of this combination is now available. Hence, this study was conducted with an objective to evaluate the efficacy of a new post-emergent herbicide bispyribac- sodium + metsulfuron- methyl + chlorimuron- ethyl (pre-mix) in managing mixed weed flora and improving transplanted rice productivity in Punjab.

MATERIAL AND METHODS

A field experiment was carried out for two consecutive *Kharif* seasons of 2019 and 2020 at the Research Farm of Department of Agronomy, Punjab Agricultural University (PAU), Ludhiana, Punjab, India. The Ludhiana district of Punjab is located at the central plain zone of northwest India (30°542 N and 75°482 E, 247 m above MSL) and experiences semi-arid, subtropical climate, marked by distinct seasonal variations. The early summer months from March to June are typically hot and dry, followed by a hot and humid monsoon period from July to September. The region then transitions into mild winter during October and November, with the coldest conditions occurring from December to February. Average annual rainfall of Ludhiana district of Punjab is 759 mm, 75-80 percent of which is received during the monsoon period. The soil of experimental field was neutral in pH (7.1-7.4) and electrical conductivity (0.14-0.17 dS/m), low in OC (0.34-0.37%), low in $KMnO_4$-N (233.1-248.2 kg/ha), high in Olsen P (29.8-32.9 kg/ha) and NH_4OAc-K (296-317 kg/ha).

Treatments evaluated include: bispyribac-sodium 38% + metsulfuron-methyl 2.5% + chlorimuron-ethyl 2.5% (hereafter: bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl) (pre-mix) at 34.4, 43 and 51.6 g/ha; penoxsulam 1.02% + cyhalofop 5.1% OD (hereafter: penoxsulam + cyhalofop) at 135 g/ha; bispyribac-sodium 10% SC (hereafter: bispyribac-sodium) at 25 and 38 g/ha, metsulfuron-methyl 10% + chlorimuron 10% WP (hereafter: metsulfuron + chlorimuron) at 4 and 5 g/ha, unsprayed weedy check (control) and hand weeding twice. All the herbicides were sprayed at 15-25 days after transplanting (DAT) except metsulfuron + chlorimuron, which was applied at 7-10 DAT. A battery-operated knapsack sprayer equipped with flat fan nozzle using 375 liters of water/ha was used for herbicides application at 2-5 leaf stage of weeds under sufficient soil moisture conditions. Hand weeding twice was done at 15 and 30 DAT. The experiment was conducted in a randomized complete block design, and replicated thrice.

Rice cv. *PR 126* was transplanted on June 26th, 2019 and June 25th, 2020, at 20 cm row spacing and 15 cm plant spacing using 20 kg/ha of seed rate for nursery sowing. Each plot was 5.5 m × 2.7 m, forming 14.85 m^2 area. All recommended cultivation practices were followed to raise the crop, except weed management. The crop was fertilized with 105 kg N, 30 kg P and 30 kg K/ha. Appropriate plant protection practices were implemented to manage insect pests and diseases, ensuring healthy crop growth. The crop was harvested manually on October 24th, 2019 and October 26th, 2020. After harvesting, the crop from each plot was labelled and bundled before threshing. Data on weeds (grasses, broad-leaved weeds and sedge) was recorded species-wise using quadrat (50 cm × 50 cm) randomly placed at two places in each plot at 7, 14, 28 and 42 days after application (DAA) of herbicide. At 42 DAA, weed species, including grasses, broad-leaved weeds, and sedges, were identified, counted, and harvested by cutting at the collar region of the plants. After being collected, each sample was put in brown paper bag and allowed to dry in the sun for 3-5 days. Once surface moisture had evaporated, the bags were transferred to a hot air oven set at 70°C (±2°C) for 72 hours until a constant weight was reached. This final weight was recorded as the weed biomass for each species. For data analysis, weed density (no./m^2) and biomass (g/m^2) were calculated by averaging the values from two quadrats. Weed control efficiency was calculated using the weed biomass recorded in control plot at 42 DAA, using the formula suggested by Mani *et al.* (1973), as shown below:

$$\text{WCE (\%)} = \frac{\text{WDC - WDT}}{\text{WDC}} \times 100$$

where,

WDC - Weed biomass in control plot

WDT - Weed biomass in treated plot

The grain yield was recorded at harvest and adjusted at 14% moisture.

Analysis of variance was performed to assess the efficacy of bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl and other weed control treatments against complex weed flora in transplanted rice. Statistical analysis of the recorded parameters was conducted separately for each year. IBM SPSS Statistics version 19 was used for analysis of variance with weed control considered as fixed effects. To achieve normal distribution, data related to weed density and biomass were transformed $(\sqrt{x+1})$ before analysis. Significant differences among treatment means were identified using Fisher's Least

Significant Difference (LSD) test at a 5% probability level (Cochran and Cox 1957). Figures of weed control efficiency and correlation between weed biomass at 42 DAA and rice grain yield were worked out by using MS Excel. Principal component analysis (PCA) was performed to assess the relationship between weed biomass at 42 DAA and rice grain yield, using OriginPro software (Origin 2024, version 10.1, OriginLab Corporation, USA).

RESULTS AND DISCUSSION

Weed flora

The predominant weed flora in the study area consisted of grasses, *viz. Echinochloa crus-galli* and *Leptochloa chinensis;* the broad-leaved weed *Ammania baccifera* and sedge *Cyperus iria.*

Weed density

All weed control treatments had significant effect on the weed density at 7, 14, 28 and 42 DAA. Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 51.6 g/ha provided effective control of *E. crus-galli, L. chinensis, C. iria* and *A. baccifera* at 7, 14, 28 and 42 DAA. While, penoxsulam + cyhalofop 135 g/ha effectively controlled *E. crus-galli* and *L. chinensis* at 7, 14, 28 and 42 DAA (**Tables 1-4**). During both years of study, penoxsulam + cyhalofop 135 g/ha and bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 51.6 g/ha recorded at par control of *E. crus-galli* at 7, 14, 28 and 42 DAA except in 2019 at 14 DAA. Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 51.6 g/ha resulted in 100.0% and 66.7% at 7 DAA, 86.2% and 73.3% at 14 DAA, 85.7% and 62.5% at 28 DAA and 94.4% and 40.0% at 42 DAA control of *E. crus-galli* during 2019 and 2020, respectively. Moreover, bispyribac-sodium 38 g/ha also resulted statistically at par efficacy as penoxsulam + cyhalofop 135 g/ha and bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 51.6 g/ha for controlling *E. crus-galli* at 7 and 14 DAA in 2020 and at 28 and 42 DAA in 2019. On the other hand, during both years, penoxsulam + cyhalofop at 135 g/ha recorded complete (100%) control of *L. chinensis* up to 42 DAA. Metsulfuron + chlorimuron 4 and 5 g/ha and bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 51.6 g/ha provided effective and statistically similar control of *A. baccifera* and *C. iria* at 7 DAA during both years of study and at 14, 28 and 42 DAA in 2019 only. Further, bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 43-51.6 g/ha provided statistically similar control of *A. baccifera* in 2020 and *C. iria* in 2019 at 7, 14, 28 and 42 DAA. However, hand weeding twice resulted in significant control (100%) of all weed flora at 7, 14, 28 and 42 DAA during both years of study (**Tables 1-4**). The effectiveness of a single herbicide is often limited when used alone. However, a combination of different herbicide chemistries can enhance the spectrum of weed control and provide more comprehensive management without any adverse effects on the crop or environment (Singh *et al.* 2011). Use of metsulfuron-methyl + chlorimuron-ethyl (pre-mix) was effective in controlling a broad spectrum of weeds (Duary *et al.* 2016). Bispyribac-sodium alone was not effective against broad-leaved weeds (Nath *et al.* 2024) and but provided good control of *E. crus-galli*. Thus, the application of pre-mix herbicides could be more effective in lowering the weed competition in rice.

Table 1. Effect of different weed control treatments on weed density (no./m^2) at 7 days after herbicide application (DAA) in transplanted rice during *Kharif* 2019 and 2020

Treatment	Grasses				Broad-leaved weed		Sedge	
	E. crus-galli		*L. chinensis*		*A. baccifera*		*C. iria*	
	2019	2020	2019	2020	2019	2020	2019	2020
Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 34.3 g/ha	2.99(8)	3.87(14)	2.63(6)	3.19(9)	2.87(7)	2.07(3)	1.96(3)	4.65(21)
Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 43 g/ha	2.32(5)	3.40(11)	2.37(5)	3.31(10)	2.73(7)	1.24(0.7)	1.24(0.7)	2.20(4)
Bispyribac-sodium + metsulfuron-ethyl + chlorimuron-ethyl 51.6 g/ha	1.00(0)	2.46(5)	2.44(5)	3.40(11)	1.41(1)	1.24(0.7)	1.00(0)	1.55(2)
Penoxsulam + cyhalofop 135 g/ha	1.00(0)	2.63(6)	1.00(0)	1.00(0)	4.35(18)	1.49(1)	1.00(0)	2.99(8)
Bispyribac-sodium 25 g/ha	2.07(3)	3.50(11)	2.51(5)	3.08(9)	3.21(9)	1.66(2)	2.67(2)	2.85(7)
Bispyribac-sodium 38 g/ha	2.20(4)	2.51(5)	2.37(5)	3.31(10)	2.88(7)	1.66(2)	2.07(3)	2.20(4)
Metsulfuron + chlorimuron-ethyl 4 g/ha	3.31(10)	3.85(14)	2.14(4)	3.87(14)	1.24(0.7)	1.00(0)	1.32(2)	1.00(0)
Metsulfuron + chlorimuron-ethyl 5 g/ha	3.46(11)	3.77(13)	2.07(3)	3.60(12)	1.00(0)	1.00(0)	1.49(1)	1.00(0)
Control	4.35(18)	3.95(15)	2.07(3)	3.69(13)	5.19(26)	2.99(8)	4.49(19)	6.75(45)
Hand weeding	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
LSD (p=0.05)	0.54	0.71	0.44	0.53	0.65	0.59	0.76	0.73

*Figures in parentheses are original means. Data were subjected to a square root transformation

Table 2. Effect of different weed control treatments on weed density (no./m²) at 14 DAA in transplanted rice during *Kharif* 2019 and 2020

Treatment	Grasses				Broad-leaved weed		Sedge	
	E. crus-galli		*L. chinensis*		*A. baccifera*		*C. iria*	
	2019	2020	2019	2020	2019	2020	2019	2020
Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 34.3 g/ha	3.32(10)	4.01(15)	2.99(8)	3.60(12)	2.99(8)	2.20(4)	1.66(2)	4.12(16)
Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 43 g/ha	2.99(8)	3.37(11)	2.83(7)	3.60(12)	2.75(7)	1.48(2)	1.24(0.7)	3.41(11)
Bispyribac-sodium + metsulfuron-ethyl + chlorimuron-ethyl 51.6 g/ha	2.20(4)	2.20(4)	3.08(9)	3.68(13)	1.55(2)	1.24(0.7)	1.00(0)	2.51(5)
Penoxsulam + cyhalofop 135 g/ha	1.24(0.7)	2.37(5)	1.00(0)	1.00(0)	3.77(13)	1.66(2)	1.24(0.7)	2.63(6)
Bispyribac-sodium 25 g/ha	1.90(3)	3.50(11)	3.31(10)	3.60(12)	2.63(6)	2.20(4)	2.51(5)	2.07(3)
Bispyribac-sodium 38 g/ha	1.24(0.7)	2.88(7)	3.08(9)	3.60(12)	1.41(1)	1.41(1)	2.07(3)	1.66(2)
Metsulfuron + chlorimuron-ethyl 4 g/ha	4.03(15)	3.41(11)	3.20(9)	3.60(12)	1.00(0)	1.00(0)	1.55(2)	1.00(0)
Metsulfuron + chlorimuron-ethyl 5 g/ha	3.60(12)	3.85(14)	3.21(9)	3.51(11)	1.00(0)	1.00(0)	1.24(0.7)	1.00(0)
Control	5.45(29)	3.92(15)	3.69(13)	3.96(15)	3.69(13)	3.69(13)	5.13(25)	4.93(23)
Hand weeding	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
LSD (p=0.05)	0.56	0.73	0.66	0.42	0.74	0.64	0.77	0.52

*Figures in parentheses are original means. Data were subjected to a square root transformation; DAA = days after herbicide application

Table 3. Effect of different weed control treatments on weed density (no./m²) at 28 DAA in transplanted rice during *Kharif* 2019 and 2020

Treatment	Grasses				Broad-leaved weed		Sedge	
	E. crus-galli		*L. chinensis*		*A. baccifera*		*C. iria*	
	2019	2020	2019	2020	2019	2020	2019	2020
Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 34.3 g/ha	3.19(9)	4.34(18)	3.31(10)	3.69(13)	3.41(11)	2.32(5)	1.00(0)	4.24(17)
Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 43 g/ha	3.21(9)	3.49(11)	3.41(11)	3.60(12)	2.88(7)	1.49(1)	1.00(0)	2.43(5)
Bispyribac-sodium + metsulfuron-ethyl + chlorimuron-ethyl 51.6 g/ha	1.73(2)	2.63(6)	3.11(9)	3.67(13)	1.67(3)	1.24(0.7)	1.00(0)	1.90(3)
Penoxsulam + cyhalofop 135 g/ha	1.24(0.7)	2.49(5)	1.00(0)	1.00(0)	2.99(8)	1.41(1)	1.66(2)	2.20(4)
Bispyribac-sodium 25 g/ha	1.49(1)	3.41(11)	3.31(10)	4.12(16)	1.80(3)	1.49(1)	1.49(1)	4.19(17)
Bispyribac-sodium 38 g/ha	1.24(0.7)	3.21(9)	3.60(12)	3.95(15)	1.66(2)	1.24(0.7)	1.49(1)	1.90(3)
Metsulfuron + chlorimuron-ethyl 4 g/ha	3.50(11)	3.68(13)	3.31(10)	3.69(13)	1.49(1)	1.00(0)	1.24(0.7)	1.00(0)
Metsulfuron + chlorimuron-ethyl 5 g/ha	3.87(14)	3.85(14)	3.60(12)	3.69(13)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Control	3.87(14)	4.10(16)	3.96(15)	3.87(14)	3.60(12)	3.89(14)	5.25(27)	4.98(24)
Hand weeding	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
LSD (p=0.05)	0.54	0.68	0.41	0.50	0.80	0.64	0.53	0.62

*Figures in parentheses are original means. Data were subjected to square root transformation; DAA = days after herbicide application

Table 4. Effect of different weed control treatments on weed density (no./m²) at 42 DAA in transplanted rice during *Kharif* 2019 and 2020

Treatment	Grasses				Broad-leaved weed		Sedge	
	E. crus-galli		*L. chinensis*		*A. baccifera*		*C. iria*	
	2019	2020	2019	2020	2019	2020	2019	2020
Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 34.3 g/ha	3.02(8)	4.43(19)	3.95(15)	3.87(14)	3.60(12)	2.04(3)	1.66(2)	4.04(15)
Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 43 g/ha	3.01(8)	3.69(13)	3.41(11)	3.87(14)	3.11(9)	1.49(1)	1.24(0.7)	2.49(5)
Bispyribac-sodium + metsulfuron-ethyl + chlorimuron-ethyl 51.6 g/ha	1.49(1)	3.21(9)	3.60(12)	3.51(11)	1.55(2)	1.24(0.7)	1.00(0)	1.66(2)
Penoxsulam + cyhalofop 135 g/ha	1.24(0.7)	2.75(7)	1.00(0)	1.00(0)	2.88(7)	2.20(4)	1.49(1)	2.07(3)
Bispyribac-sodium 25 g/ha	2.37(5)	3.85(14)	3.40(11)	3.61(12)	1.49(1)	2.37(5)	1.49(1)	1.90(3)
Bispyribac-sodium 38 g/ha	1.24(0.7)	3.60(12)	4.12(16)	3.32(10)	1.66(2)	1.41(1)	1.24(0.7)	1.49(1)
Metsulfuron + chlorimuron-ethyl 4 g/ha	3.87(14)	3.95(15)	4.12(16)	3.87(14)	1.79(3)	1.24(0.7)	1.24(0.7)	1.00(0)
Metsulfuron + chlorimuron-ethyl 5 g/ha	4.12(16)	3.20(9)	3.40(11)	3.78(13)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Control	4.34(18)	4.03(15)	3.48(11)	3.85(14)	4.12(16)	3.85(14)	5.19(26)	4.02(15)
Hand weeding	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
LSD (p=0.05)	0.67	0.51	0.46	0.38	0.83	0.72	0.59	0.57

*Figures in parentheses are original means. Data were subjected to square root transformation; DAA = days after herbicide application

Weed biomass and weed control efficiency

Hand weeding twice resulted in complete control of all weeds up to 42 DAA. All herbicidal treatments recorded significantly lower grasses, broad-leaved weeds and sedge biomass and higher weed control efficiency than control in both years. At 42 DAA, bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 51.6 g/ha recorded *E. crus-galli* biomass reduction of 84.1% in 2019 and 82.1% in 2020, over control plot and was statistically similar with penoxsulam + cyhalofop 135 g/ha. Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 51.6 g/ha provided higher weed control efficiency in case of *E. crus-galli* (84.1% in 2019 and 82.1% in 2020) and *A. baccifera* (100% in 2019 and 88.5% in 2020) at 42 DAA. However, during both years of study, penoxsulam + cyhalofop 135 g/ha recorded complete (100%) reduction of biomass and 100% weed control efficiency of *L. chinensis* and was proved superior to all other herbicidal treatments. During both years of study, metsulfuron + chlorimuron at 4 and 5 g/ha recorded statistically similar and lower weed biomass and cent percent (100%) weed control efficiency of *A. baccifera* and *C. iria* except *A. baccifera* in 2019 (**Table 5, Figure 1**). Bispyribac-sodium is an acetolactate synthase inhibiting herbicide is widely utilized in rice cultivation to manage some weeds (López-Piñeiro *et al.* 2022). Another herbicide, metsulfuron-methyl, is a low-use-rate sulfonylurea herbicide widely used for post-emergence broad-leaved weed control in rice fields due to its strong inhibitory effect on plant growth (Boutin *et al.* 2012). As other sulfonylurea herbicides, chlorimuron-ethyl acts by inhibiting acetolactate synthase (ALS), an essential enzyme involved in the synthesis of branched-chain amino acids. Chlorimuron-ethyl is effective for providing control for wide range of weeds at low application rates, exhibits good crop selectivity, and has low acute and chronic toxicity while maintaining high biological efficiency. The adoption of newly formulated pre-mix post-emergence herbicides has shown greater efficacy in controlling weed flora, leading to improved crop productivity (Babaei *et al.* 2022).

Table 5. Effect of different weed control treatments on weed biomass (g/m^2) at 42 DAA, grain yield (t/ha) of transplanted rice and benefit cost ratio (B:C) during *Kharif* 2019 and 2020

Treatment	Grasses				Broad-leaved weed		Sedge		Rice grain yield (t/ha)		B:C	
	E. crus-galli		*L. chinensis*		*A. baccifera*		*C. iria*					
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 34.3 g/ha	6.13(37)	7.44(55)	7.04(49)	7.77(59)	5.67(31)	3.90(14)	5.19(26)	4.84(22)	6.06	6.95	2.80	3.48
Bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 43 g/ha	3.87(14)	5.45(29)	7.14(50)	8.05(64)	3.51(11)	3.33(10)	3.69(13)	3.27(10)	7.18	7.19	3.45	3.59
Bispyribac-sodium + metsulfuron-ethyl + chlorimuron-ethyl 51.6 g/ha	3.31(10)	3.29(10)	6.55(42)	7.46(55)	3.60(12)	2.44(6)	1.00(0)	2.86(7)	7.38	7.39	3.53	3.66
Penoxsulam + cyhalofop 135 g/ha	3.41(11)	3.24(10)	1.00(0)	1.00(0)	3.95(15)	3.91(14)	2.64(7)	4.16(16)	7.40	7.21	3.37	3.38
Bispyribac-sodium 25 g/ha	6.00(35)	5.73(32)	6.90(47)	7.25(52)	5.03(24)	3.79(13)	3.87(14)	5.00(24)	6.99	6.98	3.43	3.55
Bispyribac-sodium 38 g/ha	3.74(13)	5.37(28)	7.37(53)	8.14(65)	2.73(8)	3.56(12)	3.46(11)	3.71(13)	7.14	6.93	3.44	3.44
Metsulfuron + chlorimuron-ethyl 4 g/ha	6.55(42)	7.30(53)	7.32(53)	7.52(56)	3.31(11)	1.00(0)	1.67(3)	1.00(0)	6.48	6.26	3.22	3.19
Metsulfuron + chlorimuron-ethyl 5 g/ha	7.09(49)	7.55(56)	6.98(48)	7.53(56)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	6.58	6.34	3.27	3.24
Control	7.20(63)	7.55(56)	6.98(48)	7.83(60)	5.57(30)	4.88(23)	7.27(52)	7.85(61)	4.70	4.89	2.08	2.30
Hand weeding	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	7.33	7.21	3.31	3.37
LSD (p=0.05)	2.26	0.57	0.38	0.27	1.10	0.74	0.97	0.41	0.41	0.43	-	-

*Figures in parentheses are original means. Data were subjected to a square root transformation; DAA = days after herbicide application

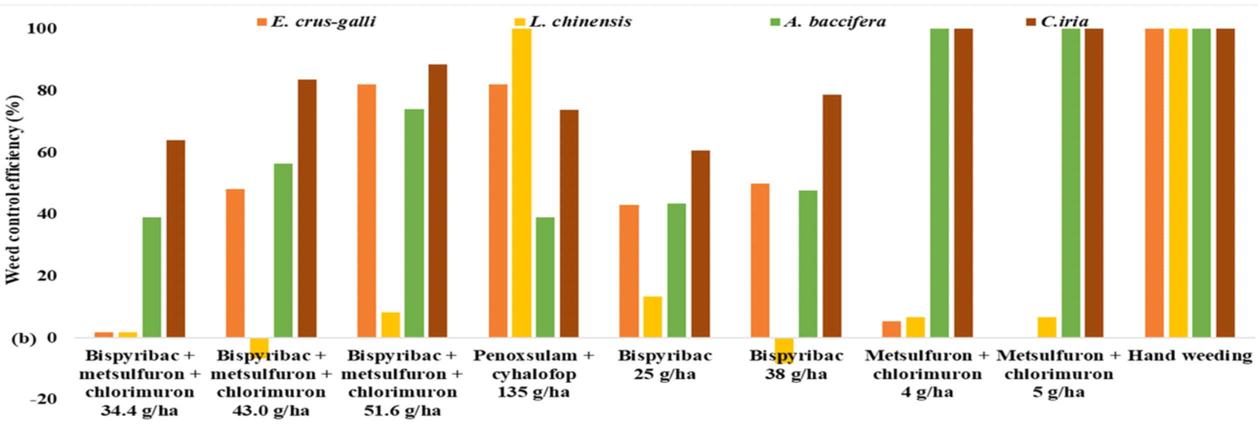

Figure 1. Weed control efficiency of grasses, broad-leaved weeds and sedges at 42 days after herbicide application (DAA) in (a) 2019 and (b) 2020

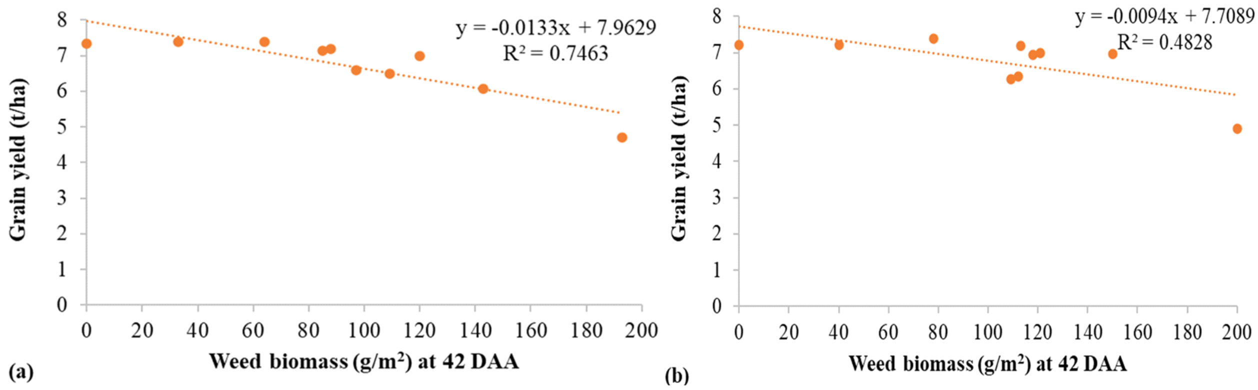

Figure 2. Relationship of grain yield of rice with weed biomass at 42 days after herbicide application (DAA) in (a) 2019 and (b) 2020

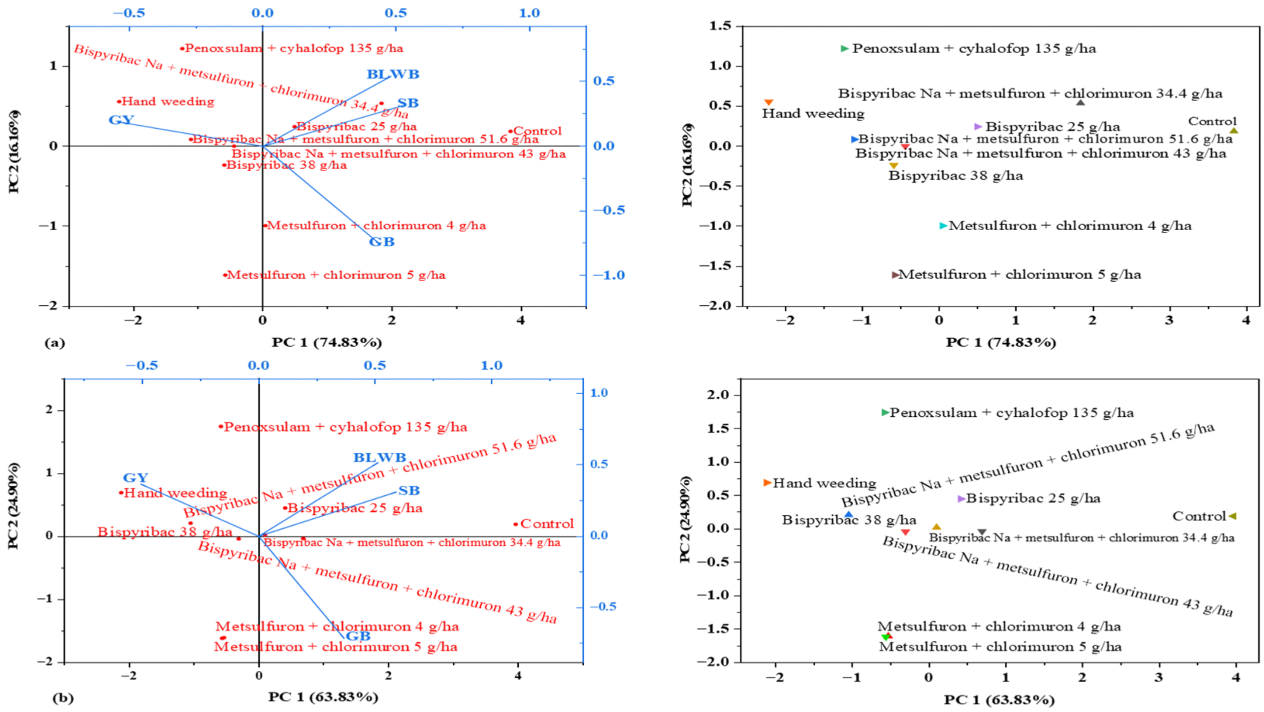

Figure 3. Principal component analysis between weed biomass at 42 days after herbicide application (DAA) and grain yield of rice in (a) 2019 and (b) 2020; GY: grain yield (t/ha), GB: grasses biomass (g/m²), BLWB: broad-leaved weed biomass (g/m²), SB: sedge biomass (g/m²)

Rice grain yield and benefit cost ratio (B:C)

Different herbicidal treatments had significant impact on the grain yield of rice (**Table 5**). The bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl (pre-mix) 51.6 g/ha PoE recorded at par grain yield with its lower dose *i.e.,* 43 g/ha, penoxsulam + cyhalofop 135 g/ha, bispyribac-sodium 25 g/ha and hand weeding. Moreover, in 2019, bispyribac-sodium 38 g/ha also resulted in grain yield of rice statistically at par with bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl (pre-mix) 43 g/ha. Furthermore, weed-free conditions under bispyribac sodium + metsulfuron methyl + chlorimuron ethyl (pre-mix) 43 g/ha led to significant increase in grain yield up to 52.8% in 2019 and 47.0% in 2020, respectively over control. Moreover, bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl (pre-mix) 51.6 g/ha recorded higher B:C (3.53 in 2019 and 3.66 in 2020) followed by its lower dose *i.e.*, 43 g/ha (3.45 in 2019 and 3.59 in 2020). During the critical growth period, weeds compete with rice for essential resources such as space, water, light and nutrients (Kaur *et al.* 2025a) and inadequate weed management has been linked to reduced crop yields (Boydston *et al.* 2017). The tested newly formulated post-emergence pre-mix herbicide achieved more effective weed control, reducing crop-weed competition, and enhancing crop productivity. Acetolactate synthase inhibiting herbicides are widely utilized in rice crop to manage weeds and their use often contributes to increased grain yields (López-Piñeiro *et al.* 2022).

A strong negative linear correlation was observed between rice grain yield and weed biomass at 42 DAA, indicating that grain yield declined as weed biomass increased (**Figure 2**). This relationship suggests that weed presence during the peak vegetative stage significantly hinders rice crop growth by competing for essential resources such as nutrients, sunlight and water. The coefficient of determination (R^2) values: 0.7463 in 2019 and 0.4828 in 2020, further support this trend, showing that weed biomass accounted for approximately 75% and 48% of the variability in rice grain yield during 2019 and 2020, respectively.

Principal component analysis (PCA) between weed biomass at 42 DAA and grain yield of rice

Principal component analysis (PCA) revealed that the first (PC1) and second principal components (PC2) together explained 91.0% of the total variation in 2019 and 88.7% in 2020 for weed biomass (grasses, broad-leaved weed, and sedge at 42 DAA) and rice grain yield across various weed control treatments (**Figure 3**). The blue arrows in the biplot depict variables such as grain yield and the biomass of different weed groups. The direction of each arrow reflects its contribution to the principal components, with longer arrows indicating greater influence. The angle between arrows shows the degree of correlation, where smaller angles indicate a positive relationship, while arrows pointing in opposite directions suggest a negative correlation. The biomass of grasses, broad-leaved weed and sedge at 42 DAA displayed long arrows-oriented opposite to that of grain yield, indicating a strong negative correlation between weed biomass and rice grain yield.

Conclusion

It can be concluded that bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl 43-51.6 g/ ha (pre-mix) PoE provided effective and economical control of grasses (*Echinochloa crus-galli* and *Leptochloa chinensis*), broad-leaved weed (*Ammania baccifera*) and the sedge (*Cyperus iria*) during the critical period of crop-weed competition in transplanted rice resulting in higher benefit: cost ratio than all other treatments.

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RESEARCH ARTICLE

Weed management efficacy of herbicides and their mixtures in transplanted rice

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ABSTRACT

An experiment was conducted at Research Farm, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Main campus at Chatha, Jammu, India during *Kharif* 2023 and 2024. The objective of this study was to evaluate the efficacy of a few herbicides and their mixtures in managing weeds and improve transplanted rice (*Oryza sativa* L.) productivity and economics. The higher number of rice effective tillers, dry matter accumulation, grain yield and straw yield were recorded with pre-emergence application (PE) of pyrazosulfuron-ethyl 15 g/ha followed by (*fb*) post-emergence application (PoE) of triafamone + ethoxysulfuron 66.5 g/ha which was statistically equivalent to pyrazosulfuron-ethyl 15 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE. Pyrazosulfuron-ethyl 15 g/ha PE *fb* triafamone + ethoxysulfuron 66.5 g/ha PoE and pyrazosulfuron-ethyl 15 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE have also recorded the lower weed density (48.68-77.36%), weed biomass (75.78-86.65%), weed index (85.61%), weed persistence index and higher weed control efficiency (75.78-86.66%); crop resistance index, higher net returns and benefit-cost ratio.

Keywords: Bispyribac-sodium, Herbicide, Pyrazosulfuron-ethyl, Transplanted rice, Triafamone + ethoxysulfuron, Weed management

INTRODUCTION

Rice is one of the most important staple foods in India and feeds nearly half of the world's population. India contributes approximately 26% of the total global rice production, with second rank amongst the leading producers in the world (USDA 2024). In India, rice is cultivated over an area of about 51.4 million hectares, with total production of 149.07 million tonnes and an average productivity of 2.93 t/ha during 2024-25 (Ministry of Agriculture and Farmers Welfare 2025). In rice cultivation, transplanting is one of the most common methods due to its better crop establishment and higher yield potential (Rao *et al.* 2017). Although transplanted rice generally experiences lower weed infestation as compared to direct-seeded rice but uncontrolled weeds can still cause the significant yield losses ranging from 25-47% in grain and 13-38% in straw yield (Salam 2022). In rice fields, 85% are grassy weeds, 7% were sedges and 8% were broad-leaved weeds. The critical period of crop-weed competition in transplanted rice was reported to be 35-40 days after transplanting (Ghandor *et al.* 2024). To control, different weed management methods are used in rice fields (Rao and Chandrasena 2024). The manual weeding is effective but not practical due to labor-intensive operations, unavailability of labor in time and high labor cost. The mechanical weeding is also less effective in puddled soil and for controlling intra-row weeds. To overcome these limitations, herbicides usage is widely adopted as they provide effective, timely and efficient diverse weed flora management with less labor (Rao *et al.* 2020). For effective weed control, factors such as herbicide selectivity, dose, timing and method of application are very important. The pre-emergence application (PE) of herbicides is generally done at 0-3 days after transplanting (DAS) and the post-emergence application (PoE) at 20-30 DAT. The response of both weeds and crop largely depend on the herbicide applied and the dose of herbicide. The application of lower dose of herbicides results in poor weed control, leading to higher weed competition, whereas higher dose may cause the phytotoxicity in rice crop and increase cost of cultivation (Jena *et al.* 2002). Therefore, it is important to evaluate the effect of herbicides on weed

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dynamics, crop growth and relative economics of rice to identify an optimum, effective and economically viable weed management option. Thus, this study was conducted to evaluate the efficacy of herbicides and their mixtures in managing weeds and improve transplanted rice (*Oryza sativa* L.) productivity and economics.

MATERIAL AND METHODS

The experiment was conducted at AICRP-Weed Management Research Farm, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Main campus at Chatha, Jammu, India (320 - 40´ N, 740 -58´ E; with 332 m above mean sea level) during *Kharif* season of 2023 and 2024. The soil was sandy clay loam with pH 7.5 with low organic carbon (4.34 g/kg), available nitrogen (236.62 kg/ha), medium available phosphorus (14.35 kg/ha) and potassium (163.74 kg/ha). The rice variety *Basmati-370* was transplanted at spacing of 20 × 10 cm. The seed rate was 20 kg/ha with fertilizer application of NPK 30:20:10 kg/ha as per package and practices. The gross plot size was 28 m^2 (4m x 7m) and net plot size 19.2 m^2 (3.2m x 6m). The pre-emergence herbicide application was done at 2 DAT whereas post-emergence herbicide application was done at 25 DAT. The treatments consist of the 100% and 75% of recommended dose of herbicides (RDH). The experiment was laid in Randomized Block Design (RBD) with three replications and nine treatments: pyrazosulfuron-ethyl 15 g/ha PE, pyrazosulfuron-ethyl 11.25 g/ha PE, pyrazosulfuron-ethyl 15 g/ha PE followed by (*fb*) triafamone + ethoxysulfuron 66.5 g/ha PoE, pyrazosulfuron-ethyl 11.25 g/ha PE *fb* triafamone + ethoxysulfuron 49.87 g/ha PoE, pyrazosulfuron-ethyl 15 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE, pyrazosulfuron-ethyl 11.25 g/ha PE *fb* bispyribac-sodium 18.75 g/ha PoE, bispyribac-sodium 25 g/ha PoE, weed free, unweeded check.

The number of tillers and dry matter accumulation were recorded at different growth stages of crop, whereas the number of panicles, number of grains per panicle, grain yield, straw yield and harvest index were recorded at harvest. The data of weeds was recorded at 30 and 60 DAT. Weed density was recorded randomly from the four spots by placing the quadrat of 1m x 1m in each plot whereas the weed dry matter (weed biomass) was determined by uprooting the weeds with roots and cleaning the soil from the roots. Collected weeds were oven-dried at 60°C for 1.5-2 days. After complete oven drying, the weed biomass was recorded. The different weed indices were estimated *viz*. weed control efficiency (WCE) (Mishra and Mishra 1997), weed index (WI) (Raju 1998), relative weed density (RWD) (Mishra and Mishra 1997), Weed Persistence Index (WPI) and Crop Resistance Index (CRI).

$$\text{WCE (\%)} = \frac{\text{Weed biomass in control plot - Weed biomass in treated plot}}{\text{Weed biomass in control plot}} \times 100$$

$$\text{WI (\%)} = \frac{\text{Yield of weed free treatment - Yield of treatment plot}}{\text{Yield of weed free treatment}} \times 100$$

$$\text{RWD} = \frac{\text{Absolute density for individual weed species}}{\text{Total number of weed species}} \times 100$$

$$\text{WPI (\%)} = \frac{\text{Weed biomass in treated plot}}{\text{Weed biomass in control plot}} \times \frac{\text{Weed density in control plot}}{\text{Weed density in treated plot}}$$

$$\text{CRI (\%)} = \frac{\text{Dry weight of crop in treated plot}}{\text{Dry weight of crop in control plot}} \times \frac{\text{Dry weight of weeds in control plot}}{\text{Dry weight of weeds in treated plot}}$$

The statistical analysis of the data collected from the field was conducted as per the methodology of Gomez and Gomez (1984). The data recorded for two consecutive years was statistically analyzed and since the treatments effect were consistent across the years, the data were pooled and analyzed. In this a Least significant difference (LSD) of 5% level has been calculated for the various parameters for minimising the treatment and row effects. The results were then tested for measuring the treatments mean by applying the F-test on the basis of null hypothesis. Further, the square root transformation *ie*. $(\sqrt{x+1})$ was applied on weed density and weed biomass for statistical analysis.

RESULTS AND DISCUSSION

Effect on weeds

The experimental field was infested with a mixed flora comprises of grasses, sedges and broad-leaved weeds. *Echinochloa colona, Dactlyloctenium aegyptium* and *Cyanodon dactylon* were the dominant grassy weeds, while *Cyperus rotundus* was the major sedge and *Caesulia axillaris* was the pre-dominant broad-leaved weed. The other weeds associated were

Eleusine indica, Physalis minima, Digitaria sanguinalis, Eclipta prostrata and Phyllanthus niruri etc. The relative weed density represents the proportion of individual weed species in the total weed population indicates the dominance and composition of weeds in the field. Among the different weed flora, the most dominant weed was *Cyperus rotundus* with relative density (33, 23%) among sedges followed by *Echinochloa colona* with relative density (18, 19%) among grasses at 30 and 60 DAT **(Figure 1)**. The main reason for the dominance of sedges was due to short life cycle, high production of seeds, dissemination to far areas, low water requirement, high light compensation points and easily adaptable to new climate.

The total weed density and weed biomass at 30 and 60 DAT were significantly lower with pyrazosulfuron-ethyl 15g/ha PE *fb* triafamone + ethoxysulfuron 66.5g/ha PoE which was statistically at par with pyrazosulfuron-ethyl 15g/ha PE *fb* bispyribac-sodium 25g/ha PoE and pyrazosulfuron-ethyl 15g/ha PE **(Table 1** and **2)**. The highest weed density and weed biomass was observed in weedy check plot. This was mainly due to the pre-emergence application of pyrazosulfuron-ethyl which was used to control grasses, sedges and broad-leaved weeds at early stages of weeds whereas triafamone + ethoxysulfuron and bispyribac-sodium managed weeds that emerged at the later stages of weeds due to its broad-spectrum activity of inhibiting weed germination and cell division (Menon *et al.* 2016).

Among different treatments, the higher weed control efficiency at 30 days and 60 DAT was recorded with pyrazosulfuron-ethyl 15g/ha PE *fb* triafamone + ethoxysulfuron 66.5g/ha PoE **(Table 2)**. This was mainly due to the fact that the herbicidal

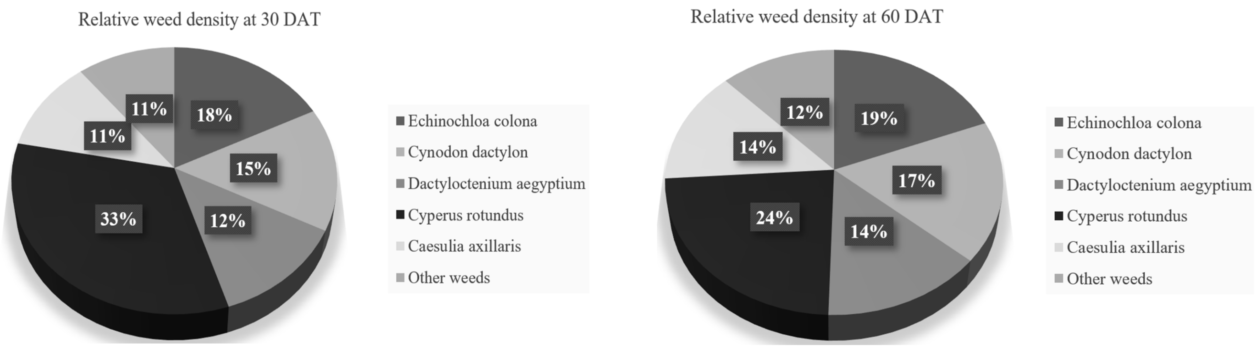

Figure 1. The relative density of weeds occurring in transplanted rice at 30 and 60 days after transplanting (pooled values for two years)

Table 1. Effect of different herbicides on density of individual weed species in transplanted rice (pooled values for two years)

Treatment	*Echinochloa colona*		*Cynodon dactylon*		*Dactyloctenium aegyptium*		*Cyperus rotundus*		*Caesulia axillaris*		Other weeds	
	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT
Pyrazosulfuron-ethyl 15 g/ha PE	2.71 (6.33)	3.79 (13.33)	2.71 (6.33)	3.79 (13.33)	2.31 (4.33)	3.11 (8.66)	3.79 (13.33)	4.16 (16.33)	2.31 (4.33)	3.26 (9.66)	2.38 (4.66)	2.89 (7.33)
Pyrazosulfuron-ethyl 11.25 g/ha PE	3.51 (11.33)	4.12 (16.00)	3.05 (8.33)	4.28 (17.33)	2.83 (7.00)	3.65 (12.33)	4.36 (18.00)	4.58 (20.00)	2.89 (7.33)	3.78 (13.33)	2.64 (6.00)	3.37 (10.33)
Pyrazosulfuron-ethyl 15 g/ha PE *fb* triafamone + ethoxysulfuron 66.5 g/ha PoE	2.64 (6.00)	2.38 (4.66)	2.51 (5.33)	2.31 (4.33)	2.38 (4.66)	2.23 (4.00)	3.83 (13.66)	2.64 (6.00)	2.23 (4.00)	2.08 (3.33)	2.31 (4.33)	2.16 (3.66)
Pyrazosulfuron-ethyl 11.25 g/ha PE *fb* triafamone + ethoxysulfuron 49.87 g/ha PoE	3.46 (11.00)	3.41 (10.66)	3.11 (8.66)	2.89 (7.33)	3.05 (8.33)	2.71 (6.33)	4.43 (18.66)	3.51 (11.33)	2.83 (7.00)	2.71 (6.33)	2.71 (6.33)	2.64 (6.00)
Pyrazosulfuron-ethyl 15 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	2.77 (6.66)	2.64 (6.00)	2.64 (6.00)	2.38 (4.66)	2.45 (5.00)	2.31 (4.33)	3.87 (14.00)	2.77 (6.66)	2.31 (4.33)	2.23 (4.00)	2.45 (5.00)	2.31 (4.33)
Pyrazosulfuron-ethyl 11.25 g/ha PE *fb* bispyribac-sodium 18.75 g/ha PoE	3.51 (11.33)	3.46 (11.00)	3.21 (9.33)	2.94 (7.66)	3.05 (8.33)	2.77 (6.66)	4.47 (19.00)	3.51 (11.33)	2.89 (7.33)	2.77 (6.66)	2.77 (6.66)	2.71 (6.33)
Bispyribac-sodium 25 g/ha PoE	3.65 (12.33)	3.32 (10.00)	3.41 (10.66)	2.77 (6.66)	3.11 (8.66)	2.64 (6.00)	5.03 (24.33)	3.46 (11.00)	2.94 (7.66)	2.89 (7.33)	2.83 (7.00)	2.64 (6.00)
Weed free	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
Unweeded check	3.74 (13.00)	4.40 (18.33)	3.51 (11.33)	4.62 (20.33)	3.21 (9.33)	4.47 (19.00)	5.10 (25.00)	5.42 (28.33)	3.00 (8.00)	4.04 (15.33)	2.89 (7.33)	3.79 (13.33)
LSD (p= 0.05)	0.44	0.47	0.40	0.46	0.38	0.31	0.47	0.54	0.42	0.45	0.20	0.36

The data were subjected to $(\sqrt{x+1})$ transformation; Figures in the parenthesis are original values; PE- pre-emergence application; PoE- post-emergence application; *fb*- followed by; DAT- days after transplanting treatment helped in better suppression of weeds, reducing the crop weed competition allowing better crop growth.

The weed index is an essential parameter for indicating percentage of yield loss due to crop weed competition. Among all treatments, the lowest yield loss was recorded with pyrazosulfuron-ethyl 15g/ha PE *fb* triafamone + ethoxysulfuron 66.5g/ha PoE with weed index (4.55 %) **(Table 2)**. This was due to the better effectiveness of herbicides in weed management which leads to efficient resource use by crops and attain maximum production (Bandyopadhyay *et al.* 2024). The weed persistence index (WPI) indicates the tolerance of weeds against the different herbicidal treatments. The lower value of WPI indicates better weed control and less tolerance against herbicides. Among different treatments, the lower value of WPI at 30 and 60 DAT (0.47, 0.59%) was recorded with pyrazosulfuron-ethyl 15 g/ha PE *fb* triafamone + ethoxysulfuron 66.5 g/ha PoE which was statistically at par with pyrazosulfuron-ethyl 15 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE **(Table 2)**. The lower value of WPI indicates the better efficacy and effectiveness of herbicides which result in lower weed density and reduce crop weed competition (Bandyopadhyay *et al.* 2024).

The crop resistance index (CRI) represents the resistance shown by the crop against a particular dose of herbicides. The higher value of CRI shows the better resistance shown by the crop and remain unaffected by application of herbicides. In different treatments, the higher CRI value at 30 and 60 DAT (4.57, 11.31%) recorded with pyrazosulfuron-ethyl 15 g/ha PE *fb* triafamone + ethoxysulfuron 66.5 g/ha PoE which was statistically at par with pyrazosulfuron-ethyl 15 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE **(Table 2)**. The higher value of CRI resulted in direct development of resistance against a particular dose of herbicides. Also, it reduces the weed growth and boosts the crop production (Prasath and Ramesh 2015).

Effect on rice

Different herbicides did not show any significant effect on crop growth at 30 DAT. However, at 60 and 90 DAT, the higher number of tillers and dry matter accumulation was recorded with pyrazosulfuron-ethyl 15 g/ha PE *fb* triafamone + ethoxysulfuron 66.5 g/ha PoE which was statistically at par with pyrazosulfuron-ethyl 15 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE **(Table 3)**. The application of high dose of herbicide caused mild leaf scorching which were disappeared after irrigation. This was mainly due to the reduced crop-weed competition by which there was decrease weed counts and weed dry matter by which help in better uptake of light, nutrients and water which ultimately improve the growth of crop (Choudhary and Dixit 2024).

A negative linear relationship was observed between weed persistence index (WPI) and crop dry matter with coefficient of determination R^2= 0.70.

Table 2. Effect of different herbicides on weed dynamics in transplanted rice (pooled values for two years)

Treatment	Total weed density (no. /m^2)		Weed biomass (g/m^2)		Weed control efficiency (%)		Weed persistence index (%)		Crop resistance index (%)		Weed index (%)
	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT	At harvest
Pyrazosulfuron-ethyl 15 g/ha PE	6.35 (39.31)	8.35 (68.64)	3.25 (9.55)	8.21 (66.37)	74.24	48.22	0.48	0.86	4.25	2.20	21.80
Pyrazosulfuron-ethyl 11.25 g/ha PE	7.68 (57.96)	9.50 (89.29)	3.96 (14.67)	9.55 (90.29)	60.44	29.55	0.50	0.90	2.71	1.60	24.64
Pyrazosulfuron-ethyl 15 g/ha PE *fb* triafamone + ethoxysulfuron 66.5 g/ha PoE	6.24 (37.95)	5.19 (25.95)	3.16 (8.98)	4.25 (17.10)	75.78	86.66	0.47	0.59	4.57	11.31	4.55
Pyrazosulfuron-ethyl 11.25 g/ha PE *fb* triafamone + ethoxysulfuron 49.87 g/ha PoE	7.81 (59.96)	7.00 (47.97)	4.05 (15.42)	6.22 (37.72)	58.41	70.57	0.51	0.70	2.58	4.16	18.41
Pyrazosulfuron-ethyl 15 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	6.48 (40.95)	5.56 (29.96)	3.32 (10.01)	4.61 (20.24)	73.00	84.21	0.49	0.60	4.06	9.24	7.13
Pyrazosulfuron-ethyl 11.25 g/ha PE *fb* bispyribac-sodium 18.75 g/ha PoE	7.94 (61.97)	7.12 (49.63)	4.08 (15.63)	6.42 (40.20)	57.85	68.64	0.50	0.72	2.52	3.86	18.09
Bispyribac-sodium 25 g/ha PoE	8.46 (70.63)	6.92 (46.95)	5.85 (33.19)	6.17 (37.09)	10.49	71.06	0.94	0.71	1.14	4.42	17.12
Weed free	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	100.00	100.00	0.00	0.00	-	-	-
Unweeded check	8.66 (73.96)	10.75 (114.64)	6.17 (37.08)	11.37 (128.17)	0.00	0.00	1.00	1.00	1.00	1.00	31.63
LSD (p= 0.05)	1.01	1.20	0.43	0.55	-	-	0.49	0.93	2.92	1.61	-

The data were subjected to $(\sqrt{x+1})$ transformation; Figures in the parenthesis are original values; PE- pre-emergence application; PoE- post-emergence application; *fb*- followed by; DAT- days after transplanting

This indicates that with the increase in crop dry matter resulted in decrease in WPI. The higher value of R^2 indicates the higher variation in WPI by changes in crop dry matter **(Figure 2a)**. This shows the different treatments were performed better in crop growth, decrease persistence of weeds and improving crop-weed competition.

Similarly, the crop dry matter also has shown a negative linear relationship with weed biomass (R^2 = 0.83). The negative trend indicates the increase in weed biomass reduces the crop dry matter due to competition for growth resources. The high R^2 value indicates a strong association between these two variables, showing that weed biomass significantly influenced by the crop dry matter production **(Figure 2b)**. This result clearly showed that the effective weed management that lowers weed biomass is essential for enhancing crop growth and production.

The rice yield parameters were significantly affected by herbicidal treatments. The highest number of panicles, grains per panicle, grain yield and straw yield were recorded with pyrazosulfuron-ethyl 15 g/ha PE *fb* triafamone + ethoxysulfuron 66.5 g/ha PoE which was statistically at par with pyrazosulfuron-ethyl 15 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE **(Table 4)**. This was mainly achieved by the effective weed suppression with herbicidal treatments which leads to better sunlight, water and nutrient uptake by the crop (Prasath and Ramesh 2015).

Economics

The first stage of adopting any technology, method and suggestion is mostly determined by its input cost and profit. In this aspect, the net returns and benefit-cost ratio were the main parameters in economic viability. Among different treatments, pyrazosulfuron-ethyl 15 g/ha PE *fb* triafamone + ethoxysulfuron 66.5 g/ha PoE recorded highest net returns and benefit-cost ratio (1.97) **(Table 5)**. This was due to better weed control which led to higher production of grain and straw yield with lesser cost (Singh *et al.* 2021)

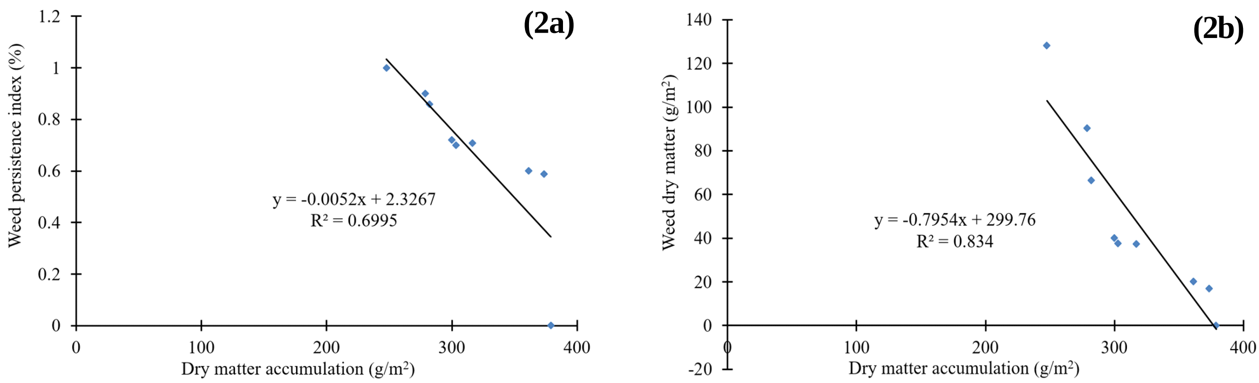

Figure 2. The relationship between crop dry matter and weed persistence index (a), crop dry matter and weed dry matter at 60 DAT(b)

Table 3. Effect of different herbicides on transplanted rice growth parameters (pooled values for two years)

Treatment*	Effective tillers (no. /m²)				Dry matter accumulation (g/m²)			
	30 DAT	60 DAT	90 DAT	At harvest	30 DAT	60 DAT	90 DAT	At harvest
Pyrazosulfuron-ethyl 15 g/ha PE	135.0	208.3	205.3	203.7	164.6	282.4	497.3	635.3
Pyrazosulfuron-ethyl 11.25 g/ha PE	132.0	206.3	202.7	198.0	161.6	278.7	487.9	610.2
Pyrazosulfuron-ethyl 15 g/ha PE *fb* triafamone + ethoxysulfuron 66.5 g/ha PoE	135.3	252.7	250.3	248.3	166.7	373.5	643.9	775.4
Pyrazosulfuron-ethyl 11.25 g/ha PE *fb* triafamone + ethoxysulfuron 49.87 g/ha PoE	132.7	220.0	217.3	215.0	161.3	303.0	524.3	676.0
Pyrazosulfuron-ethyl 15 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	134.3	250.3	248.6	245.3	164.9	361.2	625.0	763.8
Pyrazosulfuron-ethyl 11.25 g/ha PE *fb* bispyribac-sodium 18.75 g/ha PoE	131.0	217.3	215.3	212.7	159.7	300.0	505.2	656.4
Bispyribac-sodium 25 g/ha PoE	126.0	224.0	225.7	220.3	153.5	316.7	570.9	693.3
Weed free	136.3	255.7	253.7	250.3	168.6	378.9	682.7	795.1
Unweeded check	123.3	185.0	183.7	181.7	150.5	247.5	397.0	563.9
LSD (p= 0.05)	NS	24.81	22.3	21.7	NS	34.15	48.6	63.4

*PE- pre-emergence application; PoE- post-emergence application; *fb*- followed by; DAT- days after transplanting

Table 4. Effect of different herbicides on transplanted rice yield attributes and yield (pooled values for two years)

Treatment	Panicles/ m^2	Grains /panicle	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)
Pyrazosulfuron-ethyl 15 g/ha PE	200.67	64.00	2.42	4.30	36.05
Pyrazosulfuron-ethyl 11.25 g/ha PE	198.00	61.67	2.34	4.13	36.13
Pyrazosulfuron-ethyl 15 g/ha PE *fb* triafamone + ethoxysulfuron 66.5 g/ha PoE	246.00	73.00	2.96	5.57	34.70
Pyrazosulfuron-ethyl 11.25 g/ha PE *fb* triafamone + ethoxysulfuron 49.87 g/ha PoE	213.67	65.00	2.53	4.65	35.26
Pyrazosulfuron-ethyl 15 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	243.67	71.67	2.88	5.38	34.89
Pyrazosulfuron-ethyl 11.25 g/ha PE *fb* bispyribac-sodium 18.75 g/ha PoE	209.33	64.67	2.54	4.64	35.38
Bispyribac-sodium 25 g/ha PoE	216.67	65.33	2.57	4.88	34.52
Weed free	246.34	74.00	3.10	5.71	35.21
Unweeded check	179.67	59.67	2.12	3.83	35.61
LSD (p= 0.05)	24.71	6.13	0.303	0.496	NS

*PE- pre-emergence application; PoE- post-emergence application; *fb*- followed by

Table 5. Effect of different herbicides on relative economics in transplanted rice (pooled values for two years)

Treatment	Cost of cultivation (x10^3 ₹/ha)	Gross returns (x10^3 ₹/ha)	Net returns (x10^3 ₹/ha)	B:C ratio
Pyrazosulfuron-ethyl 15 g/ha PE	50.43	125.12	74.69	1.48
Pyrazosulfuron-ethyl 11.25 g/ha PE	49.37	120.56	71.18	1.44
Pyrazosulfuron-ethyl 15 g/ha PE *fb* triafamone + ethoxysulfuron 66.5 g/ha PoE	51.62	153.37	101.75	1.97
Pyrazosulfuron-ethyl 11.25 g/ha PE *fb* triafamone + ethoxysulfuron 49.87 g/ha PoE	51.25	130.86	79.61	1.55
Pyrazosulfuron-ethyl 15 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	51.46	149.13	97.68	1.90
Pyrazosulfuron-ethyl 11.25 g/ha PE *fb* bispyribac-sodium 18.75 g/ha PoE	51.02	131.33	80.31	1.57
Bispyribac-sodium 25 g/ha PoE	49.93	133.24	83.31	1.67
Weed free	65.88	160.41	94.54	1.44
Unweeded check	48.23	109.53	61.31	1.27

PE- pre-emergence application; PoE- post-emergence application; *fb*- followed by

It can be concluded that higher weed control efficiency with highest rice grain yield, net returns and benefit-cost ratio can be obtained with pyrazosulfuron-ethyl 15 g/ha PE *fb* triafamone + ethoxysulfuron 66.5 g/ha PoE and pyrazosulfuron-ethyl 15 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE.

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RESEARCH ARTICLE

Interactive effect of sowing date and weed management options on associated weeds and productivity of dry direct-seeded rice

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ABSTRACT

A field study was carried out during *Kharif*, 2023 and 2024 at Agriculture research station, Binjhagiri, Chatabar, Odissa with an objective to study the interactive effect of sowing dates and weed management options on weed growth and productivity of dry direct-seeded rice. The experiment was laid out in split plot design with three replications. The three dates of sowing, *viz.* S_1: 10th June; S_2:25th June; S_3:10th July, were in main plots and five weed management treatments, *viz.* pre-emergence application (PE) of pendimethalin1.0 kg/ha , pendimethalin 1.0 kg/ha PE followed by (*fb*) post-emergence application (PoE) of fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) 90.0 +15.0 g/ha, pendimethalin 1.0 kg/ha PE *fb* one hand weeding (HW) at 40 days after seeding (DAS), hoeing and weeding twice at 20 and 40 DAS and weedy check, were in subplots. The lowest density and biomass of all types of weeds and maximum value of rice yield attributes and yield were recorded with normal date of sowing (25th June) followed by early sowing (10th June). Among the weed management treatments, hoeing and weeding twice at 20 and 40 DAS recorded lower total weed density, maximum value of rice yield attributes and yield, and was at par with pendimethalin1.0 kg/ha PE *fb* one HW. Interaction effect was found significant and the timely sown (25th June) along with hoeing and weeding twice recorded the highest rice yield and was at par with timely sown (25th June) along with pendimethalin 1.0 kg/ha PE *fb* one HW.

Keywords: Dry direct-seeded rice, Fenoxaprop-p-ethyl + ethoxysulfuron, Integrated weed management, Pendimethalin, Sowing dates

INTRODUCTION

Rice is one of the most important food crops in India, Asia, and the World. India is the world's top rice producing country in terms of area and ranks first in terms of production. To meet global rice demand, it is projected that an additional 96 million tons of milled rice will be needed by 2040 as compared to 2015 (Balié and Valera 2020). Time of sowing of the crop is a non-monetary input, but greatly affects the productivity of rice. Several studies have shown that sowing of rice after onset of monsoon gave higher grain yield due to less infestation of weeds. However, very late sowing could reduce the vegetative and reproductive growth period of rice, resulting into low crop yield. Alternating the time of sowing and effective weed management methods can decrease losses due to weeds and improve the productivity of direct-seeded rice (DSR). Weed infestation is one of the major constraints for low productivity and causes 50-60% yield loss due to simultaneous germination of both crop and weed seeds (Rao *et al.* 2007, Pinjari *et al.* 2016). Manual weeding is considered to be the best, but it is uneconomical and hence herbicides are being considered as better alternative to hand weeding in DSR (Singh *et al.* 2006, Rao *et al.* 2017). Though herbicides are being extensively used to control weeds, single herbicide cannot control all types of weeds in the agricultural fields (Sar *et al.* 2022). Therefore, an integrated weed management strategy is strongly recommended to improve agricultural sustainability (Rao and Korres 2024). Thus, for effective weed management in DSR, integrated approaches are to be optimized. The present study was conducted to study the effect of date of sowing and weed management options on weed growth and productivity in dry-DSR.

MATERIALS AND METHODS

A field experiment was conducted during *Kharif* season at Agricultural Research Station, Faculty of Agricultural Sciences, SOADU, Odisha, India, during 2023 and 2024. Soil texture of the experimental plot was sandy loam. The experiment was laid out in split plot design with three replications. Treatments consisted of three dates of sowing, *viz.* S_1: 10th June; S_2:25th June; S_3:10th July, in main plots and five weed

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management treatments, *viz*. W_1: pre-emergence application (PE) of pendimethalin 1.0 kg/ha , W_2: pendimethalin 1.0 kg/ha PE followed by (*fb*) post-emergence application (PoE) of fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) 90.0 +15.0 g/ha, W_3: pendimethalin 1.0 kg/ha PE *fb* one HW at 40 DAS, W_4: hoeing and weeding at 20 and 40 days after seeding (DAS) and W_5: weedy check, in subplots. The field was prepared by one ploughing with disc harrow and cross ploughing using cultivators. Planking was done after each ploughing to make soil friable to ensure proper germination. The rice variety CR Dhan 205, popularly known as aerobic rice was used in this experiment using seed rate of 60 kg/ha. Fertilizers applied include: 80 kg N, 40 kg P and 40 K kg/ ha. Half the dose of N, full dose of P and K were applied as basal at the time of sowing. Remaining half dose of N was applied as top-dressing using urea in two equivalent splits at 25 and 45 DAS. The extra plants in the rows were thinned out and gap filling was done within two weeks of sowing in order to maintain optimum plant population. Herbicides were sprayed knap sack sprayer with flat fan nozzle at their respective doses at appropriate stages. All other recommended agronomic practices were followed and plant protection measures were adopted as per need. Weed density of different species was counted by placing the quadrat (50 cm × 50 cm) randomly in the sampling area and after drying of the sampled weeds in a hot air oven at 70-72°C for 72 hours, the dry weight of weeds (weed biomass) was recorded. The yield components and yield of DSR were also recorded and statistically analysed at 5% level of significance (Gomez and Gomez 1984).

RESULT AND DISCUSSION

Effect on weeds

The dominance of weeds varied across different dates of sowing and weed management treatments. Weeds observed in the experimental field include: *Digitaria sanguinalis*, *Echinochloa colona*, among grasses; *Ludwigia parviflora*, *Hedyotis corymbosa*, *Lindernia ciliata*, *Cleome viscosa*, among broad-leaved weeds and *Cyperus iria*, among sedges. Similar weed flora in DSR was also reported by Chakraborti *et al*. (2018), Dhanapal *et al*. (2018), Banjara *et al.* (2019), Yadav *et al.* (2019) and Sar *et al*. (2024). Among the different dates of sowing, the lowest density and biomass of total weeds were recorded with normal sowing date (25th June) followed by early sowing date (10th June). Similar trend was reported by Mandal *et al.* (2011). Due to high photoperiods with favourable weather condition for germination, thereby weeds emerged and established more in early sown date (Upasni *et al*. 2014).

The lowest density and biomass of total weed was recorded with hoeing and weeding twice and was at par with pendimethalin 1.0 kg/ha PE *fb* one HW **(Table 1)** as reported by Sar *et al.* (2025). The application of pre-emergent (PE) herbicide alone was not adequate to manage the weeds in rice. The herbicides application sequentially followed by manual weeding performed better against diverse weed flora as compared to herbicides use alone (Chauhan 2012). Pendimethalin 1.0 kg/ha PE *fb* one hand weeding recorded 47.43% and 48.2% lower biomass of total weeds as compared to pendimethalin

Table 1. Density and biomass of weeds at 60 days after seeding (DAS) in dry direct-seeded rice (DSR) as affected by different sowing dates and weed management treatments

Treatment*	Total weed density (no./m²)		Total weed biomass (g/m²)	
	2023	2024	2023	2024
Sowing dates				
S_1- 10th June	10.1(101.0)	9.8(94.7)	9.4(87.1)	9.0(80.4)
S_2- 25th June	9.2(84.0)	8.8(77.6)	8.5(71.1)	8.0(64.4)
S_3- 10th July	10.9(118.7)	10.6(111.5)	10.2(104.3)	9.9(97.3)
LSD (p=0.05)	0.43	0.38	0.34	0.39
Weed management treatment				
W_1- Pendimethalin 1.0 kg/ha PE at 3 DAS	12.1(145.3)	11.8(138.5)	11.5(132.6)	11.2(125.6)
W_2- Pendimethalin 1.0 kg/ha PE *fb* fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) 90+15 g/ha PoE at 20 DAS	9.7(93.6)	9.3(85.9)	9.0(80.4)	8.6(72.7)
W_3- Pendimethalin 1.0 kg/ha PE at 3 DAS followed by 1 HW at 40 DAS	7.4(54.9)	7.1(50.2)	6.5(42.3)	6.2(37.7)
W_4- Hoeing and weeding at 20 and 40 DAS	7.2(52.0)	6.9(47.4)	6.3(39.4)	5.9(34.8)
W_5-Weedy check	13.8(191.2)	13.5(182.0)	13.4(178.3)	13.0(168.3)
LSD (p=0.05)	0.45	0.49	0.52	0.56

*PE=pre-emergence application; PoE=post-emergence application; Figures in parentheses are the original values. The data was transformed to SQRT ($\sqrt{x+0.5}$) before analysis

1.0 kg/ha PE *fb* fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) 90+15 g/ha PoE, in 2024 and 2025, respectively. Interaction effect was found significant and it was observed that timely sown (25th June) along with hoeing and weeding twice or pendimethalin 1 kg/h PE *fb* 1 HW recorded the lowest biomass of total weed at 60 DAS **(Figure 1** and **2)**.

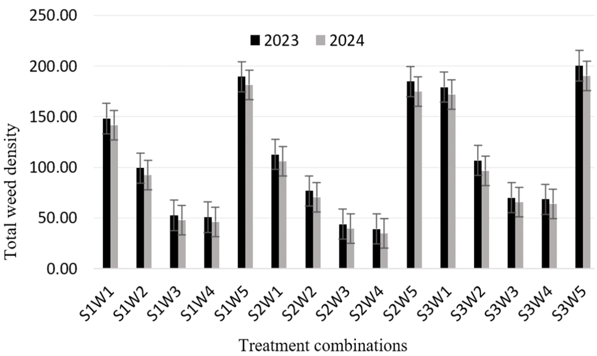

Figure 1. Interaction effect of sowing dates and weed management treatments on total weed density at 60 days after seeding (refer table 1 for details of treatments)

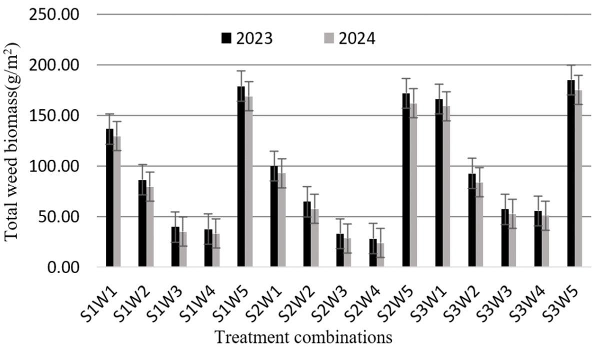

Figure 2. Interaction effect of sowing dates and weed management treatments on total weed biomass (g/m^2) at 60 days after seeding (refer table 1 for details of treatments)

Effect on rice

The yield attributes, *viz*. panicles/m^2, filled grains/panicle and thousand grain weight, and rice grin yield were markedly influenced by variations in sowing dates and weed management practices, reflecting the critical role of crop establishment time and effective weed management in optimizing rice performance. Among the sowing dates, normal sowing (25th June) was superior in recording higher values of all yield attributes, followed by early sowing (10th June), indicating that synchronization of crop phenology with prevailing favourable environmental conditions plays a decisive role in determining rice productivity. The superiority of normal sowing may be attributed to the alignment of critical growth stages with favourable temperature, radiation, and moisture regimes, thereby facilitating enhanced assimilate production and translocation. In contrast, deviations from the optimum sowing window might have imposed sub-optimal environment conditions, leading to reduce sink development and grain filling (Jena *et al.* 2024).

Weed management treatments exerted profound influence on yield attributes and rice grain yield, with hoeing and weeding twice registering the highest values of panicles/m^2, 1000 grain weight, filled grains/panicle and rice grain yield and straw yield **(Table 2)**. However, it was at par with pendimethalin 1.0 kg/ha PE *fb* one hand weeding **(Table 2)**. The greater rice productivity with these treatments can be ascribed to sustained weed management during the critical period of crop-weed competition, ensuring

Table 2. Dry direct-seeded rice yield attributes and yield as influenced by sowing dates and weed management treatments

Treatment*	Panicle weight(g)		No of panicles/ m^2		No of grains /panicle		No of filled grains/ panicles		Grain yield (t/ha)		Straw yield (t/ha)	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
Sowing dates												
S_1-10th June	1.93	2.22	217	225	103	108	93	95	2.94	3.22	3.67	4.08
S_2- 25th June	2.18	2.48	233	241	117	124	110	114	3.24	3.50	3.91	4.31
S_3- 10thJuly	1.78	2.05	200	205	95	100	82	85	2.61	2.87	3.36	3.76
LSD (p=0.05)	0.13	0.14	15	12	7	6	5	6	0.28	0.25	0.23	0.21
Weed management treatment												
W_1-Pendimethalin 1.0 kg/ha PE at 3 DAS	1.62	1.85	186	191	89	93	78	81	2.16	2.41	2.96	3.37
W_2- Pendimethalin 1.0 kg/ha PE *fb* fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) 90+15 g/ha PoE at 20 DAS	2.15	2.45	222	227	106	108	91	95	3.01	3.26	3.58	3.98
W_3- Pendimethalin 1.0 kg/ha PE at 3 DAS followed by 1 HW at 40 DAS	2.41	2.71	263	271	127	132	121	120	3.99	4.22	4.57	4.98
W_4- Hoeing and weeding at 20 and 40 DAS	2.43	2.74	267	275	133	141	125	129	4.03	4.33	4.69	5.09
W_5- Weedy check	1.21	1.50	145	157	68	80	61	66	1.55	1.75	2.44	2.84
LSD (p=0.05)	0.10	0.11	16	15	8	9	7	9	0.20	0.21	0.31	0.30

*PE = pre-emergence application; PoE = post-emergence application DAS = days after seeding uninterrupted access to essential growth resources (Mishra *et al.* 2025).

Pendimethalin 1.0 kg/ha PE *fb* one hand weeding significantly augmented yield attributes, recording increases of 81.37, 86.76, 98.36% in panicles/m^2, grains/panicle and filled grains/panicle respectively, over the weedy check, during 2023. A similar trend was observed in the second year also, with corresponding increases of 72.76%, 65.0% and 81.81%, respectively. Pendimethalin PE *fb* fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) PoE recorded 39.3% and 35.21% higher grain yield as compared to pendimethalin PE applied alone in 2023 and 2024, respectively. However, pendimethalin PE alone recorded 39.34% and 37.70% higher grain yield over weedy check in 2023 and 2024, respectively. These pronounced improvements highlight the pivotal role of early-season weed control through pre-emergent herbicides, complemented by subsequent manual intervention, in maintaining a weed-free environment during the most sensitive stages of crop growth.

Interaction effect was also found to be significant. The timely sowing (25th June) along with hoeing and weeding at 20 and 40 DAS recorded the highest grain and straw yield over others and it was at par with timely sown (25th June) along with pendimethalin 1.0 kg/ha PE *fb* one HW at 40 DAS **(Figure 3)**. It may be due to higher weed control efficiency of these treatments which maintained lower weed density as well as biomass thus least crop weed competition from the very early stage of the crop till maturity facilitating higher nutrient and water uptake, accelerated photosynthetic activity, availability of optimum space for better crop growth,

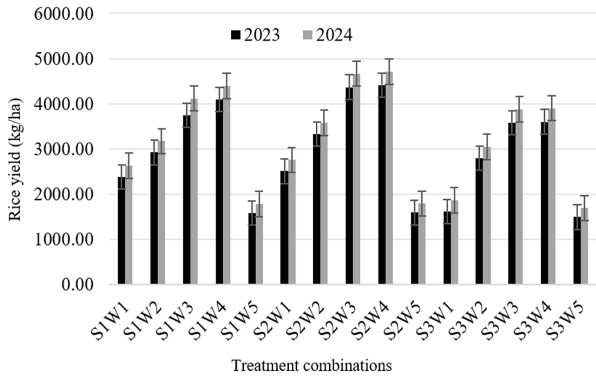

Figure 3. Interaction effect of sowing dates and weed management treatments on dry-seeded rice grain yield (refer table one for details of treatments)

resulting into higher dry matter accumulation and yield. The lowest yield was recorded under weedy check plot. The crop weed competition as a result of uninterrupted growth of weeds caused lower values of growth, yield attributes and yield of rice in unweeded check (Duary *et al.* 2016). The maximum gross return was with S_2W_4 [Timely sown (25th June) along with hoeing and weeding at 20 and 40 DAS]. The highest net return was recorded with S_2W_3 [Timely sown (25th June) along with application of pendimethalin 1.0 kg/ha at 3 DAS followed by 1 HW at 40 DAS]. Return/rupee invested was highest (2.55) with S_2W_3 [Timely sown (25th June) along with application of Pendimethalin 1kg/ha at 3 DAS followed by 1 HW at 40 DAS].

Thus, it may be concluded that the timely sowing (25th June) with pendimethalin 1.0 kg/ha PE *fb* one HW at 40 DAS is promising for attainment of effective weed management, higher rice productivity and profitability in dry direct-seeded rice in Odisha.

Table 3. Economics of dry direct-seeded rice as influenced by different treatment combination treatments (pooled mean of two years)

Treatment	Cost of cultivation (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	Return per rupee invested
S_1W_1	36626	60428	23802	1.65
S_1W_2	38115	72956	34841	1.91
S_1W_3	42026	97605	55579	2.32
S_1W_4	45506	100006	54500	2.20
S_1W_5	34706	40878	6172	1.18
S_2W_1	36626	63380	26754	1.73
S_2W_2	38115	82294	44179	2.16
S_2W_3	42026	107656	65330	2.55
S_2W_4	46506	108261	61755	2.33
S_2W_5	34706	41177	6471	1.19
S_3W_1	36626	42780	6154	1.17
S_3W_2	38115	69958	31843	1.84
S_3W_3	42026	89247	47221	2.12
S_3W_4	45506	89730	44224	1.97
S_3W_5	34706	38893	4187	1.12
LSD (p=0.05)	-	8249	8249	0.19

(Refer table one for details of treatments)

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RESEARCH ARTICLE

Impact of establishment methods and sequential herbicide application on weeds and productivity of rice

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ABSTRACT

Weed interference remains a major constraint to rice productivity under changing establishment methods and increasing labour and water scarcity. The objective of this study was to identify efficient rice establishment techniques and effective sequential herbicide application regimes to optimize weed control and improve rice productivity. The experiment was conducted in a split-plot design with three replications. The rice establishment methods, *viz.* conventional transplanting, direct dry-seeded rice, and wet-seeded rice were assigned to main plots and sequential herbicide application regimes along with weedy check and weed-free were allocated to subplots. Conventional transplanting of rice recorded the maximum rice grain yield recording a 16.5–18.5% yield increase over other establishment methods. Uncontrolled weed infestation caused severe yield losses of up to 42.3%. The pre-emergence application (PE) of pretilachlor 1000 g/ha at 3 days after transplanting (DAT)/seeding (DAS) followed by (*fb*) post-emergence application (PoE) of chlorimuron + metsulfuron 4 g/ha or bispyribac-sodium 25 g/ha at 30 DAS/DAT) were as effective as manual weeding and caused an increase in rice yield of about 69% over weedy check, while also curtailing weed seed production and thus gradually reducing the soil weed seed reserve.

Keywords: Dry-seeded rice, Sequential herbicides application, Transplanted rice, Wet-seeded rice, Weed management, Weed seed bank

INTRODUCTION

Rice remains vital for global food security, yet rice productivity faces increasing threats from weeds, labor scarcity and water deficits. The traditionally practiced puddled transplanted rice (PTR) suppresses weeds but was observed increasingly unsustainable (Manna 1991, Singh *et al.* 2005). Consequently, a strategic transition toward resource conservation technologies like dry direct-seeded rice (dry-DSR) and wet-seeded rice (WSR) is being opted by farmers (Rao *et al.* 2017). However, severe and diverse weed infestations remain the primary bottleneck for direct-seeded rice (DSR) (Rao *et al*. 2007). The magnitude of yield loss due to weeds varies with rice establishment method with yield reductions of 15–25% in TPR, 30–45% in wet-seeded rice (WSR) and 50–60% in DDSR (Rao *et al.* 2007, Rao *et al.* 2017a).

The sequential herbicide application has emerged as an alternative to manual weeding to manage weeds effectively and economically (Bhatt *et al.* 2017, Rathika *et al.* 2020). as the sequentially applied herbicides manage the weeds during critical period of early vegetative stages when competition for nutrients and Photosynthetically Active Radiation (PAR) is most intense. Beyond immediate yield protection, sequential herbicides application approach disrupts the “seed rain” that replenishes soil seed banks, ensuring long-term ecological management (Joshi *et al.* 2015). Hence, there is a critical need to identify sequential herbicides application options for different rice establishment methods to maximize rice productivity under current labour and water constraints. Thus, the present study was undertaken to evaluate the different sequential herbicide options suited to diverse rice establishment methods for optimizing weed control efficiency and rice productivity.

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MATERIALS AND METHODS

The field study was conducted over two consecutive summer cropping seasons: 2021–2022 and 2022–2023 at the College Farm, NMCA, Navsari Agricultural University (NAU), Navsari, Gujarat, India which is geographically situated in the South Gujarat Heavy Rainfall Zone (Agro-climatic Zone II).

The experimental soil was characterized as a deep black clayey textured soil (*Vertisol*) with poor drainage and good water holding capacity. Initial soil sampling (0–20 cm depth) revealed a consistent slightly alkaline soil reaction with an average pH of 7.85 and normal electrical conductivity (EC) averaging 0.36 dS/m, confirming non-saline conditions. The soil exhibited an average organic carbon content of 0.425% (classified as low to medium status). The available nutrient profile indicated specific fertility levels: the soil tested low in available nitrogen (average of 221.5 kg/ha), medium in available phosphorus (average of 38.5 kg/ha P) and was classified as fairly rich in available potassium (average of 387 kg/ha K).

The experiment was laid out in a split-plot design with four replications. The main plots comprised three establishment methods, while the sub-plots included five management treatments (**Table 1**). Herbicides were applied using a knapsack sprayer with a flat-fan nozzle, calibrated at 330 L/ha (PE) and 375 L/ha (PoE). These sequential regimes were hypothesized to provide early grass control followed by broad-spectrum suppression of late-emerging sedges and broad-leaf weeds during critical growth stages.

The rice cv. NAUR-1 was used that fertilized with 120 kg Nitrogen (N) and 30 kg Phosphorus (P)/ha. All phosphorus was applied as basal using single super phosphate. Nitrogen was applied as urea in three splits: 50% at planting, 25% at tillering, and 25% at panicle initiation. Water was kept at 2–3 cm during early growth, increased to 5 cm until the milking stage, and then kept at saturation until harvest. To maintain these levels, irrigation was provided every 4–5 days, totalling 23 times for DSR and 21 times for PTR.

Weed data was collected using a standard square quadrat (0.25 m²) placed randomly within plots. as the data on grasses, sedges and broad-leaved weeds (BLW) occurring in the plots were recorded. Relative density (RD) was determined following Misra (1968) to assess the numerical strength of individual species relative to the total community. Weed dry biomass (kg/ha) was recorded at harvest. Weeds were oven-dried at 65 ± 2°C for 24 hours until reaching a constant weight and weed dry biomass data was noted weed control efficiency (WCE) was calculated (Kondap and Upadhyay 1985). The weed index (WI) was calculated to quantify the percentage yield reduction in treated plots relative to the weed-free baseline. The soil weed seed bank was evaluated using the germination method. Representative 0.5 kg soil samples were extracted from 0–10 and 10–20 cm depths, processed, and incubated in petri plates under optimal moisture conditions for 15 days; germinated seedlings were recorded at 20 days to determine the seed count per kilogram of soil.

Statistical analysis was performed using the Statistical Tool for Agricultural Research (STAR) from IRRI (2014). Data were subjected to Analysis of Variance (ANOVA) for a split-plot design, with mean separation determined by the Least Significant Difference (LSD) at *P*=0.05. Weed density and biomass were statistically analysed by square root transformation ($\sqrt{x+0.5}$) to ensure normality.

Table 1. The details of rice establishment methods and weed management regimes tested

Method / Regime	Technical specifications	Application details
Main plot: rice establishment method (S)		
Dry direct- seeded rice (Dry-DSR)	Aerobic seedbed; 60 kg/ha seed rate; 30 cm line spacing	Sown at 2–3 cm depth; light irrigation post-sowing
Conventional puddled transplanted (PTR)	25-day-old seedlings; 30 kg/ha seed rate for nursery	Manual transplanting at 20 cm × 15 cm; 5 cm standing water
Wet-Seeded rice - Line Sown (WSR)	Pre-germinated seeds (6h soak, 24h incubate)	30 cm rows on saturated puddled soil; gradual water increase
Sub plot: weed management (W)		
Weedy check (control)	Maximum competition	No weed control interventions
Hand weeding twice	Weed-free check	Two manual weeding at 20–25 and 40–45 days after seeding (DAS)/ days after transplanting (DAT)
Herbicides sequential application regime I	Pre-emergence application (PE) of pretilachlor + fenclorim followed by (*fb*) post-emergence application (PoE) bispyribac-sodium	1000 g/ha 3 DAS/DAT followed by (*fb*) 25 g/ha 30 DAS/DAT
Herbicides sequential application regime II	Pyrazosulfuron-ethyl PE *fb* bispyribac-sodium PoE	15 g/ha 3 DAS/DAT *fb* 25 g /ha 30 DAS/DAT
Herbicides sequential application regime III	Pretilachlor + fenclorim PE *fb* (Chlorimuron + Metsulfuron) PoE	1000 g/ha 3 DAS/DAT *fb* 4 g /ha 30 DAS/DAT

RESULTS AND DISCUSSION

Weed flora

The experimental field was infested with a diverse weed community consisting of 21 weed species belonging to 11 families (**Table 2**). There were grasses (8 species), broad-leaved weeds (9 species), and sedges (4 species). Grasses were the most predominant group across all three establishment methods. In dry-DSR, grass RD increased from 63.9% to 68.5%, while in WSR, it rose from 53.9% to 60.9%. The highest overall grass pressure was observed in PTR, where RD surged from 59.6% to 72.7% by 40 DAS. *Echinochloa colona* emerged as the most dominant species in both dry-DSR and PTR, nearly doubling its density in PTR to 25.1%. However, in WSR, *Echinochloa crus-galli* was the primary competitor, reaching 15.2% due to its superior adaptation to saturated soil. Broad-leaved weeds constituted the second major group, with WSR maintaining the highest relative density (32.1% at 20 DAS to 28.1% at 40 DAS). This sustained presence in WSR was driven by moisture loving species such as *Marsilea quadrifolia* and *Alternanthera sessilis*. In contrast, the anaerobic puddled conditions of PTR effectively suppressed aerobic species like *Euphorbia hirta* and *Tridax procumbens*, leading to a significant decline in total BLW density to 20.4% by 40 DAS. Sedges maintained the lowest RD across all systems but showed distinct patterns by method. WSR recorded the highest initial sedge density at 14.0%, which gradually decreased to 11.0% by 40 DAS as grasses became more dominant. In dry-DSR, sedge RD remained relatively stable (moving from 10.0% to 9.4%), while it reached its minimum in PTR, dropping to 6.9%. While *Cyperus rotundus* persisted across all methods, moisture-loving sedges like *Cyperus iria* and *Fimbristylis miliacea* were significantly more prominent in the WSR system.

The grasses, *Echinochloa* spp. *B. ramose*; broad-leaved weeds, *A. sessilis* and *P. niruri* and sedges, *C. rotundus* and *C. difformis* were found to be the dominant weeds in puddled as well as un-puddled situations because they can tolerate and

Table 2. Weed flora and relative density (RD) of weeds in rice as influenced by establishment methods and sequential herbicide application (based on 2 years)

Scientific name	Common name	Family	Habitat	DSR - RD (%)						PTR-RD (%)	
				Dry-DSR	WSR	Mean*	Dry-DSR	WSR	Mean*		
				20 DAS			40 DAS			20 DAPTR	40 DAPTR
Grasses											
Echinochloa colona	Wild rice	*Poaceae*	*A, H, T, SU*	12.1	9.1	10.6	17.9	14.5	16.2	13.1	25.1
Echinochloa crus-galli	Barnyard grass	*Poaceae*	*A, H, T, SU*	8.7	12.5	10.6	6.0	15.2	10.6	7.1	6.8
Cynodon dactylon	Bermuda grass	*Poaceae*	*P, H, Cr, SU*	5.2	1.9	3.6	6.5	4.1	5.3	6.1	11.0
Eragrostis minor	Love grass	*Poaceae*	*A, H, T, SU*	9.0	6.6	7.8	11.2	8.4	9.8	11.1	0.0
Digitaria sanguinalis	Hairy crabgrass	*Poaceae*	*A, H, T, SU*	6.2	3.8	5.0	3.1	0.9	2.0	3.0	6.8
Dinebra retroflexa	Viper grass	*Poaceae*	*A, H, T, SU*	5.5	3.1	4.3	6.0	4.6	5.3	10.1	9.9
Brachiaria ramosa	Signal grass	*Poaceae*	*P, H, H, SU*	11.8	9.4	10.6	13.6	10.0	11.8	9.1	7.9
Dactyloctenium aegyptium	Crow foot grass	*Poaceae*	*A, H, T, SU*	5.3	7.5	6.4	4.2	3.2	3.7	0.0	5.2
				63.8	53.9	58.9	68.5	60.9	64.7	59.6	72.7
Broad-leaved weeds											
Alternanthera sessilis	Alligator weed	*Amaranthaceae*	*A/P, H, T, SU*	4.5	6.9	5.7	10.8	9.6	10.2	5.1	2.6
Marsilea quadrifolia	Water clover	*Marsileaceae*	*P, H, Cr, SU*	0.8	3.6	2.2	1.2	6.2	3.7	5.1	3.7
Phyllanthus niruri	Gale of the wind	*Phyllanthaceae*	*A, H, T, SU*	6.8	4.6	5.7	1.8	0.6	1.2	7.1	5.2
Euphorbia hirta	Milk weed	*Euphorbiaceae*	*A, H, T, SU*	3.2	1.0	2.1	2.0	0.4	1.2	0.0	0.0
Portulaca oleracea	Common purslane	*Portulacaceae*	*A, H, T, SU*	3.5	2.1	2.8	2.4	1.6	2.0	7.1	2.1
Commelina benghalensis	Wandering jaw	*Commelinaceae*	*P, H, Cr, SU*	3.1	5.5	4.3	1.4	2.6	2.0	1.0	2.1
Tridax procumbens	Tridax daisy	*Asteraceae*	*A/P, H, T, SU*	3.2	2.4	2.8	1.1	1.3	1.2	0.0	0.0
Physalis minima	Ground cherry	*Solanaceae*	*P, H, T, SU*	0.4	2.4	1.4	0.6	1.8	1.2	2.0	1.6
Digera arvensis	Digera kondra	*Amaranthaceae*	*A, H, T, SU*	0.6	3.6	2.1	0.8	4.0	2.4	3.0	3.1
				26.1	32.1	29.1	22.1	28.1	25.1	30.4	20.4
(C) Sedges											
Cyperus rotundus	Purple nut sedge	*Cyperaceae*	*A/P, H, T, SU*	6.5	4.9	5.7	4.0	3.4	3.7	4.0	3.2
Cyperus difformis	Umbrella sedge	*Cyperaceae*	*P, H, Cr, SU*	0.4	1.0	0.7	4.0	3.4	3.7	1.0	0.5
Cyperus iria	Flat sedge	*Cyperaceae*	*A, H, T, SU*	1.8	5.2	3.5	0.4	2.0	1.2	2.0	1.6
Fimbristylis miliacea	Globefingerush	*Cyperaceae*	*A, H, T, SU*	1.4	2.9	2.2	1.0	2.2	1.6	3.0	1.6
				10.1	14.0	12.1	9.4	11.0	10.2	10.0	6.9

*__A__: Annual; **P**: Perennial; **A/P**: Annual/Perennial; **H**: Herb; **T**: Therophytes; **Cr**: Cryptophytes; **Hc**: Hemicryptophytes; **SU**: Summer; **DSR**: Direct seeded rice; **WSR**: Wet-Seeded rice **PTR**: Transplanted rice; **RD**: Relative weed density, ***Mean**: Average of Dry DRS and WSR to compare PTR rice and DSR establishment methods.

flourish easily under submerged conditions as that of paddy. Similar weed flora was reported earlier under puddled conditions (Subbulakshmi and Pandian 2002), in transplanted rice and in direct-seeded rice (Rekha *et al.* 2002). Parameshwari and Srinivas (2014) also reported the dominance of grasses followed by BLWs and sedges. The habitat analysis indicated that the majority of these weeds are adapted to both aquatic and terrestrial environments, making them highly competitive in both DSR and PTR systems. Overall, DSR supports higher initial weed diversity, whereas the PTR system exerts selective pressure favoring grasses, specifically *Echinochloa* species.

Effect on weeds

The conventional transplanted rice significantly minimized grasses, BLWs and sedges at 20 and 40 DAS/DAT compared to dry-DSR and WSR systems (**Table 3**). Among herbicide treatments, pretilachlor PE *fb* bispyribac-sodium PoE recorded significantly lower weed density and biomass at 20 and 40 DAS/DAT, tailed significantly by pyrazosulfuron-ethyl PE *fb* bispyribac-sodium PoE and pretilachlor PE *fb* (chlorimuron-ethyl + metsulfuron-methyl) PoE. These sequential regimes proved superior to the weedy check. The sequential regime of pretilachlor PE *fb* bispyribac-sodium PoE emerged as the most effective treatment, in minimising the sedge density and biomass at 40 DAS/DAT and was proved statistically superior to the hand weeding twice. intervention

The reduction in weed pressure (grasses, BLWs and sedges) under conventional transplanting is due to puddling which induced seed burial and the maintenance of an anaerobic environment. These conditions inhibit the germination of photoblastic and oxygen sensitive species (Singh *et al.* 2005, Mandal *et al.* 2013). Additionally, the initial vigour of young seedlings ensures early niche occupancy, providing a competitive advantage in light and nutrient sequestration that stifles weed development (Baloch *et al.* 2006, Subbaiah and Kumar 2011).

Sequential herbicide regimes provided an extended "protection window" (Kumar *et al.* 2017). Pretilachlor PE *fb* bispyribac-sodium PoE proved superior for grasses and sedges, while pyrazosulfuron-ethyl PE *fb* bispyribac-sodium PoE excelled against broad-leaved weeds. However, this efficacy was selective; while it neutralized aggressive species like *Echinochloa*, it did not offer universal control across all taxa. Dry DSR presented a greater challenge due to aerobic diversity, unlike PTR, where puddling-induced seed burial and crop vigour provided a natural advantage that complemented the chemical barrier. Subsequent PoE applications neutralized escapes by inhibiting the ALS enzyme, disrupting the "seed rain" that replenishes the soil seed bank (Joshi *et al.* 2015, Shah and Negi 2024).

It was cleared that, weeds were present in the hand weeding treatment due to the strategic timing of data collection relative to field operations. At 20 DAS, the weed density was recorded immediately before the first scheduled weeding (20–25 DAS) to accurately quantify the initial weed pressure the crop faced since sowing, whereas at 40 DAS, the weed density captured the "second flush" of weeds—newly germinated seedlings that emerged after the first weeding, prior to the second scheduled intervention at 40–45 DAS.

At harvest, the lowest biomass and highest WCE (83.6%) was recorded with two hand weeding, closely followed by the sequential application of pretilachlor PE *fb* chlorimuron-ethyl + metsulfuron-methyl PoE. The sequential herbicidal approach (PE *fb* PoE) maintains long-term suppression by neutralizing staggered weed flushes. Initial application of pretilachlor or pyrazosulfuron-ethyl secures an early resource-dominant niche for the crop by eliminating the primary flush of weed competitors (Bhatt *et al.* 2017). Subsequent intervention with bispyribac-sodium or chlorimuron + metsulfuron arrested the development of late-emerging weeds. This overlapping control window prevents weeds from transitioning into significant vegetative stages, ensuring that vital nutrients and PAR (Photosynthetically Active Radiation) are partitioned toward grain yield rather than being sequestered in weed biomass (Pal *et al.* 2012, Sunil *et al.* 2010).

Pooled data indicated that pretilachlor 1000 g/ha PE *fb* chlorimuron-ethyl + metsulfuron-methyl 4 g/ha PoE recorded the lowest weed index (2.36%), indicating maximum yield shield (**Table 3**). This was closely followed by pretilachlor 1000 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE with a WI of 2.88%. In contrast, the weedy check exhibited the highest crop-weed competition, resulting in a 42.29% grain yield loses. The minimal WI in sequential herbicidal treatments is attributed to significantly reduced weed biomass and superior weed control efficiency. By mitigating crop-weed competition during the critical growth stages, these regimes ensured optimal resource availability for grain filling and yield development (Bhambri and Kolhe 2006, Patel *et al.* 2018a). Conversely, the substantial yield attrition in the weedy check was a direct consequence of unrestricted weed establishment, which intensified competition for solar radiation, nutrients, and moisture, thereby limiting the crop's reproductive potential (Joseph *et al.* 2008, Ravisankar *et al.* 2008, Patel *et al.* 2018).

Effect on rice

Rice establishment methods significantly influenced rice productivity, and conventional transplanting produced significantly the highest grain yield with 18.5% and 16.5% increase over dry direct-seeded and WSR methods, respectively (**Table 3**). Unlike direct-seeded systems, where seedlings face immediate inter-specific competition and abiotic stress, transplanted seedlings benefit from a controlled nursery period. This "head start" facilitates a more robust root-to-shoot ratio, allowing for optimized PAR interception. superior Leaf Area Index (LAI) that promotes more efficient dry matter partitioning towards the panicles, maximizing the number of filled spikelets per unit area (Subramanian *et al.* 2006).

Weed management treatments significantly influenced grain productivity with the weedy check suffering the most substantial losses. In contrast, two hand weeding produced significantly higher grain yield. Among herbicide treatments, pretilachlor PE *fb* chlorimuron + metsulfuron PoE and pretilachlor PE *fb* bispyribac-sodium PoE were statistically at par with manual weeding. This lack of significant difference between sequential herbicides and hand weeding underscores the high technical efficiency of these herbicides in keeping a negligible weed-to-crop competition during the critical period and preventing the sequestration of essential mobile nutrients (N, P, K) by weed biomass (Chopra and Angiras 2008). The early-season suppression provided by pretilachlor, followed by post-emergence follow-up applications prevents competition for light and nutrients that led to a 42.29% yield loss in the weedy check by limiting panicle length and grain filling (Khare *et al.* 2014).

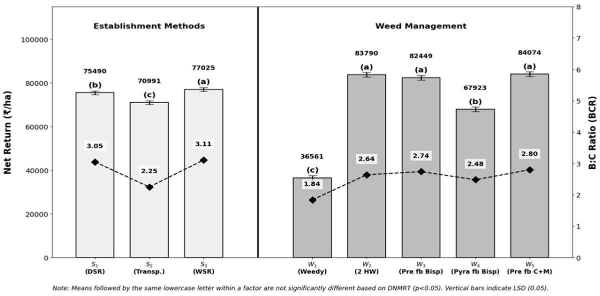

Figure 1. Impact of rice establishment methods and weed management on net returns and B:C ratio

(Bars represent net return (Rs/ha) on the primary axis; the line with markers represents the Benefit-Cost (B:C) ratio on the secondary axis. S_1: direct seeded rice, S_2: conventional transplanting, S_3: sprouted seed line sowing. W_1: weedy check, W_2: two hand weedings, W_3: pretilachlor *fb* bispyribac-sodium, W_4: pyrazosulfuron-ethyl *fb* bispyribac-sodium, W_5: pretilachlor *fb* chlorimuron + metsulfuron-methyl).

Economics

Among the evaluated treatments, line sown wet-seeded rice (WSR) was the most economically efficient, achieving a significantly superior net return with B:C ratio of 3.11. While dry direct-seeded rice (dry-DSR) followed closely in net return with a B:C

Table 3. Weed density, biomass, rice grain yield and weed indices in rice as influenced by establishment methods and sequential herbicide regimes (pooled data)

Treatment	Weed density (no./m^2)						Weed dry biomass (kg/ha)	WCI (%)	WI (%)	Grain yield (t/ha)
	20 DAS/DAT			40 DAS/DAT						
	Grasses	BLWs	Sedges	Grasses	BLWs	Sedges				
Main plot: methods of establishment										
Dry direct-seeded rice	4.63(23.9)	3.03(10.7)	2.36(5.3)	4.03(22.5)	2.90(10.0)	2.39(5.8)	19.40(461)	62.5	15.63	4.37
Conventional transplanted rice	3.98(16.8)	2.56(7.1)	1.96(3.5)	3.57(18.7)	2.60(7.5)	1.96(3.5)	17.15(334)	72.8	--	5.18
Wet-seeded rice (line sown)	4.47(21.8)	2.90(9.6)	2.30(5.0)	3.99(22.3)	2.87(9.7)	2.38(5.7)	19.14(448)	63.5	14.14	4.45
LSD (p=0.05)	0.26	0.20	0.14	0.21	0.15	0.18	0.96	--	--	0.21
Sub plot: weed management										
Weedy check	6.19(38.2)	4.40(19.1)	2.70(7.0)	8.93(79.4)	5.36(28.5)	3.22(10.3)	34.80(1228)	0.0	42.29	3.08
Hand weeding	6.04(36.4)	4.27(18.0)	2.44(5.6)	3.43(11.4)	2.39(5.3)	2.37(5.3)	14.22(202)	83.5	---	5.34
Pretilachlor PE *fb* bispyribac-sodium PoE	3.08(9.1)	1.82(2.9)	1.90(3.2)	2.14(4.3)	2.15(4.2)	1.80(2.8)	14.57(213)	82.6	2.88	5.18
Pyrazosulfuron PE *fb* bispyribac-sodium PoE	3.31(10.6)	1.76(2.7)	2.02(3.6)	2.33(5.1)	1.97(3.5)	1.99(3.6)	14.74(219)	82.2	15.17	4.53
Pretilachlor PE *fb* (chlorimuron + metsulfuron) PoE	3.19(9.8)	1.87(3.1)	1.98(3.5)	2.49(5.7)	2.08(3.9)	1.86(3.0)	14.49(210)	82.9	2.36	5.21
LSD (p=0.05)	0.32	0.13	0.21	0.34	0.18	0.22	0.82	—	—	0.18

Note: *data in parentheses are original values; those outside are ($\sqrt{x+0.5}$) transformed values.
BLW: broad-leaved weeds; **DAS/T**: days after sowing/transplanting; ***fb***: followed by; **WCI**: weed control index; **WI**: weed index; **PE** = pre-emergence application; **PoE** = post-emergence application

Table 4. Percent reduction/increase in weed seed bank influenced by rice establishment and sequential herbicidal regimes (pooled data)

Treatment	0-10 cm Initial	0-10 cm Final	vs. control (%)	10-20 cm Initial	10-20 cm Final	vs. control (%)
Main plot: methods of establishment (S)						
Dry direct-seeded rice	46.59	47.05	+11.36	26.51	26.61	+12.47
Conventional transplanted rice	46.77	42.25	--	26.62	23.66	--
Wet-seeded rice (line sown)	45.04	45.30	+7.22	25.51	25.76	+8.88
LSD (p=0.05)	NS	1.61		NS	1.00	
Sub plot: weed management (W)						
Weedy check	44.76	51.68	--	25.33	29.47	--
Hand weeding	47.47	41.25	-20.18	27.08	23.14	-21.48
Pretilachlor PE *fb* bispyribac-sodium PoE	45.39	43.07	-16.16	25.74	24.26	-17.68
Pyrazosulfuron PE *fb* bispyribac-sodium PoE	46.36	46.55	-9.93	26.36	26.30	-10.17
Pretilachlor PE *fb* (chlorimuron + metsulfuron) PoE	46.67	41.76	-19.20	26.56	23.56	-20.05
LSD (p=0.05)	NS	1.85		NS	2,14	

Note: Initial and Final data represent weed seed bank (seeds/kg of soil) before sowing and after harvest, respectively (pooled data). **vs. Control (%)**: Percent difference calculated using Conventional Transplanted Rice as the control for main plots and Weedy Check as the control for sub-plots; (+) values indicate a higher seed bank than the control, while (-) values indicate a lower seed bank than the control. **PE** = pre-emergence application; **PoE** = post-emergence application, ***fb***: followed by; **NS**: Non-significant

ratio of 3.05. In contrast, conventional transplanting recorded the lowest net return and B:C ratio (2.25); despite producing the highest grain yield, the excessive labour and input costs associated with the transplanting process drastically reduced the final profit margin compared to both wet-seeding and dry direct-seeding of rice.

Significantly higher net return and B:C ratio (2.80) were recorded with the sequential application of pretilachlor PE *fb* chlorimuron-ethyl + metsulfuron-methyl PoE, whoever remained statistically at par with hand weeding twice and pretilachlor *fb* bispyribac-sodium PoE. Moreover, herbicide-based sequences demonstrated a significantly higher B:C ratio than manual weeding, which was hampered by high labour costs (2.64). Further, sequential application of pyrazosulfuron-ethyl PE *fb* bispyribac-sodium recorded a relatively lower net return. Contrary to this, weedy check recorded the lowest B:C ratio (1.84), highlighting the shocking economic impact of uncontrolled weed competition on final rice profitability.

Weed seed bank

Initial weed seed bank density (**Table 4**) was uniform across depths. Post-harvest, the weedy check showed a 15.46% increase in weed seed, whereas the lowest final seed banks were recorded with hand weeding and sequential herbicide application. Approximately 63-65% of seeds were concentrated in the surface layer (0-10cm), a distribution typical of rice systems with minimal soil inversion (Misra 1968, Rao *et al.* 2017).

Establishment via conventional transplanting and sequential application of pretilachlor PE *fb* chlorimuron + metsulfuron PoE effectively depleted the seed bank by 9.66% and 19.20% (vs. their respective controls). The superiority of transplanting (PTR) is attributed to the puddling process, which buries seeds deeper and induces anaerobic decay or fatal germination (Mandal *et al.* 2013, Singh *et al.* 2005). Conversely, the aerobic environment in dry direct-seeded rice favoured seed bank replenishment (Chauhan 2012). The efficacy of sequential herbicide resulted from "overlapping" control by pre- and post-emergence herbicides, which eliminated late-season weed flushes and prevented "seed rain" into the soil reservoir (Joshi *et al.* 2015, Shah and Negi 2024). This suppression of the active seed bank is essential for reducing the long-term weed pressure in non-puddled intensification systems (Rathika *et al.* 2020).

Conclusion

Sequential application of pretilachlor PE followed by chlorimuron + metsulfuron PoE or bispyribac-sodium PoE proved statistically comparable to manual weeding twice, in managing weeds and achieving substantial yield gains while minimizing weed seed rain and progressively depleting the soil weed seed bank. This suppression of seed bank replenishment is central to long-term sustainability and the successful intensification of direct-seeded rice systems.

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RESEARCH ARTICLE

Weed management and yield of *Kharif* hybrid maize as affected by post-emergence herbicides and plant growth promoters

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ABSTRACT

A field experiment was conducted during two consecutive *Kharif* seasons (2022 and 2023) at the Students' Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur Uttar Pradesh, India, to study the effect of post-emergence herbicides and plant growth promoters in managing weeds and improve productivity of *Kharif* maize (*Zea mays* L.). On the pooled data basis, the application of Amino acid + Humic acid + Sea weed extract 2ml/liter of water recorded significantly highest values of maize growth attributes, *viz.* plant height, dry weight and leaf area index at 90 days after seeding (DAS) and yield attributes, *viz.* number of cob/plants, number of grain rows/cob, number of grains/row and seed index along with maize grain yield and harvest index. Among herbicidal treatments, tembotrione at 120 g/ha significantly reduced total weed density, fresh weight and dry weed biomass, and recorded the highest weed control efficiency (85.92%). It also recorded maximum growth attributes, improved yield attributes and higher grain yield, harvest index and benefit-cost ratio. There was no substantial interaction between herbicide treatments and plant growth regulators.

Keywords: Amino acid, Humic acid, Maize, Tembotrione, Weed management and Sea weed extract

INTRODUCTION

Maize (*Zea mays* L.) is the veritably most important cereal crop in the world with enormous yield potential. It occupies a central place in global agriculture, ranking third after rice and wheat in total production, but surpassing both in productivity potential. Globally, during 2022-23 around 200.53 million hectares area is under maize along with 1157.53 million tonnes production and 5.7 t/ha productivity (USDA 2024). In India around 11.24 million hectares area is under maize with 37.66 million tonnes production and 3.35 t/ha productivity in 2023-24 (DA&FW 2025). A major source of food for people, feed for fish and cattle, and a vital raw material for a variety of businesses, maize is an important cereal on a global scale. In addition to significant levels of vitamin A, nicotinic acid, phosphorus, riboflavin, and vitamin E, its grains have around 10% protein, 4% oil, 70% carbs, 2.3% crude fibre, 10.4% albuminoids and 1.4% ash. Additionally, maize offers cattle a plenty of green forage. Because of its versatility, it is widely grown in a variety of agro-ecological zones and is a crucial industrial feedstock for the production of ethanol and a number of value-added goods, including corn oil, flour, syrups, flakes, cosmetics, wax and tanning agents.

Maize cultivation often suffers from weak early growth, inadequate root development, low nutrient uptake and reduced photosynthesis, while drought, heat, salinity and nutrient deficiencies intensify stress, weaken crop vigor and significantly reduce yield potential. According to Etesami and Maheshwari (2018), the use of plant growth boosters has demonstrated encouraging results in increasing maize growth metrics like shoot length, root development, leaf area, and eventually yield. It has been demonstrated that plant growth promoters greatly increase the efficiency of nutrient uptake, especially for nitrogen, phosphorus, and potassium, all of which are critical for the growth of maize. Additionally, they strengthen maize's resistance to harsh climatic circumstances by making it more resilient to abiotic stresses such salinity, drought, and high temperatures (Iqbal *et al.* 2023).

Rainy-season maize experiences intense weed competition depending on weed density, type, growth stage and duration, causing yield losses of 28–100% (Patel *et al.* 2006). Wider spacing and slow initial

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growth during the *Kharif* season further aggravate infestation. Weeds also deplete 30–40% of available nutrients and utilize a major portion of applied fertilizers, thereby reducing nutrient-use efficiency and limiting crop access to essential growth factors. Consequently, maize growth and productivity decline severely if weeds remain unchecked (Ramesh *et al.* 2017). Herbicides play a crucial role in weed suppression by targeting specific weed species while minimizing adverse effects on maize plants (Abbas *et al.* 2018). Halosulfuron-methyl is a selective, systemic post-emergence herbicide effective against *Cyperus rotundus* in maize (Chand *et al.* 2014). Topramezone controls broad-leaved and narrow-leaved weeds, while atrazine, a triazine herbicide, is widely used as pre- and early post-emergence, absorbed through roots and foliage (Singh 2018). The premix mesotrione + atrazine provides long-lasting control of grasses and broad-leaved weeds (Singh *et al.* 2024). Thus, the combined use of herbicides for effective weed control and foliar application of plant growth promoters enhances crop physiology, supports better plant growth, and ultimately improves maize productivity and yield potential. This study was conducted to assess the effect of post-emergence herbicides and plant growth promoters in managing weeds and improve productivity of *Kharif* maize.

MATERIALS AND METHODS

The field experiment was conducted during the *Kharif* seasons of 2022 and 2023 at the Students' Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India, which is situated 26.4148^0 North latitude, 80.2321^0 East longitude and at the 125.9 meters above sea level in the alluvial tract of Indo - Gangetic Plain zone of central part of Uttar Pradesh. The farm was well equipped with adequate and reliable irrigation facilities. The experiment was laid out in a Split Plot Design, with plant growth promoters allocated to the main plots and herbicides to the subplots. Eighteen treatment combinations were replicated three times. The experimental setup included three plant growth promoters, *viz.* gibberellic acid at 2 ml/liter of water (P_1), cytokinin + enzymes at 2ml/liter of water (P_2) and amino acid + humic acid + sea weed extract at 2 ml /liter of water (P_3) along with six herbicides, *viz.* weedy check, tembotrione 42% SC (tembotrione) at 120 g/ha, halosulfuron-methyl 75% WG (halosulfuron-methyl) at 72 g/ha, topramezone 33.6 SC (topramezone) at 25.2 g/ha, atrazine 50%WP (atrazine) at 1.0 kg /ha and mesotrione + atrazine (pre-mix) at 750 g/ha. The seeds of maize variety DKC-9144 were sown at the depth of 5 cm, at the rate of 25 kg/ha, with 50 × 20 cm spacing using seed drill. The crop was sown on 7th July during 2022 and 17th July during 2023. The experimental field had silty loam soil with 0.37% and 0.34% organic carbon, 179.5 and 152.2/ kg/ha available N, 12.5 and 13/ kg/ ha available P, 142.0 and 139.0/ kg/ha available K and pH 7.7 and 7.7 in 2022 and 2023, respectively. The recommended dose of nutrients was 120 kg N, 60 kg P, 40 kg K and 25 kg zinc sulphate per hectare through urea, di-ammonium phosphate, muriate of potash and heptahydrate zinc sulphate. One third dose of nitrogen, entire amount of phosphorus, potassium and zinc sulphate were applied below the seeds at the time of sowing. Remaining nitrogen was applied in two equal splits at knee height and tasselling stage. Plant growth promoters (2 ml/liter of water) were applied in two equal splits at knee-height and silking stages. As per the treatments, all herbicides were applied as post-emergence sprays at 25 DAS in aqueous solution using 400 liters of water/hectare. The required quantities of herbicides and water were calculated carefully according to the gross plot area and were sprayed uniformly using a knapsack sprayer fitted with a flat-fan nozzle. The crop was harvested at full maturity stage on October 25th in 2022 and November 2nd in 2023.

At 25, 50, 75 and 90 DAS the number of individual weeds was recorded by using a quadrat of 0.5 × 0.5 m from the area marked for observations. Weed species present within three randomly selected 0.5 × 0.5 m quadrat in each net plot area were counted separately, converted into number of weeds / m^2. For dry weight of weed the samples were dried under shade for 24 hours, followed by oven dried at ± 70 p C till constant weight was achieved. Then dried weed samples weighed done on pan balance and the weight was expressed as weed biomass (g/m^2) before subjecting to statistical analysis. The data on density of weed species and their fresh and dry biomass were analyzed after square root transformation ($r = \sqrt{(x+1)}$). The treatment comparisons were made at 5% level of significance.

Weed control efficiency (WCE) is usually determined by calculating weed dry biomass recorded from each treatment by utilizing the formula-

$$W.C.E\ (\%) = \frac{Wo - Wt}{Wo} \times 100$$

where,

W_0 = weed dry biomass of weedy check plot (g/m^2)

W_t = weed dry biomass of treated plot (g/m^2)

The plant height of selected plants was measured with the help of meter scale from ground level to the tip of the newly emerged leaf before tasselling while after tasselling it was measured from ground level up to the ligule of the upper most fully opened leaf. Average plant height was worked out in cm. For dry weight the samples were dried in sun for few days and then in electric oven for constant drying at 65 p C temperature for 24-48 hours. After drying weight of this sample was done on physical balance and figures obtained were used for computing dry weight per plant.

Five plants were selected randomly and the leaves were detached and categorized into small, medium and large size group. The total leaf area of the sample was calculated by multiplying the mean leaf area value by total number of leaves in each category and summing them up. Leaf area index was computed taking into account, the area occupied by each plant as per the following formula (Watson 1952).

Leaf area = K × length of leaf × width of leaf

where,

K = constant or factor (0.75).

$$LAI = \frac{\text{Total leaf area of plant}}{\text{Ground area}}$$

Harvest index was calculated by the formula (Donald and Hamblin, 1976).

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

where,

Economic yield = Grain yield (kg/ha)

Biological yield = Grain yield + Stover yield (kg/ha)

Recorded data was analysed using appropriate method of 'Analysis of Variance (ANOVA)' given by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect on weeds

The experimental field was infested with several weed species, *viz. Echinochloa colona* (16.10%), *Digitaria sanguinalis* (8.41%), *Dactyloctenium aegyptium* (8.63%). and *Eleusine indica* (3.08%) were among grassy weeds. Broad-leaved weeds, *viz. Trianthema portulacastrum* (15.38%), *Digera muricata* (9.11%), *Commelina benghalensis* (9.94%), *Phyllanthus niruri* (2.41%), *Cucumis melo* (2.48%) and *Convolvulus arvensis* (1.76%) were dominant. *Cyperus rotundus* (22.66%). was the only sedge.

Analysis of the pooled data revealed that the application of plant growth promoters did not show any significant variation in the weed parameters.

The weed density (no./m^2) was significantly influenced by the application of herbicides in *kharif* maize (**Table 1**). The density of *Cyperus rotundus* was significantly reduced by halosulfuron-methyl 72 g/ha as compared to other treatments. It inhibits the acetolactate synthase (ALS) enzyme, crucial for the synthesis of branched-chain amino acids, leading to the cessation of cell division and effectively translocate to underground tubers of sedges and suppresses reserve food and regrowth plant growth, ultimately killed the weed (Dey *et al.* 2018, Kumar 2018 and Patil *et al.* 2017). Among herbicidal treatments, tembotrione 120g/ha has significantly reduced the density of grassy weeds (*Echinochloa colona, Digitaria sanguinalis* and *Dactyloctenium aegyptium*) and broad-leaved weeds (*Trianthema portulacastrum, Digera muricata* and *Commelina benghalensis*) and other weeds over other treatments. However, mesotrione + atrazine 750 g/ha was found at par with tembotrione 120 g/ha. Similarly, in case of total weed density, fresh and dry weed biomass were significantly reduced by tembotrione 120 g/ha, while the maximum fresh and dry weed biomass were recorded under weedy check (**Table 2**). Tembotrione, a selective post-emergence herbicide, targets broad-leaved and grassy weeds by inhibiting the 4-hydroxyphenylpyruvate dioxygenase (HPPD) enzyme, disrupting carotenoid biosynthesis and leading to chlorosis and eventual weed death (Balaji *et al.* 2023, Kumar and Chawla 2019 and Mali *et al.* 2019). Mesotrione + atrazine 750 g/ha effectively checked early emerging broad-leaved and grassy weeds by inhibiting carotenoid formation and photosynthesis, resulting in reduced weed density and improved crop growth throughout the critical period (Chhokar *et al.* 2019). Among herbicidal treatment, tembotrione 120 g/ha recorded significantly higher weed control efficiency (85.92% at 90 DAS) in maize due to its strong post-emergence activity against dominant grassy and broad-leaved weeds (Singh 2024 and Kaur *et al.* 2018).

Effect on maize

The pooled data clearly indicate that different plant growth promoters and herbicides had significant influence on the growth characteristics of maize (**Table 2**). Amino acid + humic acid + sea weed extract 2 ml/liter of water recorded significantly maximum maize plant height and dry weight at 90 DAS. Amino acids enhance nutrient uptake by chelating nutrients, making them more available, while humic acid releases essential nutrients, reduces transpiration, improves stomatal conductance and promotes plant growth (Maurya *et al.* 2025 and Wang *et al.* 2021).

In herbicidal treatments, tembotrione 120g/ha in *Kharif* maize recorded significantly maximum maize plant height, dry weight and leaf area index at 90 DAS (**Table 2**) due to its superior weed control, which reduces competition for space, light, moisture and nutrients. Better root development, effective nutrient uptake, enhanced photosynthesis and increased assimilate accumulation are all facilitated by this favourable environment, which raises plant height, increases biomass production and improved maize growth performance (Mhlanga *et al.* 2016).

Table 1. Effect of plant growth promoters and herbicides on weed density at 90 DAS in *Kharif* maize (pooled data of two years)

Treatment	Weed density (no./m^2) at 90 DAS							
	Cyperus rotundus	*Digitaria sanguinalis*	*Echinochloa colona*	*Dactyloctenium aegyptium*	*Digera muricata*	*Commelina bengalensis*	*Trianthema portulacastrum*	Other weeds
Plant growth promoters (a)								
Gibberellic acid 2 ml /liter of water	3.41(11.12)	1.76(2.31)	2.40(5.24)	1.85(2.65)	1.88(2.74)	1.83(2.64)	2.29(4.59)	1.81(2.60)
Cytokinin + enzymes 2 ml /liter of water	3.41(11.08)	1.77(2.37)	2.41(5.27)	1.81(2.47)	1.89(2.77)	1.84(2.69)	2.30(4.67)	1.84(2.60)
Amino acid + humic acid + sea weed extract 2 ml /liter of water	3.39(10.96)	1.75(2.28)	2.39(5.25)	1.83(2.57)	1.88(2.72)	1.82(2.65)	2.26(4.50)	1.82(2.62)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Herbicide (b)								
Weedy check	4.02(15.14)	2.57(5.62)	3.43(10.76)	2.60(5.77)	2.66(6.09)	2.76(6.64)	3.36(10.28)	2.74(6.50)
Tembotrione 120 g/ha	3.37(10.35)	1.36(0.85)	1.73(1.99)	1.37(0.88)	1.50(1.26)	1.37(0.89)	1.50(1.26)	1.38(0.90)
Halosulfuron-methyl 72 g/ha	2.14(3.59)	2.25(4.05)	3.29(9.81)	2.32(4.40)	2.34(4.45)	2.46(5.05)	2.68(6.18)	2.43(4.90)
Topramezone 33.6 25.2 g/ha	4.01(15.07)	1.45(1.09)	2.05(3.19)	1.56(1.43)	1.58(1.51)	1.44(1.07)	1.74(2.02)	1.45(1.09)
Atrazine 1.0 kg/ha	3.98(14.81)	1.53(1.34)	2.13(3.52)	1.67(1.78)	1.66(1.76)	1.51(1.29)	2.10(3.41)	1.53(1.34)
Mesotrione + atrazine 750 g/ha	2.89(7.38)	1.41(0.97)	1.79(2.22)	1.45(1.11)	1.55(1.40)	1.42(1.02)	2.31(4.37)	1.43(1.05)
LSD (p=0.05)	0.115	0.050	0.083	0.054	0.055	0.048	0.089	0.059
Interaction (A × B)								
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Note: LSD, least significant difference at the 5% level of significance; the values in parentheses represent the original data, while the values without parentheses are the transformed data, DAS=Days after sowing.

Table 2. Effect of plant growth promoters and herbicides on total weed density, fresh and dry weed biomass, weed control efficiency, maize plant height, dry weight per plant and leaf area index in *Kharif* maize (pooled data of two years)

Treatment	Total weed density (no./m^2) at 90 DAS	Fresh weed biomass (g/m^2) at 90 DAS	Dry weed biomass (g/m^2) at 90 DAS	Weed control efficiency (%) at 90 DAS	Maize plant height (cm) at 90 DAS	Dry weight of plant maize (g) at 90 DAS	Maize leaf area index at 90 DAS
Plant growth promoters (a)							
Gibberellic acid 2 ml/liter of water	5.76(33.9)	11.56(154.0)	7.04(55.6)	58.18	193.15	264.24	4.90
Cytokinin + enzymes 2 ml/liter of water	5.77(34.0)	11.52(152.8)	7.09(56.3)	57.26	198.05	269.91	5.01
Amino acid + humic acid + sea weed extract 2 ml/liter of water	5.72(33.6)	11.51(153.4)	6.97(54.5)	58.28	200.04	276.97	5.06
LSD (p=0.05)	NS	NS	NS	NS	4.90	9.27	NS
Herbicide (b)							
Weedy check	8.23(66.8)	19.40(375.8)	11.53(132.0)	0.00	168.56	240.53	4.51
Tembotrione 120 g/ha	4.40(18.4)	7.11(49.6)	4.42(18.5)	85.92	208.74	287.01	5.23
Halosulfuron-methyl 72 g/ha	6.59(42.4)	16.27(264.0)	9.72(93.5)	28.94	192.75	260.51	4.91
Topramezone 25.2 g/ha	5.24(26.5)	8.69(74.7)	5.38(28.0)	78.73	203.49	277.44	5.10
Atrazine 1.0 kg/ha	5.50(29.2)	9.71(93.3)	6.15(36.8)	72.01	201.97	273.72	5.04
Mesotrione + atrazine 750 g/ha	4.53(19.5)	7.99(62.9)	4.99(23.9)	81.83	206.95	283.01	5.16
LSD (p=0.05)	0.112	0.416	0.236	2.64	7.50	15.62	0.28
Interaction (A × B)							
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS

Note: LSD, least significant difference at the 5% level of significance; the values in parentheses represent the original data, while the values without parentheses are the transformed data, DAS=Days after sowing.

Table 3. Effect of plant growth promoters and herbicides on maize yield attribute, yield and B:C ratio in *Kharif* maize (pooled data of two years)

Treatment	No. of cobs/ plant	No. of grain rows/cob	No. of grains/ row	Seed index 100 seed weight (g)	Grain yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)	B:C ratio
Plant growth promoters (A)								
Gibberellic acid 2ml /liter of water	1.10	13.06	37.27	26.33	6493	12502	33.95	2.96
Cytokinin + enzymes 2 ml /liter of water	1.15	14.01	38.73	26.62	6680	12727	34.20	2.97
Amino acid + humic acid + sea weed extract 2 ml/liter of water	1.21	14.42	39.57	26.83	6836	12995	34.26	3.14
LSD (p=0.05)	NS	0.96	1.73	NS	167	NS	NS	0.05
Herbicide (B)								
Weedy check	1.02	11.49	31.52	24.98	4065	9103	30.90	2.00
Tembotrione 120 g/ha	1.26	15.14	41.56	27.47	7600	13959	35.27	3.40
Halosulfuron-methyl 72 g/ha	1.10	12.51	35.33	25.93	6113	11931	33.86	2.71
Topramezone 25.2 g/ha	1.18	14.67	40.94	27.07	7412	13811	34.94	3.30
Atrazine 1.0 kg/ha	1.14	14.39	40.71	26.86	7343	13748	34.82	3.38
Mesotrione + atrazine 750 g/ha	1.21	14.77	41.09	27.26	7483	13895	35.02	3.33
LSD (p=0.05)	0.14	1.10	1.64	0.74	262	657	0.93	0.10
Interaction (A × B)								
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Note: LSD= least significant difference at the 5% level of significance, B-C ratio= Benefit-cost ratio

Amino acid + humic acid + sea weed extract 2 ml/liter of water was enhanced number of cob/plant, number of grain rows/cob, number of grains/row and seed index. This treatment has also recorded 5.28%, 3.94% and 0.91% higher grain yield, stover yield and harvest index, respectively when compared to gibberellic acid (**Table 3**). Improving maize yield attributes is achieved through integrating amino acids, humic acids, and seaweed extracts, which enhance protein synthesis, promote growth, improve nutrient uptake, boost enzymes and increase stress tolerance. (Eryigit and Husamalddin 2023 and Ebrahimi *et al.* 2020). Seaweed extracts enhance the source-sink relationship and the translocation of photo assimilates, improving plant's photosynthetic ability, which significantly improved in growth and yield attributing characters were ultimately reflected in higher yield (Aalipour *et al.* 2023, Mahmood *et al.* 2020 and Hegab *et al.* 2020).

Tembotrione 120g/ha recorded significantly better yield attribute, *viz.* number of cob/plant, number of grain rows/cob, number of grains/row and seed index. Tembotrione 120g/ha has recorded an increase of 86.96%, 53.34% and 14.14% increase in grain yield, stover yield, and harvest index, respectively compared to weedy check (**Table 3**). Tembotrione targets broad-leaved and grassy weeds, which compete with maize for essential nutrients, water and light (Singh *et al.* 2025). By controlling these weeds, the maize plants grew more robustly and access resources more efficiently. For optimal results, application of herbicide during the early post-emergence stage of the maize crop, when weeds are actively growing but before they become established found successful. This strategy helps in minimizing competition and maximizing the maize crop yield potential (Sahoo *et al.* 2024, Gupta *et al.*2023 and Kaur *et al.* 2018). The interaction effect between plant growth promoters and herbicides did not show statistical significance.

The combined application of amino acid + humic acid + sea weed extract recorded the highest B:C ratio. Tembotrione 120 g/ha recorded higher B:C ratio, which was 70% higher compared to the weedy check. The improvement in B:C ratio was mainly attributed to higher grain yield and better weed control efficiency in the maize crop (Sundari *et al.* 2019).

Conclusion

It can be concluded that the combined application of Amino acid + humic acid + sea weed extract 2 ml/liter of water resulted in better growth, yield attributes and higher grain yield. Among the herbicidal treatments, tembotrione 120 g /ha recorded the highest weed control efficiency (85.92%) and significantly improved maize growth and yield attributes with maximum *Kharif* maize grain yield, harvest index and benefit–cost ratio.

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RESEARCH ARTICLE

Influence of integrated weed and nutrient management on weeds and productivity of finger millet

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ABSTRACT

A field experiment was conducted to evaluate the performance of integrated weed and nutrient management treatments on weed dynamics, crop growth, yield and economics of finger millet under rainfed agroecosystem of eastern India. Experiment was laid out in factorial randomized block design with three replications. Four weed management treatments were tested, including weedy check, hand weeding twice at 25 and 45 days after seeding (DAS), pre-emergence application (PE) of pyrazosulfuron-ethyl 20 g/ha followed by (*fb*) hand weeding (HW) once at 30 DAS, pyrazosulfuron-ethyl 20 g/ha PE *fb* post-emergence application (PoE) of 2,4-D 0.50 kg/ha at 25 DAS in combination with four integrated nutrient management (INM) treatments comprising of 100% recommended dose of nitrogen (RDN), 75% RDN (inorganic nitrogen)+25% RDN as farm yard manure (FYM), 50% RDN (IN) +50% RDN (FYM), 50% RDN (IN)+25% RDN (FYM)+25% RDN vermicompost (VC). Among the treatments, pyrazosulfuron-ethyl 20 g/ha *fb* HW once at 30 DAS proved the most effective in managing the weeds throughout critical crop growth period. Application of 100 % RDN gave significantly higher crop grain and straw yields. Economic analysis indicated that HW twice at 25 and 45 DAS had significantly the highest gross, net returns, B:C ratio, production and economic efficiency as compared to weedy check and pyrazosulfuron 20 g/ha PE *fb* 2,4-D 0.50 kg/ha PoE at 25 DAS. Significantly higher gross, net returns, B:C ratio, production and economic efficiency were observed with 100% RDN.

Keywords: 2,4-D, Economics, Finger millet, Nutrient management, Pyrazosulfuron, Rainfed agro-ecosystem, Weed management

INTRODUCTION

Finger millet (*Eleusine coracana* L.), commonly known as ragi, is a vital minor millet crop grown extensively in rainfed agro-ecosystems across India, particularly in the eastern, central and southern regions. It is valued for its nutritional quality, resilience to abiotic stresses and adaptability to low-input systems, making it a staple for food and fodder in resource-poor farming communities (Kumar *et al.* 2019). Finger millet is rich in Ca, dietary fiber, essential amino acids, and phenolic compounds, which contribute to food security as well as nutritional well-being of millions of rural households in semi-arid and dryland conditions across the country (Kumar *et al.* 2021a, b). Its importance is underscored by its cultivation on significant acreage with considerable production volumes though crop productivity levels remain low compared to potential yields due to multiple biotic/abiotic constraints, among which weed infestation and nutrient limitations are key yield-limiting factors in rainfed production system (Kumar *et al.* 2023a, b). In rainfed agro-ecosystem, finger millet often faces the adverse growing conditions such as erratic rainfall distribution, nutrient-poor soils and intense biotic pressures like weeds. Crop exhibits slow initial crop growth, which prolong crop vulnerable window to weed competition during early growth period (Rao 2021). Weeds exploit this early growth lag phase to establish and compete aggressively with crop for essential growth resources, *viz.* moisture, nutrients, space, and light particularly during the critical period 20 to 45 days after sowing (DAS). It was found that heavy infestation by weed particularly the grassy weeds such as: *Brachiaria ramosa*, *Digitaria*

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sanguinalis; sedges like *Cyperus rotundus* and broad-leaved weeds (BLW) such as: *Phyllanthus niruri, Amaranthus viridis, Caesulia axillaris, Portulaca oleracea, Trianthema portulacastrum,* poses serious constraint of finger millet production. Competitive interference from weeds can cause up to 70% crop yield loss depending on species and density of weed flora, and management practices (Rao 2021, Kumar *et al.* 2022a,b,c). Several studies demonstrated that pre-emergence herbicide applications and timely intercultural operations such as hand weeding/ mechanical hoeing can significantly reduce weeds and improve finger millet yield by reducing nutrient removal by weeds and improving crop nutrient uptake (Kumar *et al*. 2017). This underlines synergistic relationship between weed management and nutrient dynamics in crop production, well-managed weeds allow crops to utilize available nutrients more efficiently, improving yield component and economic returns (Rameshraddy *et al.* 2017, Nayak *et al.* 2025). Integrated nutrient management (INM) has emerged as a sustainable agronomic approach to enhance nutrient use, build soil fertility and improve crop performance in rainfed agro-ecosystems. Thus, the present study was undertaken with an objective to identify the effective integrated nutrient and weed management options to manage weeds and improve finger millet productivity.

MATERIALS AND METHODS

A field experiment was conducted during *Kharif* 2023 and 2024 at ICAR Research Complex for Eastern Region, Patna, Bihar, India (25°30'N, 85°15'E, 52 m above mean sea levels). Precipitation was recorded during crop growing season was 891.1 and 649.1 mm during 2023 and 2024, respectively. Consequently, during the second year of experimentation, amount of precipitation was unequally distributed, fluctuated variably high during crop growing period compared to first year where equal distribution of precipitation was occurred. Average maximum and minimum temperature were observed 35.1, 26.3 and 34.8, 27.5 ^{0}C during crop growth period of 2023 and 2024, respectively. Soil of experimental site was loamy in texture (50.4, 35 and 14.6% sand, silt and clay) with pH of 7.6, EC of 0.14 dS/m, soil organic carbon (SOC) content of 6.5 g/kg, $KMnO_4$ oxidizable N of 67.4 mg/kg, Olsen P 22.5 mg/kg, NH_4OAc exchangeable K 77.8 mg/kg and DTPA-extractable Zn 0.62 mg/kg (0-15 cm soil). This field trial comprised of 4-weed management treatments, *viz.* weedy check, hand weeding twice at 25 and 45 days after seeding (DAS), pre-emergence application (PE) of pyrazosulfuron-ethyl 20 g/ha followed by (*fb*) hand weeding (HW) once at 30 DAS, pyrazosulfuron-ethyl 20 g/ha PE *fb* post-emergence application (PoE) of 2,4-D 0.50 kg/ha at 25 DAS and nutrient management, *viz.* 100% of nitrogen (RDN), 75% RDN (inorganic nitrogen) + 25% RDN as farmyard manure (FYM), 50% RDN (IN) + 50% RDN (FYM), 50% RDN (IN) + 25% RDN (FYM) + 25% RDN vermicompost (VC). A factorial randomized block design with three replications was used.

The standard agronomic management practices were followed as per crop requirement. Gross plot size of the experimental plot was 5.0 m×4.0 m with spacing of 25 cm×5 cm. To control the initial weed flushes the pre-emergence herbicides were applied as per treatments using 500 liters water/ha with help of knap-sack sprayer, fitted with flat-fan nozzle. Hand-hoeing (HW) was also done at 25 and 45 DAS and intra-row weeds were removed by the hand-weeding simultaneously recommended dose of P and K i.e. 40 kg/ha each was applied in all treatment through di-ammonium phosphate (DAP) and muriate of potash (MOP), respectively. The N (60 kg/ha) was applied as per treatment using urea after subtracting N supplied through DAP as basal. Further, N was applied in 2-equal splits, 50% as basal and remaining at 35 DAS. Gross plot size (20 m^2) was harvested separately for estimation of grain and straw/stover yields. After harvesting, threshing was done and crop yield was recorded. The crop yield was further adjusted at 12% moisture content. Weed density and biomass were recorded at 20 and 40 DAS using a quadrat (0.5 m × 0.5 m) placed randomly at 4-places in each plot. Weeds within each quadrat were uprooted, separated species wise and counted. Weed samples were oven dried before weighing at 70 °C till to constant weight was achieved. The relative abundance of weed was calculated by following formula:

$$\text{Relative abundance (\%)} = \frac{\text{Total number of individual weed species}}{\text{Total number of individual of all weed species}} \times 100$$

Weed control efficiency of each treatment was computed by using the following formula.

$$\text{Weed control efficiency (\%)} = \frac{\text{DMC} - \text{DMT}}{DMC} \times 100$$

Where, DMC= Weed biomass in weedy check plot; DMT= Weed biomass in treated plot

Weed index is a measure of crop yield loss accrued across treatments in comparison to a weed free plot adopted in an experiment. Following formula was used in calculating weed index.

$$\text{Weed index (\%)} = \frac{X - Y}{Y} \times 100$$

Where, X=Crop yield in weed free plots; Y=Crop yield in the treated plot

Data on weed counts were subjected to square root transformation ($\sqrt{x+0.5}$) before statistical analysis to normalize their distribution. All recorded data were analyzed with the help of analysis of variance (ANOVA) technique using Indian NARS Statistical Computing Portal. Least significant difference test (LSD) was used for comparison of treatment means at 5% level of significance (p=0.05).

RESULTS AND DISCUSSION

Effect on weeds

At 20 DAS relative abundance of weed flora/ diversity in finger millet was significantly affected by the weed management and INM (**Table 1**). Among the weed management treatments, weedy check recorded the highest relative abundance of weeds dominated mainly by *Brachiaria ramosa* (53.7%), followed by *Trianthema portulacastrum* (14.4%) and *Cyperus rotundus* (11.5%). This indicates severe weed infestation in absence of control measures, with grassy weed being predominant during early crop growth. Hand weeding twice at 25 and 45 DAS significantly reduced dominance of *Brachiaria ramosa* (36.1%) as compared to weedy check; however, higher proportions of *Trianthema portulacastrum* (22.9%) and other weeds (7.71%) were also observed, suggesting partial control and possible weed regeneration between weeding operations. Pyrazosulfuron-ethyl 20 g/ha PE *fb* HW once at 30 DAS had significantly reduced the relative abundance of *Digitaria sanguinalis* (3.82%) and *Trianthema portulacastrum* (0.86%). However, *Brachiaria ramosa* remained dominant (43.9%). Most effective treatment was pyrazosulfuron-ethyl 20 g/ha PE *fb*2, 4-D 0.50 kg/ha PoE at 25 DAS, which had resulted in complete elimination of several BLWs, *viz. A. viridis, Caesulia axillaris, Portulaca oleracea* and *Trianthema portulacastrum*. However, higher relative abundance of *Brachiaria ramosa* (42.7%) and *Cyperus rotundus* (21.9%) (**Table 1**).

The INM had positive influenced on weed flora composition in finger millet during the experimentation. The 100% RDN caused relatively lower abundance of *Brachiaria ramosa* (42.4%) and moderate presence of *Trianthema portulacastrum* (10.3%). 75% RDN inorganic nitrogen (IN) + 25% RDN (FYM) and 50% RDN (IN) + 50% RDN farmyard manure (FYM) had higher relative abundance of *Brachiaria ramosa* (45.5 and 45.7%, respectively), indicating that addition of organic sources favored grassy weed proliferation during early crop stages. Integrated application of 50% RDN (IN) + 25% RDN (FYM) + 25% RDN resulted in comparatively balanced weed flora with reduced dominance of grasses and moderate distribution of BLWs, suggesting more uniform nutrient availability that supported crop competitiveness against weed.

Table 1. Effect of weed management and integrated nutrient management treatments on relative abundance (%) of weeds in finger millet at 20 and 40 DAS (mean data of 2-years)

Treatment*		*Weed management*					*Nutrient management*				
		Weedy check	Hand weeding (HW) twice at 25 and 45 DAS	Pyrazosulfuron 20 g /ha PE *fb* HW once at 30 DAS	Pyrazusulfuron 20 g/ha PE *fb* 2,4-D 0.50 kg/ha PoE at 25 DAS	LSD (p=0.05)	100% RDN	75% RDN (IN)+25% RDN (FYM)	50% RDN (IN)+50% RDN (FYM)	50% RDN (IN)+25% RDN (FYM)+25% RDN (VC)	LSD (p=0.05)
Brachiaria ramosa	20 DAS	53.7	36.1	43.9	42.7	7.4	42.4	45.8	45.1	43.1	7.4
	40 DAS	23.1	32	21.9	21.2	7.6	28.6	23.2	23.3	23.1	7.6
Cyperus rotundus	20 DAS	11.5	14.9	25.4	21.8	6.6	21.3	16.3	18.2	18	6.59
	40 DAS	26.2	31.2	28.7	31.7	9.9	32.9	33.1	24.4	27.3	9.9
Digitaria sanguinalis	20 DAS	11.4	12.4	3.8	0.6	2.9	8.9	5.3	7.4	6.7	2.9
	40 DAS	20.9	22.1	25.9	24.3	12.6	18.7	23.2	23.9	27.5	12.6
Phyllanthus niruri	20 DAS	2.5	3.8	5.5	5.2	4.2	5.6	2.7	3.3	5.3	4.2
	40 DAS	6.4	0.4	0.6	0.8	2.3	0.9	1.8	3.1	2.3	2.3
Amaranthus viridis	20 DAS	1.6	1.1	6.5	0.0	2.9	0.7	4.0	2.5	1.9	2.9
	40 DAS	3.1	0.0	3.2	0.8	3.4	1.2	1.9	3.9	0.0	3.4
Caesulia axillaris	20 DAS	0.9	0.4	1.3	0	1.7	0.5	1.6	0.1	0.4	1.7
	40 DAS	0.2	0.0	0.0	0.8	1.4	0.0	0.2	0.8	0.0	1.43
Portulaca oleracea	20 DAS	0.8	0.6	0.0	0.0	0.7	0.5	0.2	0.5	0.1	0.7
	40 DAS	0.4	0.0	0.0	0.8	1.6	0.0	0.4	0.8	0.0	1.6
Trianthema portulacastrum	20 DAS	14.4	23.0	0.9	0.0	3.9	10.3	9.4	7.7	10.8	3.9
	40 DAS	7.9	0.0	0.0	0.8	3.0	2.6	1.6	3.2	1.2	3.0
Other weeds	20 DAS	3.2	7.7	12.7	29.6	4.7	9.7	14.5	15.2	13.8	4.7
	40 DAS	11.9	14.3	19.6	18.8	7.7	15.0	14.5	16.5	18.7	7.7

*PE = pre-emergence application; PoE = post-emergence application; *fb* = followed by, FYM = farm yard manure; RDN = recommended dose of nitrogen, VC= vermicompost, IN=inorganic nitrogen; DAS = days after seeding

Relative abundance of weed flora in finger millet at 40 DAS was significantly altered by different weed management and INM in rainfed agro-ecosystem of eastern India (**Table 1**). Hand weeding twice at 25 and 45 DAS markedly altered the composition by suppressing most BLWs, resulting in negligible abundance of *Phyllanthus niruri*, *Amaranthus viridis*, *Caesulia axillaris*, *Portulaca oleracea* and *T. portulacastrum*. However, grassy weeds remained dominant; with higher relative abundance of *Brachiaria ramosa* (32%), *Cyperus rotundus* (31.2%) and *Digitaria sanguinalis* (22.1%) significantly lowered relative abundance over weedy check. *Cyperus rotundus* (26.1%), *Brachiaria ramosa* (23.1%) and *Digitaria sanguinalis* (21%), along with appreciable presence of BLWs i.e. *Trianthema portulacastrum* (7.86%) and *Phyllanthus niruri* (6.4%). Pyrazosulfuron-ethyl 20 g /ha PE *fb* HW once at 30 DAS effectively reduced the relative abundance of BLWs, particularly *Phyllanthus niruri* (0.56%) and completely suppressed *Caesulia axillaris*, *Portulaca oleracea* and *T. portulacastrum*. Nevertheless, grassy weeds, *viz*. *Digitaria sanguinalis* (25.9%) and *Cyperus rotundus* (28.7%) continued to dominate weed flora. Integration of pyrazosulfuron-ethyl PE *fb* 2, 4-D 0.5 kg/ha PoE at 25 DAS resulted in comparatively uniform reduction of grassy and BLWs. Although *Cyperus rotundus* (31.7%) and *Digitaria sanguinalis* (24.3%) remained predominant, relative abundance of BLWs reduced to less (<1) indicating effectiveness of sequential herbicide application.

Nutrient management also exerted a notable influence on weed composition. Application of 100% RDN favored dominance of *Cyperus rotundus* (32.9%) and *Brachiaria ramosa* (28.6%), while BLWs occurred in negligible. Substitution of inorganic nitrogen with organic sources increased relative abundance of certain BLWs. Treatment 50% RDN (IN) + 50% RDN (FYM) had higher proportion of *Phyllanthus niruri* (3.1%), *Amaranthus viridis* (3.9%) and *T. portulacastrum* (3.2%), indicating a more diversified weed flora. Similarly, application of 50% RDN (IN) + 25% RDN (FYM) + 25% RDN vermicompost (VC) resulted in increased dominance of *D. sanguinalis* (27.5%) higher proportion of another weed (18.7%).

Weed species, total weed density, weed dry biomass, WCE and weed index

Species wise weed composition, total weed density and dry biomass of finger millet at 20 DAS were significantly reduced by different weed management and INM in rainfed agro-ecosystem of eastern India (**Table 2**). Weedy check was found the maximum density of major grassy, sedges and BLWs, particularly *Brachiaria ramosa*, *Cyperus rotundus* and *Digitaria sanguinalis*, along with higher populations of *Phyllanthus niruri* and *Trianthema portulacastrum*. Consequently, this treatment was registered the highest total weed density and weed dry-biomass, indicating severe weed competition under unchecked conditions (Patil *et.al*. 2013). The HW twice at 25 and 45 DAS significantly reduced the density of BLW compared to weedy check, particularly *P. niruri*, *Amaranthus viridis*, *Caesulia axillaris*, *Portulaca oleracea* and *T. portulacastrum*. However, grassy weeds such as *Brachiaria ramosa* and sedge like *Cyperus rotundus* remained relatively high. This treatment resulted in a moderate reduction in total weed density and weed dry biomass over weedy check. Pyrazosulfuron-ethyl 20 g/ha PE *fb* HW once at 30 DAS proved more effective in suppressing both grassy and BLWs as it significantly reduced density of *B. ramosa* and *D. sanguinalis*, along with marked suppression of BLWs. As a result, total weed density and dry biomass were significantly lower than other treatments. Integration of pyrazosulfuron-ethyl 20 g/ha PE *fb* 2, 4-D 0.50 kg/ha PoE at 25 DAS recorded the lowest total weed density and significantly reduced weed dry biomass. This treatment effectively controlled both grassy and BLWs, indicating an advantage of sequential herbicide application under the rainfed conditions.

Among the nutrient management practices, application of 100% RDN and 75% RDN (IN) + 25% RDN (FYM} recorded comparatively higher densities of grassy weed, especially *B. ramose* and *C. rotundus*, resulting in higher total weed density and weed dry biomass. In contrast, greater substitution of inorganic N with organic sources significantly reduced weed pressure. Application of 50% RDN (IN) + 50% RDN (FYM) recorded the lowest total weed density and weed dry biomass, followed by 50% RDN (IN) + 25% RDN (FYM) + 25% RDN (VC), which also resulted in significantly lower weed density and weed biomass.

Weed species composition, total weed density/ biomass of finger millet at 40 DAS were significantly reduced by different weed management and INM options (**Table 2**). Weedy check recorded the highest density of major grassy and BLWs, particularly *Brachiaria ramosa*, *Cyperus rotundus* and *Digitaria sanguinalis*, along with higher density of *Phyllanthus niruri* and *Trianthema portulacastrum*. Weedy check registered the maximum total weed density and weed dry-biomass, indicating severe weed competition under unchecked conditions (Patil *et.al.* 2013). 2-HW at 25 and 45 DAS significantly reduced density of BLW compared to weedy check, particularly *P. niruri*, *Amaranthus viridis*, *Caesulia axillaris*, *Portulaca oleracea* and *T. portulacastrum*. However, grassy weeds such as *Brachiaria ramosa* and *Cyperus rotundus* remained relatively higher with a moderate reduction in total weed density and weed dry biomass over weedy check. Pyrazosulfuron-ethyl 20 g/ha (PE) *fb* 1-HW at 30 DAS proved more effective in suppressing both grassy and BLWs with significantly reduced density of *B. ramosa*, *C. rotundus* and *D. sanguinalis*, along with marked suppression of BLWs. As a result, total weed density, dry biomass at 20 and 40 DAS and weed index were significantly lower than HW twice and weedy check. Integration of pyrazosulfuron-ethyl 20 g/ha PE *fb* 2,4-D 0.50 kg/ha PoE at 25 DAS recorded the lowest total weed density and significantly reduced weed dry biomass and higher weed control efficiency, which was at par with pyrazosulfuron-ethyl 20 g/ha PE *fb* HW once at 30 DAS. This treatment effectively controlled both grassy and BLWs, indicating an advantage of sequential herbicide application under the rainfed conditions.

Among the nutrient management practices, application of 100% RDN and 75% RDN (IN)+25% RDN (FYM) recorded comparatively higher densities of grassy weed, especially *B. ramosa* and *C. rotundus*, resulting in higher total weed density and weed dry biomass. In contrast, greater substitution of inorganic N with organic sources significantly reduced weed pressure.

Effect on finger millet yield and economics

Weed management practices significantly influenced finger millet grain, straw yield, productivity and economic returns of finger millet **(Table 3)**. Weedy check has recorded the lowest grain yield, straw yield, gross returns, net returns, crop productivity and crop profitability, indicating severe yield and economic losses due to unchecked weed competition. Among weed control treatments, twice HW at 25 and 45 DAS proved the most effective, producing the highest grain yield, straw yield, maximum gross returns, net returns, B-C ratio

Table 2. Effect of weed management and integrated nutrient management practices on weed density, dry-biomass, weed control efficiency and weed index in finger millet at 20 and 40 DAS (mean data of 2-years)

Treatment*		*Weed management*					*Nutrient management*				
		W1	W2	W3	W4	LSD (p=0.05)	N1	N2	N3	N4	LSD (p=0.05)
Brachiaria ramosa	20 DAS	13.8(194)	8.1(67.7)	6.3(40.0)	4.1(16.7)	1.23	7.8(70.3)	8.4(88.0)	8.1(82.3)	8.1(78.0)	1.23
	40 DAS	4.6(21.3)	5.3(27.7)	3.3(11.0)	3.2(10.7)	0.68	4.6(22.0)	4.3(19.0)	3.7(14.3)	3.8(15.3)	0.68
Cyperus rotundus	20 DAS	6.4(40.7)	5.1(25.7)	4.8(23.0)	2.9(8.3)	0.74	4.9(25.7)	4.6(22.7)	4.8(24.7)	4.8(24.7)	0.74
	40 DAS	5.1(26.0)	5.2(28.3)	3.7(13.7)	4.1(16.7)	1.04	4.7(23.3)	5.2(28.3)	3.8(14.7)	4.1(18.3)	1.04
Digitaria sanguinalis	20 DAS	6.3(40.0)	4.7(22.3)	1.7(3.7)	0.8(0.3)	0.73	3.7(20.0)	3.0(14.7)	3.4(16.7)	3.4(15.0)	0.73
	40 DAS	4.5(21.0)	4.3(19.7)	3.5(15.0)	3.3(11.3)	1.25	3.6(14.7)	4.5(21.3)	3.7(14.3)	3.9(16.7)	1.25
Phyllanthus niruri	20 DAS	2.9(9.3)	2.5(6.7)	2.1(5.0)	1.4(2.0)	1.01	2.2(5.3)	1.9(4.3)	2.3(6.3)	2.5(7.0)	1.01
	40 DAS	2.5(6.0)	0.8(0.3)	0.8(0.3)	0.8(0.3)	0.47	1.0(1.0)	1.4(2.3)	1.3(2.0)	1.2(1.7)	0.47
Amaranthus viridis	20 DAS	2.3(6.0)	1.4(2.0)	2.2(6.0)	0.7(0.0)	0.89	1.2(1.7)	2.0(5.7)	1.6(3.3)	1.7(3.3)	0.89
	40 DAS	1.6(3.0)	0.7(0.0)	1.2(1.7)	0.8(0.3)	0.62	1.0(1.0)	1.2(1.7)	1.4(2.3)	0.7(0.0)	0.62
Caesulia axillaris	20 DAS	1.7(3.3)	1.0(1.0)	1.1(1.3)	0.7(0.0)	0.74	1.2(1.7)	1.4(2.7)	0.8(0.3)	1.0(1.0)	0.74
	40 DAS	0.8(0.3)	0.7(0.0)	0.7(0.0)	0.8(0.3)	0.28	0.7(0.0)	0.8(0.3)	0.8(0.3)	0.7(0.0)	0.28
Portulaca oleracea	20 DAS	1.6(2.7)	1.1(1.0)	0.7(0.0)	0.7(0.0)	0.54	1.1(1.3)	1.0(1.0)	1.1(1.0)	0.8(0.3)	0.54
	40 DAS	0.9(0.7)	0.7(0.0)	0.7(0.0)	0.8(0.3)	0.37	0.7(0.0)	0.9(0.7)	0.8(0.3)	0.7(0.0)	0.37
Trianthema portulacastrum	20 DAS	7.0(51.0)	6.5(42.7)	0.9(1.0)	0.7(0.0)	0.92	4.0(25.0)	3.8(23.7)	3.2(17.3)	4.1(28.7)	0.92
	40 DAS	2.6(7.3)	0.7(0.0)	0.7(0.0)	0.8(0.3)	0.53	1.3(2.3)	1.3(2.3)	1.2(2.0)	1.0(1.0)	0.53
Other weeds	20 DAS	3.5(11.7)	3.7(13.7)	3.5(11.7)	3.3(11.0)	0.5	3.1(9.7)	3.6(12.7)	3.6(13.0)	3.6(12.7)	0.5
	40 DAS	3.3(10.7)	3.4(12.0)	3.2(10.0)	2.9(8.7)	0.77	3.3(10.7)	3.2(10.7)	3.1(9.3)	3.2(10.7)	0.77
Total weed density (no./m^2)	20 DAS	18.9(359.0)	13.4(182.7)	9.6(91.7)	6.2(38.3)	1.21	11.9(161)	12.2(175)	11.8(165)	12.2(171)	1.21
	40 DAS	9.7(96.3)	9.3(88.0)	7.2(51.7)	6.9(49.0)	1.08	8.5(75.0)	9.1(86.7)	7.7(59.7)	7.9(63.7)	1.08
Total weed dry-biomass (g/ m^2)	20 DAS	10.0(101)	6.5(42.7)	4.9(24.2)	3.3(10.5)	0.67	6.5(48.3)	6.3(48.2)	6.1(44.2)	5.9(37.9)	0.67
	40 DAS	4.50(19.9)	4.1(16.7)	3.3(10.3)	3.3(10.8)	0.43	3.9(15.6)	3.9(15.2)	3.7(13.6)	3.7(13.3)	0.43
Weed control efficiency (%)	20 DAS	0	34.1	49.9	66.7	5.2	35.2	42.5	41.6	31.3	5.2
	40 DAS	0.0	8.1	26.9	25.3	10.3	17.2	20.5	10.2	12.4	10.3
Weed index (%)		40.1	8.1	10.8	21.5	10.3	12.8	14.8	23.4	21.4	3.9

*Figures in parentheses are original values; data transformed to $\sqrt{x+0.5}$ transformations; *PE = pre-emergence application; PoE = post-emergence application; *fb* = followed by, FYM = farm yard manure; RDN = recommended dose of nitrogen, VC= vermicompost, IN=inorganic nitrogen; DAS = days after seeding; W1: Weedy check; W2: Hand weeding (HW) twice at 25 and 45 DAS; W3: Pyrazosulfuron 20 g /ha PE *fb* HW once at 30 DAS; W4: Pyrazosulfuron 20 g/ha PE *fb* 2,4-D 0.50 kg/ha PoE at 25 DAS; N1: 100% RDN; N2: 75% RDN (IN) +25% RDN (FYM); N3: 50% RDN (IN) + 50% RDN (FYM); N4: 50% RDN (IN)+25% RDN (FYM)+25% RDN (VC)

Table 3. Effect of weed management and integrated nutrient management practices on yield and economics of finger millet (mean data of 2-years)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Cost of cultivation (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C ratio	Crop productivity (kg/ha/day)	Crop profitability (Rs /ha/day)
Weed management								
Weedy check	1.38	1.50	36009*	51420	15412	1.45	10.3	115.0
Hand weeding (HW) twice at 25 and 45 DAS	2.29	2.13	50409	84433	34024	1.69	17.1	253.9
Pyrazosulfuron 20 g /ha PE *fb* HW once at 30 DAS	2.06	1.81	46409	75595	29186	1.65	15.3	217.8
Pyrazusulfuron 20 g/ha PE *fb* 2,4-D 0.50 kg/ha PoE at 25 DAS	1.81	1.68	45609	66643	21034	1.48	13.5	157.0
LSD (p=0.05)	0.08	0.14	178.6	2946	2946	0.07	0.62	21.99
Nutrient management								
100% RDN	2.25	2.23	41643	83091	41448	1.99	16.8	309.3
75% RDN (IN)+25% RDN (FYM)	2.07	2.09	42693	76629	33936	1.79	15.4	253.3
50% RDN (IN)+50% RDN (FYM)	1.50	1.08	43744	54558	10814	1.23	11.2	80.7
50% RDN (IN)+25% RDN (FYM)+25% RDN (VC)	1.73	1.71	50355	63813	13458	1.26	12.9	100.4
LSD (p=0.05)	0.08	0.14	178.6	2946	2946	0.07	0.62	21.99

Prices used for grain-Rs. 35.0/kg, straw- Rs. 2.0/kg, Urea- Rs. 6.0/kg, DAP- Rs. 14.0/kg, MOP- Rs. 8.0/kg, FYM- Rs. 1.0/kg, Vermicompost- Rs. 5.0/kg and labor wages- Rs. 300/man-days; *PE = pre-emergence application; PoE = post-emergence application; *fb* = followed by, FYM = farm yard manure; RDN = recommended dose of nitrogen, VC= vermicompost, IN=inorganic nitrogen; DAS = days after seeding

Table 4. Interaction effect of weed management and integrated nutrient management practices on grain yield of finger millet (mean data of 2-years)

Treatment	Weedy check	Hand weeding (HW) twice at 25 and 45 DAS	Pyrazosulfuron 20 g/ha PE *fb* HW once at 30 DAS	Pyrazusulfuron 20 g/ha PE *fb* 2,4-D 0.50 kg/ha PoE at 25 DAS	Mean
100% RDN	1715	2581	2501	2190	2247
75% RDN (IN)+25% RDN (FYM)	1521	2431	2302	2026	2070
50% RDN (IN)+50% RDN (FYM)	1033	1955	1566	1433	1497
50% RDN (IN)+25% RDN (FYM)+25% RDN (VC)	1266	2196	1857	1583	1726
Mean	1384	2291	2057	1808	1885
LSD (p=0.05)				166.92	

PE = pre-emergence application; PoE = post-emergence application; *fb* = followed by, FYM = farm yard manure; RDN = recommended dose of nitrogen, VC= vermicompost, IN=inorganic nitrogen; DAS = days after seeding

(1.69), crop productivity, crop profitability. Pyrazosulfuron-ethyl 20 g/ha PE *fb* HW once at 30 DAS was next best treatment, recording higher grain yield and net returns/ha with B:C ratio of 1.65. Pyrazosulfuron-ethyl PE *fb* 2,4-D PoE, though superior to weedy check, resulted in comparatively lower yield, WCE and economics than HW twice 25 and 45 DAS and pyrazosulfuron-ethyl 20 g/ha PE *fb* HW once at 30 DAS.

Nutrient management exerted marked effect on crop yields and economics of finger millet (**Table 3**). Application of 100% recommended dose of N produced the highest grain yield, straw yield, gross returns and net returns with highest B:C ratio (1.99), crop productivity (16.8 kg/ha/day) and crop profitability (Rs. 309.3/ha/day), indicating its economic superiority.

Interaction effect on grain yield

Interaction effect of weed and nutrient management combinations, HW twice at 25 and 45 DAS with 100% RDN recorded the highest grain yield, clearly demonstrating synergistic effect of effective weed control and adequate nutrient supply (**Table 4**). This treatment was closely followed by pyrazusulfuron-ethyl 20g/ha PE *fb* HW once at 30 DAS with 100% RDN. Considering mean values, HW twice at 25 and 45 DAS recorded the highest mean grain yield among weed management practices, while 100% RDN produced the highest mean grain yield (2247 kg/ha) among the nutrient management treatments.

Pyrazosulfuron-ethyl PE at 20 g/ha followed by hand weeding once at 30 DAS effectively controlled weeds during critical crop growth period. However, hand weeding twice at 25 and 45 DAS proved more economical and resulting in higher returns, better B:C ratio, and improved efficiency. Additionally, applying 100% recommended dose of nitrogen (RDN) significantly enhanced grain and straw yield as well as overall economic benefits.

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RESEARCH ARTICLE

Weed complex in chickpea as influenced by topramezone + methylated seed oil (MSO) adjuvant

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ABSTRACT

An experiment was conducted at the Agricultural Research Farm, Banaras Hindu University, Varanasi, Uttar Pradesh, India during the *Rabi* season of 2022-23 and 2023-24 to evaluate the effect of varying rates of topramezone, both alone and in conjunction with methylated seed oil (MSO) adjuvant on complex weed flora and chickpea seed yield. The early post-emergence application (EPoE) of topramezone 20.16 g/ha and 25.20 g/ha with MSO were statistically similar in recording the lowest weed density and biomass, higher weed control efficiency, herbicide efficiency index and lowest weed index. However, all herbicidal treatments tested, except oxyfluorfen 250 g/ha and topramezone 10.08 g/ha, recorded statistically similar chickpea seed yield. In terms of economics, topramezone 20.16 g/ha and 25.20 g/ha with MSO adjuvant recorded statistically similar B:C ratio. Therefore, topramezone 20.16 g/ha is recommended for effective weed control, optimal chickpea seed yield and net profitability in chickpea.

Keywords: Adjuvant, Chickpea, Methylated seed oil (MSO), Topramezone, Weed flora, Weed management.

INTRODUCTION

Chickpea (*Cicer arietinum* L.), a staple pulse crop in India, plays a crucial role in the agricultural economy by enhancing food security and providing a vital source of protein (Malik 2021). India is the largest producer of chickpea with a production of 13.5 million tonnes (World Population Review 2025).

Weed management remains a significant challenge in chickpea cultivation in India. This is largely due to the crop's slow growth rate and insufficient leaf development during its establishment phase, which allows weeds to dominate and hinder chickpea development (Rao and Kumar 2025). Secondly, broad-leaved weeds in chickpea, with about 93% of the weed flora, are detrimental to yield as compared to grasses (Merga and Alemu 2019). In India, weeds like *Chenopodium album*, *Amaranthus viridis*, *Phalaris minor, Anagallis arvensis* and *Solanum nigrum* are prevalent in chickpea fields and can reduce yields by up to 50%, if left uncontrolled (Kashyap *et al.* 2022, Gairola *et al*. 2024). Chickpea must be kept weed free from four leaf stage to beginning of flowering stage (17- 49 days after emergence) (Mohammadi *et al*. 2005). Manual weeding is one of the most effective methods of weed control, however, it is labour-intensive and expensive, making it less sustainable, particularly during peak agricultural seasons when labour shortages are prevalent (Ray *et al.* 2022).

The use of herbicides with broader spectra, such as topramezone, could offer a promising solution by targeting a wider range of weed species. However, there is still limited knowledge on the optimal dosages and application timing for topramezone in chickpea. Topramezone 25.7 g/ha, applied at 21 days after sowing (DAS), was observed to provide effective weed control (Kumar *et al*. 2023). However, the variability in weed species and environmental conditions across different regions in India highlights the need for further research to identify location specific dosage rate of topramezone.

Performance of herbicides can be influenced by the use of adjuvants by enhancing its absorption and overall efficacy. Methylated Seed Oil (MSO) is a refined oil made from methylated fatty acids derived from seeds such as canola, soybean, or other oil crops. MSO adjuvants are particularly beneficial in improving the absorption and penetration of

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herbicides into plant tissues, especially in crops like chickpea, where leaf surfaces are often waxy and resistant to herbicide penetration (Zhang *et al.* 2022). By altering the surface tension of herbicides, MSO allows the active ingredients to spread more evenly on the leaf surface, promoting better adhesion and reducing herbicide runoff (Zhang *et al*. 2013). However, while MSO is known to improve herbicide performance, studies on interaction of MSO with topramezone in chickpea is limited. Therefore, this study was conducted with an objective to evaluate the optimal doses of topramezone, both with and without MSO adjuvants for weed control in chickpea, while comparing it with other weed control options.

MATERIALS AND METHODS

The study was conducted during the *Rabi* season of 2022-23 and 2023-24 at the Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (U.P.) in randomized block design (RBD) with eleven treatments and three replications. The treatments include early post emergence application (EPoE) of topramezone at 10.08, 15.12, 20.16 and 25.20 g/ha, with 2 mL/L MSO adjuvant; oxyfluorfen 250 g/ha; hand weeding twice at 20 and 40 DAS and untreated control. During the study period, the mean monthly maximum and minimum temperature ranged from 29.91-12.54°C in the first year and 26.37-12.85°C in the second year, and monthly average rainfall of 0.09 and 3.78 mm respectively. Initial soil status of the study site indicates sandy clay loam texture with 0.44% organic carbon, 198 kg/ha available N, 22.18 kg/ha available P and 216 kg/ha available K. *Pusa Kabuli* variety of chickpea was sown on 25.11.2022 and 20.11.2023 in a 4.5 m × 5.0 m plot size with 45 cm × 10 cm spacing. All herbicide applications were done at 2-3 leaf stage of weeds (18 days after sowing) using a knapsack sprayer fitted with flat fan nozzle as per treatment dose. One irrigation at 7-8 days after herbicide application (DAA) was done to get good efficacy. The crop was harvest at physiological maturity on 10.04.2023 and 28.03.2024.

The observations on weed density were recorded using a 1 m × 1 m quadrat placed randomly at five places per plot and cumulative weed density expressed as no./m^2. Weed density was recorded species-wise at 10 and 45 DAA. The weeds were dried separately species-wise in the sun and further in the oven at 70^{o}C to record weed dry weight (weed biomass) as g/m^2. Weed control efficiency (WCE), weed index (WI) and herbicide efficiency index (HEI) were computed using the equation suggested by Mani *et al*. (1973), Gill and Kumar (1969) and Krishnamurthy *et al.* (1975), respectively.

Weed density and weed biomass data were square root transformed ($\sqrt{x + 0.5}$) prior to analysis. ANOVA was performed using *Statistical Tool for Agricultural Research* (STAR), IRRI, version 2.0.1. The same software was used for correlation analysis.

RESULTS AND DISCUSSIONS

Weed flora

The weed flora observed in the experimental site consisted of ten species including broad-leaved weeds and grasses belonging to six families (**Table 1**).

Weed density

At 10 and 45 days after application (DAA), the highest density of *Melilotus officinalis* was observed, followed by *Sonchus oleraceus* and *Chenopodium album* (**Table 2**). The lowest density was of *Solanum nigrum*. At 10 DAA, among the herbicidal treatments, topramezone 20.16 g/ha + MSO adjuvant recorded the lowest density of all weed species, which was statistically at par with

Table 1. Weed flora observed in the experimental site

Scientific name	Common name	Family	EPPO code
Broad-leaved weeds			
Melilotus officinalis	Yellow sweet clover	Fabaceae	MEUOF
Medicago spp.	Burclover	Fabaceae	MEDSS
Chenopodium album	Lambsquarters	Amaranthaceae	CHEAL
Sonchus oleraceus	Common sowthistle	Asteraceae	SONOL
Rumex spp.	Dock	Polygonaceae	RUMSS
Anagallis arvensis	Scarlet pimpernel	Primulaceae	ANGAR
Polygonum plebeium	Small knotweed	Polygonaceae	POLPB
Parthenium hysterophorus	Carrot grass	Asteraceae	PTNHY
Solanum nigrum	Black nightshade	Solanaceae	SOLNI
Grass			
Phalaris minor	Little seed canary grass	Poaceae	PHAMI

Table 2. Species wise weed distribution at various stages after herbicidal application

Species	10 DAA	45 DAA
MEUFO	11%	11%
MEDSS	10%	11%
CHEAL	11%	11%
SONOL	11%	11%
RUMSS	10%	10%
ANGAR	10%	10%
POLPB	9%	10%
PTNHY	9%	9%
SOLNI	8%	8%
PHAMI	11%	9%

Please refer to Table 1 for full form of weed species

topramezone 25.20 g/ha + MSO adjuvant. All the herbicide treatments were found to be equally effective to minimize *P. minor* density at 10 DAA. Topramezone 20.16 g/ha + MSO adjuvant recorded a decrease of 18.55% and 5.75% in total weed density as compared to oxyfluorfen 250 g/ha and topramezone 20.16 g/ha respectively. AT 45 DAS, topramezone 20.16 and 25.20 g/ha both recorded almost similar values of weed density across different species, except for *Phalaris minor*, which was statistically lower with 20.16 g/ha dose. Nonetheless, there was no statistical difference between the two treatments (**Table 3** and **4**). Throughout the study period, the highest weed density was with oxyfluorfen 250 g/ha. Oxyfluorfen being a contact herbicide, do not have the same systemic action as topramezone and likely limited the effectiveness over time (Patel *et al.* 2024). Topramezone's mechanism involves inhibiting the 4-hydroxyphenylpyruvate dioxygenase (HPPD) enzyme, which disrupts carotenoid biosynthesis, leading to bleaching and death of the weed. MSO enhances this effect by improving the penetration of topramezone into the plant tissues, thereby increasing its herbicidal activity (Boyd *et al.* 2020). Moreover, the efficacy of weed control may be attributed to the interaction between the chemical properties of the herbicide and the surfactant nature of MSO. In terms of application, addition of MSO with topramezone ensures that the herbicide adheres more effectively to the leaf surface, allowing for a more uniform distribution and maximized exposure time (Idziak *et al.* 2023). Overall, the combination led to significant reductions in weed density as compared to other herbicides (Nguyen and Liebman 2022).

Weed biomass

The weed biomass at 45 DAA was significant effected by weed control treatments. Topramezone (20.16 and 25.20 g/ha) + MSO adjuvant recorded the lowest weed biomass compared to the rest of the herbicidal treatments (**Table 5**). However, statistically, all topramezone treatments (alone or in combination with MSO adjuvant) were at par with each other and significantly more effective than oxyfluorfen 250 g/ha treatment and untreated control. The highest weed biomass was recorded with oxyfluorfen 250 g/ha among herbicide treatments. Similar effect of topramezone on chickpea was also reported by Gajanand *et al.* (2023). Moreover, the

Table 3. Weed species density (no./m^2) at 10 DAA as influenced by weed control treatments (pooled data of two years)

Treatment	MEUFO	MEDSS	CHEAL	SONOL	RUMSS	ANGAR	POLPB	PTNHY	SOLNI	PHAMI
Topramezone 10.08 g/ha	2.31 (4.84)	2.27 (4.63)	2.18 (4.25)	2.26 (4.59)	2.13 (4.04)	2.03 (3.62)	1.92 (3.17)	1.73 (2.49)	1.60 (2.04)	2.13 (4.04)
Topramezone 15.12 g/ha	2.23 (4.47)	2.19 (4.27)	2.11 (3.95)	2.18 (4.23)	2.06 (3.74)	1.97 (3.36)	1.86 (2.94)	1.68 (2.31)	1.55 (1.89)	2.15 (4.10)
Topramezone 20.16 g/ha	2.13 (4.02)	2.09 (3.85)	2.01 (3.54)	2.08 (3.81)	1.96 (3.34)	1.88 (3.02)	1.77 (2.62)	1.60 (2.06)	1.48 (1.69)	2.16 (4.14)
Topramezone 25.20 g/ha	2.11 (3.95)	2.07 (3.78)	2.00 (3.50)	2.06 (3.74)	1.96 (3.32)	1.86 (2.96)	1.76 (2.58)	1.59 (2.03)	1.47 (1.66)	2.21 (4.36)
Topramezone 10.08 g/ha + MSO adjuvant 2 ml/l of water	2.30 (4.79)	2.25 (4.56)	2.17 (4.21)	2.24 (4.50)	2.13 (4.04)	2.02 (3.56)	1.91 (3.13)	1.72 (2.46)	1.59 (2.01)	2.25 (4.56)
Topramezone 15.12 g/ha + MSO adjuvant 2 ml/l of water	2.12 (3.99)	2.08 (3.81)	2.00 (3.50)	2.07 (3.76)	1.96 (3.34)	1.87 (2.98)	1.76 (2.60)	1.60 (2.04)	1.48 (1.68)	2.19 (4.30)
Topramezone 20.16 g/ha + MSO adjuvant 2 ml/l of water	1.98 (3.42)	1.94 (3.26)	1.87 (3.00)	1.93 (3.22)	1.83 (2.83)	1.75 (2.55)	1.65 (2.22)	1.50 (1.75)	1.39 (1.43)	2.13 (4.02)
Topramezone 25.20 g/ha + MSO adjuvant 2 ml/l of water	2.06 (3.74)	2.02 (3.58)	1.95 (3.30)	2.01 (3.52)	1.92 (3.19)	1.82 (2.79)	1.72 (2.44)	1.56 (1.93)	1.44 (1.57)	2.38 (5.14)
Oxyfluorfen 250 g/ha	2.50 (5.75)	2.45 (5.50)	2.36 (5.07)	2.44 (5.45)	2.31 (4.84)	2.20 (4.32)	2.07 (3.76)	1.86 (2.96)	1.71 (2.41)	2.19 (4.30)
Hand weeding twice 20 and 40 DAS	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Untreated control	3.34 (10.62)	2.02 (3.56)	3.15 (9.39)	3.25 (10.06)	3.07 (8.89)	2.91 (7.97)	2.73 (6.95)	2.44 (5.45)	2.24 (4.50)	2.18 (4.23)
LSD (p=0.05)	0.24	0.24	0.24	0.23	0.26	0.26	0.28	0.24	0.25	0.25

Data was square root transformed ($\sqrt{x+0.5}$), original data within parenthesis, DAA- days after application, DAS- days after sowing, *Please refer to Table 1 for full form of weed EPPO code.

adjuvant ensured that the herbicide remains effective even under conditions where weed density might typically challenge the efficacy of standalone herbicide applications. This synergy between topramezone and MSO adjuvant contributes to the lower weed biomass, thus providing better growth conditions for chickpea (Zhang *et al.* 2022).

Weed control efficiency, herbicide efficiency index and weed index

Among the herbicidal treatments, the highest weed control efficiency (WCE) was recorded with topramezone 20.16 g/ha, closely followed by topramezone 25.20 g/ha and topramezone 25.20 g/ha (**Figure 1**). The lowest WCE was observed with oxyfluorfen 250 g/ha. Compared to topramezone 20.16 g/ha, oxyfluorfen 250 g/ha recorded approximately 30% lesser WCE. Since WCE is directly influenced by weed biomass, the lower weed biomass observed with topramezone 20.16 and 25.20 g/ha reflected in the WCE, making these treatments the highest WCE. Nath *et al.* (2021) also made similar observations. Topramezone 25.20 g/ha + MSO adjuvant recorded the highest value of herbicidal efficiency index (HEI), among all herbicidal treatments. HEI being a factor of yield, the highest yield and lower weed biomass were observed with this treatment reflected in the HEI. The lowest HEI was again recorded with oxyfluorfen 250 g/ha treatment.

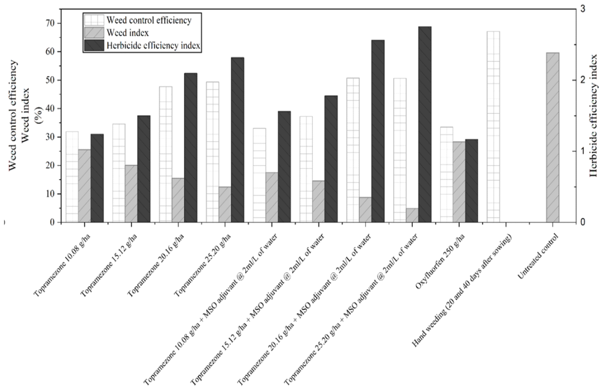

Figure 1. Weed control efficiency and herbicidal efficiency index at 45 DAA, and weed index under different weed control treatments (pooled data of two years)

The highest and lowest weed index was observed under oxyfluorfen 250 g/ha and topramezone 25.20 g/ha + MSO adjuvant respectively (**Figure 1**). Weed index reflects the percent loss in yield with treatment as compared to weed free plot. As observed in the study, oxyfluorfen 250 g/ha consistently recorded the highest weed density and biomass, this may be likely created an environment where chickpea crop was under constant competition with the weeds which likely led to yield penalty. Higher weed density under oxyfluorfen compared to topramezone was also reported by Patel *et al.* (2024).

Table 4. Weed species density (no./m^2) at 45 DAA as influenced by weed control treatments (pooled data of two years)

Treatment	MEUFO	MEDSS	CHEAL	SONOL	RUMSS	ANGAR	POLPB	PTNHY	SOLNI	PHAMI
Topramezone 10.08 g/ha	1.77 (2.63)	1.74 (2.51)	1.68 (2.32)	1.73 (2.49)	1.64 (2.19)	1.57 (1.96)	1.49 (1.72)	1.36 (1.35)	1.27 (1.10)	1.34 (1.28)
Topramezone 15.12 g/ha	1.66 (2.24)	1.63 (2.14)	1.57 (1.96)	1.62 (2.11)	1.54 (1.86)	1.48 (1.68)	1.40 (1.45)	1.29 (1.15)	1.20 (0.94)	1.27 (1.10)
Topramezone 20.16 g/ha	1.53 (1.83)	1.50 (1.75)	1.45 (1.60)	1.49 (1.72)	1.43 (1.53)	1.37 (1.36)	1.30 (1.19)	1.20 (0.94)	1.13 (0.77)	1.19 (0.90)
Topramezone 25.20 g/ha	1.47 (1.65)	1.44 (1.57)	1.40 (1.45)	1.43 (1.54)	1.37 (1.36)	1.32 (1.23)	1.25 (1.06)	1.16 (0.83)	1.09 (0.69)	1.15 (0.82)
Topramezone 10.08 g/ha + MSO adjuvant 2 ml/l of water	1.73 (2.49)	1.70 (2.37)	1.65 (2.21)	1.69 (2.36)	1.62 (2.11)	1.54 (1.86)	1.46 (1.63)	1.34 (1.28)	1.25 (1.05)	1.33 (1.27)
Topramezone 15.12 g/ha + MSO adjuvant 2 ml/l of water	1.56 (1.92)	1.53 (1.83)	1.48 (1.69)	1.52 (1.81)	1.45 (1.60)	1.39 (1.43)	1.33 (1.26)	1.22 (0.99)	1.14 (0.80)	1.21 (0.96)
Topramezone 20.16 g/ha + MSO adjuvant 2 ml/l of water	1.42 (1.50)	1.39 (1.43)	1.35 (1.31)	1.38 (1.40)	1.32 (1.23)	1.27 (1.11)	1.22 (0.98)	1.13 (0.77)	1.06 (0.62)	1.11 (0.73)
Topramezone 25.20 g/ha + MSO adjuvant 2 ml/l of water	1.41 (1.47)	1.39 (1.42)	1.35 (1.31)	1.38 (1.40)	1.33 (1.26)	1.27 (1.11)	1.22 (0.98)	1.13 (0.77)	1.06 (0.62)	1.14 (0.79)
Oxyfluorfen 250 g/ha	2.05 (3.70)	2.01 (3.54)	1.94 (3.26)	2.00 (3.50)	1.90 (3.11)	1.81 (2.76)	1.71 (2.42)	1.55 (1.90)	1.43 (1.54)	1.53 (1.84)
Hand weeding twice 20 and 40 DAS	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Untreated control	4.29 (17.86)	2.50 (5.73)	4.05 (15.86)	4.19 (17.06)	3.95 (15.06)	3.74 (13.49)	3.50 (11.75)	3.13 (9.27)	2.85 (7.59)	3.08 (8.96)
LSD (p=0.05)	0.36	0.37	0.37	0.35	0.23	0.30	0.24	0.36	0.37	0.37

Data was square root transformed ($\sqrt{x+0.5}$), original data within parenthesis, DAA- days after application, DAS- days after sowing. *Please refer to Table 1 for full form of weed EPPO code.

Chickpea seed yield

The highest chickpea seed yield was recorded with hand weeding twice at 20 and 40 DAS, while the lowest chickpea seed yield was recorded under weedy check among all treatments (**Figure 2**). Topramezone 25.20 g/ha + MSO adjuvant recorded the highest chickpea seed yield, during both the years, (**Figure 2**) which was 24% and 7.8% higher compared to oxyfluorfen 250 g/ha and topramezone 20.16 g/ha, respectively and was 4.9% lower than hand weeding twice treatment. All herbicidal treatments except topramezone 10.08 g/ha and oxyfluorfen 250 g/ha were statistically at par with topramezone 25.20 g/ha treatment. The higher seed yield observed with topramezone 25.20 g/ha may be due to combined effects of weed suppression and improved plant growth. Reduced weed density likely favoured growing environment for the chickpea, allowing the crop to achieve higher yield (Kumar *et al*. 2025). Higher chickpea seed yield with topramezone application was also reported by Nath *et al.* (2018).

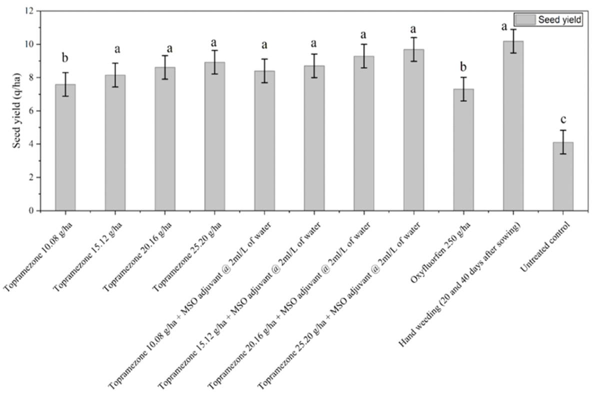

Figure 2. Seed yield of chickpea as affected by different weed control treatments (pooled data of two years)
(Similar letters across bar indicate non-significance at p=0.05 as per LSD)

Correlation analysis

Correlation analysis among seed yield and various weed efficiency indices indicate that there was a strong positive correlation between seed yield and WCE at 45 DAS, moderately positive relation between seed yield and HEI at 45 DAA, and a perfect negative correlation between seed yield and weed index (**Figure 3**). The improved higher yield with reduced weed competition was reported earlier by Bhosale *et al.* (2023), Nath *et al.* (2021) and Nath *et al.* (2018). The perfect negative correlation between seed yield and yield index indicates that as weed density increases, seed yield decreases (Choudhary *et al.* 2025).

Economics

Economic analysis indicated that weed management treatments significantly affected cost of cultivation, returns, and benefit-cost (B:C) ratio

Table 5. Weed species* biomass (g/m^2) at 45 DAA as influenced by weed control treatments (pooled data of two years)

Treatment	MEUOF	MEDSS	CHEAL	SONOL	RUMSS	ANGAR	POLPB	PTNHY	SOLNI	PHAMI
Topramezone 10.08 g/ha	1.69 (2.36)	1.67 (2.26)	1.61 (2.09)	1.65 (2.24)	1.57 (1.97)	1.51 (1.77)	1.43 (1.55)	1.31 (1.22)	1.23 (1.00)	1.29 (1.16)
Topramezone 15.12 g/ha	1.61 (2.12)	1.59 (2.03)	1.54 (1.87)	1.58 (2.00)	1.51 (1.77)	1.45 (1.58)	1.38 (1.39)	1.26 (1.09)	1.18 (0.89)	1.25 (1.05)
Topramezone 20.16 g/ha	1.26 (1.09)	1.25 (1.05)	1.21 (0.96)	1.24 (1.04)	1.19 (0.91)	1.15 (0.82)	1.10 (0.72)	1.04 (0.56)	0.98 (0.46)	1.02 (0.54)
Topramezone 25.20 g/ha	1.21 (0.98)	1.20 (0.94)	1.17 (0.86)	1.20 (0.93)	1.15 (0.82)	1.11 (0.74)	1.07 (0.64)	1.01 (0.50)	0.96 (0.42)	1.00 (0.50)
Topramezone 10.08 g/ha + MSO adjuvant 2 ml/l of water	1.65 (2.25)	1.63 (2.15)	1.58 (1.98)	1.62 (2.13)	1.55 (1.89)	1.48 (1.68)	1.41 (1.47)	1.29 (1.15)	1.21 (0.95)	1.28 (1.15)
Topramezone 15.12 g/ha + MSO adjuvant 2 ml/l of water	1.54 (1.89)	1.52 (1.81)	1.48 (1.67)	1.51 (1.79)	1.45 (1.59)	1.39 (1.41)	1.32 (1.24)	1.22 (0.98)	1.14 (0.80)	1.20 (0.95)
Topramezone 20.16 g/ha + MSO adjuvant 2 ml/l of water	1.18 (0.89)	1.17 (0.86)	1.14 (0.79)	1.16 (0.85)	1.12 (0.75)	1.08 (0.67)	1.04 (0.59)	0.98 (0.46)	0.94 (0.38)	0.97 (0.44)
Topramezone 25.20 g/ha + MSO adjuvant 2 ml/l of water	1.18 (0.89)	1.17 (0.85)	1.14 (0.79)	1.16 (0.85)	1.13 (0.76)	1.08 (0.67)	1.04 (0.59)	0.98 (0.46)	0.94 (0.38)	0.99 (0.47)
Oxyfluorfen 250 g/ha	1.65 (2.22)	1.62 (2.12)	1.57 (1.96)	1.61 (2.10)	1.54 (1.86)	1.47 (1.66)	1.40 (1.45)	1.28 (1.14)	1.20 (0.94)	1.27 (1.11)
Hand weeding twice 20 and 40 DAS	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Untreated control	2.6 (6.25)	2.51 (5.78)	2.37 (5.10)	2.51 (5.80)	2.32 (4.87)	2.19 (4.28)	2.09 (3.88)	1.87 (2.99)	1.72 (2.44)	1.85 (2.91)
LSD (p =0.05)	0.15	0.26	0.25	0.22	0.14	0.18	0.18	0.14	0.16	0.18

Data was square root transformed ($\sqrt{x+0.5}$), original data within parenthesis, DAA- days after application, DAS- days after sowing, *Please refer to Table 1 for full form of weed EPPO code.

Table 6. Economic of chickpea cultivation under various weed control treatments

Treatment	Total cost (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C ratio
Topramezone 10.08 g/ha	27177	42855	40864	1.5
Topramezone 15.12 g/ha	28006	46019	45074	1.61
Topramezone 20.16 g/ha	28836	48647	48474	1.68
Topramezone 25.20 g/ha	29666	50398	50524	1.7
Topramezone 10.08 g/ha + MSO adjuvant 2 ml/l of water	29223	47460	46287	1.58
Topramezone 15.12 g/ha + MSO adjuvant 2 ml/l of water	30053	49183	48067	1.6
Topramezone 20.16 g/ha + MSO adjuvant 2 ml/l of water	30883	52489	52187	1.69
Topramezone 25.20 g/ha + MSO adjuvant 2 ml/l of water	31713	54720	54867	1.73
Oxyfluorfen 250 g/ha	26147	41273	41083	1.57
Hand weeding twice 20 and 40 DAS	39917	57545	51523	1.29
Untreated control	25517	23250	11523	0.45
LSD (p= 0.05)	1281	2113	1746	0.09

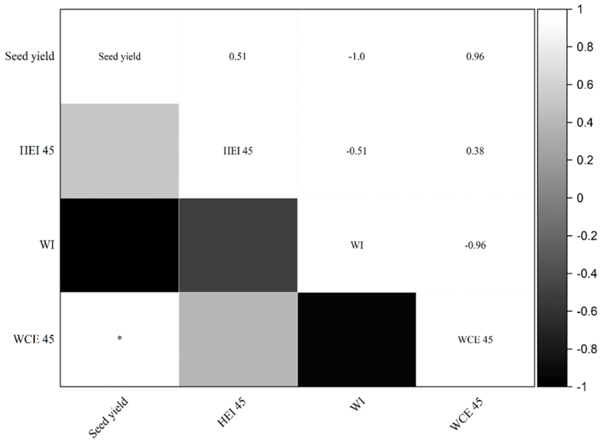

Figure 3. Correlation analysis between chickpea's seed yield and weed control indices
(*Significant at *pd" 0.05,* HEI 45: herbicide efficiency index at 45 DAA, WI: weed index, WCE 45: weed control efficiency index at 45 DAA)

(**Table 6**). Among the treatments, topramezone at 25.20 g/ha + MSO adjuvant recorded the highest gross return, net return, and B:C ratio. However, this treatment was statistically at par with topramezone at 20.16 g/ha + MSO adjuvant and topramezone at 25.20 g/ha alone. Although hand weeding twice at 20 and 40 DAS recorded the highest gross return, its higher cost of cultivation resulted in a lower B-C ratio compared to herbicidal treatments. The untreated control recorded the lowest gross and net returns and a B:C ratio.

Conclusion

It can be concluded that topramezone 20.16 g/ha + MSO adjuvant (2 ml/l of water) effectively controlled both broad-leaved and grassy weeds in chickpea resulting in higher chickpea seed yield and profitability.

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RESEARCH ARTICLE

Bio-efficacy of sequential herbicide application on weed control and yield of field-pea under temperate conditions of Kashmir

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ABSTRACT

A field experiment was conducted at Agronomy Research Farm, Division of Agronomy, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Wadura during *Rabi* seasons of 2021-22 and 2022-23 to study the effect of sequential application of herbicides on weeds and yield of field-pea under temperate conditions. The experiment consisted of 14-treatments which were tested in a complete randomized design replicated thrice. Weeds caused 63.8 and 61.0 per cent reduction in seed yield of field pea during 2021-22 and 2022-23, respectively. Among the herbicides tested, pre-emergence application of pendimethalin 1.00 kg/ha followed by post-emergence application of imazethapyr 0.125 kg/ha recorded significantly lowest weed biomass, weed index and highest weed control index, field-pea growth and yield attributes, seed and stover yield, and better economics over the rest treatments. Hand weeding recorded higher growth and yield of field pea but it was not cost-effective.

Keywords: Economics, Field pea, Imazethapyr, Pendimethalin, Weed management

INTRODUCTION

Field pea (*Pisum sativum* L.) is one of the most important *rabi* season pulse crop in Northern and Central parts of India. Its cultivation maintains soil fertility by enabling biological nitrogen fixation through a symbiotic relationship with *Rhizobium* bacteria found in its nodules, therefore contributing significantly to sustainable agriculture (Negi *et al*. 2006). In India, field pea is cultivated in an area of 0.64-million-hectare with an annual production of 0.88 million tons and an average productivity of 1.4 tons/ha (IIPR 2021). Among the pea growing states, Uttar Pradesh ranks first accounted for 48.33% of peas production in India during 2021-22 followed by Madhya Pradesh with 15.67% of peas production (Numerical 2023). Peas are widely consumed as part of the human diet across the globe and are a rich source of protein (21-25%), carbohydrates (42.65%), vitamin A & C, calcium, phosphorus and essential amino acids such as lysine and tryptophan (Bhat *et al*. 2013). Pea has great potential for grain as well as vegetable purposes. Peas are consumed as a vegetable in fresh, frozen or canned form during the off-season and are also cultivated for producing dry peas, such as split peas. The dried grains are used in various forms including snacks like chat and chhola as well as in dal, flour and other culinary dishes and constitutes an important food supplement for the majority vegetarian population of India.

The quality and productivity of peas tend to reduce due to various biotic and abiotic factors. Among the several factors, competition between crops and weeds is the most serious. Peas compete poorly with weeds because of their slow growth at the early stages and short stature, resulting in huge yield loss (Chaudhary *et al*. 2009). Peas face intense crop weed competition up to 60 days after seeding (DAS) (Kumar *et al*. 2014) which can reduce yields ranging from 40 - 70% (Harker 2001). Peas are vulnerable to grasses, broad-leaved weeds and sedges, resulting in significant yield loss and quality. In addition, late season weeds can decrease harvest efficiency and reduce the quality of pea grains (Singh and Survey 2016). For the control of weeds, generally farmers adopt manual or hand weeding (Singh and Wright 2006) but it is labor-intensive, time consuming and un-economical and hence farmers tend to opt for alternative, cheaper and easier methods of chemical weed control for controlling different types of weeds. Pre-emergence application (PE) of pendimethalin 1.00 kg/ha, is a selective and

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effective herbicide used in pea against annual grasses and few broad-leaved weeds. However, only pre-emergence applications are not adequate to control diverse weeds, which differ in physiology, morphology and tolerance. Continuous use of single herbicide may also favour weed shifts and resistance. Brijbhooshan *et al*. (2017) reported that pendimethalin at 1.00 kg/ha PE was inferior to one hand weeding employed at 25 days after sowing (DAS). Besides, during winter, the efficacy of pre-emergence herbicides is greatly affected by the soil surface dryness and change in weather variables namely rainfall, sunshine and humidity. However, post-emergence application (PoE) of herbicides may help growing field pea which is severely infested by weeds even after one month of sowing due to its initial slow growth. Post-emergence herbicide can protect pea crop from weed competition throughout the season. Post-emergence herbicide imazethapyr control weeds in peas led to optimum seed yield (Das 2016). Thus, sequential herbicide applications *i.e*., pre-emergence followed by (*fb*) post-emergence in pea may provide complete control of weeds up to 45-50 days stage after which crop smoothers the weeds and may shift the competition in favour of the crop and prevent weed shift and delay resistance (Das *et al*. 2014).

MATERIALS AND METHODS

The objective of the experiment was to evaluate the efficacy of sequential herbicide application on weeds and field pea crop yield. The experiment was carried out at Agronomic Research Farm, of the Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Wadura, India during *Rabi* season of 2021-22 and 2022-23. The soil of the experimental site was silty-clay loam in texture, acidic in reaction (6.4), and medium in available nitrogen (275.5 kg/ha), phosphorus (17.5 kg/ha) and potassium (174.2 kg/ha). The experiment consisted of 14-treatments, *viz*. pendimethalin (30% EC) (pendimethalin) 1.00 kg/ha PE 2 DAS; oxyfluorfen (23.5% EC) (oxyfluorfen) 0.150 kg/ha PE; pendimethalin 1.00 kg/ha PE *fb* imazethapyr (10% SL) (imazethapyr) 0.025, 0.050, 0.075, 0.100 and 0.125 kg/ha PoE; oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.025, 0.05, 0.075, 0.100 and 0.125 kg/ha PoE; pendimethalin 1.00 kg/ha PE *fb* manual weeding twice; oxyfluorfen 0.150 kg/ha PE *fb* manual weeding (HW) twice; weedy check and weed free check (HW at 20 days interval after mid-February) A complete randomized design replicated thrice was used. In Kashmir valley, the field-pea is a winter (*Rabi*) crop with a long duration of 210 days and is subjected to a prolonged period of winter-induced dormancy from late November to February. Due to low temperature the crop exhibits minimal metabolic and vegetative development. With the onset of early spring and the gradual rise in temperature, the plants resume active vegetative growth, typically beginning in the first week of March (at 135 DAS). A pronounced flush of weeds was observed immediately following the crop's dormancy phase, coinciding with the resumption of vegetative growth. So, the post-emergence herbicides were applied during the first week of March when the crop and the newly emerged weeds were at growth stages most responsive to weed control. As rising soil temperatures in the spring stimulate rapid weed growth, the 210-day field pea crop grown in the Kashmir valley, faces a second peak of weed competition in the spring. Hence, the manual weeding at 135 and 160 DAS effectively targets these spring weeds before they can overshadow the pea during their peak flowering and pod-filling stages and also removes the mature winter weeds before they set seeds (shattering) which were suppressed by winter snow. During 2021-22 crop growth period, the temperatures dropped below ^{0}0C from 46- 08 Standard Meteorological week (SMW), and during 2022-23 crop growth period from 47-07 SMW as shown in **Figure 1** and **2** respectively. Manually operated knapsack sprayer fitted with a flat fan nozzle was used for spraying the herbicides. Pendimethalin and oxyfluorfen were applied by spraying, uniformly, at 2 DAS. Imazethapyr was applied during the first week of March *i.e*. 135 DAS when the weeds were at 2-4 leaf stage and also no irrigation was given at the time of imazethapyr application as the soil was having sufficient moisture. The field pea crop (Shalimar pea-1) was sown in rows, 30 cm apart with plant-to-plant distance of 10 cm on 22 October 2021 and 25 October 2022 (43rd Standard Meteorological Weeks) during both the crop growing periods of 2021-22 and 2022-23 respectively by using 80 kg per hectare seed rate. The mean weekly maximum and minimum temperature was 14.4 ^{0}C and 3.6^{0}C, respectively in 2021-22 while 20 ^{0}C and 2.4 ^{0}C in 2022-23, respectively. A total of 544.5 mm and 671.6 mm rainfall was received at experimental site during 2021-22 and 2022-23, respectively. The soil moisture at the time of sowing was sufficient for germination and emergence. At the time of sowing, uniform doses of 45 kg, 70 kg and 40 kg of N, P and K were applied as basal doses through urea, DAP and MOP, respectively. The data recorded for each parameter was subjected to analysis for variance for randomized complete block design. From each experimental plot,

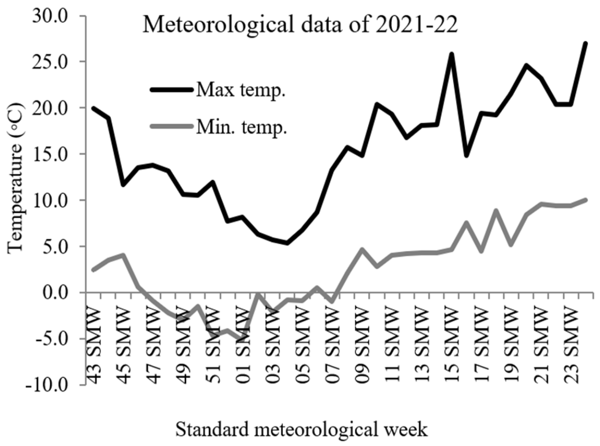

Figure 1. Weather parameter (max. and min. temp.) during crop growth period of 2021-22

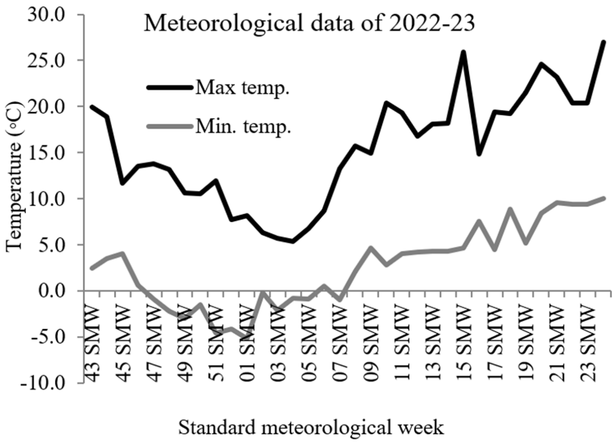

Figure 2. Weather parameter (max. and min. temp.) during crop growth period of 2022-23

five random plants were chosen to record observations on plant height, leaf area index, dry matter accumulation and crop growth analysis at 30 days interval from last week of February (120 DAS) up to harvest. While field-pea yield and yield attributing parameters (number of pods per plant, number of seeds per pod and seed index) were recorded at harvest. For weed population, weed dry matter (biomass) and weed control index, were recorded at 150 DAS and 175 DAS. The weed biomass was recorded using 0.25 m × 0.25 m quadrat placed randomly at five places in each plot and the weeds falling within the frames of the quadrat were uprooted and placed for sun drying. After, sun drying, they were dried in a hot air oven at 65-70 ^{0}C until reaching a constant weight, and the mean values were expressed as weed biomass (g/m^2).

The calculated weed control performance indices include: weed control index and weed index, based on weed biomass and seed yield, respectively.

1. **Weed control index (WCI**) reflects a per cent reduction in weed dry weight by a treatment (Nath *et al.* 2016).

WCI (%) = [(WMC –WMT)*100] / WMC.

Where, WMC and WMT are the corresponding biomass of weeds in the control and treated plots.

2. **Weed index (WI)** is a measure of the efficacy of a treatment in terms of yield output when compared with weed free treatment. It reflects a per cent yield loss. (Asres and Das 2011).

WI (%) = (YF – YT) / YF

Where, YF and YT, respectively, stand for yields in weed-free and treated plots.

With the help of the minimum support price and the current market price of the products, the economics of different treatments was also computed. The B:C, which is the ratio of net returns to total cost of cultivation, was determined to evaluate the treatments' economic viability. Prior to statistical analysis, the density and biomass of weeds were subjected to square root transformation using ($\sqrt{x+0.5}$). The data were subjected to analysis of variance and significant differences among treatments were tested by calculating CD at 5% level of significance differences evaluated by using one way ANOVA (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Field-pea growth parameters

The field-pea growth parameters of field-pea were significantly affected by tested herbicide treatments. The oxyfluorfen 0.150 kg/ha PE showed some level of phytotoxicity on field pea which led to reduced field-pea emergence than with pendimethalin 1.00 kg/ha PE. However, after emergence of the crop, no phytotoxicity symptoms were observed on the crop.

Plant height: Field-pea plant height increased continuously with advancement in crop age and reached its maximum at harvesting stage (**Table 1**). At 150 and 180 DAS during both the years, the hand weeding treatments produced significantly taller plants which were at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075, 0.100 and 0.125 kg/ha PoE and manual weeding twice. At 210 DAS and at harvest, the hand weeding treatments produced significantly taller plants which were at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075, 0.100 and 0.125 kg/ha PoE. This may be ascribed to less competition from weeds owing to their effective suppression. Similar results were reported by Rana *et al.* (2015).

Leaf area index: Field-pea leaf area index at 150 DAS during both the years were observed highest with the hand weeding treatment which was at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100, 0.125 kg/ha PoE and manual weeding twice (**Table 1**). Similar trend was observed at 180 DAS during the first year of experiment but during second year at 180 DAS, highest leaf area index was observed with hand weeding treatment which was followed by pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100, 0.125 kg/ha PoE. At 210 DAS during both the years, highest leaf area index was observed with hand weeding treatment which were at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE or *fb* manual weeding twice during 2021-22 but during 2022-23, it was at par with pendimethalin 1.00 kg/ha PE *fb* manual weeding twice. At harvest, leaf area index was observed highest with hand weeding treatment during both years but during second year (2022-23) it was at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE. The lowest leaf area index was recorded with weedy check treatment during both the years.

Dry matter accumulation: Field-pea dry matter accumulation was recorded highest with the hand weeding treatment at all the stages of crop growth (**Table 2**). However, during the first year of experiment (2021-22) at 150 and 180 DAS, hand weeding treatment was at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075, 0.100, 0.125 kg/ha PoE and during second year at 150 DAS, hand weeding was followed by pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE but at 180 DAS, hand weeding treatment was at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE. However, at 210 DAS and at harvest, pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100,

Table 1. Plant height (cm) and leaf area index of field-pea as influenced by treatments (pooled 2021-22 and 2022-23)

Treatment	Plant height (cm)				Leaf area index			
	150 DAS	180 DAS	210 DAS	At harvest	150 DAS	180 DAS	210 DAS	At harvest
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	35.6	98.7	19.3	19.7	2.28	3.43	4.47	2.32
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	38.2	101.0	19.4	19.8	2.29	3.51	4.93	2.69
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	43.4	103.8	19.7	20.3	2.32	3.58	5.00	2.75
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	43.6	104.2	19.8	20.3	2.34	3.61	5.14	2.81
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	43.8	104.7	19.8	20.4	2.34	3.66	5.28	2.89
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	26.8	75.7	16.3	16.8	2.05	2.96	4.48	2.32
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	28.8	77.0	16.6	17.1	2.10	3.22	4.94	2.71
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	31.4	78.6	16.7	17.2	2.07	3.27	5.01	2.75
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	32.3	80.3	17.0	17.5	2.12	3.36	5.09	2.77
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	32.4	81.1	17.1	17.6	2.14	3.49	5.10	2.77
Pendimethalin 1.00 kg/ha PE *fb* manual weeding twice	42.1	103.3	19.5	20.1	2.32	3.42	4.94	2.73
Oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice	32.6	84.3	17.9	18.4	2.11	3.18	4.47	2.35
Hand weeding (continuously at 20 days interval from Mid-February)	46.1	108.3	20.1	20.6	2.48	3.83	5.91	3.47
Weedy check	22.3	65.8	15.0	15.8	1.99	2.62	4.07	2.00
LSD (p=0.05)	6.9	28.9	1.1	1.0	0.06	0.08	0.06	0.26

*DAS= Days after sowing; PE= pre-emergence application; PoE=post-emergence application; *fb*= followed by

Table 2. Dry matter accumulation (g/plant) and mean crop growth rate (g/m^2/day) of field-pea as influenced by treatments (pooled 2021-22 and 2022-23)

Treatment	Dry matter accumulation (g/plant)				Mean crop growth rate (g/m^2/day)			
	150 DAS	180 DAS	210 DAS	At harvest	150 DAS	180 DAS	210 DAS	At harvest
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	2.88	5.26	6.95	7.44	2.92	4.64	4.79	2.76
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	3.09	5.84	7.80	8.53	3.14	5.22	5.45	3.61
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	3.31	6.28	8.65	9.46	3.38	5.62	6.28	4.00
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	3.33	6.39	8.77	9.50	3.39	5.74	6.34	3.84
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	3.37	6.46	8.82	9.53	3.43	5.80	6.33	3.80
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	2.29	4.31	6.02	6.30	2.37	3.85	4.43	1.74
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	2.34	4.45	6.24	6.58	2.41	3.99	4.60	2.14
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	2.39	4.92	7.06	7.31	2.45	4.54	5.34	1.97
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	2.42	5.10	7.45	7.82	2.48	4.73	5.72	2.50
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	2.43	5.32	7.76	8.12	2.49	4.99	5.95	2.43
Pendimethalin 1.00 kg/ha PE *fb* manual weeding twice	3.23	6.20	8.54	9.11	3.30	5.57	6.19	3.30
Oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice	2.29	4.86	6.80	7.30	2.38	4.52	5.01	2.80
Hand weeding (continuously at 20 days interval from Mid-February)	3.63	6.55	9.04	9.66	3.64	5.73	6.56	3.60
Weedy check	2.15	4.04	5.56	5.79	2.14	3.60	16.18	1.69
LSD (p=0.05)	0.08	0.08	0.07	0.07	0.09	0.08	0.34	0.27

*DAS= Days after sowing; PE= pre-emergence application; PoE=post-emergence application; *fb*= followed by

0.125 kg/ha PoE were found either at par or next to the hand weeding treatment during both the years. These results indicated that the sequential application of pendimethalin 1.00 kg/ha PE and imazethapyr 0.100 and 0.125 kg/ha PoE significantly minimized crop-weed competition and promoted plant growth in an effective and efficient manner. The observed enhancement in crop growth with increasing doses of post emergence application of imazethapyr is primarily attributable to lower density and dry matter of weeds which might have created congenial environment for crop growth and development which led to more accumulation of dry matter per plant. The weedy check treatment resulted in reduced dry matter accumulation due to increased weed growth, leading to intense competition for essential growth factors. Similar findings were also reported by Rana *et al.* (2013) and Sultana *et al.* (2009).

Crop growth analysis

Mean field-pea crop growth rate (CGR) (g/m^2/day) which indicates growth rate of the crop based on dry matter accumulation (DMA) per unit ground area over a period. From 120-150 DAS and 180-210 DAS, higher values of mean CGR were observed with hand weeding treatment which were at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 and 0.125 kg/ ha PoE (**Table 3)** Mean relative growth rate (RGR) (mg/g/day) indicates growth rate based on increase in dry matter over initial dry matter produced. Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075, 0.100 and 0.125 kg/ha PoE were either at par or were the next best treatments after hand weeding (**Table 3)** Mean net assimilation rate (NAR) (g/m^2/day) indicated net dry matter accumulation depending on total leaf areas produced at various growth stages. Hand weeding treatment recorded highest NAR followed by pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075, 0.100 and 0.125 kg/ha PoE (**Table 3**). Mean RGR and mean NAR declines as the crop proceeds towards maturity as leaves advance towards senescence. Thus, leaf area decreases at the later stage consequently rate of dry matter production diminishes. This indicates that any weed management practice that decreases the crop-weed competition sets higher growth rate of crop. Due to effective control of weeds, reduced crop-weed competition resulted in better growth and development of crop as reported by Rana *et al.* (2015).

Field pea yield attributes and yield

The field pea yield attributes indicate final output of total growth and development of a crop (**Table 4**). During both the years, hand weeding treatment recorded significantly higher number of pods/ plant, number of seeds/pod and seed index over herbicidal treatments. However, all the herbicidal treatments were significantly superior over weedy check during both the years. Among the herbicidal treatments application of pendimethalin 1.00 kg/ha PE *fb* manual weeding twice and pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 and 0.125 kg/ha PoE recorded significantly highest number of pods/plant, number of seeds/pod and seed index during both the years. Higher yield attributes with herbicidal treatments might be due to lesser crop weed competition.

During both the years, higher biological yield of field pea was recorded with hand weeding treatment (**Table 4**). Among the herbicidal treatments, higher

Table 3. Mean relative growth rate (mg/g/day) and net assimilation rate (g/m^2/day) of field pea as influenced by treatments (pooled 2021-22 and 2022-23)

Treatment	Mean relative growth rate (mg/g/day)				Mean net assimilation rate (g/m^2/day)			
	120-150 DAS	150-180 DAS	180-210 DAS	At harvest	120-150 DAS	150-180 DAS	180-210 DAS	At harvest
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	16.15	11.00	7.48	3.66	4.61	2.85	2.35	5.74
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	16.45	11.32	7.62	4.22	5.35	3.16	2.59	6.09
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	16.59	11.32	8.04	4.21	5.98	3.33	2.92	6.43
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	16.40	11.42	7.98	3.99	5.98	3.38	2.92	6.44
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	16.37	11.44	7.89	3.93	6.09	3.40	2.87	6.40
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	17.98	11.27	8.17	2.74	4.41	2.67	2.32	4.25
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	17.37	11.35	8.19	3.21	4.43	2.62	2.26	4.43
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	17.20	12.05	8.50	2.59	4.58	2.97	2.60	4.81
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	17.12	12.21	8.70	3.16	4.49	3.01	2.73	4.89
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	16.98	12.50	8.72	2.91	4.48	3.10	2.80	4.79
Pendimethalin 1.00 kg/ha PE *fb* manual weeding twice	16.77	11.43	8.00	3.56	5.67	3.41	2.95	6.04
Oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice	18.40	12.32	8.19	3.78	4.49	3.01	2.54	5.05
Hand weeding (continuously at 20 days interval from Mid-February)	15.27	10.88	8.02	3.66	6.22	3.20	2.83	6.35
Weedy check	14.77	11.25	7.97	2.85	3.17	2.72	2.28	4.01
LSD (p=0.05)	NS	NS	NS	0.39	0.40	0.08	0.07	0.52

*DAS= Days after sowing; PE= pre-emergence application; PoE=post-emergence application; *fb*= *followed by* biological yield was recorded with pendimethalin 1.00 kg/ ha PE *fb* imazethapyr 0.125 kg/ha PoE which were at par pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 and 0.100 kg/ha PoE. Seed yield during both the years also followed the same trend but pendimethalin 1.0 kg/h PE *fb* imazethapyr 0.125 kg/ha PoE was at par with pendimethalin 1.0 kg/ha PE *fb* imazethapyr 0.075 and 0.100 kg/ha PoE and followed by manual weeding. Stover yield was also higher with hand weeding treatment during both the years. The minimum biological, seed and stover yield of field pea was observed with weedy check treatment during both the years due to more weed infestation which resulted in poor crop growth and poor development of yield attributing characters. Similar findings have been reported by Bhyan *et al.* (2004) and Rajeev *et al.* (2006).

Economics

Pendimethalin 1.0 kg/ha PE *fb* imazethapyr 0.125 kg /ha PoE recorded the highest B:C of 2.66 and 3.01 during the first and second year, respectively followed by pendimethalin 1.0 kg/ha PE *fb* imazethapyr 0.100 and 0.075 kg/ha PoE. This could be primarily due to superior weed control at low cost and increased yield. Similar findings were noted by Singh (2011) and Kumar *et al.* (2010).

Effect on weeds

Weed biomass: The predominant weed species infesting the field pea crop at 150 DAS and 175 DAS were *Lolium perenne, Ranunculus arvensis, Caposella bursa pastoris, Stellaria media, Fumaria parviflora, Angelis arvensis* and *Matric aria chamomilla*. Weed biomass was significantly lower with the hand weeding treatment during both the years (**Table 5**). Among herbicidal treatments at 150 DAS during both the years, pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075, 0.100 and 0.125 kg/ha PoE significantly reduced weed biomass which were next to hand weeding treatment. At 175 DAS during both the years, application of pendimethalin 1.00 kg/ha PE or oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice reduced the weed biomass which were followed by pendimethalin 1.00 kg/ ha PE *fb* imazethapyr 0.100 and 0.125 kg/ha PoE. None of the treatments were comparable to hand weeding treatment in controlling weeds. However, all the herbicide treatments were significantly superior to weedy check treatment. It might be because the manual weeding consistently exhibits lower weed biomass compared to herbicide treatments. Besides, effective weed control by manual weeding, the main reason of reducing weed biomass under sequential application of herbicides was because of first flush of weeds was controlled by pendimethalin PE and the second flush of weeds were controlled by imazethapyr PoE due to its broad-spectrum properties. Also, dense crop canopy at later stages might have suppressed weed growth and ultimately reduced dry weight. Similar findings were also reported by Kumar *et al.* (2002), Buttar *et al.* (2008) and Mathukia *et al.* (2015).

Weed control index (WCI): During both the years at 150 DAS and at 175 DAS, the mean WCI of 83.52% and 95.61% was recorded with hand weeding (**Table 5**). Among the herbicidal treatments, at 150 DAS, the highest mean WCI was recorded with pendimethalin

Table 4. Yield attributing parameters and yield parameters of field pea as influenced by treatments (pooled 2021-22 and 2022-23)

Treatment	Yield attributing parameters			Biological yield (t/ha)		Seed yield (t/ha)		Stover yield (t/ha)		B:C	
	No. of pods/plant	No. of seeds/pod	Seed index (g)	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	20.3	5.18	16.38	5.86	6.47	1.09	1.51	4.77	4.96	1.43	1.91
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	20.5	5.30	16.62	7.72	8.45	1.32	1.92	6.39	6.54	1.73	2.41
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	20.8	5.33	18.28	9.81	10.07	1.98	2.35	7.83	7.72	2.55	2.94
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	20.9	5.37	18.33	9.88	10.18	2.03	2.37	7.85	7.81	2.59	2.94
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	21.0	5.42	18.42	9.96	10.24	2.10	2.45	7.85	7.79	2.66	3.01
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	20.2	5.05	15.67	4.22	4.59	1.03	1.44	3.19	3.15	1.35	1.83
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	20.3	5.10	16.19	4.60	5.04	1.16	1.52	3.44	3.53	1.46	1.86
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	20.4	5.13	17.09	5.54	6.36	1.47	1.75	4.06	4.61	1.84	2.14
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	20.5	5.17	17.62	6.56	7.04	1.54	2.00	5.02	5.03	1.93	2.43
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	21.0	5.22	17.87	7.31	7.35	1.72	2.07	5.59	5.29	2.14	2.49
Pendimethalin 1.00 kg/ha PE *fb* manual weeding twice	21.4	5.47	18.35	9.18	9.25	1.99	2.36	7.19	6.90	1.98	2.31
Oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice	20.5	5.33	15.47	5.86	5.99	1.53	1.77	4.33	4.23	1.51	1.67
Hand weeding (continuously at 20 days interval from Mid-February)	24.7	6.09	19.74	10.33	10.66	2.47	2.76	7.86	7.90	2.24	2.46
Weedy check	16.2	3.62	14.74	3.78	3.90	0.89	1.06	2.88	2.84	1.26	1.47
LSD (p=0.05)	0.50	0.13	0.30	0.55	0.31	0.24	0.19	0.67	0.36		

*PE= pre-emergence application; PoE=post-emergence application; *fb= followed by*

Table 5. Weed biomass (g/m²), weed control index (%) and weed index (%) of field pea as influenced by treatments (pooled 2021-22 and 2022-23)

Treatment	Weed biomass (g/m²)		Weed control index (%)		Weed index (%)
	150 DAS	175 DAS	150 DAS	175 DAS	
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	2.85	3.99	69.38	46.06	50.3
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	2.82	3.82	70.35	54.69	38.3
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	2.56	3.46	80.28	69.66	16.9
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	2.55	3.46	80.53	69.83	15.2
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	2.54	3.45	80.94	70.02	12.4
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	2.76	3.80	72.84	55.79	52.8
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	2.74	3.78	73.78	56.51	48.7
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	2.74	3.78	73.78	56.79	38.0
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	2.72	3.76	74.29	57.83	32.1
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	2.72	3.76	74.50	57.80	27.2
Pendimethalin 1.00 kg/ha PE *fb* manual weeding twice	2.75	2.61	73.36	90.84	17.1
Oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice	2.63	2.45	77.69	93.22	36.6
Hand weeding (continuously at 20 days interval from Mid-February)	2.44	2.23	83.52	95.61	0.0
Weedy check	3.81	4.65	0.00	0.00	62.4
LSD (p=0.05)	0.04	0.05			

*DAS= Days after sowing; PE= pre-emergence application; PoE=post-emergence application; *fb= followed by*

1.00 kg/ha PE *fb* imazethapyr 0.125, 0.100 and 0.075 kg/ha PoE with mean WCI of 85.5, 85.0 and 83.5% respectively. Also at 175 DAS, pendimethalin 1.00 kg/ha PE or oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice recorded highest mean WCI with mean WCI of 93.2 and 90.8% respectively which was further followed by pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125, 0.100 and 0.075 kg/ha PoE with mean WCI of 70.0, 69.8 and 69.7% respectively. The hand weeding treatment underscores the importance of maintaining weed free environment for maximizing crop productivity (Brown and Green 2024). The reason for the highest WCI can be attributed to its effective control of all types of weeds as reported by Rana *et al*. (2004).

Weed index (WI): The lowest weed biomass was recorded under hand weeding treatment resulted in lowest weed index (0.00%) during both the years (**Table 5**). Among the herbicidal treatments, lowest mean weed index was observed in pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 and 0.100 kg/ha PoE with mean WI of 12 and 15% respectively. It was 17% with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE and manual weeding twice. Maximum mean WI was observed with weedy check treatment of 62.4%. Similar findings were also reported by Kumar and Singh (2014) and Johnson and Holm (2010).

Conclusion

It can be concluded that pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE was the most cost-effective treatment to manage weeds and realizing higher seed yield in field pea.

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RESEARCH ARTICLE

Effect of rice residue and nitrogen management on weeds and productivity of oilseed rape (*Brassica napus* L.)

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ABSTRACT

A field experiment was conducted during the winter (*Rabi*) seasons of 2023-24 and 2024-25 at Punjab Agricultural University, Ludhiana, to evaluate the effects of rice residue and nitrogen management on weeds in oilseed rape (*Brassica napus* L.) of rice (*Oryza sativa* L.)- should be in the middle oilseed rape rotation. The experiment was laid out in a split-plot design with three replications. Main plot treatments included three rice residue management practices involving oilseed rape seeding with Happy seeder (Happy seeder), surface seeding-cum-mulching, and conventional method while the sub-plot treatments comprised of three nitrogen levels, *viz.* 75%, 100% and 125% of the recommended dose of nitrogen (RDN). Among the rice residue management practices, both the surface seeding-cum-mulching and Happy seeder method recorded significantly lower weed density and biomass compared to the conventional method at 30 days after sowing (DAS). Application of 75% RDN resulted in significantly lower weed density and biomass at 30 DAS compared with 100% and 125% RDN. Further, application of 125% RDN increased seed yield by 19.6% over 75% RDN, whereas 100% RDN produced a 15.3% higher yield than 75% RDN. The highest weed density and biomass were observed with the conventional method, indicating that residue retention practices using Happy seeder and surface seeding-cum-mulching methods, combined with 75% nitrogen dose were more effective in suppressing weed emergence and growth in oilseed rape based on the two-year pooled analysis. Happy seeder-sown oilseed rape produced 10.4% and 23.3% higher seed yield than conventional method and surface seeding-cum-mulching, respectively.

Keywords: Happy seeder, Nitrogen management, Surface seeding-cum-mulching, Weed management

INTRODUCTION

In northwest part of India, *Brassica napus* (oilseed rape/*gobhi sarson*) and *B. juncea* (mustard/*raya*) are grown on a commercial scale. In Punjab, oilseed rape, especially canola quality is exclusively grown under irrigated conditions while mustard is grown under both irrigated and rainfed conditions. Weed competition is one of the major constraints limiting the productivity of canola quality of oilseed rape. The crop-weed interference is severe particularly during the early growth period of 15 to 40 days after sowing (DAS), when the crop is highly sensitive to competition for light, moisture, and nutrients due to its short stature and wide row spaces of 45 cm (Yernaidu *et al.* 2024). Yield losses due to unchecked weed growth in rapeseed–mustard systems range from 25-50%, depending on weed flora, infestation intensity, and crop growth stage (Yadav *et al.* 2017). Traditionally, hand weeding has been the predominant weed control method in mustard; however, this practice is becoming unsustainable due to high labour costs, seasonal worker scarcity and the time and efforts required. Moreover, a single hand weeding at 25-30 DAS is often inadequate, as new weed flushes emerge after irrigation or winter rains, leading to renewed competition at later stages. The weed infestations deplete soil moisture and nutrients, reducing crop vigour and yield potential. Although herbicides are widely used, over-reliance on chemical control increases the risk of evolution of herbicide-tolerant weed species, especially under frequent or high-dose applications (Asaduzzaman *et al.* 2020). In addition, herbicides alone are often less effective against the diverse and dense weed populations found in mustard fields. Therefore, integrated weed management (IWM) strategies combining cultural, mechanical and chemical approaches are gaining importance. The rice residue retention as surface mulch has emerged as a promising component option of IWM.

The challenge in intensified in rice-mustard cropping systems is the large amount of rice residue left after rice combine harvesting, which typically leaves 30-40 cm stubbles and a thick rice straw layer. Rice residue burning, though common, is

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environmentally harmful, causing greenhouse gas emissions, nutrient loss and soil degradation (Bhuvaneshwari *et al.* 2019). The conservation agriculture practices involving residue retention and reduced tillage have shown potential to modify weed flora composition and reduce weed emergence in rice-based systems (Kaur *et al.* 2025, Sraw *et al.* 2025). The residue management strategies such as retention, incorporation, or mulching are being increasingly explored to enhance soil health and reduce weed infestation. The surface retention of rice residues acts as mulching material and affect soil microclimate including the microbial health, and thus affect the transformations of carbon, nitrogen and phosphorus in soil (Sraw *et al.* 2025).

Nitrogen management plays a crucial role in determining crop vigour, canopy structure, and competitive ability. Adequate nitrogen supply enhances crop photosynthetic efficiency, vegetative growth, and canopy closure, reducing light availability for weeds. Conversely, excessive nitrogen may favour certain weed species, intensifying competition. Although residue retention improves soil moisture and crop competitiveness, it also influences nutrient dynamics particularly nitrogen availability as microbial decomposition of residues can temporarily immobilize nitrogen, affecting both crop and weed growth. Keeping in view the advantages of residue retention on weed suppression, there is a need to evaluate the interactive effects of crop residues and nitrogen levels on weed growth. Understanding the interaction between nitrogen levels and residue management is vital for developing effective and sustainable weed management strategies in oilseed rape under rice-oilseed rape rotation. Therefore, this study was conducted to study the interactive effects of residue retention and nitrogen levels on weeds dynamics and productivity of oilseed rape.

MATERIALS AND METHODS

The field experiment was conducted at the Students' Research Farm, Punjab Agricultural University, Ludhiana, during the *Rabi* seasons of 2023-24 and 2024-25. The site is situated at 30°542 N latitude and 75°482 E longitude, at an elevation of 247 m above mean sea level, representing a semi-arid subtropical climate. The experimental soil was sandy loam in texture, medium in organic carbon (0.44%), available nitrogen (304 kg/ha), and available potassium (247 kg/ha), and high in available phosphorus (26.4 kg/ha). The soil pH was nearly neutral (7.36) with normal electrical conductivity (0.20 dS/m).

Meteorological data recorded at the Meteorological Observatory of Punjab Agricultural University, Ludhiana, during the 2023-24 and 2024-25 crop seasons are presented in **Figure 1**. In 2023-24, the weekly maximum temperature ranged from 11.4°C to 32.0°C, while the minimum temperature varied between 5.0°C and 17.0°C. The total rainfall during the season was 127.1 mm, with mean relative humidity between 53% and 87%, and total weekly sunshine hours ranging from 0.3 to 10.9 hours. During 2024-25, the weekly maximum temperature ranged from 11.0°C to 36.0°C, and the minimum temperature varied between 5.0°C and 17.0°C. The season received 127 mm of rainfall, with mean relative humidity ranging from 43% to 86.5%, and total sunshine hours between zero and 11 hours.

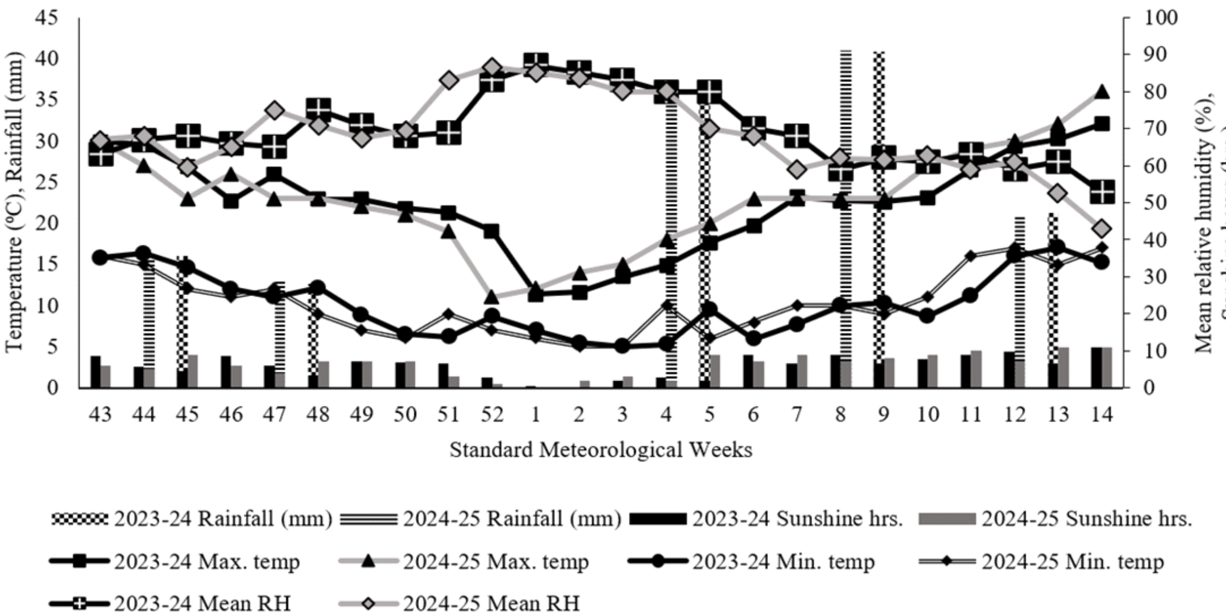

Figure 1. Weekly meteorological data during crop season of 2023-24 and 2024-25

The experiment was laid out in a split-plot design with three replications. The main plot treatments included three rice residue management methods involving oilseed rape seeding with Happy seeder, broadcast of oilseed rape seeds on rice straw, followed by copping of straw with mulcher (surface seeding-cum-mulching) and rice residue removed and oilseed rape seeding done in cultivated field (conventional method). The sub-plot treatments comprised three nitrogen levels, *viz*. 75% of the recommended dose of nitrogen (RDN) (75 kg N/ha), 100% RDN (100 kg N/ha), and 125% RDN (125 kg N/ha). Oilseed rape cv. GSC 7 was sown on was sown on 27 October, 2023 and 30 October, 2024 using 3.75 kg seed per hectare with methods as per main plot treatments. Each plot had a gross area of 20.5 m² and a net area of 12.4 m². A basal dose of 30 kg P/ha was applied at sowing through single superphosphate while nitrogen was applied through urea in two equal splits.

In Happy seeder treatment, oilseed rape was directly sown into standing and loose rice residues (a total residue load of 5.5 t/ha) using the PAU Happy seeder machine after uniform distribution of loose straw. Under surface seeding-cum-mulching method, oilseed rape seeds were broadcasted over the field immediately after combine harvesting, and then mulcher was used to cut and spread the straw. Entire phosphorus was applied as a basal dose at sowing and half of the nitrogen dose was applied as per treatment details, followed by uniform straw spreading with a straw cutter-cum-spreader. A light irrigation was applied immediately after sowing to ensure germination. In the conventional method, the field was prepared after complete residue removal, and oilseed rape sowing was performed using a tractor-drawn dual seed drill. In Happy seeder and conventional method plots, sowing was done in rows spaced 45 cm apart, and seedlings were thinned three weeks after sowing to maintain a uniform plant-to-plant spacing of 10 cm.

Weeds were counted species-wise using a 0.5 m × 0.5 m quadrat placed randomly at two spots in each plot at 30 days after sowing (DAS) before the manual weeding. Later, two hand weedings were performed, the first at 35 DAS and the second at 60 DAS. Weeds within each quadrat were cut at ground level and sorted by species. The collected samples were first sun-dried and then oven-dried at 60 ± 2 °C until constant weight was achieved. The dry weight of each weed species (weed biomass) was recorded separately and expressed as grams per square meter (g/m^2). Oilseed rape seed yield per plot was recorded at harvesting on 2 April 2024 and 3 April 2025 and was expressed in quintals per hectare after threshing, cleaning and drying. Lodging was recorded at harvest using a 0-9 scale, where 0 denoted no lodging and 9 indicated complete lodging. Net returns were calculated by deducting the variable cost of cultivation from the gross returns.

Data were analysed using CPCS-1 software to evaluate differences among treatments. Weed density and biomass values were subjected to square-root transformation before statistical analysis. Statistical analysis was carried out following the split-plot design as outlined by Gomez and Gomez (1984). Differences among treatment means were evaluated using the Fisher's Protected Least Significance Test (LSD) at the 5% probability level.

RESULTS AND DISCUSSION

Effect on weeds

Weed flora was dominated by broad-leaved weed species, particularly *Rumex dentatus*, *Medicago denticulata*, *Anagallis arvensis*, *Lepidium didymum* and *Alternanthera philoxeroides*. Weed density was significantly lower under surface seeding-cum-mulching method compared to Happy seeder and conventional method at 30 DAS (**Table 1**). This reduction was mainly due to complete soil coverage by residues, which limited light penetration and created a physical barrier to weed emergence. Similar findings were reported by Iqbal *et al.* (2020), where mulching suppressed weed growth by reducing light availability. The higher density of *A. philoxeroides* in surface seeding-cum-mulching plots was likely caused by stem fragmentation due to one operation of cutter-cum-spreader during straw cutting and its spreading, which promoted its regrowth from plant fragments. In contrast, Happy seeder method recorded significantly lower density of *A. philoxeroides* and other broad-leaved weed species as compared to conventional method, as surface-retained residues restricted weed emergence as reported earlier by Kaur *et al.* (2024) and Sraw *et al.* (2025) However, slightly higher weed density in the Happy seeder plots than in surface seeding-cum-mulching might be attributed to uneven residue distribution within crop rows. Overall, residue retention through both surface seeding-cum-mulching and Happy seeder effectively suppressed weed emergence compared with residue removal in conventional method. Choudhary and Bhagawati (2019) also found that groundnut haulm mulch at 4 t/ha in *toria* reduced the density of broad-leaved, grassy and sedge weeds by 49.1%, 20.5%, and 27.3%, respectively, over the no-mulch treatment.

A significant influence of nitrogen levels on weed density was observed (**Table 1**). Application of 75% RDN consistently resulted in lower weed density at 30 DAS compared with 100% and 125% RDN. Weed density was also significantly lower with the application of 100% RDN than 125% RDN. The reduction under lower nitrogen levels could be attributed to limited nutrient availability, which suppressed the growth and competitiveness of fast-growing weeds that respond vigorously to higher nitrogen supply. Shafiullah *et al.* (2018) similarly reported that increasing nitrogen application enhanced seed yield, biological yield and harvest index but also promoted higher weed infestation in rapeseed.

A significant interaction between rice residue management and nitrogen levels was observed for the density of *R. dentatus* (**Table 1**). Under Happy seeder, significantly lower weed density was recorded with 75% RDN than 100% RDN. In surface seeding-cum-mulching, 75% RDN was at par with 100% RDN, and 100% RDN was at par with 125% RDN, while 75% RDN recorded significantly lower density than 125% RDN. Under the conventional method, 75% RDN remained significantly lower than 100% and 125% RDN, and 100% RDN was significantly lower than 125% RDN. The influence of nitrogen was more pronounced in the conventional system, where exposed soil promoted faster weed establishment. Similarly, Sharma (2022) reported higher weed density under conventional tillage with flat-bed sowing and 100% N, while the lowest density occurred in permanent flat-beds with residue retention at 75% and 100% N. Among residue management practices, surface seeding-cum-mulching with 75% RDN recorded the lowest density of *R. dentatus*, and all other treatment combinations differed significantly. A similar pattern occurred in *M. denticulata* (**Table 1**), except that under Happy seeder, 100% RDN was at par with 125% RDN, and under surface seeding-cum-mulching, 100% RDN was significantly lower than 125% RDN. Surface seeding with 75% RDN again recorded the lowest density, with all remaining treatments differing significantly. For *A. arvensis*, trends matched those of *R. dentatus* (Table 1), except that surface seeding-cum-mulching with 75% RDN was at par with 125% RDN. Across residue management practices, surface seeding with 75%, 100%, and 125% RDN recorded statistically similar and significantly lower densities than other treatments and all other combinations differed significantly. For *A. philoxeroides*, the trend again resembled *R. dentatus* (**Table 1**), though under Happy seeder, 100% RDN was at par with 125% RDN, and under surface seeding-cum-mulching, 75% RDN recorded significantly lower density than 100% RDN. Among residue management practices, Happy seeder with 75% RDN recorded the lowest density, with conventional method under 75% RDN was at par with Happy seeder under 100% and 125% RDN.

Weed biomass of recorded weed species was significantly lower under surface seeding-cum-mulching method compared to Happy seeder and conventional method at 30 DAS (**Table 1**). However, this trend did not hold for *A. philoxeroides*, as Happy seeder method recorded the lowest biomass of this species due to its comparatively lower density under this treatment than under surface seeding-cum-mulching and the conventional method. The Happy seeder method also showed reduced weed biomass relative to conventional method, highlighting the effectiveness of residue retention in suppressing weed growth. This reduction may be attributed to uniform residue cover that restricted light penetration and acted as a physical barrier to weed emergence. Similar results were reported by Choudhary and Bhagawati (2019), who found that groundnut haulm mulch at 4 t/ha reduced weed dry biomass in *toria* (*Brassica campestris* L. *var. toria*) at 30 DAS compared to no-mulch plots.

A significant influence of nitrogen levels on weed biomass was also observed (**Table 1**). Application of 75% RDN consistently produced lower weed biomass at 30 DAS than 100% and 125% RDN. Application of 100% RDN also resulted in significantly lower weed biomass than 125% RDN for all recorded weed species, except for *A. arvensis* and *A. philoxeroides*, where 100% RDN remained at par with 125% RDN. The lower biomass under reduced nitrogen levels may be due to limited nutrient availability, which restricted weed growth and competitiveness. Conversely, higher nitrogen rates favoured weed proliferation, as many weed species utilize available nutrients more efficiently than crops (Blackshaw *et al.* 2003). Hu *et al.* (2017) similarly reported that nitrogen fertilization increased weed biomass and nitrogen uptake, though the response was less pronounced than in rapeseed.

There was a significant interaction between rice residue management practices and nitrogen levels on the weed biomass of *R. dentatus* at 30 DAS (**Table 1**). Under Happy seeder, 75% RDN recorded significantly lower biomass than 100% RDN, and 100% RDN was significantly lower than 125% RDN; similarly, 75% RDN remained significantly lower than 125% RDN. In surface seeding-cum-mulching, 75%

RDN was at par with 100% RDN, 100% RDN at par with 125% RDN, and 75% RDN at par with 125% RDN. In conventional method, 75% RDN recorded significantly lower biomass than 100% and 125% RDN, and 100% RDN was significantly lower than 125% RDN. Among residue management practices, surface seeding-cum-mulching with 75% RDN recorded the lowest *R.* biomass, while conventional 75% RDN was at par with Happy seeder 125% RDN.

A similar trend was observed in *M. denticulata* (**Table 1**), except that under surface seeding-cum-mulching, 75% RDN recorded significantly lower biomass than both 100% and 125% RDN. Surface seeding with 75% RDN recorded the lowest biomass of *M. denticulata*, while Happy seeder 75% RDN was at par with surface seeding 75% and 100% RDN. Conventional 75% RDN was at par with Happy seeder 125% RDN. *A. arvensis* also followed a trend

Table 1. Interactive effect of rice residue management and nitrogen level on weed density and biomass in oilseed rape at 30 DAS (pooled data of two years)

Rice residue management × Nitrogen levels treatment	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean
	Rumex dentatus (no./m^2)				*Rumex dentatus* (g/m^2)			
Happy seeder	4.70 (21)	5.25 (27)	5.70 (32)	5.23 (27)	1.73(2.08)	2.06(3.25)	2.39(4.75)	2.04(3.36)
Surface seeding-cum-mulching	2.88 (8)	3.12 (9)	3.23 (10)	3.08 (9)	1.42(1.01)	1.45(1.11)	1.44(1.18)	1.42(1.11)
Conventional method	6.76 (45)	8.45 (71)	9.30 (86)	8.17 (67)	2.41(4.88)	3.03(8.19)	3.65(12.36)	3.02(8.49)
Mean	4.79 (25)	5.61 (35)	6.07 (42)		1.84(2.67)	2.17(4.19)	2.47(6.10)	
LSD (p=0.05)	Rice residue management: 0.34; Nitrogen levels: 0.20; Nitrogen levels at same level of rice residue management: 0.34; Rice residue management at same and different level of nitrogen levels: 0.42				Rice residue management: 0.19; Nitrogen levels: 0.12 Nitrogen levels at same level of rice residue management: 0.21; Rice residue management at same and different level of nitrogen levels: 0.25			
	Medicago denticulata (no./m^2)				*Medicago denticulata* (g/m^2)			
Happy seeder	3.48(11)	3.93(15)	4.06(16)	3.83(14)	1.36(0.92)	1.77(2.22)	2.19(3.82)	1.76(2.33)
Surface seeding-cum-mulching	2.34(5)	2.59(6)	2.97(8)	2.61(6)	1.23(0.53)	1.42(1.09)	1.56(1.46)	1.41(1.04)
Conventional method	6.60(43)	7.48(55)	8.41(70)	7.48(56)	2.26(4.15)	2.99(8.00)	3.61(12.05)	2.95(8.07)
Mean	4.13(19)	4.66(25)	5.14(31)		1.62(1.88)	2.05(3.78)	2.46 (5.79)	
LSD (p=0.05)	Rice residue management: 0.26; Nitrogen levels: 0.17; Nitrogen levels at same level of rice residue management: 0.29; Rice residue management at same and different level of nitrogen levels: 0.33				Rice residue management: 0.17; Nitrogen levels: 0.09 Nitrogen levels at same level of rice residue management: 0.16; Rice residue management at same and different level of nitrogen levels: 0.20			
	Anagallis arvensis (no./m^2)				*Anagallis arvensis* (g/m^2)			
Happy seeder	1.83(3)	2.26(4)	2.68(6)	2.23 (4)	1.26(0.59)	1.40(0.96)	1.41(1.00)	1.35(0.85)
Surface seeding-cum-mulching	1.00(0)	1.00(0)	1.00(0)	1.00 (0)	1.00(0.00)	1.00(0.00)	1.00(0.00)	1.00(0.00)
Conventional method	3.11(9)	3.65(12)	4.04(15)	3.60 (12)	1.74(2.05)	1.88(2.55)	1.94(2.77)	1.84(2.45)
Mean	1.98(4)	2.29(6)	2.56(7)		1.33(0.88)	1.42(1.16)	1.44(1.25)	
LSD (p=0.05)	Rice residue management: 0.31; Nitrogen levels: 0.13; Nitrogen levels at same level of rice residue management: 0.22; Rice residue management at same and different level of nitrogen levels: 0.33				Rice residue management: 0.07; Nitrogen levels: 0.04 Nitrogen levels at same level of rice residue management: 0.07; Rice residue management at same and different level of nitrogen levels: 0.08			
	Lepidium didymum (no./m^2)				*Lepidium didymum* (g/m^2)			
Happy seeder	2.65(6)	3.18(9)	3.70(13)	3.18(9)	1.10(0.21)	1.38(0.91)	1.79(2.21)	1.41(1.10)
Surface seeding-cum-mulching	1.14(0)	1.49(1)	2.00(3)	1.53(2)	1.16(0.34)	1.20(0.47)	1.38(0.91)	1.23(0.58)
Conventional method	6.58(43)	7.37(54)	7.87(61)	7.26(52)	2.30(4.30)	2.56(5.58)	2.84(7.12)	2.53(5.67)
Mean	3.44(16)	4.01(21)	4.52(26)		1.50(1.62)	1.68(2.32)	1.99(3.41)	
LSD (p=0.05)	Rice residue management: 0.39; Nitrogen levels: 0.18; Nitrogen levels × rice residue management: NS				Rice residue management: 0.11; Nitrogen levels: 0.08 Nitrogen levels at same level of rice residue management: 0.13; Rice residue management at same and different level of nitrogen levels: 0.15			
	Alternanthera philoxeroides (no./m^2)				*Alternanthera philoxeroides* (g/m^2)			
Happy seeder	1.00(0)	1.49(1)	1.72(2)	1.39(1)	1.04(0.09)	1.07(0.14)	1.08(0.19)	1.07(0.14)
Surface seeding-cum-mulching	3.52(12)	4.02(15)	3.91(14)	3.81(14)	1.94(2.79)	2.10(3.44)	2.18(3.76)	2.07(3.32)
Conventional method	1.67(2)	2.08(4)	2.56(6)	2.08(4)	1.09(0.20)	1.43(1.05)	1.44(1.08)	1.29(0.78)
Mean	2.06(5)	2.51(7)	2.71(7)		1.35(1.03)	1.52(1.54)	1.57(1.68)	
LSD (p=0.05)	Rice residue management: 0.24; Nitrogen levels: 0.15; Nitrogen levels at same level of rice residue management: 0.27; Rice residue management at same and different level of nitrogen levels: 0.31				Rice residue management: 0.07; Nitrogen levels: 0.06 Nitrogen levels at same level of rice residue management: 0.10; Rice residue management at same and different level of nitrogen levels: 0.10			

Weed data was subjected to square root transformation ($\sqrt{x+1}$) and means of original values were given in parentheses like *R. dentatus*, except that under Happy seeder, 100% RDN was at par with 125% RDN, and in conventional method, 100% RDN was at par with 125% RDN. Among residue management practices, surface seeding with 75%, 100% and 125% RDN recorded statistically similar and significantly lower biomass than all other treatment combinations. For *L. didymum*, the trend again resembled *R. dentatus*, except that under surface seeding-cum-mulching, 100% RDN recorded significantly lower biomass than 125% RDN, and 75% RDN also remained significantly lower than 125% RDN. Surface seeding with 75% RDN recorded the lowest biomass, while Happy seeder 75% RDN was at par with surface seeding 75% and 100% RDN, and Happy seeder 100% RDN was at par with surface seeding 125% RDN. In *A. philoxeroides*, the trend was like *R. dentatus*, except that under Happy seeder, 75% RDN was at par with 100% RDN and 100% RDN was at par with 125% RDN. In surface seeding-cum-mulching, 75% RDN recorded significantly lower biomass than both 100% and 125% RDN, while in conventional method, 100% RDN was at par with 125% RDN. Among residue management practices, the Happy seeder with 75% RDN recorded the lowest biomass and was at par with conventional 75% RDN, while conventional 75% RDN was at par with Happy seeder 100% and 125% RDN.

Effect on oilseed rape seed yield and net returns

Rice residue management practices and nitrogen application rates had a pronounced effect on the seed yield of oilseed rape (**Table 2**, **Figure 2**). Among rice residue management practices, sowing with happy seeder consistently outperformed surface seeding-cum-mulching as well as conventional method. The higher oilseed rape yield under the happy seeder treatment could be linked to improved crop growth conditions and better expression of yield-contributing traits. On pooled data of two years, happy seeder recorded a 10.6% higher oilseed rape seed yield than the conventional method and 24.2% more than surface seeding-cum-mulching. Similar yield advantages with residue retention have been noted earlier by Kadam *et al.* (2022) who documented a 7.1% rise in oilseed rape seed yield and an 8.3% increase in oilseed rape stover yield under residue-retained conditions. Improved moisture conservation, moderated soil temperature and reduced soil compaction likely contributed to better root development and enhanced productivity (Mondal *et al.* 2008). The conventional method also produced significantly higher oilseed rape yield than surface seeding-cum-mulching. The higher lodging of oilseed rape under surface seeding-cum-mulching (**Figure 2**) occurred because seeds were broadcasted on the soil surface during sowing, developed shallow root anchorage, resulting in weaker root-soil contact. Reduced root development under broadcasting method was also observed by Pandit *et al.* (2025). This vulnerability was further exacerbated by adverse weather, particularly rainfall during the reproductive stage (**Figure 1**). In contrast, Happy seeder and conventional sowing placed oilseed rape seeds at an optimal depth (4-5 cm), enabling stronger root development and greater lodging resistance and consequently significantly higher oilseed rape seed yield than surface seeding-cum-mulching method of sowing.

Table 2. Interactive effect of rice residue management and nitrogen levels on seed yield (t/ha) of oilseed rape (pooled analysis of two years)

Rice residue management × Nitrogen levels treatment	Seed yield (q/ha)			
	75% RDN	100% RDN	125% RDN	Mean
Happy seeder	2.05	2.40	2.55	2.33
Surface seeding-cum-mulching	180	1.97	1.88	1.89
Conventional method	1.82	2.17	2.34	2.11
Mean	1.89	2.18	2.26	

LSD (*p*=0.05) Rice residue management: 1.01; Nitrogen levels: 0.98; Nitrogen levels at same level of rice residue management: 1.70; Rice residue management at same and different level of nitrogen levels: 1.67

With respect to nitrogen, applying 125% of the recommended dose resulted in the highest seed yield, remaining statistically comparable to 100% RDN but superior to 75% RDN (**Table 2, Figure 2**). The improved nitrogen supply likely enhanced oilseed rape vegetative vigour, assimilate generation and their translocation to the reproductive structures, which collectively strengthened oilseed rape yield attributes such as siliquae formation and seed filling. Although higher nitrogen levels increased oilseed rape lodging due to taller plants and heavier canopies but lodging occurred late in the crop cycle. By this stage, the crop had already achieved superior growth and yield attributes under higher nitrogen supply, which minimized the impact of lodging on productivity. Consequently, higher nitrogen still resulted in greater oilseed rape seed yield than reduced nitrogen levels. On pooled analysis basis, oilseed rape seed yield increased by 19.4% with 125% RDN and by 15.4% with 100% RDN compared to 75% RDN. These findings align with those of Nayak *et al.* (2022), who reported notable improvements in seed yield with nitrogen applications of 120 and 150 kg/ha over 90 kg/ha.

A significant interaction was observed between rice-residue management practices and nitrogen levels on oilseed rape seed yield. Under Happy seeder method, the application of 100% RDN resulted in significantly higher oilseed rape seed yield than 75% RDN, while 100% RDN remained statistically at par with 125% RDN. However, application of 125% RDN recorded significantly higher yield than 75% RDN. Under surface seeding-cum-mulching method, application of 100% RDN produced significantly higher oilseed rape yield than 75% RDN, and 100% RDN remained at par with 125% RDN. In this method, 125% RDN also remained statistically at par with 75% RDN, which might be due to relatively higher lodging at 125% RDN that offset the benefits of additional nitrogen, while 100% RDN produced the highest yield by providing adequate nutrition without inducing lodging-related losses. In conventional method, application of 100% RDN recorded significantly higher yield than 75% RDN, while 100% RDN remained statistically at par with 125% RDN. Moreover, oilseed rape seed yield under 75% RDN remained significantly lower than 125% RDN.

Across residue management practices, the highest oilseed rape seed yield was observed under Happy seeder method with 125% RDN. The Happy seeder method of sowing with 75% RDN produced oilseed rape yield at par with surface seeding-cum-mulching method under 100% RDN and conventional method under 100% RDN. Surface seeding-cum-mulching method with 75% RDN also remained at par with conventional method under 75% RDN. The conventional method with 75% RDN also remained at par with surface seeding with 100% RDN and 125% RDN. Additionally, the seed yield produced under Happy seeder method with 100% RDN also remained statistically at par with conventional method with 125% RDN.

Rice residue management practices and nitrogen levels exerted a significant impact on the economics of oilseed rape. Among rice residue management methods, sowing with Happy seeder resulted in the highest net returns and it was higher than conventional and surface seeding-cum-mulching method. Amongst zero tillage-cum-residue retention, Happy seeder sowing method generated greater net returns than surface seeding-cum-mulching. The cost of oilseed rape cultivation was maximum under conventional method due to multiple field operations such as discing, harrowing, and planking, which substantially increased labour and fuel requirements. In contrast, sowing of oilseed rape with Happy seeder and surface seeding-cum-mulching method minimized production costs by integrating sowing and residue retention into a single operation and direct broadcasting with minimal field preparation, respectively. Net returns in surface seeding-cum-mulching remained lower than Happy seeder due to significantly reduced oilseed rape seed yield caused by lodging (**Figure 2**). Consequently, the combined advantages of effective weed suppression, reduced labour input, and superior oilseed rape yield made the Happy seeder method the most profitable and agronomically efficient rice residue management practice. Similar findings were reported by Jakhar *et al.* (2018) and Jat *et al.* (2024), who observed that zero-tillage practices with residue retention resulted in significantly greater net returns compared to conventional tillage.

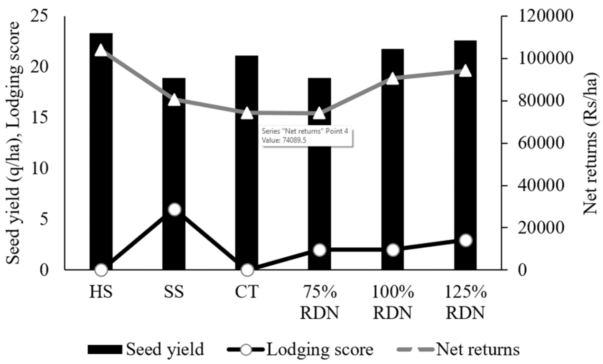

Figure 2. Effect of rice residue management and nitrogen levels on seed yield, lodging score and net returns of oilseed rape (pooled data of two years); HS, Happy seeder; SS, Surface seeding-cum-mulching; CT, Conventional method; 75% RDN, 75% of recommended dose of nitrogen; 100% RDN, 100% of recommended dose of nitrogen; 125% RDN, 125% of recommended dose of nitrogen

It is concluded that the Happy seeder combined with optimal nitrogen provided the most sustainable weed management in oilseed rape with higher crop productivity under rice-oilseed rape rotation.

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RESEARCH ARTICLE

Participatory research on management of guinea grass (*Megathyrsus maximus*) in sugarcane with pre- and post-emergence herbicides

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ABSTRACT

In India, guinea grass (*Megathyrsus maximus*) is a valuable forage since its introduction during 1793 to increase the forage quality. Lately, it invaded variable environments as weed in crops such as sugarcane and citrus orchards. A total of four participatory research experiments were conducted during spring season using a randomized complete block design with three replications. The objective was to evaluate efficacy of different pre- and post-emergence herbicides to manage *M. maximus* in sugarcane. The pre-emergence application (PE) of metribuzin 1.4 kg/ha, diuron 1.6 kg/ha, sulfentrazone + clomazone 1.45 kg/ha and post-emergence application (PoE) of 2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl 2.4 kg/ha and 2,4-D sodium salt + metribuzin + chlorimuron 2.02 kg/ha recorded maximum control of *M. maximus* at 30, 60 days after application and at harvest. Furthermore, these treatments resulted in significantly higher cane yield and were at par with each other. Multiple cohorts of *M. maximus* appears in crop up to 5-6 months of planting of sugarcane, and hence, the highest cane yield was observed in weed free, while physical control measures were costly resulting in lower B:C. Thus, this study underscores the importance of integrated weed management practices for the profitable and sustainable control of *M. maximus* in sugarcane.

Keywords: Chlorimuron, Clomazone, 2,4-D, Diuron, Guinea grass, Metribuzin, Pyrazosulfuron-ethyl, Sulfentrazone, Sugarcane, Weed management

INTRODUCTION

Sugarcane occupied 90.2 thousand hectares in Punjab with average cane yield of 832.5 quintals per hectare during 2023-24. Among the several factors affecting sugarcane productivity, weed infestation is considered as one of the most significant biotic constraints responsible for yield reduction (Kaur *et al.* 2025a). Sugarcane is grown primarily in Hoshiarpur and some pockets of Patiala, Gurdaspur and Jalandhar of Punjab. In sugarcane, guinea grass (*Megathyrsus maximus* (Jacq.) B.K. Simon and Jacobs) is becoming a major weed problem at farmers' fields in Hoshiarpur and Jalandhar. The infestations of this weed in sugarcane fields could cause yield losses of up to 40% (Kuva *et al.* 2003).

Megathyrsus maximus is considered an important forage species due to its high biomass production, palatability and tolerance to grazing, it has also become a highly invasive plant in several ecosystems. Although it originates from the humid tropical and subtropical regions of Africa but has been widely introduced into many other parts of the world (Soti and Thomas 2022). It is a perennial, C_4, tufted invasive plant that is capable of reproducing through both seeds and vegetative structures such as rhizomes and stolons. This adaptability allows it to thrive in diverse environments, including savannas, grasslands, tropical forests, cultivated pastures and agricultural fields, particularly in sugarcane-growing areas (Rhodes *et al.* 2021). The characteristics that contribute to the high productivity and rapid growth of *M. maximus* also make it difficult to manage, and its spread beyond intended areas often results in its establishment as a problematic weed (Ho *et al.* 2016).

Megathyrsus maximus is tolerant to shade but sensitive to frost and its aggressive growth can suppress native grass species, thereby affecting their establishment. Each plant produces numerous panicles bearing seeds that mature and disperse gradually over several weeks. Seeds are commonly spread by birds and arthropods that feed on them, while their ability to adhere to moist surfaces facilitates mechanical dispersal (CABI 2020). Human-mediated dispersal also plays an important role, as

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seeds can be transported through vehicles, machinery and mowing equipment (Veldman and Putz 2010). The species spreads rapidly, maintains a high reproductive capacity and forms long-lived, robust plants that compete strongly with other vegetation (Zanine *et al.* 2018). Its ability to form dense stands may lead to mono-dominance, altering plant community structure by shading and outcompeting other plant species (Hejda *et al.* 2009). *M. maximus* has higher photosynthetic efficiency, rapid seedling growth, and substantial biomass accumulation (Ho *et al.* 2016).

Frequent irrigation and fertilizer application further promote weed growth in sugarcane cropping systems (Krishnaprabhu 2020). Furthermore, the slow initial growth of sugarcane leaves inter-row spaces exposed for an extended period, creating favourable conditions for rapid weed proliferation in later crop growth stages (Kaur *et al.* 2025a, 2025b). This weed has become very problematic as it continues to emerge during monsoon months even after 4-5 months of planting. Considering the strong competitive ability of *M. maximus* and the substantial yield losses associated with its infestation, timely and efficient weed management is essential to maintain higher productivity in sugarcane (Kaur *et al.* 2025a, 2025b). Therefore, the present participatory studies were conducted at the farmers' fields with known history of infestation by *M. maximus* to evaluate the efficacy of different pre- and post-emergence herbicides for effective and economical management of *M. maximus* in sugarcane.

MATERIALS AND METHODS

Two separate participatory research experiments were conducted in 2024 and 2025 at of four locations in Punjab. One experiment involved evaluation of pre-emergence herbicides (Trial-I) against *M. maximus* in sugarcane and it was conducted at one location of district Hoshiarpur (31.8686° N latitude and 75.6019° E longitude) Punjab, India for two years (2024 and 2025). In other experiment, evaluation of post-emergence herbicides (Trial-II) against *M. maximus* in sugarcane was carried out at two locations in Hoshiarpur (31°32'N and 75°55'E), and one location in Jalandhar (31°19'34"N and 75°34'34"E), *i.e.* a total of three locations during 2024. These locations are characterized by a semi-humid, subtropical climate, featuring hot, dry summers from April to June, followed by a humid monsoon period between July and September. The winter season starts mildly in October and November and becomes colder through December to February. In Trial-I, five treatments were evaluated including pre-emergence application (PE) of metribuzin 70% WP (metribuzin) 1.4 kg/ha, diuron 80% WP (diuron) 1.6 kg/ha, sulfentrazone 28% + clomazone 30% WP (sulfentrazone + clomazone) 1.45 kg/ha along with weed free and weedy check. In Trial-II, post-emergence application (PoE) of two brands of 2,4-D sodium salt 44% + metribuzin 35% + pyrazosulfuron-ethyl 1% WDG (2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl) 2.40 kg/ha and 2,4-D sodium salt 48% + metribuzin 32% + chlorimuron 0.8% WDG (2,4-D sodium salt + metribuzin + chlorimuron) 2.02 kg/ha were evaluated along with weed free and weedy check. A randomized complete block design with three replications was used.

The seedbed was prepared by one ploughing with a disc harrow followed by two ploughings with a cultivator, and each ploughing was followed by planking to obtain a fine tilth. Sugarcane cv. Co 15023 was sown in experiment of pre-emergence herbicides while Co 5009, Co 118 and Co 238 were planted in fields where post-emergence herbicides were evaluated. During both years, planting of sugarcane setts was done in mid- to end-March at four locations (Trial I: 15-3-2024 and 22-3-2025, and Trial II: 16-3-2024, 18-3-2024 at Hoshiarpur & 22-3-2024 at Jalandhar) with a seed rate of 87.5 q/ha (three-budded setts) in 75 cm wider rows using the trench method and irrigation was given thereafter. The gross plot area was 50 m × 10 m (500 m^2). Pre-emergence herbicides were sprayed as soon as field comes in field capacity (within 4 days of planting, 18-3-2024 and 26-3-2025) using flood jet nozzle with a spray volume of 500 litres. Application of post-emergence herbicides was done during mid-June (12-6-2024, 15-6-2024 and 16-6-2024 at three locations) at 3-5 weed leaf stage using flood jet nozzle with a spray volume of 500 L/ha under sufficient soil moisture conditions. Before the application of post-emergence herbicides, weeds were controlled by blind tillage and interculture operations till the complete emergence of sugarcane plants (farmers' practice). The plots were kept weed free with regular weeding (manual/ mechanical) throughout the crop season.

All recommended agronomic practices for fertilizer, water and insect-pest management were followed for raising the crop (Kaur *et al.* 2025a). The crop was fertilized with 150:30 kg N and P/ha through application of 325 kg urea/ha and 187 kg/ha single super phosphate. The entire dose of phosphorus was applied at the time of planting at all experimental locations. Nitrogen was applied in two equal splits: half of the recommended dose was top-dressed along the crop rows at the time of first irrigation after crop emergence, while the remaining half was applied alongside the cane rows one month later. To protect the crop from lodging, earthing up was carried out at the end of June before the onset of the monsoon. The crop was propped at the end of August using the trash-twist method. The crop was harvested manually in November-December (depending upon maturing time of each variety) during both years.

The bio-efficacy of treatments was assessed based on weed density and biomass of *M. maximus*. Weed observations were recorded using a quadrat of 50 cm × 50 cm placed at two randomly selected locations within each plot at 30 and 60 days after application (DAA) and at harvest. For analysis, the average values from both quadrats were converted to number per square meter (no./m^2) for weed density and grams per square meter (g/m^2) for weed biomass. Observations on cane length, number of millable canes and cane yield were also recorded at harvest. Economics were worked out and B:C was calculated by dividing net returns over variable cost of cultivation. Analysis of variance (ANOVA) was performed to evaluate the efficacy of different pre- and post-emergence herbicides for the control of *M. maximus* in sugarcane. Statistical analysis of the recorded data was performed using CPCS-1 software, version 3.2.3 (Cheema and Singh 1991). The data was subjected to pooled analysis after performing Levene's test for checking homoskedasticity of variance of locations and years. Weed density and biomass data were subjected to square root transformation before analysis to normalize the data distribution. The significance of treatment means was tested using Fisher's least significant difference (LSD) test at the 5% probability level (p=0.05).

RESULTS AND DISCUSSION

Density and biomass of *M. maximus*

The density and biomass of *M. maximus* at 30, 60 DAA and at harvest were significantly influenced by all the pre- and post-emergence herbicidal treatments over the weedy check. The pre- and post-emergence herbicides were effective in controlling *M. maximus*. In Trial-I, metribuzin 1.4 kg/ha, diuron 1.6 kg/ha and sulfentrazone + clomazone 1.45 kg/ha recorded cent percent (100%) control of *M. maximus* density at 30 DAA, 58.3%, 83.3% and 75.0%, respectively at 60 DAA and 38.2%, 47.1% and 44.1%, respectively at harvest over weedy check (**Table 1**). This indicated that the pre-emergence herbicides were effective up to 30 days of planting. But thereafter, metribuzin was least effective while diuron and premix of sulfentrazone + clomazone retained its effectiveness even up to 60 days of planting. Pre-emergence application of diuron permits normal germination of weed seeds but inhibits chlorophyll synthesis, which subsequently results in depletion of food reserves and eventual death of young seedlings (Ferrell *et al.* 2004). Pre-emergence application of sulfentrazone 1.2 kg/ha provided higher control of weeds in sugarcane (Kalaiyarasi 2012). Further, pre-emergence application of metribuzin 1.4 kg/ha, diuron 1.6 kg/ha and sulfentrazone + clomazone 1.45 kg/ha recorded 100.0% control of *M. maximus* biomass at 30 DAA, 77.9%, 85.4% and 82.9% at 60 DAA and 39.5%, 52.3% and 50.3% at harvest, respectively over weedy check plots (**Table 1**). These results are in line with Pringgani *et al.* (2025) and de Castro *et al.* (2024) who reported that application of pre-emergence herbicides significantly reduced the weed biomass in sugarcane.

In Trial-II, all post-emergence herbicides namely formulations of 2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl 2.4 kg/ha and 2,4-D sodium salt + metribuzin + chlorimuron 2.02 kg/ha resulted in 97.4%, 97.9% and 97.9% control of *M. maximus* density at 30 DAA, 57.7%, 59.6% and 60.9%, respectively at 60 DAA and 38.5%, 39.2% and 39.6%, respectively at harvest over weedy check plots (**Table 3**). Similarly, these herbicides recorded 93.6%, 93.7% and 93.8% control of *M. maximus* biomass at 30 DAA, 67.2%, 67.5% and 67.9% at 60

Table 1. Effect of pre-emergence application of herbicides on density and biomass of *M. maximus* at 30 days after application (DAA), 60 DAA and at harvest in Trial-I at Hoshiarpur farmers fields (pooled over two years)

Treatment	Density (no./m^2)			Biomass (g/m^2)		
	30 DAA	60 DAA	At harvest	30 DAA	60 DAA	At harvest
Metribuzin 1.40 kg/ha	1.00 (0)	2.32 (5)	4.71 (21)	1.00 (0)	6.67 (44)	19.77 (391)
Diuron 1.60 kg/ha	1.00 (0)	1.82 (2)	4.40 (18)	1.00 (0)	5.44 (29)	17.50 (308)
Sulfentrazone + clomazone 1.45 kg/ha	1.00 (0)	1.91 (3)	4.51 (19)	1.00 (0)	5.91 (34)	17.86 (321)
Weedy check	3.05 (8)	3.60 (12)	5.92 (34)	9.62 (92)	14.14 (199)	25.43 (646)
Weed free	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
LSD (p=0.05)	0.21	0.52	0.32	0.27	1.47	2.74

*Data were subjected to ($\sqrt{x+1}$) transformation. Figures in parentheses are original values

DAA and 50.2%, 50.4% and 50.7% at harvest, respectively over weedy check plots (**Table 4**). These results are in line with Jaiswal *et al.* (2024) who reported that 2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl 2.4 kg/ha produced lowest density of grasses, broad-leaved weeds and sedges at 75 DAA in sugarcane. The use of three-way post-emergence herbicide is important for achieving a greater extent of weed control as reported by Kumar *et al.* (2023). Ramesha *et al.* (2018) also observed that 2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl recorded significantly lower weed biomass over weedy check in sugarcane. Metribuzin is a synthetic organic compound commonly used as both a pre- and post-emergence herbicide. Pyrazosulfuron-ethyl and chlorimuron-methyl herbicides act by inhibiting the enzyme acetolactate synthase, which is essential for the biosynthesis of certain amino acids. It is effective against newly emerging and difficult to control

Table 2. Effect of pre-emergence application of herbicides on yield attributes and yield of sugarcane in Trial-I at Hoshiarpur farmers fields (pooled over two years)

Treatment	Cane length (m)	Millable canes (000/ha)	Cane yield (t/ha)	Economics	
				Net returns ($x10^3$ Rs./ha)	B:C
Metribuzin 1.40 kg/ha	3.13	145	84.03	229.98	1.92
Diuron 1.60 kg/ha	3.20	151	87.70	246.11	2.07
Sulfentrazone + clomazone 1.45 kg/ha	3.17	149	86.03	234.06	1.89
Weedy check	3.10	114	57.37	122.83	1.06
Weed free	3.20	163	93.37	230.94	1.47
LSD (p=0.05)	NS	14	11.27	-	-

*Data were subjected to $(\sqrt{x+1})$ transformation

Table 3. Effect of post-emergence application of herbicides on density of *M. maximus* at 30 days after application (DAA), 60 DAA and at harvest in participatory trials at different locations (Trial-II: pooled over three locations)

Treatment	Density (no./m^2)											
	30 DAA				60 DAA				At harvest			
	HSR-I	HSR-II	JAL	Pooled mean	HSR-I	HSR-II	JAL	Pooled mean	HSR-I	HSR-II	JAL	Pooled mean
2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl 2.40 kg/ha	1.21 (0.50)	1.14 (0.33)	1.00 (0.00)	1.12 (0.28)	2.70 (6.33)	3.03 (8.33)	2.86 (7.33)	2.86 (7.33)	4.19 (16.67)	4.49 (19.33)	4.25 (17.33)	4.30 (17.77)
2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl 2.40 kg/ha	1.14 (0.33)	1.14 (0.33)	1.00 (0.00)	1.09 (0.22)	2.62 (6.00)	2.95 (8.00)	2.80 (7.00)	2.79 (7.00)	4.16 (16.33)	4.67 (19.00)	4.27 (17.33)	4.29 (17.55)
2,4-D sodium salt + metribuzin + chlorimuron 2.02 kg/ha	1.14 (0.33)	1.14 (0.33)	1.00 (0.00)	1.09 (0.22)	2.55 (5.66)	2.99 (8.00)	2.74 (6.66)	2.76 (6.77)	4.16 (16.33)	4.67 (19.00)	4.24 (17.00)	4.28 (17.44)
Weedy check	3.15 (9.0)	3.43 (13.0)	3.29 (10.00)	3.39 (10.66)	3.99 (15.00)	4.57 (20.00)	4.23 (17.00)	4.26 (17.33)	5.22 (26.33)	5.74 (32.00)	5.40 (28.33)	5.46 (28.88)
Weed free	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
LSD (p = 0.05)	0.48	0.67	0.53	0.28	0.90	0.95	0.99	0.47	0.69	0.80	0.85	0.39

*Data were subjected to $(\sqrt{x+1})$ transformation. Figures in parentheses are original values; HSR-I & II: Two locations in Hoshiarpur, and JAL: Jalandhar

Table 4. Effect of post-emergence application of herbicides on biomass of *M. maximus* at 30 days after application (DAA), 60 DAA and at harvest in participatory trials at different locations (Trial-II: pooled over three locations)

Treatment	Biomass (g/m^2)											
	30 DAA				60 DAA				At harvest			
	HSR-I	HSR-II	JAL	Pooled mean	HSR-I	HSR-II	JAL	Pooled mean	HSR-I	HSR-II	JAL	Pooled mean
2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl 2.40 kg/ha	3.24 (13.3)	2.85 (14.0)	1.00 (0.0)	2.37 (9.11)	10.11 (103.0)	11.84 (139.7)	11.46 (131.0)	11.14 (124.5)	16.33 (268.3)	18.56 (345.0)	17.24 (298.3)	17.38 (303.9)
2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl 2.40 kg/ha	2.80 (13.3)	2.83 (13.7)	1.00 (0.0)	2.20 (9.00)	9.98 (101.7)	11.74 (138.3)	11.39 (130.0)	11.04 (123.4)	16.29 (266.7)	18.54 (344.3)	17.19 (296.7)	17.34 (302.5)
2,4-D sodium salt + metribuzin + chlorimuron 2.02 kg/ha	2.77 (13.0)	2.83 (13.7)	1.00 (0.0)	2.20 (8.88)	10.00 (100.0)	11.72 (136.7)	1.39 (129.3)	11.04 (122.0)	16.03 (263.3)	18.44 (344.0)	17.00 (294.0)	17.17 (300.4)
Weedy check	11.88 (140.6)	12.17 (147.7)	11.94 (141.3)	11.99 (143.2)	1934 (375.0)	19.71 (388.3)	19.43 (377.3)	19.49 (380.2)	24.30 (593.3)	25.19 (635.0)	24.49 (601.7)	24.66 (610.0)
Weed free	1.00(0)	1.00(0)	1.00(0)	1.00 (0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00 (0)
LSD (p = 0.05)	4.90	5.72	0.77	3.75	3.84	2.46	2.51	1.49	4.48	3.34	3.86	1.94

*Data were subjected to $(\sqrt{x+1})$ transformation. Figures in parentheses are original values; HSR-I & II: Two locations in Hoshiarpur, and JAL: Jalandhar weeds, being absorbed through both roots and foliage and subsequently translocated to the meristematic regions. Kaur *et al.* (2025a) also reported that 2,4-D sodium salt + metribuzin + chlorimuron 2.02 kg/ha resulted in 136.2% and 133.9%, 87.9% and 375% and 41.9% and 37.9% reduction of biomass of grasses, broad-leaved weeds and sedges at Kapurthala and Ludhiana, respectively compared to weedy plots at 60 DAA.

Sugarcane yield attributes and yield

Different pre- and post-emergence herbicidal treatments had significant impact on the sugarcane's yield attributes and yield over weedy check but there was non-significant effect of all weed control treatments on cane length in both experiments (**Table 2** and **5**). Weed free plots recorded higher number of millable canes and cane yield which was statistically at par with pre-emergence applications of metribuzin 1.4 kg/ha, diuron 1.6 kg/ha and sulfentrazone + clomazone 1.45 kg/ha. The millable canes and cane yield in various treatments of Trial-I ranged from 114 to 163 thousand/ha and 57.37 to 93.37 t/ha, respectively (**Table 2**). Metribuzin 1.4 kg/ha, diuron 1.6 kg/ha and sulfentrazone + clomazone 1.45 kg/ha recorded 27.2%, 32.5% and 30.7% more number of millable canes and 46.5%, 52.9% and 50.0% higher cane yield over weedy check plots. Lower competition between crop and *M. maximus* in weed free plots reflected a greater number of millable cane and cane weight. Thus, sugarcane yield could be increased with integration of pre-emergence herbicides with interculture or follow-up application of post-emergence herbicides. Effective management of weeds with pre-emergence herbicides reduces competition for essential resources such as space, light, moisture and nutrients between younger plants of sugarcane plants and weeds, thereby contributing to improved crop productivity (Singh *et al.* 2019).

In Trial-II, all post-emergence herbicides resulted in at par number of millable canes and cane yield but significantly higher than weedy check (**Table 5**). However, effect of all weed control treatments on cane length was found non-significant. two tested formulations of 2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl 2.4 kg/ha and 2,4-D sodium salt + metribuzin + chlorimuron 2.02 kg/ha recorded 28.6%, 27.6% and 27.6% more number of millable canes and 44.5%, 43.3% and 42.4%, respectively higher cane yield over weedy check. Weed infestation adversely affects sugarcane tillering, leading to a reduction in the number of millable canes and consequently lowering cane yield (Zafar *et al.* 2010). Application of herbicidal treatments resulted in a marked increase in number of millable canes, which consequently resulted significantly higher cane yield over the weedy check treatment. Weed competition can decrease millable stalks by 32% compared to weed free plots was also reported by El-Shafai *et al.* (2010). Results of our study are in line with Jaiswal *et al.* (2024) also reported that weed management through application of 2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl 2.4 kg/ha could improve the cane yield by 36.76% over the weedy check plots. Further, Kaur *et al.* (2025a) reported that 2,4-D sodium salt + metribuzin + chlorimuron 2.02 kg/ha resulted in 33.7% and 24.5% more millable canes and 38.6% and 35.2% higher cane yield at Kapurthala and Ludhiana, respectively, over unsprayed weedy check.

Furthermore, the yield in weed free plots were numerically higher than standalone application of pre- (**Table 2**) and post-emergence (**Table 5**) herbicides. Since cohorts of *M. maximus* emerging later in the season (in monsoon months) may have caused yield reduction. Therefore, it was observed that the tested pre- and post-emergence provided effective control of *M. maximus* for 60-90 days. Moreover, sugarcane is a long duration crop and grand growth of the crop occurring late in June-July months leads to delayed canopy closure, leading to first 120 days of planting as critical period of crop-weed competition (Kaur *et al.* 2025a). The young seedlings of *M. maximus* can

Table 5. Effect of post-emergence application of herbicides on yield attributes and yield of sugarcane in participatory trials at different locations (Trial-II: pooled over three locations)

Treatment	Cane length (m)				Millable canes (000/ha)				Cane yield (t/ha)				Economics	
	HSR-I	HSR-II	JAL	Pooled mean	HSR-I	HSR-II	JAL	Pooled mean	HSR-I	HSR-II	JAL	Pooled mean	Net returns (x10^3 Rs./ha)	B:C
2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl 2.40 kg/ha	3.23	2.93	3.03	3.06	144	123	138	135	89.66	73.33	82.66	81.89	220.36	1.83
2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl 2.40 kg/ha	3.20	2.93	3.00	3.04	143	123	136	134	89.00	73.00	81.33	81.22	217.58	1.81
2,4-D sodium salt + metribuzin + chlorimuron 2.02 kg/ha	3.16	2.90	3.00	3.02	143	122	136	134	88.33	72.66	81.00	80.66	215.00	1.78
Weedy check	3.10	2.83	2.93	2.95	118	95	101	105	63.00	50.66	56.33	56.66	119.88	1.03
Weed free	3.25	2.94	3.06	3.08	150	133	143	142	95.12	80.21	87.65	87.66	207.19	1.32
LSD (p = 0.05)	NS	NS	NS	NS	16	18	17	9	13.50	13.32	16.50	7.19	-	-

HSR-I and II: Two locations in Hoshiarpur, and JAL: Jalandhar be effectively managed with suitable pre-emergence and early post-emergence herbicides, however, optimal application window is often missed in practice at farmers' fields, resulting in the persistence of well-established stools in sugarcane fields (Fillols and Staier 2019). The B:C was lower in weed free plots in both trials (**Table 2** and **5**) than pre- and post-emergence herbicides, indicating chemical weed management is both cost-effective and timely method to control the weeds. The monitoring and timely control is the foundation for the control of *M. maximus* in sugarcane.

It may be concluded that application of metribuzin 1.4 kg/ha PE, diuron 1.6 kg/ha PE and sulfentrazone + clomazone 1.45 kg/ha PE (within 3-5 days of planting), and 2,4-D sodium salt + metribuzin + pyrazosulfuron-ethyl 2.4 kg/ha PoE and 2,4-D sodium salt + metribuzin + chlorimuron 2.02 kg/ha PoE (at 4-5 weed leaf stage) provided comparable, effective and economical control of *M. maximus* and improved sugarcane productivity.

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RESEARCH ARTICLE

Effect of herbicides on weeds, rhizospheric microorganisms, tea green leaf yield and nutrient uptake in tea plantation

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ABSTRACT

Field experiment was conducted in the Tarai region of Jalpaiguri, West Bengal, India during 2021 and 2022 to evaluate the effect of post-emergence herbicides on weeds, non-target soil organisms, nutrient dynamics and productivity of tea (var. *TV-25*) under natural weed infestations in tea a garden. The experimental treatments were comprised of: post-emergence application (PoE) of five doses of 2-methyl-4-chlorophenoxyacetic acid (MCPA): 0.5, 0.8, 1.0, 1.25 and 1.5 kg/ha; 2,4-D Sodium salt 1.0 kg/ha PoE and untreated control. A randomized complete block design replicated thrice was used. MCPA 1.50 kg/ha PoE was most effective against broad-leaved weeds, achieving higher weed control efficiency (> 85%) and producing the highest total tea green leaf yield. No phytotoxicity was observed on mature tea leaves due to any of the herbicidal treatment. Although transient reductions in rhizospheric micro-flora (total bacteria, fungi, and actinomycetes) were detected after herbicide application, microbial communities recovered over time, indicating no persistent adverse effects due to herbicides tested. Maximum nutrients uptake and soil available nutrients were recorded with higher dose of MCPA. MCPA at 1.5 kg/ha was observed as the best substitute for others post-emergent herbicide to manage broad-leaved weeds in tea garden.

Keywords: MCPA, Soil Microbes, Soil nutrient uptake, Tea plantation, Weed management

INTRODUCTION

Tea (*Camellia sinensis*) is one of the most important perennial crops in the north -eastern region of India as well as the northern region of West Bengal. It is a significant cash crop used for domestic consumption and export (FAO 2024). West Bengal stands at the second position in the list of tea producing states with 420.91 million kilograms of tea production in the year 2022-23, which is roughly 30% of the national produce (Tea Board of India 2023). It not only contributes to Indian economy but also helps in employment generation (Saha 2024). India has an annual turnover of 776 million USD from tea industry (IBEF 2024). It is most commonly used in the preparation of non-alcoholic caffeine containing beverages. Tea has been consumed socially and habitually by people since 3000 BC but apart from the stringent taste, its medicinal properties are often overlooked. However, traditional healers have long believed that taking tea is a means of prolonging life. Nutritional and therapeutic importance of tea arises from its unique combination of large number of constituents such as proteins, carbohydrates, amino acids (L-theanine), lipids, vitamins, minerals, alkaloids (theophylline, caffeine and theobromine) and polyphenols (Alemu *et al*. 2025). Previously tea was taken only as a stimulant drink, but today it has proved that it activates the central nervous system, which may aid the body's ability to burn calories and unwanted fats through thermogenic process (Rondanelli *et al*. 2021). A manifold increase in production of tea in India is mainly attributed to efficient and integrated agricultural practices including efficient weed management practices.

Weed management is a fundamental practice, failure of which may result in severe losses in terms of production and economic return. The reduction in tea leaves yield due to weeds can be as high as 12 to 21% (Kundu *et al*. 2020) depending upon the management practices followed. Besides reducing the yield, weeds also have adverse effects on tea *viz*.

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restricted branching, frame development in young tea, reduce plucking efficiency, harbor and serve as an alternate host for some important insect and disease pests of tea (Kumar *et al.* 2017). Weeds remove huge quantities of nitrogen, phosphorous and potassium from soil than a beverage crop leading to low tea yield (Roy *et al.* 2021). Weeds are dynamic in nature and a shift in their abundance and dominance is likely with changes in management practices. Because of the non-availability of labor at the critical time of weeding and high labor costs weed management practices are rapidly shifting towards chemical methods (Rao 2022).

The studies on effect of pre- and post-emergence herbicides to manage weeds in tea are meagre. Among different popular group of herbicides used worldwide, phenoxyacetic acid herbicides are widely used due to their selective action against broad-leaved weeds (Paszko *et al.* 2016; Kundu *et al.* 2020). Low price and high selectivity prompted their wide usage in modern, highly efficient agriculture. The most common representatives of this group are 2,4-dichlorophenoxyacetic acid (2,4-D) and 2-methyl-4-chlorophenoxyacetic acid (MCPA) (Paszko *et al.* 2016). They are synthetic auxins *i.e.* phytohormones which are involved in a range of physiological process essential for the proper plant growth. Their mode of action is based on mimicking indole-3-acetic acid (IAA). They stimulate plant development by cell division and elongation, vascular differentiation, oxygen species (ROS) production. Contrary to natural auxins, synthetic formulations are active for a significantly longer time, thereby exerting prolonged effects on root formation and apical dominance (Gao *et al.* 2024). On the other hand, high herbicide concentrations significantly disturb the proper plant growth and trigger damage processes leading to the final plant destruction (Romero Puertas *et al.* 2022).

The present study was carried out to identify the optimum dose MCPA to manage diverse weed flora in tea garden without compromising the tea productivity.

MATERIALS AND METHODS

A field experiment was conducted at Sunrise Tea Estate, Batabari, Jalpaiguri at $88^0 80'$ E longitudes and $26^0 88'$ N latitudes in 2021 and 2022 (September to December) in a pre-established tea garden (var. *TV-25*). Randomized Complete Block Design was used with seven treatments replicated thrice. Soil pH of the experimental block was acidic (6.60) in reaction, blackish grey in colour mostly due to high organic matter and poor bases, rich in available major nutrients (N, P, K). The experimental site was situated in warm and temperate climate. Temperature reaches maximum in June and it starts dropping from middle of October and recorded minimum in January. Rainfall started during May and very erratic thereafter up to October (average annual rainfall is 3000 mm). The relative humidity gradually decreases from July to December.

When weeds are at active vegetative growth stage (4-6 leaf), the tested herbicide MCPA 750 SL (MCPA) in different doses, *viz.* 0.5, 0.8, 1.0, 1.25 and 1.5 kg/ha and standard check 2,4-D Sodium salt 58% SL (2,4-D Sodium salt) 1.0 kg/ha were sprayed using Knapsack sprayer with a flood jet nozzle WFN 0.040 in a spray volume of 500 lit/ha. The observations were recorded on weed density (m^{-2}) and weed dry weight (weed biomass) (g/m^2) at 20, 40 and 60 days after application (DAA) by placing a quadrat of 0.5 × 0.5 m^2 randomly in each plot. The count and dry weight of weeds were analyzed after subjecting the original data to square root transformation ($\sqrt{x+0.5}$). Reduction in weed density (%), weed biomass (%) and herbicide efficiency index (HEI) were worked out using equations as below.

$$\text{Reduction in weed number (\%)} = \frac{WD_c - WD_t}{WD_c} \times 100 \ldots\ldots\text{(i)}$$

Where WD_c is the weed density (no./m^2) in control plot; WD_t is the weed density (no./m^2) in treated plot.

$$\text{Reduction in weed biomass (\%)} = \frac{\mathrm{WDM_c} - \mathrm{WDM_t}}{\mathrm{WDM_c}} \times 100 \quad \ldots\ldots\text{(ii)}$$

Where WDM_c is the weed biomass (g. m^{-2}) in control plot; WDM_t is the weed biomass (g/m^2) in treated plot.

$$\text{Herbicide efficiency Index (HEI)} = \frac{\mathrm{Y_t} - \mathrm{Y_c}}{\mathrm{Y_t}} \times \frac{\mathrm{WDM_c}}{\mathrm{WDM_t}} \ldots\ldots\text{(iii)}$$

Where Y_t is the crop yield from treated plot; Y_c is the crop yield from control plot. WDM_c is the weed biomass (g/m^2) in control plot; WDM_t is the weed biomass (g. m^{-2}) in treated plot.

Weed control efficiency (WCE) was calculated based on the data recorded on 20, 40 and 60 DAA as per the formula given below:

$$\mathrm{WCE} = \frac{\mathrm{X} - \mathrm{Y}}{\mathrm{X}} \times 100 \ldots\text{(iv)}$$

Where, X = Weed biomass in unweeded plot; Y = Weed biomass in treated plot.

The observations on the level of phytotoxicity due to application of tested herbicide were recorded on 1, 3, 5, 7 and 10 DAA. The parameters of phytotoxicity on chlorosis, necrosis, wilting, scorching, hyponasty and epinasty were observed to assess the phytotoxicity according to Biswas *et al.*

(2023). Yield data of green leaf tea was also recorded month wise from each picking for 3 months and calculated total yield of 3 months from each herbicidal treatment including plots of untreated weedy check.

Soil was collected at initial, 7, 14, 30 and 45 DAA with an auger (5 cm diameter) from the mid-points between tea rows randomly at five locations per plot from a depth of 15 cm and bulked, having almost 200–250 g fresh weight. The colony-forming units (cfu) of fungi, bacteria, and actinomycetes were enumerated in Czapek's Dox medium, nutrient agar, and actinomycetes isolation agar (Hi media), respectively, following serial dilution technique and agar/pour plate method using a 1 mL soil solution for plating (Alexander 1978). The microbes were incubated at 30 ^{o}C after serial dilution and spreading of the soil solution on the respective plates. The populations of bacteria per plate were scored within 3 days, whereas the populations of fungi and actinomycetes were observed after an incubation period of 5–7 days (Mondal *et al.* 2018). The nitrogen, phosphorous and potassium content of the sample were analyzed by micro-kjeldahl method, vanadomolybdo phosphoric yellow colour method and flame photometric method, respectively and subsequently the nutrient uptake by weeds and green leaf of tea was computed on hectare basis as given by Sunil *et al.* (2011).

Data on crops and weeds were analyzed using the analysis of variance (ANOVA) technique to evaluate the differences among treatments, and the means were separated using the least significant difference (LSD) at the 5% level (Gomez and Gomez 1984). The variance over the years was estimated for homogeneity of data by Bartlett's chi-square test. The effect of the years was non-significant and there were no significant interactions between treatments and years. Therefore, the data were pooled over the years and subjected to ANOVA.

RESULTS AND DISCUSSION

Weed density and biomass

The experimental plots were infested with mixed weed flora where broad-leaved weeds were the most dominating followed by grasses and sedges, irrespective of the dates of observations at 20, 40 and 60 DAA. Weed density and biomass were significantly higher in weedy check. Amongst the evaluated herbicidal treatments MCPA 1250 g/ha was most effective against monocot weeds, though treatments were non-significant among each other (**Table 1**). The highest dose of MCPA (1500 g/ha) proved significantly (p=0.05) superior over standard check herbicide 2,4-D salt to control *Borreria hispida* and *Ludwigia octovalvis* which was closely followed by MCPA at 1250 g/ha. During the total experiment periods all other broad-leaved weeds followed the same trend as previously. The reduction of total weed density over control was lowest with MCPA 500 g/ha and it continuously increased with the increasing dose of MCPA, accounting 42.75 % reduction in total weed density with MCPA at 1500 g/ha than unweeded control plot at 20 DAA (**Table 2**). Gao *et al.* (2019) and Kundu *et al.* (2020) reported more than 80 % control of weeds with herbicides applied alone or as mixtures in tea garden.

Among the evaluated treatments, the lower dry biomass of monocot weeds was observed with

Table 1. Effect of weed control treatments on density (no./m^2) of grasses, sedges, monocot weeds and broad-leaved weeds: *B. hispida, L. octovalvis, S. media* and *A. viridis* at 20, 40 and 60 DAA in tea (pooled over of two years)

Treatment	Grasses and sedges Monocot weeds			Broad-leaved weeds *Borreria hispida*			*Ludwigia octovalvis*			*Stellaria media*			*Amaranthus viridis*		
	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA
MCPA 500 g/ha	6.24 (38.43)	6.38 (40.19)	6.69 (44.22)	3.03 (8.67)	3.34 (10.63)	3.65 (12.83)	2.60 (6.27)	3.03 (8.69)	3.14 (9.37)	2.06 (3.73)	2.52 (5.85)	2.83 (7.51)	2.09 (3.87)	2.23 (4.49)	2.52 (5.85)
MCPA 800 g/ha	6.28 (38.94)	6.47 (41.38)	6.75 (45.05)	2.87 (7.73)	3.32 (10.55)	3.60 (12.47)	2.47 (5.61)	2.85 (7.61)	3.08 (8.97)	2.01 (3.55)	2.39 (5.21)	2.63 (6.43)	1.96 (3.33)	2.19 (4.28)	2.43 (5.39)
MCPA 1000 g/ha	6.19 (37.80)	6.50 (41.77)	6.66 (43.79)	2.78 (7.25)	3.28 (10.28)	3.60 (12.43)	2.41 (5.33)	2.79 (7.26)	3.01 (8.57)	1.91 (3.13)	2.29 (4.76)	2.55 (6.00)	1.89 (3.07)	2.15 (4.12)	2.26 (4.62)
MCPA 1250 g/ha	6.17 (37.51)	6.30 (39.14)	6.67 (43.93)	2.74 (7.03)	3.20 (9.77)	3.49 (11.67)	2.25 (4.57)	2.71 (6.84)	3.01 (8.54)	1.87 (3.00)	2.25 (4.57)	2.46 (5.57)	1.87 (3.00)	2.09 (3.88)	2.22 (4.45)
MCPA 1500 g/ha	6.21 (38.07)	6.33 (39.58)	6.56 (42.50)	2.69 (6.75)	3.14 (9.35)	3.41 (11.15)	2.20 (4.33)	2.61 (6.32)	2.88 (7.77)	1.88 (3.03)	2.23 (4.47)	2.41 (5.33)	1.87 (3.00)	1.96 (3.35)	2.04 (3.65)
2,4-D sodium salt 1000 g/ha	6.23 (38.35)	6.54 (42.25)	6.76 (45.19)	2.92 (8.00)	3.29 (10.31)	3.65 (12.80)	2.49 (5.71)	2.83 (7.53)	3.04 (8.73)	2.14 (4.07)	2.40 (5.26)	2.62 (6.37)	1.96 (3.33)	2.19 (4.30)	2.37 (5.13)
Untreated control	6.34 (39.72)	6.57 (42.68)	6.81 (45.87)	4.36 (18.47)	4.60 (20.68)	4.73 (21.92)	3.09 (9.03)	3.28 (10.25)	3.67 (12.94)	2.67 (6.61)	3.00 (8.50)	3.50 (11.72)	2.86 (7.67)	3.03 (8.68)	3.28 (10.25)
LSD (p=0.05)	NS	NS	NS	0.02	0.50	0.04	0.04	0.03	0.01	0.01	0.07	0.01	0.12	0.01	0.02

Values in the parentheses are original which were subjected to $\sqrt{x+0.5}$) transformations; DAA: days after application; NS: Non-significant

MCPA 1250 g/ha PoE which was statistically at par with highest dose of same herbicide (**Table 3**). But the later one recorded lower biomass of broad-leaved weeds *viz. Borreria hispida, Ludwigia octovalvis, Stelleria media, Amaranthus viridis* irrespective of the dates of observation. Lower biomass of *Pouzolzia zeylanica* at 20 DAA was observed with MCPA 1250 g/ha PoE which was statistically at par with MCPA 1500 g/ha PoE (**Table 4**). Another broad-leaved weed species, *viz. Ageratum conyzoides* and *Commelina benghalensis* recorded highest biomass with MCPA at 750 g/ha, among the herbicide treated plots. The weed biomass was reduced by 67.07 % with MCPA 1500 g/ha compared to control at 20 DAA (**Table 4**). Subsequent dates of observation (40 DAA and 60 DAA) also followed the same trend.

Weed control efficiency and herbicide efficiency index

The weed control efficiency based on the weed dry matter at different dates of observations varied significantly among the herbicide treatments (**Table 5**). MCPA 1500 g/ha recorded the highest weed control efficiency (WCE) of 85.40 %, 81.00 % and 77.45 % at 20, 40 and 60 DAA, respectively. MCPA 1250 g/ha also recorded satisfactory WCE (> 80 %) at 20 DAA closely followed by MCPA at 1000 g/ha and the same dose of 2,4-D Sodium salt. Herbicide

Table 2. Effect of weed control treatments on weed density (no. /m^2) of *P. zeylanica, A. conyzoides, C. benghalensis and other BLWs* at 20, 40 and 60 DAA and percentage reductions in total weed densities in tea (pooled over of two years)

Treatment	Broad-leaved weeds												Total weed density reduction (%) over control*		
	Pouzolzia zeylanica			*Ageratum conyzoides*			*Commelina benghalensis*			Others					
	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA
MCPA 500 g/ha	1.87 (3.00)	2.30 (4.78)	2.59 (6.20)	1.68 (2.33)	1.98 (3.41)	2.24 (4.50)	1.48 (1.70)	1.69 (2.35)	2.07 (3.80)	1.58 (2.00)	2.04 (3.67)	2.83 (7.51)	34.29	31.63	28.51
MCPA 800 g/ha	1.78 (2.67)	2.15 (4.14)	2.40 (5.28)	1.58 (2.00)	1.93 (3.23)	2.17 (4.22)	1.46 (1.62)	1.68 (2.32)	1.82 (2.82)	1.58 (2.00)	2.01 (3.55)	2.63 (6.43)	36.68	33.08	31.30
MCPA 1000 g/ha	1.68 (2.31)	1.98 (3.42)	2.18 (4.24)	1.47 (1.67)	1.76 (2.60)	1.95 (3.32)	1.43 (1.55)	1.57 (1.97)	1.77 (2.65)	1.49 (1.73)	1.98 (3.44)	2.55 (6.00)	40.07	35.24	35.43
MCPA 1250 g/ha	1.58 (2.00)	1.93 (3.24)	2.18 (4.24)	1.36 (1.35)	1.76 (2.60)	1.84 (2.90)	1.40 (1.45)	1.56 (1.93)	1.66 (2.25)	1.44 (1.57)	1.83 (2.86)	2.46 (5.57)	42.29	39.13	37.69
MCPA 1500 g/ha	1.51 (1.77)	1.87 (3.00)	2.13 (4.04)	1.35 (1.33)	1.64 (2.18)	1.78 (2.68)	1.37 (1.38)	1.43 (1.55)	1.75 1.50	1.35 (1.33)	1.76 (2.60)	2.41 (5.33)	42.75	41.11	41.18
2,4-D sodium salt 1000 g/ha	1.69 (2.35)	2.04 (3.65)	2.27 (4.66)	1.54 (1.87)	1.87 (3.0)	2.10 (3.91)	1.58 (2.00)	1.65 (2.22)	3.34 1.96	1.47 (1.67)	1.94 (3.25)	2.62 (6.37)	36.78	33.49	32.47
Untreated control	2.92 (8.00)	3.27 (10.19)	11.58 (3.48)	2.80 (7.33)	3.04 (8.75)	3.18 (9.60)	2.05 (3.70)	2.23 (4.48)	5.95 2.54	2.55 (6.00)	3.04 (8.70)	3.50 (11.72)	0.00	0.00	0.00
LSD (p=0.05)	0.03	0.16	0.29	0.16	0.13	0.23	0.20	0.12	0.13	0.05	0.19	0.15	0.07	0.07	0.05

Values in the parentheses are original which were subjected to $\sqrt{x+0.5}$) transformations; DAA: days after application.
*Total weed density reduction (%) over control was calculated based on original (non-transformed) data.

Table 3. Effect of weed control treatments on weed biomass (g/ m^2) of grasses, sedges, monocot weeds and broad-leaved weeds: *B. hispida, L. octovalvis, S. media and A. viridis* at 20, 40 and 60 DAA in tea (pooled over of two years)

Treatment	Grasses and sedges			Broad-leaved weeds											
	Monocot weeds			*Borreria hispida*			*Ludwigia octovalvis*			*Stellaria media*			*Amaranthus viridis*		
	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA
MCPA 500 g/ha	3.53 (11.96)	3.81 (14.04)	4.17 (16.86)	1.87 (3.01)	2.22 (4.42)	2.67 (6.62)	1.82 (2.81)	2.22 (4.45)	2.49 (5.72)	1.08 (0.67)	1.36 (1.36)	1.57 (1.95)	1.54 (1.87)	1.70 (2.38)	2.03 (3.61)
MCPA 800 g/ha	3.46 (11.45)	3.78 (13.81)	4.11 (16.4)	1.72 (2.46)	2.09 (3.87)	2.40 (5.27)	1.69 (2.37)	2.07 (3.77)	2.37 (5.1)	0.92 (0.35)	1.10 (0.72)	1.19 (0.91)	1.40 (1.47)	1.62 (2.13)	1.89 (3.07)
MCPA 1000 g/ha	3.58 (12.34)	3.76 (13.63)	4.13 (16.59)	1.64 (2.19)	2.02 (3.59)	2.35 (5.03)	1.52 (1.82)	1.80 (2.75)	2.08 (3.81)	0.88 (0.28)	1.06 (0.63)	1.13 (0.77)	1.24 (1.05)	1.46 (1.62)	1.56 (1.92)
MCPA 1250 g/ha	3.41 (11.16)	3.91 (14.8)	4.20 (17.12)	1.63 (2.15)	1.99 (3.45)	2.28 (4.71	1.51 (1.79)	1.84 (2.88)	2.13 (4.05)	0.85 (0.23)	1.01 (0.52)	1.03 (0.57)	1.26 (1.08)	1.44 (1.58)	1.56 (1.93)
MCPA 1500 g/ha	3.46 (11.44)	3.80 (13.94)	4.22 (17.33)	1.53 (1.85)	1.86 (2.95)	2.12 (4.01	1.38 (1.41)	1.71 (2.42)	1.97 (3.39)	0.85 (0.23)	0.99 (0.48)	0.99 (0.49)	1.22 (0.99)	1.28 (1.14)	1.45 (1.6)
2,4-D sodium salt 1000 g/ha	3.55 (12.08)	3.87 (14.48)	4.17 (16.9)	1.77 (2.63)	2.08 (3.81)	2.45 (5.48	1.54 (1.88)	1.93 (3.22)	2.24 (4.53)	1.02 (0.54)	1.13 (0.78)	1.21 (0.96)	1.33 (1.27)	1.53 (1.85)	1.71 (2.44)
Untreated control	3.50 (11.74)	3.79 (13.89)	4.10 (16.29)	3.14 (9.38)	3.45 (11.42)	3.55 (12.11	2.54 (5.94)	2.80 (7.33)	3.11 (9.17)	1.80 (2.75)	2.09 (3.85)	2.39 (5.19)	2.13 (4.02)	2.36 (5.05)	2.65 (6.51)
LSD (p=0.05)	0.03	0.02	0.02	0.02	0.01	0.06	0.01	0.04	0.05	0.03	0.01	0.01	0.01	0.02	0.005

Values in the parentheses are original which were subjected to $\sqrt{x+0.5}$) transformations; DAA: days after application.

efficiency index (HEI) reflects the efficacy of a herbicidal treatment in killing weeds and its effect on the crop (Kundu *et al.* 2025). In this study, MCPA with its highest dose, proved itself as a most efficient (0.56) than other herbicides in terms of HEI. In contrast, MCPA at 750 g/ha was the least efficient herbicide with a HEI value of only 0.17 (**Table 5**).

Tea green leaf yield

All the treatments significantly recorded higher green leaf yield in comparison to weedy check during both years of experiment (**Table 5**). Among the treatments tested, MCPA 1500 g/ha yielded maximum green leaf of 0.96 t/ha, 0.98 t/ha and 0.96 t/ha from the month of October to December respectively, which ultimately reflected in the total yield green tea leaf (2.90 t/ha). It was statistically at par with MCPA 1000 g/ha and 1250 g/ha **(Table 5)**. The **Figure 1** shows a positive linear relationship between weed control efficiency (%) and green leaf yield (t/ha). Green leaf yield increases as weed control efficiency improves, following the regression equation y = 0.0195x + 1.3844, with a strong coefficient of determination (R^2 = 0.8697) (**Figure 1**). This indicates that higher weed control efficiency substantially contributes to increased green tea leaf yield. Similar trend was observed with herbicide efficiency index, weed density reduction and biomass while contrasting relationship was observed with microbial population (**Figure 2**) demonstrating that it is essential to control weeds effectively in tea garden. A similar observation was reported by Kumar *et al.* (2017) and Kundu *et al.* (2020).

Phytotoxicity

No phytotoxicity symptoms regarding epinasty, hyponasty, vein clearing, necrosis, leaf tip and surface injury and wilting of plants were observed on

Table 4. Effect of weed control treatments on weed biomass (g /m²) of *P. zeylanica, A. conyzoides, C. benghalensis and other BLWs* at 20, 40 and 60 DAA and percentage reductions in total weed biomass in tea (pooled over of two years)

Treatment	Broad-leaved weeds												Total weed biomass (g m⁻²) reduction (%) over control*		
	Pouzolzia zeylanica			*Ageratum conyzoides*			*Commelina benghalensis*			Other BLWs					
	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA	20 DAA	40 DAA	60 DAA
MCPA 500 g/ha	1.13 (0.77)	1.43 (1.55)	1.70 (2.4)	1.46 (1.64)	1.93 (3.21)	2.14 (4.07)	1.29 (1.17)	1.61 (2.08)	1.64 (2.2)	1.13 (0.77)	1.64 (2.18)	2.04 (3.65)	53 .50	46.72	41.32
MCPA 800 g/ha	1.01 (0.53)	1.25 (1.07)	1.42 (1.51)	1.33 (1.26)	1.73 (2.48)	2.07 (3.78)	1.15 (0.83)	1.37 (1.37)	1.52 (1.82)	1.07 (0.65)	1.51 (1.79)	1.82 (2.8)	59.72	53.68	49.32
MCPA 1000 g/ha	0.86 (0.24)	1.05 (0.6)	1.14 (0.79)	1.17 (0.86)	1.49 (1.71)	1.83 (2.85)	1.09 (0.68)	1.21 (0.96)	1.41 (1.49)	0.93 (0.36)	1.32 (1.23)	1.65 (2.22)	62.64	60.09	55.79
MCPA 1250 g/ha	0.81 (0.16)	0.96 (0.43)	1.05 (0.6)	1.06 (0.63)	1.49 (1.73)	1.59 (2.04)	1.11 (0.73)	1.23 (1.01)	1.30 (1.2)	0.94 (0.39)	1.35 (1.31)	1.64 (2.19)	65.47	58.61	57.11
MCPA 1500 g/ha	0.82 (0.18)	0.93 (0.36)	1.01 (0.53)	1.02 (0.55)	1.30 (1.2)	1.57 (1.97)	1.04 (0.58)	1.06 (0.63)	1.14 (0.81)	0.86 (0.24)	1.18 (0.9)	1.46 (1.62)	67.07	64.12	60.43
2,4-D sodium salt 1000 g/ha	0.96 (0.42)	1.03 (0.57)	1.32 (1.23)	1.26 (1.08)	1.59 (2.03)	1.94 (3.26)	1.09 (0.69)	1.24 (1.05)	1.57 (1.98)	1.06 (0.63)	1.47 (1.67)	1.87 (3)	60.00	56.00	50.42
Untreated control	2.21 (4.39)	2.53 (5.89)	2.61 (6.29)	2.77 (7.18)	3.10 (9.12)	3.23 (9.92)	2.08 (3.84)	2.30 (4.77)	2.72 (6.9)	2.08 (3.81)	2.48 (5.63)	2.89 (7.85)	0.00	0.00	0.00
LSD (p=0.05)	0.01	0.03	0.02	0.003	0.02	0.07	0.02	0.01	0.01	0.03	0.01	0.17	0.86	1.20	0.79

Values in the parentheses are original which were subjected to $\sqrt{x+0.5}$) transformations; DAA: days after application. *Total weed density reduction (%) over control was calculated based on original (non-transformed) data

Table 5. Effect of treatments on weed control efficiency (%) and green leaf yield (t/ha) of tea (pooled over of two years)

Treatment	Weed control efficiency (%)			HEI	Tea green leaf yield (t/ha)											
					October			November			December			Total		
	20 DAA	40 DAA	60 DAA		Year I	Year II	Pooled	Year I	Year II	Pooled	Year I	Year II	Pooled	Year I	Year II	Pooled
MCPA 500 g/ha	69.23	59.23	52.74	0.17	0.77	0.86	0.81	0.81	0.89	0.85	0.79	0.86	0.82	2.37	2.61	2.49
MCPA 800 g/ha	75.99	67.58	62.06	0.24	0.79	0.88	0.84	0.82	0.90	0.86	0.81	0.88	0.85	2.42	2.66	2.54
MCPA 1000 g/ha	81.89	75.33	70.47	0.38	0.84	0.94	0.89	0.87	0.97	0.92	0.84	0.94	0.89	2.55	2.84	2.69
MCPA 1250 g/ha	82.67	75.67	72.96	0.47	0.88	0.97	0.92	0.90	1.00	0.95	0.88	0.98	0.93	2.66	2.95	2.80
MCPA 1500 g/ha	85.40	81.00	77.45	0.56	0.91	1.01	0.96	0.93	1.03	0.98	0.91	1.01	0.96	2.75	3.06	2.90
2,4-D sodium salt 1000 g/ha	77.87	71.77	64.22	0.27	0.81	0.90	0.86	0.85	0.94	0.89	0.79	0.88	0.84	2.45	2.72	2.58
Untreated control	0.00	0.00	0.00	0.00	0.60	0.66	0.63	0.62	0.71	0.67	0.65	0.67	0.66	1.87	2.04	1.96
LSD (p=0.05)	---	---	---	-	0.07	0.07	0.07	0.08	0.08	0.08	0.07	0.07	0.07	0.199	0.198	0.198

HEI- Herbicide efficiency index

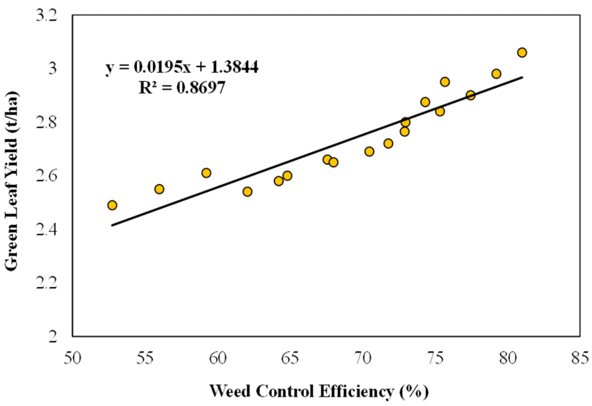

Figure 1. Relationship between weed control efficiency and tea leaf yield

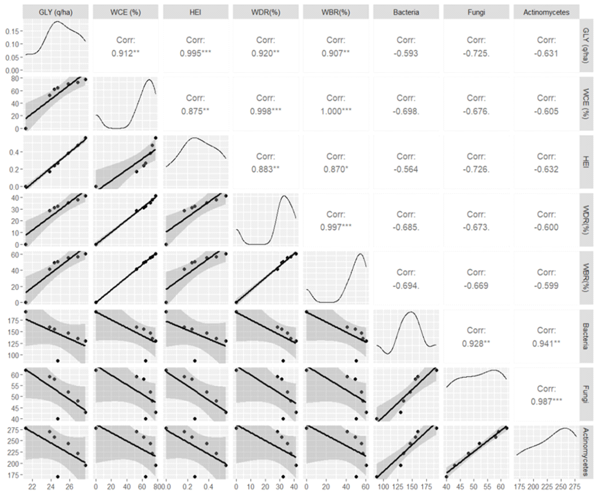

Figure 2. Pearsons correlation between different parameters observed in the study

tea due to application of tested herbicides on 1, 3, 7, 10 and 15 DAA.

Soil micro-organism populations

Different weed management treatments significantly (p=0.05) influenced the microbial populations at different tea growing phases. Microbes were least affected when treatment plots were free from herbicides (*i.e.* weedy check). Bacterial population sharply reduced (from 180.75 CFU × 10^4/g to 45.50 CFU × 10^4/g) by 2,4-D Sodium salt 1000 g/ha followed by MCPA 1500 g/ha (from 174.83 CFU × 10^4/g to 53.42 CFU × 10^4/g) at 7 DAA from initial but in case of former herbicide due to its high residuality, bacterial population remained low at 45 DAA than others (**Figure 3a**). Fungi and actinomycetes populations follow the same trend as bacterial population irrespective of all dates of observations (**Figure 3b and 3c**). These results are in tune with the findings of Kundu *et al.* (2020). The observed decline in microbial population may be attributed to the continuous application of chemical herbicides, which significantly alters the taxonomic composition of the rhizospheric microbiome by exerting selective pressure that favors opportunistic pathogens over beneficial symbionts (Cusaro *et al.* 2024). These chemical interventions often result in a marked reduction in microbial richness, specifically diminishing overall populations. Moreover, certain herbicides exhibit direct toxicity to soil microorganisms by interfering with the shikimic acid pathway, which suppresses the proliferation of diverse bacterial and fungal taxa (Velmourougane *et al.* 2021).

Nutrient removal by weeds

Uptake of N, P and K by weeds followed the trend of weed biomass. Total uptake of nitrogen, phosphorus and potassium by weeds at 60 DAA recorded significantly lowest (7.05, 0.90, 1.60 kg/ha respectively) with MCPA 1500 g/ha due to effective control of all the categories of weeds (**Figure 4**). Nutrient removal by weeds were continuously increased with decreasing the HEI. Because of no herbicide application, maximum nutrient was removed under weedy check treatment as observed by Chacko *et al.* (2022).

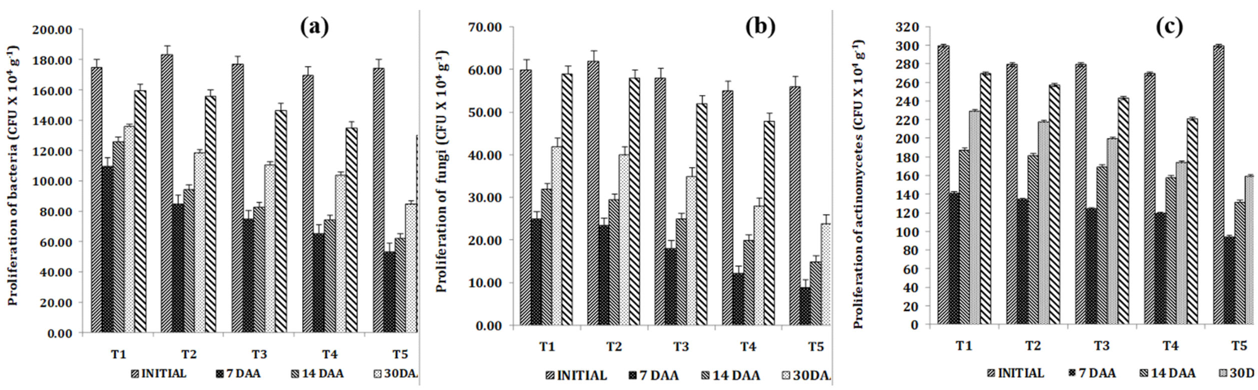

Figure 3. Microbial populations in soil as affected by weed control treatments at Initial, 7 days, 14 days, 30 days and 45 days after herbicide application (DAA): (a) bacterial; (b) fungal; (c) actinomycetal (based on pooled data of two years). Error bars represent LSD (p=0.05)

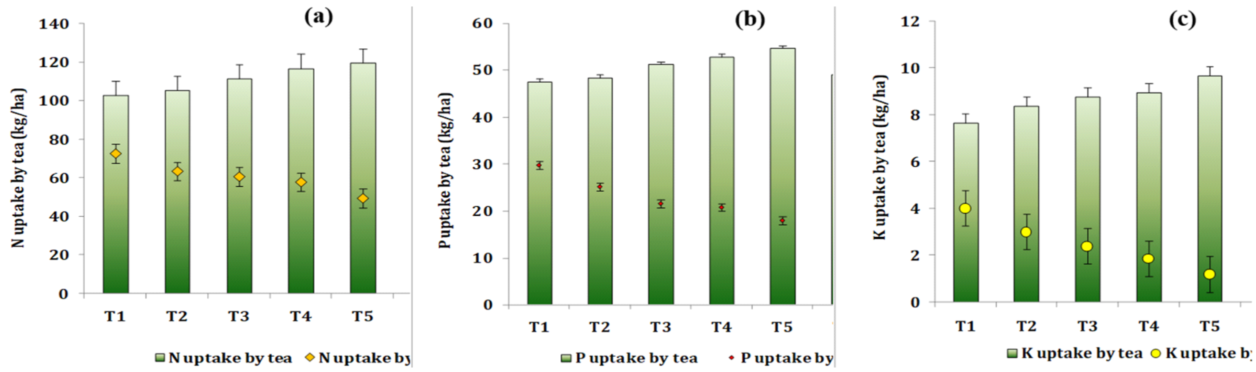

Figure 4. Nutrient uptake (kg/ha) by tea green leaves and weeds: (a) nitrogen; (b) phosphorous; (c) potassium (based on pooled data of two years). Error bars represent LSD (p=0.05)

Nutrient uptake by tea

The nutrient uptake by tea was inversely proportional to nutrient uptake by weeds. All weed control treatments significantly superior to weedy check in increasing NPK uptake by tea at 60 DAA (**Figure 4**). Irrespective of three major nutrients total maximum uptake (119.54 kg/ha, 54.73 kg/ha and 9.67 kg/ha NPK respectively) was noticed with MCPA 1500g/ha which was closely followed by descending doses MCPA (**Figure 4a**). Raj and Syriac (2017) also reported that maximum uptake of soil available nutrients by the crop was achieved from the higher of dose post-emergent herbicidal application followed by its lower doses.

CONCLUSION

MCPA 1500 g/ha controlled diversified broad-leaved weeds in tea garden during the critical crop-weed interference period that resulted in nearly ~48% yield increment of green tea leaves over control without showing any phytotoxicity symptoms on plants. There was no persistent detrimental effect of the applied herbicides on the rhizospheric microbial population and on soil available nutrients. Furthermore, the same treatment contributed to a noticeable enhancement in nutrient uptake by tea leaves, reaffirming its agronomic safety and effectiveness.

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RESEARCH ARTICLE

Dal-lake's dominant submerged aquatic weed valorisation for bioremediation of nitrogenous and metallic stressors from a variety of aquaculture waters

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ABSTRACT

The present study aims to determine ammonia, nitrite, lead (II) and chromium (VI) removal efficiencies of the products developed from aquatic weeds, *Ceratophyllum demersum* and *Hydrilla verticillata,* collected from Dal-lake, for the first time, from a variety of aquaculture waters (pond, aquaponics, and ornamental) under controlled conditions, followed by a wet-lab-based large-scale experiment. Aquatic weeds were found to be effective in the removal of ammonia, nitrite, Pb(II), and Cr(VI) from a variety of aquaculture waters, which can be attributed to adsorption and ion exchange of priority pollutants on functional moieties, alkali metals, and alkaline earth metals present in the aquatic weeds. The experimental results showed that ammonia and nitrite removal was effective at pH 7.5, whereas Cr(VI) removal was observed at pH 2 in treatment with 100 mg/L and 200 mg/L of weed. The average lead biosorption observed was 14 mg/g. The removal efficiencies observed were 60-65% for ammonia, 50% for nitrite, 99% for Cr(IV), and 90% for lead. By integrating bioremediation and livelihood generation, this initiative can not only contribute to environmental restoration but also create sustainable opportunities for local communities, fostering economic growth and social well-being. Utilizing aquatic weeds for bioremediation to generate livelihood opportunities for local communities can be an innovative and sustainable approach. Capacity building of the farmers for plant-assisted bioremediation is also suggested, enabling them to effectively integrate these techniques into their aquaculture operations.

Keywords: Dal-lake, Aquatic weeds, Aquaculture, Toxicants, Bioremediation, Circular bioresource utilisation, Environmental sustainability

INTRODUCTION

Globally, aquatic foods provide about 17 per cent of animal protein. Total fisheries and aquaculture production reached a record 214 million tonnes in 2020, comprising 178 million tonnes of aquatic animals and 36 million tonnes of algae, largely due to the growth of aquaculture, which refers to the rearing of aquatic organisms such as fish, molluscs, crabs, and plants (FAO 2022). The evolution of aquaculture operations from traditional to semi-intensive and intensive culture operations results in increased aquaculture production levels. However, intensive aquaculture operations lead to the deterioration of pond water quality due to the generation of high nitrogen and phosphorus metabolic waste, which can induce eutrophication (Abisha *et al.* 2022). The most prevalent toxicants in pond water are ammonia and nitrite through the decomposition of unconsumed feed and excretion by aquatic organisms in protein catabolism. The other class of pollutants is heavy metals. By accumulating in sediments, these contaminants can enter the food chain through plants and aquatic animals and can cause acute or chronic toxicity, leading to mortality in extreme cases. Lead can accumulate in the body and disrupt the health of humans, animals, and phytoplankton. Lead primarily binds to sulhydryl and oxo-groups in enzymes, affecting nearly every stage of haemoglobin synthesis and metabolism (Jomova *et al.* 2024). Chromium contamination of water bodies occurs as a result of both natural and anthropogenic sources. The hexavalent form Cr (VI) is of special concern due to its high toxicity, because of intense oxidation capabilities, and its effects on humans and animals are carcinogenic, mutagenic, and teratogenic (McCarroll *et al.* 2010), and many of its derivatives are highly water-soluble, making it readily bioavailable (Kotas 2000). Thus, it becomes necessary to remove these toxicants to maintain a healthy aquaculture operation.

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There is a big challenge to mitigate inorganic and organic contaminants, which together have been coined as contaminants of environmental and emerging concern (CEECs) (Krishnani *et al.* 2023). The most common methods for ammonia and heavy metals removal are ion exchange using zeolites, adsorption, filtration, chemical precipitation, and water exchange (Arunkumar *et al.* 2023, Chakraborty *et al.* 2024). These technologies, on the other hand, have some disadvantages, such as low efficiency and high operating and maintenance costs. Hence, to maintain a healthy aquatic environment and prevent and control disease infections, it becomes essential to develop a sustainable and eco-friendly aquaculture technology. Plants are considered to possess a natural ability to remove inorganic pollutants from water in an eco-friendly and low-cost process called plant-assisted bioremediation. Non-living plant biomass can be used profitably for the uptake and recuperation of contaminants, which is one way to put this principle into practice, and has successfully been demonstrated by Krishnani *et al.* (2021, 2023) and Singh *et al.* (2025a, 2025b). Successive use of dried and dead plant biomass to remove nitrogenous and metallic toxicants from industrial effluents, municipal waste water, and sewage water has gained popularity in the past few years because it is easily handled and is an affordable natural product (Parnian *et al.* 2022, Eliasova *et al.* 2021).Phycoremediation/Algae-assisted bioremediation in brackish water/coastal aquaculture has gained popularity (Kashem *et al.* 2023). Aquatic weed-assisted bioremediation may be considered a new, eco-friendly, and low-cost practice of removing contaminants from aquaculture water. However, reports on aquatic weed-assisted bioremediation for freshwater aquaculture are scanty.

Aquaponics combines hydroponics and aquaculture - a recirculatory system of the farming of aquatic organisms into a single system, where the nutrient-rich water from aquaculture is used as fertiliser for the cultivated plant, and the plants clean the water, creating a suitable environment for the fish to grow (John *et al.* 2022, Meena *et al.* 2023) and microorganisms, act as the third vital component because of their crucial role in the transformation of nutrients (Eck *et al.* 2019).

Freshwater habitats are under serious threat due to the diverse pressures of development, and the restoration of these ecosystems is an important challenge in the present era. Dal-lake (Union Territory of Jammu and Kashmir) is an urban lake that, being the state's most picturesque lake, is vital for tourism and enjoyment. The Dal-lake annually produces about 70,000 tonnes of lake waste, according to data from the Jammu and Kashmir Lake Conservation and Management Authority (LCMA). The floating/ submerged aquatic ecology of Dal-lake is a living repository of aquatic weed plants. The lake, which once covered an area of 75 square kilometres, has shrunk to 12 square kilometres in the last two decades. The lake's depth has also come down by nearly 12 metres, and it is a grave sign of the dangers the lake faces. The manual de-weeding of iconic Dal-lake might be an uphill task in restoring the pristine glory of the water body. The project is being implemented to convert lake weeds into usable organic manure and allied products, with the major objective of significantly promoting the cleaning of Dal-lake as it will not only eradicate the organic waste from the lake but also aid scientific treatment of all organic waste and create a useful product.

Enormous quantities of organic wastes such as sewage sludge (SS) and aquatic weed compost (AWC) are produced in large quantities on the banks of Dal-lake. It is a challenging task for authorities to manage them properly (Dar *et al.* 2023). From time to time, many scholars have focused their efforts on various ecological features of Dal-lake. Qadri *et al.* (2022) presented a case study of *Certophyllum demersum* as an efficient tool for heavy metal remediation in the order of $Co^{2+} > Cd^{2+} > Mn^{2+}$, followed by other metals in Dal-lake, a natural freshwater system in the Union territory of Jammu and Kashmir, India. However, the use of non-living biomass of aquatic weeds for biosorption of heavy metals and removal of ammonia and nitrite in aquaculture waters has been scantly reported. The present study evaluates the phytoremediation efficiency of aquatic weeds to determine nitrogenous and metallic toxicants for the first time from a variety of aquaculture waters. In this regard, aquatic weeds were collected from Dal-lake for the development of the product. The aquatic weeds were identified as *Ceratophyllum demersum and Hydrilla verticillata* and used in powder form to study ammonia and nitrite removal, biosorption of Pb (II), and detoxification of chromium Cr (VI).

MATERIALS AND METHODS

Collection of the aquatic weed for the preparation of the product

The aquatic weeds used in this study were collected from the freshwater habitat of Dal-lake (Union Territory of Jammu and Kashmir, India) in clean plastic bags. Plants were carefully washed using tap water to remove visible debris. After drying under sunlight, the plants were crushed and powdered in an electric mixer and passed through a 60-mesh sieve. Collections and product development were done from October 2020 to December 2020.

FTIR of aquatic weed-based product

Fourier Transform Infrared spectroscopy (FTIR) was used to characterize the functional moieties of an aquatic weeds. FT-IR spectra were recorded using an FTIR-Imaging system (Thermo Fisher Scientific) using the potassium bromide (KBr) pellet technique. The sample was scanned from 4,000 to 400 cm^{-1} wave number.

Removal of ammonia and nitrite from aquaculture water

Total ammonia-N (TAN) and nitrite-N concentrations in different water samples (fish pond, aquaponics, and ornamental) were estimated in separate experiments using a UV-VS Spectrophotometer (2080 UV/Vis Spectrophotometer) at 640 nm and 540nm of wavelength (APHA, 2005) and compared with the standard graph. The concentration was expressed as mg/L. For experimenting on aquatic weed-assisted bioremediation of ammonia and nitrite, spiking of three different water samples was done with 1000 mg/L stock solution of $(NH_4)_2SO_4$ to obtain a 1.5 mg/L concentration in addition to traces of TAN already present in collected water samples from aquaponics and ornamental. Spiking of three different water samples was done with a stock solution of $NaNO_2$ to obtain 0.5mg/L for estimation of Nitrite-N. The experiments were assigned different concentrations of the aquatic plant in different sources of water, with a Control (0 mg/L), and all were arranged with three replicates in 50 mL flasks. The test durations were kept at 3, 6, 12, 24, 48, and 72 hours, respectively. The solutions were agitated using a rotary shaker. In all the experiments, the plant biomass-contained solutions were filtered using a no. 41 Whatman filter papers. After getting successful results for ammonia removal activity, a large-scale experiment was carried out in eighteen numbers of 140 L tanks containing 100 L of water from an Aquaponics facility spiked with a stock solution of TAN for obtaining 1.5mg/L ammonia. A completely randomized design was followed for the experiment, using three replicates for each treatment. The experiment was assigned with treatments as 100 mg/L, 200 mg/L, and 0 mg/L (Control) of *Ceratophyllum,* and *Hydrilla verticillata* and all treatments were arranged with 3 replicates in nine 140L capacity tanks containing 100 L of water. The stocking density was kept at 6 per 100L. The experiment was conducted for 72 hours for TAN removal by keeping fish without feed, and then was extended up to 30 days by feeding fish twice daily and siphoning after a 4-day interval for measuring growth parameters. *Pangasianodon hypophthalmus* (Sauvage, 1878) fingerlings of length (cm) and weight (g) were stocked in the experiment. During the experimental period, the following parameters were maintained: pH 7.5 ± 0.5, water temperature 27 ± 2.0ºC. The percentage removal efficiency was calculated according to the following formula.

$$\%\, efficiency = \frac{co - c1}{co} \times 100$$

where C0 and C1 are initial and final concentrations of ammonia in a medium (mg/L).

Cr (VI) detoxification

Hexavalent Cr in the pond water sample was determined spectrophotometrically (Standard Methods, 1989) by measurement of the intense red-violet complex formed by the reaction of Cr (VI) with 1,5-diphenyl carbazide at different pH (2, 3, 4, 5, 6, 7) and compared with a standard graph. The concentration was expressed as mg/L. Spiking of different water samples was done with 100mg/L stock solution of $K_2Cr_2O_7$ to obtain a 2 mg/L concentration of Cr (VI) using the equation($N_1V_1=N_2V_2$). Nitric acid was used to adjust the pH of the pond water in which the chromium samples (Cr-VI) were prepared. The experiment was assigned three different concentrations of the aquatic plant, with 0 mg/L as the Control, and all concentrations were arranged with three replicates in 50 mL flasks. The test durations were kept at 3, 6, 12, and 24 hours, respectively. The solutions were agitated using a rotary shaker. In all the experiments, the plant biomass-containing solutions were filtered using a no. 41 Whatman filter papers.

Lead biosorption

Water samples were collected from the pond, and spiking of the water samples was done with a stock solution of $PbNO_3$ to obtain a 10 mg/L Pb concentration. The test duration was kept at 24 hours. The solutions were agitated using a rotary shaker. In all the experiments, the plant biomass-containing solutions were filtered using No. 41 Whatman filter papers. The samples were analysed by Inductively Coupled Plasma Mass spectrometry (ICP-MS-Agilent Technologies Model 7800).

All reagents were analytical grade, and instruments were pre-calibrated appropriately prior to measurement. Replicate analyses were carried out for each determination to ascertain reproducibility and quality assurance. The treated samples were also analyzed by Flame photometry (Labard LIM-204) to determine the effective ion-exchange mechanism.

All the above experiments and analyses were carried out from February 2021 to July 2021.

RESULTS AND DISCUSSION

Identification of aquatic weeds

To determine the nitrogenous and metallic toxicants removal activity of an aquatic weed-based product, the aquatic weeds were collected from Dal-lake, India (**Figure-1 A, B**) and identified as *Ceratophyllum demersum* (**Figure-1C**) and *Hydrilla verticillata* (**Figure-1D**). *Ceratophyllum demersum* known as coon tail, is a submerged macrophyte commonly seen in freshwater ponds and is well-adjusted to aquarium conditions in temperate climates. *Ceratophyllum demersum* species is rootless; a completely submerged dicotyledon's seed belonging to the family Ceratophyllaceae grows well in subtropical and tropical weather regimes and is commonly seen in ponds, lakes, ditches, and quiet streams. It does not produce roots; instead, it absorbs all the nutrients it requires from the surrounding water.

Determination of functional moieties of aquatic weed using Fourier Transform Infrared spectroscopy (FTIR)

The intense peak at 3433.15 cm^{-1} was observed, which indicated that the hydroxyl functional group is present in an aquatic weed. Also, OH stretching of the carboxylic acid functional group was present in 2928.10 cm^{-1} and 2360.14 cm^{-1}, and carbonyl (C=O) group stretching occurred at 1646.14cm^{-1}, and C-O stretching appeared in 1026.81 cm^{-1}. FTIR spectra revealed the presence of various functional moieties in the aquatic weed. The other absorption peaks appeared at 875.31, 712.7, 666.68, 572.73, and 506.98 cm^{-1} (**Figure 2**).

Determination of TAN removal activity in different water samples under lab conditions

The effect of four different concentrations of *Ceratophyllum* (40, 100, and 200 mg/L) on the removal of the initial TAN concentration of 1.37 mg/L from pond water, aquaponics water and ornamental water at different time intervals is presented in **Figure 3** (A, B, C). This shows that TAN levels decreased up to 31%, 45%, and 67% in treatments with 100 mg/L of *Ceratophyllum* and decreased up to 45%, 63%, and 67% in treatment with 200 mg/L of *Ceratophyllum* in 24, 48, and 72 hours respectively

(A). Dal-lake

(B). Collection of aquatic weeds

(C). *Ceratophyllum demersum* (Dried)

(D). *Hydrilla verticillata* (Dried)

Figure 1. Dal-lake and the Site of sample collection and aquatic weeds

(**Figure 3A**). Similarly, from aquaponics water, TAN levels decreased 10%, 27%, and 36% with 100 mg/L of *Ceratophyllum* and decreased up to 14%, 43%, 61% with 200 mg/L of *Ceratophyllum* in 24, 48, and 72 hours respectively (**Figure 3B**). In ornamental water, aquatic weed was able to reduce TAN 18%, 34%, and 40% with 100 mg/L of *Ceratophyllum* and decreased up to 20%, 48%, and 51% with 200 mg/L of *Ceratophyllum* in 24, 48 and 72 hours respectively (**Figure 3C**).

The effect of four different concentrations of *Hydrilla verticillata* (40, 100, and 200 mg/L) on the removal of the initial TAN concentration of 1.37 mg/L from pond water, aquaponics water and ornamental water at different time intervals is presented in **Figure 4** (A, B, C). This shows that TAN levels decreased up to 29% and 53% in treatments with 100 mg/L of *Hydrilla verticillata* and decreased up to 55%, and 60% in the treatment with 200 mg/L of *Hydrilla verticillata* in 48 and 72 hours, respectively. Similarly, from aquaponics water, TAN levels decreased 26% and 33% with 100 mg/L of *Hydrilla verticillata* and decreased up to 40% and 53% with 200 mg/L of *Ceratophyllum* in 48 and 72 hours, respectively. In ornamental water, aquatic weed was able to reduce TAN by 33% and 39% with 100 mg/L of *Hydrilla verticillata* and decreased up to 47% and 49% with 200 mg/L of *Hydrilla verticillata* in 48 and 72 hours, respectively.

Determination of Nitrite-N removal activity in different water samples under lab conditions

The effect of four different concentrations of *Ceratophyllum* (40, 100, and 200 mg/L) on the removal of the initial Nitrite-N concentration of 0.5 mg/L at different time intervals in pond water, aquaponics water and ornamental water is presented in **Figure 5** (A, B, C). The nitrite-N level decreased

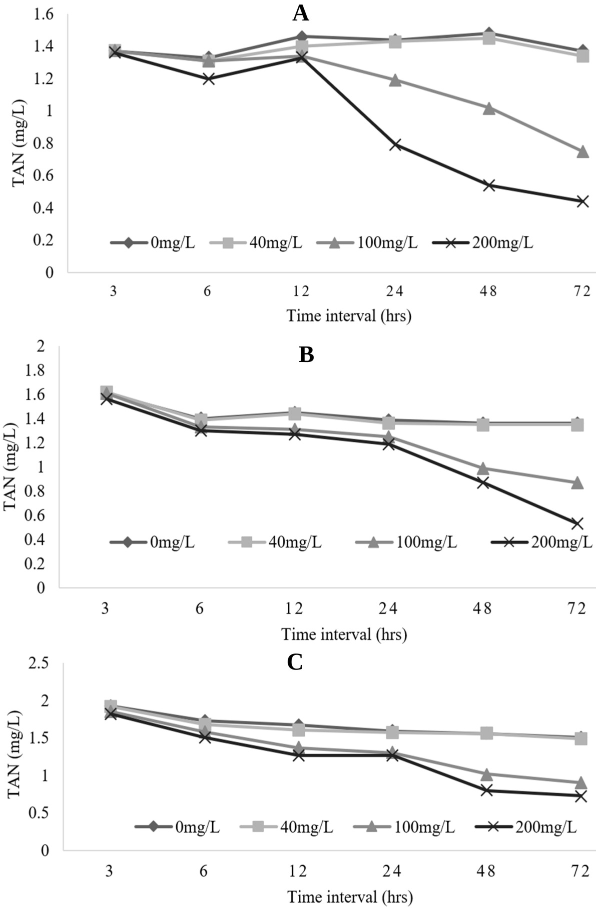


Figure 3. TAN removal from (A). Pond water (B). Aquaponics water (C). Ornamental water using *Ceratophyllum* at different time intervals under lab conditions

from 0.46 to 0.38, 0.45 to 0.28 (37%) in 48 and 72 hours, respectively with 100 mg/L of *Ceratophyllum*. Nitrite-N levels showed a further decrease from 0.46 to 0.30 (34%), and 0.45 to 0.22 (51%) in 48 and 72 hours, respectively, with 200 mg/L of *Ceratophyllum* (**Figure 5A**). Similarly, in Aquaponics water, the effect of various concentrations of *Ceratophyllum* (0,

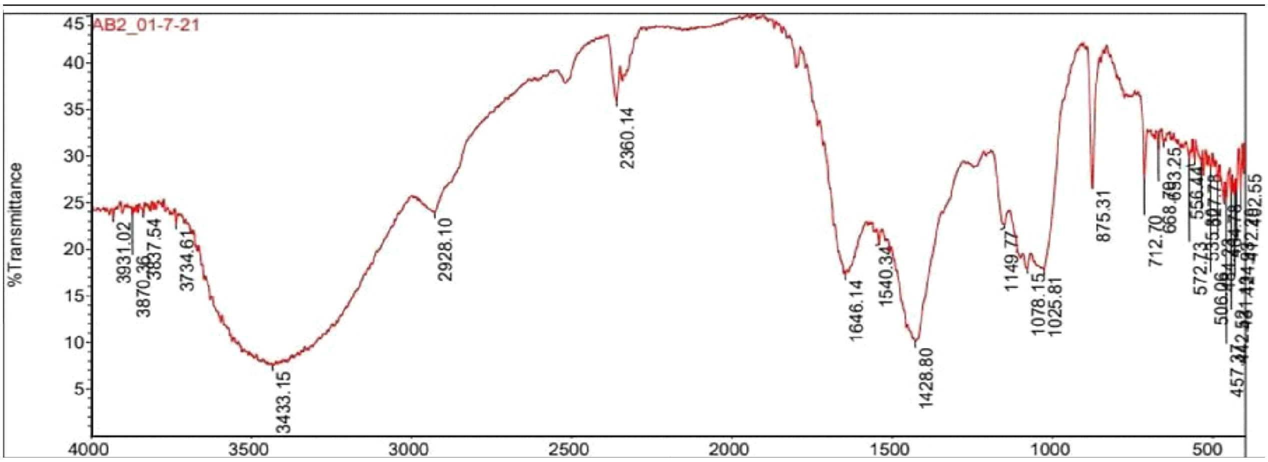


Figure 2. FT-IR of *Ceratophyllum* product

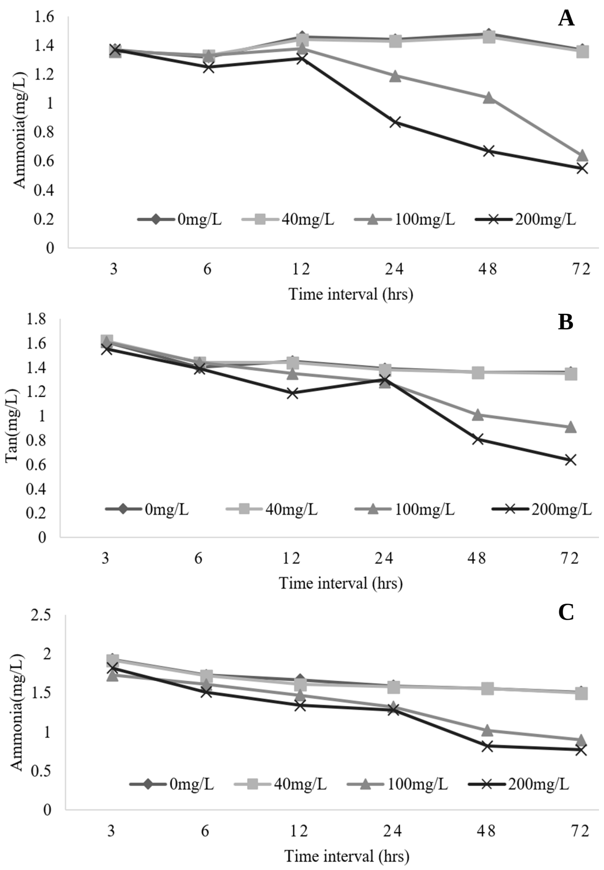


Figure 4. TAN removal from (A). Pond water (B). Aquaponics water (C). Ornamental water using *Hydrilla verticillata* at different time intervals under lab conditions

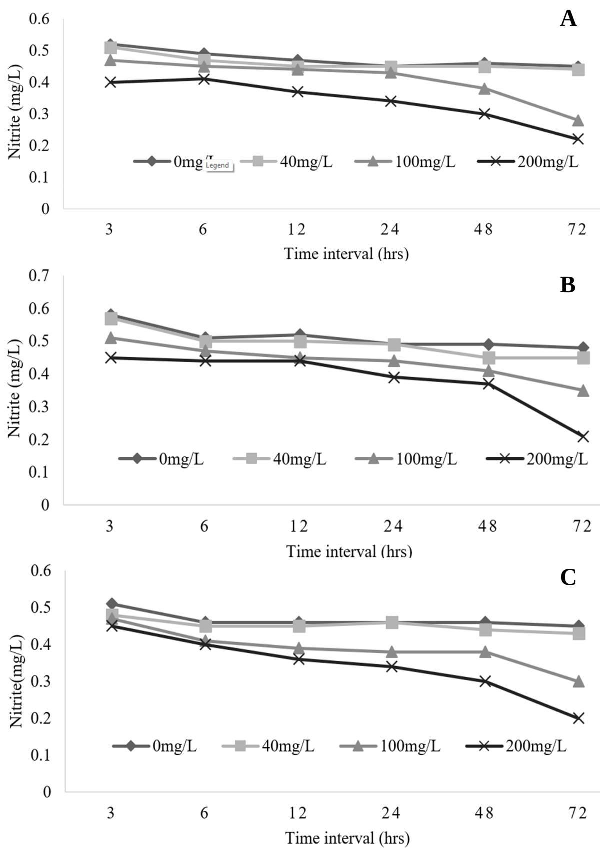


Figure 5. Nitrite-N removal from (A). Pond water (B). Aquaponics water, (C). Ornamental water using *Ceratophyllum* at different time intervals under lab conditions

40, 100, and 200 mg/L) on the removal of the initial concentration of 0.58 mg/L Nitrite-N in 72 h is shown in **Figure 5B**. The nitrite-N level decreased from 0.49 to 0.42 (14%), and from 0.48 to 0.35 (27%) in 48 and 72 hours, respectively, with 100 mg/L of *Ceratophyllum.* A nitrite-N level further showed a decrease from 0.49 to 0.38 (22%), and 0.48 to 0.21 (56%) in 48 and 72 hours, respectively, with 200 mg/L of *Ceratophyllum.* The effect of various concentrations of *Ceratophyllum* in ornamental water ranging from 0 to 200 mg/L on the removal of Nitrite-N in 72 hours is shown in **Figure 5C**. The nitrite-N level decreased from 0.46 to 0.38(17%), and from 0.45 to 0.30 (33%) in 48 and 72 hours, respectively, with 100 mg/L of *Ceratophyllum*. Nitrite-N level decreased from 0.46 to 0.30(34%), 0.45 to 0.20(55%) in 48 and 72 hours respectively with 200 mg/L of *Ceratophyllum.* The effect of four different concentrations of *Hydrilla verticillata* (40, 100, and 200 mg/L) on the removal of the initial Nitrite-N concentration of 0.5 mg/L at different time intervals in pond water, aquaponics water and ornamental water is presented in **Figure 6** (A, B, C). Nitrite-N decreased from 0.46 to 0.42(9%),0.45 to 0.32(28%) with 100 mg/L of *Hydrilla verticillata* and it decreased from 0.46 to 0.37(19%),0.45 to 0.28(37%) in 48 and 72 hours respectively with 200 mg/L of *Hydrilla verticillata.* In aquaponics, nitrite-N decreased from 0.49 to 0.42(14%),0.48 to 0.36(25%) with 100 mg/L of *Hydrilla verticillata,* and it decreased from 0.49 to 0.37(24%),0.48 to 0.26 (45%) in 48 and 72 hours, respectively, with 200 mg/L of *Hydrilla verticillata.* Similarly, in ornamental water, Nitrite-N decreased from 0.46 to 0.38(17%), 0.45 to 0.30(33%) with 100 mg/L of *Hydrilla verticillata*, and it decreased from 0.46 to 0.30(34%), 0.45 to 0.23 (49%) in 48 and 72 hours, respectively, with 200 mg/L of *Hydrilla verticillata.*

Determination of TAN removal activity of *Ceratophyllum* and *Hydrilla verticillata* under wet lab conditions

Under wet lab conditions, TAN levels decreased from 1.64 to 1.52(7%), 1.41(10%), 1.38(10%), 1.34 (15%), 1.19 (20%), and 0.92(33%) with 100 mg/L of *Ceratophyllum* and TAN decreased from 1.64 to 1.48(10%), 1.31(16%), 1.35(12%), 1.26(20%), 0.87(41%), and 0.53(61%) with 200 mg/L of

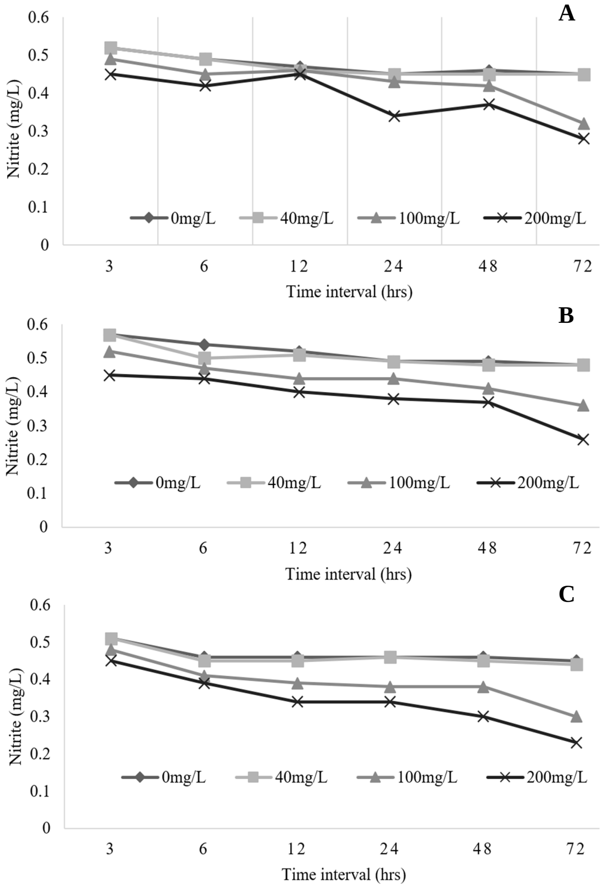


Figure 6. Nitrite-N removal from (A). Pond water, (B). Aquaponics water (C). Ornamental water using *Hydrilla verticillata* at different time intervals under lab conditions

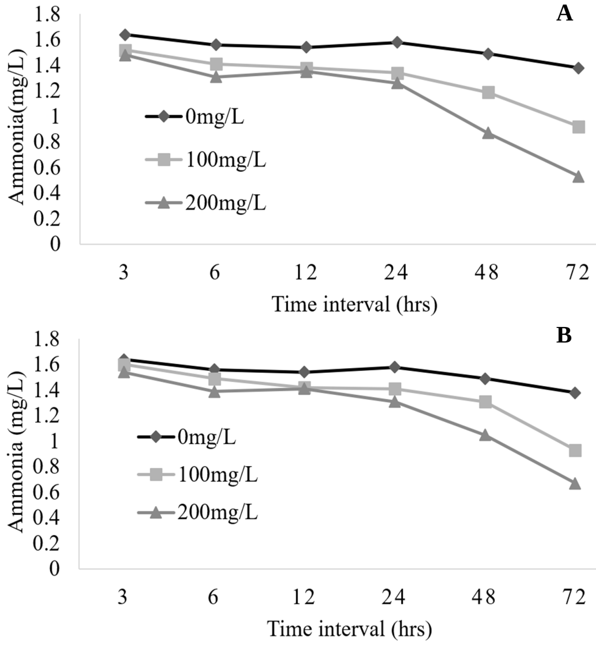
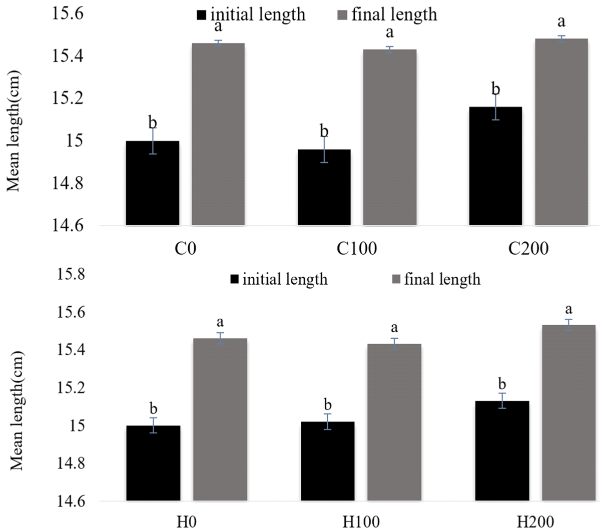


Figure 7. Effect on TAN removal activity using (A). *Ceratophyllum* and (B). *Hydrilla* (under wet lab conditions)



Figures 8. Mean Length of fish in treatment with *Ceratophyllum* and *Hydrilla*

Ceratophyllum in 3, 6, 12, 24, 48, and 72 hours respectively (**Figure 7A**). TAN level decreased from 1.49 to 1.31 (12%) and from 1.38 to 0.93(32%) in 48 and 72 hours, respectively, with 100mg of *Hydrilla verticillata*. TAN level showed further decrease from 1.49 to 1.05(29%) and1.38 to 0.67(51%) in 48 and 72 hours respectively with 200 mg/L of *Hydrilla verticillata* (**Figure 7B**).

The present analysis has revealed the excellent performance role of the aquatic weed-based product developed from *Ceratophyllum and Hydrilla verticillata* in phytoremediation technology for TAN and Nitrite-N removal from a variety of aquaculture waters, including the pond, aquaponics, and ornamental systems in a 72-hour experimentation period. The present findings gain support from the work of Krishnani *et al.* (2002), who have found a similar trend of reduction in TAN removal activity using neem oil, neemazal, and neemgold at 90 mg/L in decreasing the total TAN nitrogen (TAN) level of 0.40–0.45 mg/L in 96 hours. The removal efficiency after a 72-hour time duration was observed to be higher in pond water and aquaponics water than in ornamental water, which may be due to the presence of beneficial bacteria and enhanced periphytic bacterial growth due to the addition of the plant material that causes the removal of TAN from the water. These studies are in line with the findings of Krishnani *et al.* (2006), where bagasse was used for nitrate removal.

The present findings gain support from the work of Silva *et al.* (2006), who found the removal of NH_3-N by *E. crassipes* and *P. stratiotes* in catfish aquaculture wastewater that reached up to 74% and 78%, respectively, and 69% and 65% respectively, in tilapia fish aquaculture wastewater. Katsuya (2002) reported removing nitrate, nitrite-N, ammonium, and phosphate ions from water by the aerial microalga *Trentepohlia aurea*. Shahar *et al.* (2021) have reported *the* removal of nitrogen, particularly nitrate, from fishpond effluent using *Ulva fasciata* and periphyton. When the experiment was conducted on a large scale with fish, *Pangsianodon hypothalamus*, with 100 and 200 mg/L concentrations of *Ceratophyllum* and *Hydrilla* in 100L of water, the same results were obtained. The water quality parameters like DO, Temperature, alkalinity, hardness, pH, phosphate, and nitrite-N were maintained within normal ranges in both experiments during the 30 days. The growth parameters were also studied during the experiment, and it was found that the maximum weight gain observed was 2.9%, and the mean length was 15.48±0.05cm at 200 mg/L of *Ceratophyllum*. Hence, it was observed that in the experiment with different treatments, no significant difference was observed in weight gain, SGR, and mean length, respectively. Thus, it was concluded that among 40, 100, and 200 mg/L of plant product used, 100 and 200 mg/L doses showed a significant reduction in TAN and nitrite-N levels from the pond, aquaponics, and ornamental water, respectively.

Determination of the heavy metal removal capacity of the aquatic weed-based products

Cr (VI) Detoxification using *Ceratophyllum*

It was observed that chromium removal activity was significantly higher at pH 2 in treatment with 100 mg/L and 200 mg/L of *Ceratophyllum* in 24 hr, which indicates that the *Ceratophyllum* was able to reduce Chromium from 2.28 to 0.07(96%) and 0.01(99%) at 100 and 200 mg/L, respectively as shown in **Table 1**. The effect of pH 2 on chromium removal showed a significant difference. Similarly, the effect of the concentration of the plant at 100 and 200 mg/L showed a significant difference for the removal of chromium.

Cr Removal using *Hydrilla*

It was observed that chromium removal activity was significantly higher at pH = 2 at 200 mg/L of *Hydrilla* in a 24 h time interval, which indicates that the plant was able to remove Chromium from 1.66 to 1.38(17%) as shown in **Table 2**. The effect of pH=2 on Chromium Removal showed a significant difference. Similarly, the effect of the concentration of the plant at 200 mg/L showed a significant difference for the removal of Chromium.

In the present study, the best removal of chromium was observed at pH 2 at 100 and 200 mg/L *Ceratophyllum* during the 24-hour experimentation period. Since Chromium is negatively charged in aqueous solutions, it offers repulsion to functional moieties present in the plant material; hence, by decreasing pH, H+ ions cause adsorption of Cr (VI) on plant material. Also, the presence of lignin in plant material acts as an electron donor, reducing toxic Cr (VI) to less toxic Cr (III). A similar study was conducted to ascertain the removal efficiency of chromium (VI), and it was found that the adsorption process was optimal at pH 2 for Cr (VI) (Alemu *et al.* 2018). The result was consistent with the previous observations conducted for the removal of Cr (VI)

Table 1. Concentration of total Cr (VI) at different pH levels in treatment with different doses of *Ceratophyllum demersum*

Weed dose (mg/L)	pH	3hr	6hr	12hr	24hr
0	2	1.81	2.04	2.13	2.28
0	3	1.74	1.68	1.71	1.78
0	4	1.81	1.81	1.84	1.86
0	5	1.79	1.64	1.76	1.87
0	6	1.71	1.75	1.82	1.94
0	7	1.86	2.41	2.45	2.67
40	2	1.62	1.75	1.16	0.58
40	3	1.72	1.50	1.63	1.77
40	4	1.75	1.70	1.83	1.86
40	5	1.74	1.56	1.69	1.86
40	6	1.72	1.73	1.76	1.91
40	7	1.79	2.12	2.24	2.17
100	2	1.5	1.55	0.40*	0.07*
100	3	1.63	1.40	1.38	1.55
100	4	1.6	1.49	1.57	1.83
100	5	1.71	1.55	1.62	1.80
100	6	1.67	1.61	1.61	1.79
100	7	1.8	2.12	2.03	2.12
200	2	0.74	0.62	0.15*	0.01*
200	3	1.52	1.31	1.36	1.45
200	4	1.46	1.40	1.53	1.83
200	5	1.64	1.44	1.51	1.72
200	6	1.63	1.45	1.40	1.61
200	7	1.73	2.05	1.94	2.11
	SEM	0.005	0.04	0.01	0.01

*Indicates significant difference (p<0.05); Individual effect on Chromium removal activity using *Ceratophyllum* product

Ceratophyllum conc(mg/L)	3hr	6hr	12hr	24hr
0	1.79	1.88	1.94	2.06
40	1.72	1.72	1.71	1.68
100	1.65	1.62	1.43	1.52*
200	1.45	1.37	1.31	1.45*
SEM	0.002	0.01	0.01	0.01
pH				
2	1.42	1.49	0.96	0.74*
3	1.65	1.47	1.52	1.64
4	1.66	1.60	1.69	1.84
5	1.72	1.55	1.64	1.81
6	1.68	1.63	1.64	1.81
7	1.79	2.18	2.16	2.26
SEM	0.003	0.02	0.01	0.01

*Indicates significant difference (p<0.05)

Table 2. Concentration of total Cr(VI) at different pH in treatment with different doses of *Hydrilla verticillate* at different pH

Treatment	3hr	6hr	12hr	24hr
Effect of Hydrilla pH Chromium Concentration (mg/L)				
H0P2	1.84	1.92	1.88	1.66
H0P3	2.20	2.43	2.21	1.98
H0P4	1.86	1.87	1.87	1.51
H0P5	1.71	1.77	1.69	1.76
H0P6	1.78	2.00	1.76	1.76
H0P7	1.79	1.97	1.87	1.85
H40P2	1.61	1.92	1.62	1.66
H40P3	1.92	2.19	2.15	1.78
H40P4	1.76	1.75	1.76	1.52
H40P5	1.68	1.73	1.69	1.73
H40P6	1.69	1.94	1.76	1.69
H40P7	1.78	1.86	1.84	1.79
H100P2	1.60	1.51	1.59	1.53
H100P3	1.84	2.19	2.03	1.70
H100P4	1.61	1.69	1.76	1.49
H100P5	1.66	1.68	1.67	1.72
H100P6	1.66	1.66	1.74	1.69
H100P7	1.73	1.81	1.82	1.75
H200P2	1.52	1.51	1.51	1.38
H200P3	1.84	2.15	1.86	1.57
H200P4	1.53	1.64	1.62	1.47
H200P5	1.65	1.66	1.66	1.70
H200P6	1.64	1.84	1.72	1.67
H200P7	1.69	1.74	1.81	1.67
SEM	0.01	0.01	0.01	0.01
P Value	<0.001	<0.001	<0.001	<0.001
Individual effect on Chromium removal activity				
Effect of Hydrilla Concentration				
H0	1.86[a]	1.99[a]	1.87[a]	1.75[a]
H40	1.64[d]	1.76[c]	1.69[d]	1.59[d]
H100	1.73[b]	1.90[b]	1.80[b]	1.69[b]
H200	1.68[c]	1.76[c]	1.76[c]	1.64[c]
SEM	0.01	0.002	0.003	0.002
P Value	<0.001	<0.001	<0.001	<0.001
Effect of pH				
P2	1.64[d]	1.72[e]	1.65[e]	1.56[e]
p3	1.94[a]	2.24[a]	2.06[a]	1.76[b]
p4	1.69[c]	1.74[d]	1.75[c]	1.49[f]
P5	1.68[c]	1.71[f]	1.68[d]	1.73[c]
P6	1.69c	1.85[b]	1.75[c]	1.71[d]
P7	1.75[b]	1.84[c]	1.84[b]	1.77[a]
SEM	0.007	0.003	0.003	0.002
P Value	<0.001	<0.001	<0.001	<0.001

Values with the same superscript in a column did not show any significant difference(p>0.05); H = *Hydrilla;* 0, 40,100, 200 = Concentrations of plant in mg/l; P=pH

when the material was charred with sulphuric acid, with five different products prepared from bagasse for evaluating the detoxification of Cr (VI) from high saline coastal water (Krishnani *et al.* 2004). Other aquatic plant species such as *Eichhornia crassipes*, *Potamogeton lucens*, and *Salvinia herzegoi* have been reported as excellent biosorbent materials used successfully in several studies for removing Cr, Ni, Cd, Zn, Cu, and Lead (Wang *et al.*1998, 2019).

Table 3. Biosorption capacities of *Ceratophyllum demersum* and *Hydrilla verticillate* on lead (data shown are mean values)

Treatment Conc	Ceratophyllum		Hydrilla	
	mmol	mg/g	mmol	mg/g
40	0.08	16.93	0.12	25.82
100	0.07	14.99	0.06	12.93
200	0.05	10.07	0.05	9.63
Av.	0.07	14.00	0.08	16.13

Lead removal using *Ceratophyllum*

It was also observed that lead concentration decreased from 10.44 mg/L to 7.17 mg/L, 3.21 mg/L, and 0.72 mg/L in treatment with 40, 100, and 200 mg/L of *Ceratophyllum,* respectively, after a 24-hour time duration and there was a significant difference in Lead removal at different concentrations of the plant used and maximum removal was observed at 200 mg/L. Biosorption capacities of *Ceratophyllum* for Lead were varying from 0.05 to 0.08 mmol/g as shown in **Table 3**.

Lead removal using *Hydrilla*

It was observed that Lead concentration decreased from 10.44 mg/L to 5.45 mg/L, 4.2 mg/L, 1.14 mg/L in treatment with 40, 100, 200 mg/L of *Hydrilla* respectively after 24-hour time duration and there was a significant difference in Lead removal at different concentrations of the plant used and maximum removal was observed at 200 mg/L. Biosorption capacities of *Hydrilla* for Lead were varying from 0.05 to 0.08 mmol/g as shown in **Table 3**.

Characterisation of the *Ceratophyllum* using FT-IR spectroscopic technique indicated the presence of functional moieties -COOH, -OH, -CO that is negatively charged attract positively charged ammonium and metal ions, due to which efficient ion exchange occurs (Krishnani and Ayyappan, 2006). This result was consistent with the previous observations showing that pollutants and heavy metals are naturally absorbed by aquatic plants (Pratas *et al.* 2014). The most efficient and profitable method of removing various heavy metals and other contaminants is aquatic plants (Ali *et al.* 2013, Guittonny-Philippe *et al.* 2015).

The use of biological materials for heavy metal removal and recovery technologies (Biosorption) has gained significant recognition in recent years due to its good performance and inexpensive cost. In the present study, the aquatic weed-based product was tested for the removal of Lead from aqueous solutions having an initial lead concentration of 10 mg/L. The present investigation has revealed the role of the aquatic weed-based product developed from *Ceratophyllum* for *the* biosorption of lead. The *Ceratophyllum* was able to reduce lead from 10.44 to 7.17 mg/L, 3.21 mg/L, and 0.72 mg/L at 40, 100, and 200 mg/L, respectively, during a 24-hour time duration. The average value of biosorption capacity found was 14 mg/g. A similar study was conducted where water hyacinths (*Eichornia crassipes*) dried roots showed the potential to remove cadmium and lead effectively from wastewater (Wang *et al*, 1998). The flame photometry analysis indicated that there is a significant ion-exchange mechanism taking place between lead with calcium and potassium, which suggests that the plant materials possess good ion-exchange properties.

Metal ions have been removed by both living and dead (metabolically inactive) biological materials. It was discovered that certain functional groups present on their cell wall produce certain forces of attraction for metal ions, resulting in high removal efficiency. This explains the ion exchange mechanism for heavy metal removal. The results of the present study coincide with the work carried out by Krishnani *et al.* (2008), where paddy straw was used for heavy metal biosorption. In the present study, the different concentrations of plant material used (40, 100, and 200 mg/L) resulted in significant reduction and biosorption of Lead, and the high removal of Lead was observed with 200 mg/L in a 24-hour time duration.

Metal removal mechanism using flame photometry

The flame photometry analysis indicated that there is a significant ion-exchange mechanism taking place between lead and calcium and potassium, while sodium showed no significant difference in ion-exchange mechanism with lead, which indicated that sodium has no role to play in ion-exchange with lead as presented in **Table 4**. Silver has also been reported in *Hydrilla*, which may be attributed to the natural occurrence of silver in aquatic plants in Dal-lake. During the last decade, there has been considerable work done in the field of nanobiotechnology for the synthesis of nanoparticles by using plants, animals, fish and microorganisms (Krishnani *et al.* 2022). Terrestrial and aquatic plants can synthesise silver nanoparticles under natural conditions. Sable *et al.* (2012) reported the extracellular phytosynthesis of silver nanoparticles (65 nm) using aquatic plants *Hydrilla verticilata* and re4commended that the phytofabricated Ag-NPs can be used in the field of medicine and agriculture, due to their antimicrobial potential. Jha *et al.* (2009) synthesized AgNPs (2–5 nm) using plant extracts of *Bryophyllum* sp., *Cyperus* sp. and *Hydrilla* sp.

Fish growth parameters

It was observed that there was no significant difference in the mean length, weight gain, and SGR of fish when treated with 100 and 200 mg/L of plant *Ceratophyllum* and *Hydrilla,* probably due to the short duration of the experiment under the wet lab conditions (**Figure 8A, B**).

Submerged macrophytes distributed in freshwater ecosystems are highly important for maintaining water quality as well as the ecological functions of such ecosystems. Eliasova *et al.* (2021) found that *Ceratophyllum demersum* is a good source of flavonoids/glycosides (Tricetin, Luteolin, Selgin, Apigenin, Tricin, and Chrysoeriol) with good antioxidant properties, which were induced by ammonium. Nitrogenous toxicants such as ammonia and nitrite removal from discharge water has been of concern. Gopal (2014) studied the removal efficiency of organic load and nutrients from sewage water and observed that the physicochemical properties such as turbidity, ammonia, phosphate, Chemical Oxygen Demand, and Biological Oxygen Demand showed a significant decrease in values due to bio-digestion of organic nutrients during phytoremediation. Foroughi *et al.* (2013) have demonstrated that the *Ceratophyllum demersum* reduced ammonium and nitrate by more than 62% and 41.66% from wastewater. Parnian *et al.* (2022) have successfully demonstrated that hydrophyte (*Ceratophyllum demersum* L.) has good potential for the phytoremediation of cadmium and nickel from a saline aquatic environment under controlled conditions. The potential of soft submerged aquatic macrophytes, including *Ceratophyllum demersum* as

Table 4. Concentration of K, Ca and Na in water samples treated with *Ceratophyllum demersum* and *Hydrilla verticillata*

Treatment	*Ceratophyllum demersum*			*Hydrilla verticillata*				
	Potassium (K^+)	Calcium (Ca^{2+})	Sodium (Na^+)	Potassium (K^+)	Calcium (Ca^{2+})	Sodium (Na^+)	Ag	Cu
0	10.20±0.15^c	26.4 ± 1.4^c	45 ± 0.90^a	10.2±0.15^c	26.4±1.44^b	45±0.90^a	--	--
40	11.27±0.16^c	30.5 ± 1.0^b	44.8±0.15^a	10.7±0.06^c	27±0.85^b	45.5±0.24^a	0	0.18
100	12.67±0.20^b	29.6 ± 0.4^b	45.8±0.52^a	11.3±0.25^b	30.9±0.54^a	44.3±0.57^a	0.01	0.73
200	14.60±0.70^a	34.9±0.55^a	46.2±0.16^a	11.9±0.13^a	32.6±1.50^a	44.9±0.51^a	0.03	1.43
P Value	<0.001	<0.001	0.259	<0.001	<0.001	0.58		

a feed ingredient for herbivorous/omnivorous fish, such as tilapia, has also been demonstrated (Balkhashera *et al.* 2021).

Beheary *et al.* (2019) recommended the application of *C. demersum* in tilapia farms for the phytoremediation of contaminants from aquaculture wastewater. Aquaculture wastes and sub-products need to be reutilized to achieve a more efficient production system based on the application of circular bio-economy and the One-Health concept, protecting human, animal health and the environment (Fraga-corral *et al.* 2022; Krishnani *et al.* 2021; 2022; 2023). Climate change-induced abiotic stresses are an inevitable event that obstructs the output of aquaculture farms (Patel *et al.* 2022) and culture-based fisheries in open waters (Abisha *et al.* 2022). Mitigating abiotic stresses using natural and modified stilbites, synergizing with changes in oxidative stress markers in aquaculture, has been successfully demonstrated by Arunkumar *et al.* (2023).

The study proposes a solution through plant-assisted bioremediation using aquatic weeds (*Ceratophyllum demersum* and *Hydrilla*). Local communities can be involved in harvesting and collecting aquatic weeds, creating direct livelihood opportunities. Thereafter, collection centres can be made where harvested weeds can be brought and processed. For value addition, the local communities can be trained in processing techniques, such as drying, grinding and pelletizing to develop harvested aquatic weeds into usable products. Alternatively, local entrepreneurs can develop bioremediation marketable products from the processed aquatic weeds, and the Government can assist local entrepreneurs in establishing marketing channels for their products. Later, the formation of community-based organizations/cooperatives/self-help groups focusing on aquatic weed bioremediation can be encouraged so that these organizations can collectively manage harvesting, processing, and marketing efforts, ensuring equitable distribution of benefits. By integrating these strategies, Dal-lake's aquatic weed bioremediation initiative can not only contribute to environmental restoration but also create sustainable livelihood opportunities for local communities, fostering economic growth and social well-being.

The DWR developed and demonstrated a sequential, multi-weed phytoremediation system using combinations of semi-aquatic, free-floating, and submerged weeds (e.g., *Arundo donax*, *Eichhornia crassipes* and *Hydrilla verticillata*) to treat wastewater effectively (Khankhane and Varshney 2011; Khankhane *et al.* 2014). The studies primarily focused on the removal of heavy metals, including iron (Fe), cadmium (Cd), manganese (Mn), nickel (Ni), and copper (Cu), from sewage and polluted pond water.

Conclusions

Present study is the first report of using non-living biomasses of the aquatic weeds *Ceratophyllum demersum* and *Hydrilla verticillata* of Dal-lake for uptake and removal of nitrogenous stressors (ammonia, nitrite) and metallic stressors - lead (II), and chromium (VI) : a solution through plant-assisted bioremediation from different types of aquaculture waters, including ponds, aquaponics and ornamental setups, which can be attributed to functional moieties for adsorption and cations for ion exchange present in the aquatic weeds. This has future potential applications in circular bioresource utilization of aquatic weeds for aquaculture applications, which will help treat wastewater generated from aquaculture and industrial discharges to protect aquatic life from adverse impacts. These aquatic plants play a major role in the environmental conditions of stagnant and flowing waters, and could adsorb elements and decrease pollution.

Research and development in the field of aquaculture bioremediation for exploring the potential of various aquatic plant species in removing pollutants from aquaculture waters is necessary. As a policy suggestion, it is recommended to establish a comprehensive water quality monitoring programme for aquaculture systems. Regular monitoring of parameters such as ammonia, nitrite and heavy metals is suggested as it will help in early detection of pollution issues and ensure timely corrective actions. Based on the positive results of this study, some of the policy recommendations suggested are incorporating plant-assisted bioremediation techniques using aquatic weeds. Government agencies and regulatory bodies can provide incentives and guidelines for implementing such practices to reduce the impact of toxicants on aquatic ecosystems. Capacity building of the aquaculture farmers and industry professionals on the benefits of plant-assisted bioremediation is required so that they can effectively integrate these techniques into their aquaculture operations. These are some policy recommendations that can enhance the aquaculture sector's sustainability, reduce pollution, and contribute to the overall health of aquatic ecosystems.

Dal-lake, it is known that the lake is besieged by obnoxious weeds. By encouraging public-private partnerships and collaborations between government agencies, research institutions and private aquaculture enterprises, the implementation of bioremediation technologies on a larger scale can be undertaken, which will help in the adoption of sustainable practices in the fisheries and aquaculture sector. For this, awareness campaigns within local communities to highlight the positive impact of using aquatic weeds for bioremediation and livelihood generation, along with advocacy for policy support and recognition of this innovative approach at the regional and national levels, are suggested.

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RESEARCH ARTICLE

Efficacy of adjuvant augmented glyphosate against purple nutsedge (*Cyperus* spp.) and its regrowth

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ABSTRACT

A field study was conducted in the *Vertisols* of South Gujarat to evaluate the efficacy of glyphosate-adjuvant combinations against a complex weed flora dominated by perennial sedges. The uniform pretreatment weed flora in the experimental area includes: *Cyperus rotundus*, *Echinochloa crus-galli* and *Trianthema portulacastrum*. Assessment revealed significant variation in mortality and regrowth of *Cyperus* spp. at 40 days after application (DAA). Glyphosate + ammonium sulphate (1.5 kg/ha + 2%) recorded complete mortality (100.0%) of *Cyperus* spp., and was statistically at par with glyphosate + 2,4-D (99.52%) and glyphosate + sugar (99.14%). Mechanical inter-culturing was ineffective as rhizome fragmentation triggered dormant bud release and caused a regrowth surge, while glyphosate + ammonium sulphate recorded minimum regrowth of *Cyperus* spp. Economic analysis at 40 DAA indicated glyphosate + ammonium sulphate and glyphosate + 2,4-D as the most viable strategies achieving the highest *Cyperus* control efficiency (>72%) with the lowest cost per percent control. The growth and yield parameters of the successively grown blackgram confirmed the lack of any significant residual effect from the applied herbicides. Thus, for the sustainable management of tuberous perennials, the adjuvant augmented glyphosate was found significantly more effective than traditional mechanical methods.

Keywords: Adjuvants, *Cyperus* spp., Glyphosate, Glyphosate + ammonium sulphate, Weed management

INTRODUCTION

Interference by weeds often results in substantial yield and economic losses (Rao 2022). Effective assessment of weed-induced losses is therefore essential for developing appropriate management strategies. Among perennial weeds, nutsedge (*Cyperus* spp.), particularly purple nutsedge (*Cyperus rotundus* L.) is recognized as one of the most problematic species worldwide (Benvenuti 2025). In India, it is widely distributed across cultivated lands up to 2000 m above mean sea level (Dev 2023.). Nutsedge infests numerous field and vegetable crops including rice, maize, cotton, sugarcane, onion, okra, cabbage, carrot and cucumber across tropical and subtropical regions (Dor and Hershenhorn 2013). The persistence and aggressiveness of *Cyperus* spp. are primarily attributed to vegetative reproduction through tubers and rhizomes, rather than seed propagation (Sharma and Gupta 2007; Lati *et al.* 2011). Purple nutsedge exhibits an exceptionally high multiplication rate with a single tuber capable of producing extensive daughter tubers within a short period leading to dense infestations (Dor and Hershenhorn 2013). Its C_4 photosynthetic pathway and positive response to nitrogen further enhance its competitive advantage in cropping systems (Lati *et al.* 2011).

Crop yield reductions due to nutsedge interference have been widely reported, reaching severe levels in several vegetable crops (Roozkhosh *et al.* 2025). Although cultural and mechanical practices such as tillage, solarization and shading can suppress nutsedge growth and their effectiveness are often limited by rapid vegetative regrowth (Benvenuti 2025). Consequently, chemical weed control has become an integral component of nutsedge management (Varanasi *et al.* 2025).

Glyphosate [*N*-(phosphonomethyl) glycine] is a non-selective, systemic, post-emergence herbicide extensively used for broad-spectrum weed control (Baylis 2000). It inhibits the shikimate pathway leading to disruption of aromatic amino acid biosynthesis and plant growth inhibition (Duke and Powles 2008). However, its performance against perennial weeds such as *Cyperus* spp. is influenced by environmental conditions, formulation type, spray solution characteristics and plant growth stage (McMullan 2000). Recent studies emphasize that the use of herbicide mixtures and suitable adjuvants can enhance glyphosate absorption, translocation, and

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overall efficacy, while allowing reduction in application rates (Miller *et al.* 2013; Mahajan and Chauhan 2015). Combinations involving herbicides with different modes of action such as glyphosate with 2,4-D or oxyfluorfen may provide synergistic effects, improved control of perennial sedges and economic advantages over single or sequential applications.

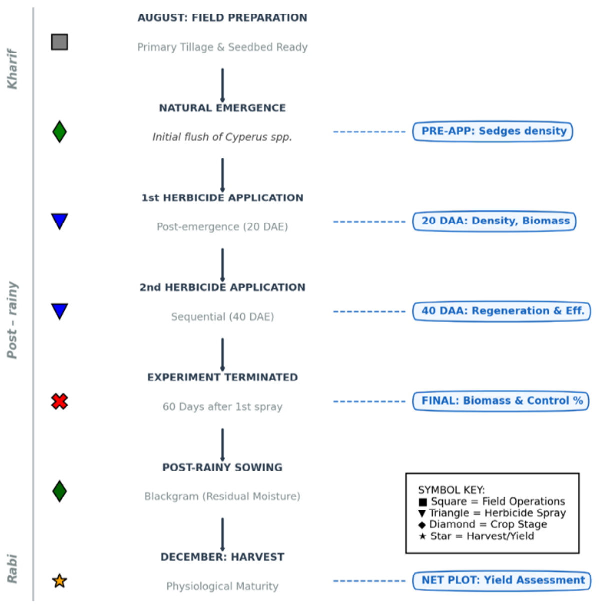
In view of the persistent nature of nutsedge and the need for cost-effective and efficient weed control strategies, the present study was undertaken to evaluate the synergistic potential of glyphosate- based herbicide combinations and additives for the management of nutsedge (*Cyperus* spp.) without any residual effect on crops grown in succession.

MATERIAL AND METHODS

Field trials were conducted during 2021–22 at Plot No. 11-A, College Farm, NAU, Bharuch (21.70° N, 72.99° E; 16.5 m AMSL) in the South Gujarat Agro-climatic Zone II. The study was carried out during the *Kharif* season to evaluate the efficacy of herbicides on *Cyperus* spp., and assess residual phytotoxicity of herbicides tested on blackgram sown in the rabi season as a bioassay. The experiment was conducted on fallow-cultivated land naturally, uniformly and heavily infested with *Cyperus* spp. for identifying cost effective and efficient control option. The tropical monsoon climate featuring a high thermal regime (max. 35.3°C) and morning relative humidity (94.1%) with 41 rainy days maintained a substantial vapor pressure deficit (evaporation 2.7–9.3 mm/day) that facilitated rapid subterranean tuber differentiation and shoot emergence. The edaphic situation was a clayey *Vertisol* characterized by high shrink-swell potential and moisture retention. Pre-experimental analysis (0–30 cm) revealed a sub-alkaline pH (7.8), non-saline EC (0.26 dS/m) and 0.45% OC. The fertility status was low in available N (242 kg/ha), medium in P, O… (36.1 kg/ha) and high in K, O (318 kg/ha) representing conditions highly conducive to the competitive vigour of the weed-crop association. The experimental field had been under a dill/soybean/sorghum cultivation during the previous three years followed by fallow periods. The predominantly nutsedge (*Cyperus* spp.) was associated with major weeds like *Digera arvensis*, *Commelina benghalensis*, *Echinochloa* spp. and *Trianthema portulacastrum*, in the experimental field.

The experiment was laid out in a randomized block design with three replications. Nine treatments were evaluated including: W_1: weedy check, W_2: inter culturing twice 20 and 40 days after seeding (DAS), W_3: glyphosate 41% SL (glyphosate) 2.0 kg/ha, W_4: glyphosate + ammonium sulphate 1.5 kg/ha + 2%, W_5: glyphosate + sugar 1.5 kg/ha + 2%, W_6: glyphosate + urea 1.5 kg/ha + 2%, W_7: glyphosate + kaolin 1.5 kg/ha + 1.5 kg/ha, W_8: glyphosate + 2,4-D amine 1.0 kg/ha + 1.0 kg/ha, W_9: glyphosate + oxyfluorfen 2.0 kg/ha. To ensure complete solubility and homogeneity, all adjuvants were dissolved separately in small aliquots of water prior to incorporation into the final spray mixture. The herbicidal were applied using a battery-operated knapsack sprayer fitted with a flat-fan nozzle. The equipment was calibrated to an operating pressure of 1.5–2.0 kg/cm² to deliver a constant spray volume of 375 L/ha, ensuring uniform droplet distribution and coverage on the target foliage. Required quantities of commercial formulations were calculated based on active ingredient (*a.i.*) concentration and gross plot area (12 m²).

Weed flora observations were recorded pre-spraying and at 20 and 40 days after herbicide application (DAA). Sedge density (no./m²) was determined using a 1.0 m² quadrat. Weed mortality (%) was computed based on the population of surviving plants relative to the initial stand. Regrowth count (no./plot) was monitored at 20 and 40 DAA to evaluate the longevity of suppression. *Cyperus* control efficiency (CCE, %) was calculated according to the formula suggested by Kondap and Upadhyay (1985).



Flowchart 1. Experimental timeline illustrating field preparation, herbicide applications against *Cyperus* spp. during the *Kharif* season and subsequent evaluation of residual effects on green gram grown in the *rabi* season

Experimental data were analysed using ANOVA for RBD (Panse and Sukhatme 1967). Weed density and regrowth counts were normalized using square root ($\sqrt{x+0.5}$) transformation and mortality percentages were arcsine ($\sin^{-1}\sqrt{x/100}$) transformed prior to analysis (Steel and Torrie 1960). Treatment means were compared using the F-test (P=0.05), with Least Significant Difference (LSD)and Duncan's Multiple Range Test (DMRT) utilized to separate significant means.

RESULTS AND DISCUSSION

Weed flora

A comprehensive floristic survey revealed a heterogeneous weed population comprising 15 species. Taxonomic distribution showed a dominance of *Amaranthaceae* and *Poaceae* among broad-leaved weeds and grasses, respectively. Among monocots, *Echinochloa crus-galli* and *Commelina benghalensis* were the major species, the latter possessing a dual seeding survival mechanism. The broad-leaved weeds were dominated by *Trianthema portulacastrum* and *Digera arvensis,* both exhibiting high ecological amplitude and succulent growth habits. The sedge complex was uniquely diverse featuring the perennial *Cyperus rotundus* alongside annual species like *C. iria*. The persistence of *C. rotundus* linked to its underground tuber/rhizome chain, which serves as a primary perennating organ (Rathod *et al.* 2025). The existence of fast growing C_4 grasses prostrate succulents and tuberous perennials created a high intensity competitive situation characterized by rapid occupation and significant resource depletion potential (Grime 2001).

Prior to treatment, sedges (*Cyperus* spp.) dominated the weed flora with a relative density of 41.87% followed by BLWs (35.87%) and grasses (22.26%). This hierarchy in the heavy *Vertisols* of South Gujarat reflects the adaptive plasticity of the *Cyperaceae* complex as edaphic factors favour sedges over annual grasses (Mishra *et al.* 2021). The initial weed density recorded prior to the application of treatments at 20 days showed a uniform distribution across the experimental site with no significant differences observed among the various plots (W_1 to W_9). The resilience of *Cyperus* spp. stems from a "basal bulb-rhizome-tuber" network acting as a carbohydrate sink for rapid colonization (Peerzada *et al.* 2017) alongside a C_4 pathway that optimizes resource acquisition (Biruk *et al.* 2025). Lower grass abundance suggests competitive exclusion by these prostrate dicots and perennial sedges (Vila *et al.* 2011). Well managing this population requires translocation intensive herbicides like glyphosate with adjuvants to disrupt tuber apical dominance (Chauhan *et al.* 2017, Singh *et al.* 2025).

Pre-treatment weed density did not differ significantly confirming uniform weed pressure and ensuring that observed differences in weed control and performance were due to treatment effects rather than field variability (Das and Gupta 2021). Such lack of statistical significance indicates a uniform weed seed bank, a phenomenon typically observed in high density field evaluations. The stability of the weed community structure suggests that the soil seed bank was well distributed, and initial flushes were unaffected by short term management variables (Shamina *et al.* 2022). Consequently, this uniformity provides a robust baseline for evaluating the direct effects of treatments on crop-weed competitive interactions and long-term weed flora shifts (Cordeau *et al.* 2022).

Impact of treatments on *Cyperus* density

The effect of herbicides and adjuvants on *Cyperus* density showed significant changes among treatments at 20 and 40 days after application, while initial *Cyperus* counts were uniform and not significant **(Figure 1)** indicating uniform invasion across plots and providing a reliable baseline for evaluating treatments. At 20 days after application, the weedy check had the highest *Cyperus* density significantly higher than all other treatments. Inter-culturing reduced weed density moderately and was significantly better than the weedy check but less effective than herbicides. Glyphosate alone provided moderate suppression and was statistically at par with glyphosate + urea, glyphosate + kaolin and glyphosate + oxyfluorfen. Glyphosate + sugar and glyphosate + ammonium sulphate were most effective and found significantly superior to all other treatments. Glyphosate + 2,4-D also provided strong suppression and was statistically at par with glyphosate + sugar and glyphosate + ammonium sulphate (Singh *et al.* 2025).

By 40 days after application, weedy check continued the highest *Cyperus* density, significantly exceeding all other treatments and confirming weed persistence without intervention. While inter-culturing offered moderate reduction over the control, its efficacy was statistically comparable to glyphosate alone or combined with kaolin or oxyfluorfen, highlighting the limited long-term impact of mechanical methods. In contrast, glyphosate + sugar and glyphosate + ammonium sulphate remained the most effective treatments, significantly hiding others while remaining at par with the glyphosate + 2,4-D application. Meanwhile, glyphosate combinations with urea, kaolin or oxyfluorfen provided only intermediate control showing no significant improvement over glyphosate applied alone.

The superior performance of glyphosate + sugar and glyphosate + ammonium sulphate is attributed to improved herbicide absorption and translocation. Sugar based adjuvants enhance retention on leaf surfaces and facilitate uptake, while ammonium sulphate reduces antagonistic effects of water hardness ions, improving glyphosate performance (Travlos *et al.* 2017, Basílio *et al.* 2024). Moderate adjuvants such as urea, kaolin, 2,4-D and oxyfluorfen provide partial enhancement through improved uptake or mechanical/oxidative stress, but their effect is less sustained over time (Idziak *et al.* 2023, Patel *et al.* 2023). Mechanical control methods, including weeding and inter-culturing were less effective in both short- and long-term suppression highlighting the limitations of cultural practices alone. Statistical validation at 20 and 40 DAA confirms that adjuvant assisted glyphosate applications are significantly more effective than mechanical control or glyphosate alone emphasizing the importance of integrated chemical-adjuvant strategies for sustainable *Cyperus* management (Chaudhari *et al.* 2024).

Mortality and regrowth of *Cyperus* spp.

Cyperus spp. management **(Table 1)** showed rapid chlorosis and necrosis within 7 days reaching total desiccation by 3-4 weeks. At 20 DAA, mortality was significantly highest in the glyphosate + 2,4-D treatment (89.68%), beating standalone glyphosate. This rapid kill is attributed to complementary modes of action; while glyphosate inhibits the EPSPS pathway, 2,4-D acts as a systemic auxin inducing vascular tissue collapse. This hormonal disruption significantly "primes" the plant, increasing metabolic sink activity and potentially accelerating the translocation of glyphosate into subterranean tuber chains (Larini *et al.* 2025). By 40 DAA, glyphosate + ammonium sulphate achieved significant superiority with complete (100.0%) mortality. However, it was statistically at par with glyphosate + 2,4-D (99.52%) and glyphosate + sugar (99.14%) forming a high efficacy cluster. This highlights the role of AS and humectants in mitigating antagonistic cations and acidifying the leaf surface to enhance cuticular flux (Daramola *et al.* 2022, Zangoueinejad *et al.* 2022).

Regrowth dynamics further confirmed the significant superiority of chemical suppression over mechanical intervention. Inter-culturing (twice) failed significantly resulting in a surge of regrowth (397.3 individuals/plot) by 40 DAA that was significantly higher than even the weedy check (24.0 individuals/ plot). This counterproductive response confirms that mechanical tillage fragments rhizome chains and breaks apical dominance. In the absence of systemic herbicides, physical disturbance significantly

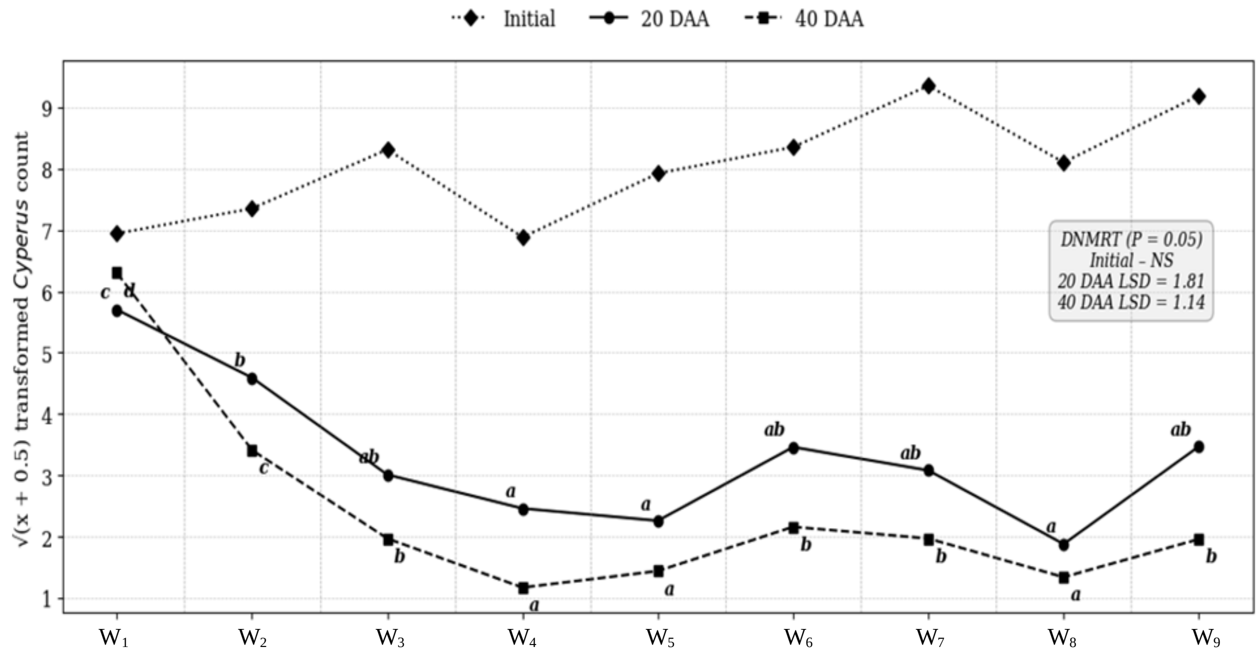


Figure 1. Effect of weed management on *Cyperus* spp. counts at Initial, 20 and 40 days after application.

(Values at 20 and 40 DAA were compared using Duncan's multiple range test (p=0.05); initial counts were not significant. Least significant difference (LSD) at 20 DAA = 1.81 and 40 DAA = 1.14. Different letters indicate significant differences between treatments]. (W_1: weedy (control; no weed management); W_2: inter-culturing (20 and 40 DAS); W_3: glyphosate 2.0 kg/ha; W_4: glyphosate 1.5 kg/ha + ammonium sulphate 2%; W_5: glyphosate 1.5 kg/ha + sugar 2%; W_6: glyphosate 1.5 kg/ha + urea 2%; W_7: glyphosate 1.5 kg/ha + kaolin 1.5 kg/ha; W_8: glyphosate 1.0 kg/ha + 2,4-D amine 1.0 kg/ha; W_9: 2.0 kg/ha + oxyfluorfen.

stimulates dormant secondary buds to sprout (Peerzada 2017). Conversely, chemical treatments achieved a significant residual suppression (>93%) of the tuber bank. The minimum regrowth (9.0 individuals/plot) observed in glyphosate + ammonium sulphate was statistically comparable to the glyphosate + 2,4-D and glyphosate + sugar treatments highlighting that biochemical exhaustion of reproductive organs is a significantly more sustainable strategy than physical disturbance (Palma *et al.* 2020, Chaudhari *et al.* 2024). These findings advocate for an integrated approach prioritizing glyphosate augmented with systemic partners or nitrogenous adjuvants for long-term sedge control.

Economic viability of *Cyprus* control efficacy

All glyphosate-based treatments differed significantly **(Figure 2)** in cost per percent control and *Cyperus* control efficiency. Application of glyphosate + ammonium sulphate and glyphosate + 2,4-D combined low cost (ranks I–II) with the highest *Cyprus* control efficacy (72.09 and 72.53%), whereas Inter-culturing and glyphosate + oxyfluorfen were costly with the lower CCE (46.61 and 62.13%). Intermediate treatments such as glyphosate + sugar, glyphosate + kaolin, and glyphosate alone showed moderate cost and *Cyprus* control efficacy. The higher cost in some treatments is primarily due to the use of more expensive adjuvants or combined chemicals and lower efficacy per unit cost, which

Table 1. Effect of glyphosate-adjuvant on mortality and regrowth of *Cyperus* spp.

Treatment	Dose (kg/ha)	Mortality (%)		Regrowth (no./plot)	
		20 DAA*	40 DAA*	20 DAA*	40 DAA*
Weedy check (control)	—	—	—	3.46 (11.67)	4.93 (24.00)
Inter-culturing (twice)	—	—	—	15.78 (249.7)	19.80 (397.3)
Glyphosate	2.0	69.33 (87.02)	82.97 (97.77)	3.36 (15.33)	4.41 (21.33)
Glyphosate + ammonium sulphate	1.5 + 2%	62.27 (77.99)	90.00 (100.0)	2.34 (5.33)	3.04 (9.00)
Glyphosate + sugar	1.5 + 2%	66.91 (83.96)	86.92 (99.14)	2.67 (6.67)	3.71 (13.67)
Glyphosate + urea	1.5 + 2%	68.43 (86.25)	80.81 (97.38)	3.06 (9.00)	3.98 (15.67)
Glyphosate + kaolin	1.5 + 1.5	70.97 (88.85)	83.57 (98.39)	3.94 (17.00)	4.68 (23.33)
Glyphosate + 2,4-D	1.0 + 1.0	73.12 (89.68)	87.70 (99.52)	3.18 (11.00)	4.17 (17.33)
Glyphosate + oxyfluorfen (ready-mix)	2.0	59.52 (72.57)	85.72 (98.64)	3.97 (17.33)	4.90 (26.00)
LSD (p=0.05)	--	12.91	7.21	2.44	2.42

Note: The treatment abbreviations used are DAA-Days after application. Figures in parentheses represent original values, while those outsides are transformed: square root ($\sqrt{x+0.5}$) for regrowth and arcsine ($\sin^{-1}\sqrt{x}$) for mortality.

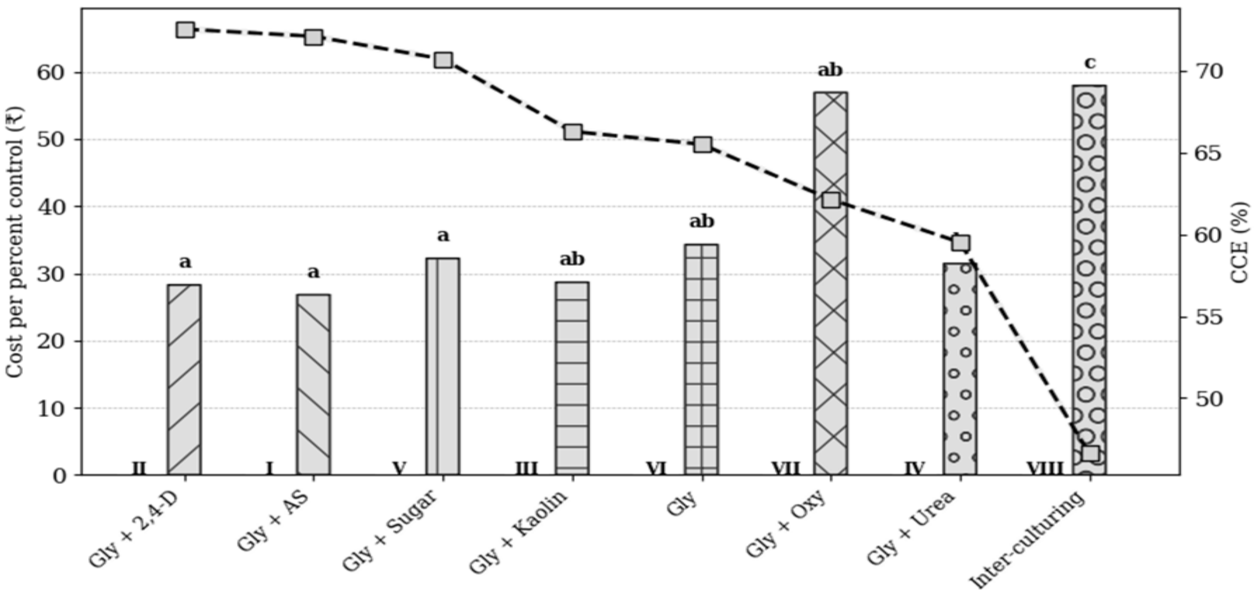


Figure 2. Impact of glyphosate-adjuvant on cost per percent control and *Cyperus* control efficiency

[Bars indicate cost per percent control with DNMRT letters above showing significant differences ($p < 0.05$). Cost rank (I–VIII) is shown to the left of each bar, where I = lowest cost]. Inter-culturing = 20 and 40 DAS; Gly = glyphosate 2.0 kg/ha; Gly + AS = glyphosate 1.5 kg/ha + ammonium sulphate 2%; Gly + Sugar = glyphosate 1.5 kg/ha + sugar 2%; Gly + Urea = glyphosate 1.5 kg/ha + urea 2%; Gly + Kaolin = glyphosate 1.5 kg/ha + kaolin 1.5 kg/ha; Gly + 2,4-D = glyphosate 1.0 kg/ha + 2,4-D amine 1.0 kg/ha; Gly + Oxy = glyphosate + oxyfluorfen (ready-mix) 2.0 kg/ha.

Table 2. The residual effect of herbicides on growth parameters of succeeding blackgram (Bioassay)

Treatment*	Plant stand (per m²)	Plant height (cm)	Branches/ plant (no.)	Pods/ plant (no.)	Yield (g/plot)	
					Seed	Stover
Weedy check (control)	31.33	50.13	9.00	33.61	564	804
Inter-culturing twice at 20 and 40 DAS	31.33	51.47	9.73	33.79	565	863
Glyphosate 2.0 kg/ha at 20 DAS	31.33	53.13	9.33	35.60	581	863
Glyphosate 1.5 kg/ha + ammonium Sulphate 2% at 20 DAS	32.33	51.20	927	32.74	592	874
Glyphosate 1.5 kg/ha + sugar 2% at 20 DAS	31.33	53.80	9.67	32.40	571	878
Glyphosate 1.5 kg/ha + urea 2% at 20 DAS	32.67	51.93	9.67	34.20	591	859
Glyphosate 1.5 kg/ha + kaolin 1.5 kg/ha at 20 DAS	32.00	52.53	9.60	36.65	590	818
Glyphosate 1.0 kg/ha + 2,4-D amine salt 1.0 kg/ha (tank-mix) at 20 DAS	31.00	58.73	10.20	35.93	589	873
Glyphosate + oxyfluorfen (ready-mix) 2.0 kg/ha at 20 DAS	32.16	52.20	9.93	33.67	590	815
LSD (p=0.05)	NS	NS	NS	NS	NS	NS

*DAS = days after seeding

requires higher doses or repeated applications to achieve comparable control. Conversely, lower-cost treatments achieved high efficiency due to synergistic effects of adjuvants improving glyphosate uptake and weed control, reducing the amount of chemical needed. These results indicate that combining economic analysis with physiological assessment effectively identifies cost-effective and agronomically efficient weed management strategies (Heap 2021, Barbieri *et al.* 2022).

Carryover effect of herbicides on blackgram

The data (**Table 2)** revealed that herbicide carryover treatments had no significant effect on growth, development, and yield of blackgram, as all parameters were statistically non-significant. Uniform plant population indicated unaffected crop establishment, while plant height, branches per plant, and pods per plant showed no measurable variation. Seed and stover yields remained at par across treatments, confirming the absence of any measurable residual effect of the applied herbicides. These results suggest that under the experimental conditions, the residual activity of the tested herbicides did not interfere with physiological processes governing blackgram growth and productivity.

Blackgram yield was unaffected by sowing after six weeks of glyphosate application, indicating negligible residual effects, consistent with rapid microbial degradation and soil adsorption limiting carryover (Hernandez Guijarro *et al.* 2018, Robayo *et al.* 2024). Glyphosate residues are therefore unlikely to persist at levels that affect succeeding crop growth and yield (Zhan *et al.* 2018, Hernandez Guijarro *et al.* 2018).

Glyphosate combined with ammonium sulphate (AS), sugar, or 2,4-D effectively controlled *Cyperus* spp., achieving >99% mortality and minimal regrowth by 40 days. Mechanical methods were less effective and often stimulated rhizome sprouting. Adjuvant-combined glyphosate applications enhanced its uptake and translocation, offering a sustainable and cost-efficient management of dense population of perennial sedges.

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RESEARCH NOTE

Non-chemical weed management options for enhancing transplanted rice productivity and profitability

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ABSTRACT

A field experiment was conducted during *Navarai* season (Jan–April 2024) at Annamalai University to evaluate the efficacy and identify non-chemical weed management options for enhancing the productivity of transplanted rice (*Oryza sativa* L.). The experiment was laid out in a Randomized Block Design (RBD) with twelve treatments and three replications. The tested treatments include: hand weeding; cono-weeding; and incorporation of: rice residues (straw, husk, husk ash, bran), *Azolla*, and tree leaves (neem, pongamia, mango, sapota) in different combinations. Hand weeding twice at 15 and 35 days after transplanting (DAT) recorded the higher weed control efficiency (87.86%) and highest rice grain yield. *Azolla* 250 kg/ha applied 3 DAT followed by cono-weeding on 35 DAT was on par with hand weeding twice, in recording higher gross return, net return and B: C ratio.

Keywords: *Azolla*, Non-chemical weed management, Rice residues, Weed control efficiency

India ranks first in area (43.9 million ha), second in production (150 million tons) with a productivity of 4.38 t/ha (USDA 2025). The relentless proliferation of weeds presents a formidable challenge to rice cultivation, frequently leading to considerable reductions in rice yield and necessitating the adoption of efficacious management strategies (Rao and Chandrasena 2024). This pervasive agricultural issue significantly impacts global food security, especially given that rice serves as a staple for more than half of the world's population (Camacho *et al*. 2024). Conventional weed control methods, predominantly relying on herbicides, have raised environmental and health concerns, prompting an urgent need for sustainable and non-chemical alternatives (Rao and Chandrasena 2024). This imperative for eco-friendly practices has spurred extensive research into alternative weed management approaches, emphasizing integrated strategies that minimize ecological footprints while maintaining agricultural productivity (Rao and Korres 2024). Furthermore, the escalating cost of synthetic herbicides, coupled with the development of herbicide-resistant weed biotypes, accentuates the necessity for viable non-chemical interventions (Abhinandan *et al*. 2020). Consequently, exploring and optimizing non-chemical weed management strategies, such as mechanical weeding, mulching, and the application of allelopathic plant materials, becomes critical for augmenting rice productivity in an environmentally sustainable manner (Singh and Singh 2023). This study was specifically aimed at assessing the efficacy of a range of non-chemical weed management options, including manual weeding, cono-weeding, and various organic amendments like rice straw, rice husk, Azolla, and different leaves mulches, and identify best option for managing weeds and consequently improving transplanted rice productivity.

A field study was conducted during the *Navarai* season of 2024 (Jan to April 2024) in Department of Agronomy, Annamalai University, Chidambaram, Tamil Nadu. The experimental soil was characterized by low organic carbon (0.47%), low in available nitrogen (230 kg/ha), medium in available phosphorus (17.85 kg/ha) and high in available potassium (353 kg/ha). The rice variety ADT 43 was used in the field trial.

The experiment was laid out in a randomized block design (RBD) with three replications. The weed management treatments tested include: unweeded control, hand weeding on 15 and 35 days after transplanting (DAT), cono-weeding on 15 and 35 DAT, application of rice straw as organic mulch (rice straw) at 2 t/ha on 3 DAT followed by (*fb*) cono-weeding on 35 DAT, application of rice husk as

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organic mulch (rice husk) at 2 t/ha on 3 DAT *fb* cono-weeding on 35 DAT, application of rice husk ash as organic mulch (rice husk ash) at 2 t/ha on 3 DAT *fb* cono-weeding on 35 DAT, application of rice bran as organic mulch (rice bran) at 2 t/ha on 3 DAT *fb* cono-weeding on 35 DAT, application of *Azolla* at 250 kg/ha on 3 DAT *fb* cono-weeding on 35 DAT, application of neem leaves as organic mulch (neem leaves) at 3 t/ha on 3 DAT *fb* cono-weeding on 35 DAT, application of *Pongamia* leaves as organic mulch (*Pongamia* leaves) at 3 t/ha on 3 DAT *fb* cono-weeding on 35 DAT, application of mango leaves as organic mulch (mango leaves) at 3 t/ha on 3 DAT *fb* cono-weeding on 35 DAT, application of sapota leaves as organic mulch (sapota leaves) at 3 t/ha on 3 DAT *fb* cono-weeding on 35 DAT. Organic mulches (rice straw, rice husk, rice husk ash, rice bran, neem leaves, pongamia leaves, mango leaves, and sapota leaves) were air-dried, chopped into small pieces (5–7 cm) where applicable, and uniformly broadcast on the soil surface between rice rows at 3 DAT under shallow standing water conditions (2–3 cm). Organic mulch rates of 2–3 t/ha were used to ensure uniform coverage without affecting rice seedling establishment.

The field was thoroughly puddled and evenly levelled using a wooden plank. Rice seedlings were grown separately in a nursery. Twenty-one-day old rice seedlings were transplanted at a spacing of 20 × 10 cm. Data on weed density and dry weight (biomass) were recorded at 30 and 60 DAT using four quadrats of size 0.5 x 0.5 m and the weed control efficiency (WCE) and weed index were calculated using standard procedure (Saravanane 2020). The existing market prices of rice (₹21/kg) and straw (₹1/kg) were considered, to workout economics returns. Data on weed density and biomass were transformed with square root transformation $\sqrt{(x+0.5)}$) before analysis. The relationship between grain yield and weed biomass at harvest was evaluated through linear regression analysis. The data were analysed statistically following the standard procedures outlined by Panse and Sukhatme (1967).

Effect on weeds

Weed flora of the experimental field during the cropping period primarily comprised of grasses, sedges and broad-leaved weeds. The major weeds in the experimental plots were: *Echinochola colonum, Echinochola crus-galli* and *Leptochloa chinensis* amongst grasses, *Cyperus iria, Cyperu difformis, Cyperus rotundus, Fimbristylis littoralis* amongst sedges and *Eclipta alba*, *Bergia capensis* and *Sphenoclea zeylanica* amongst broad-leaved weeds. The sedges dominated the experimental field followed by grasses as observed earlier by Vikram *et al.* (2023) in the *Navarai* season.

All the weed control treatments significantly influenced the weed flora at 30 and 60 DAT (**Table 1**). The lowest weed density, biomass and highest WCE were recorded with hand weeding on 15 and 35 DAT, which was on par with *Azolla* 250 kg/ha on 3 DAT followed by (*fb*) cono-weeding on 35 DAT, as the rapid proliferation of Azolla, forming a thick mat over the water surface that blocks sunlight and suppresses the germination of photosensitive weeds, and subsequent cono-weeding at 35 DAT simultaneously improved soil aeration and weed control, thereby enhancing root growth and nutrient uptake in rice, falling in line with the earlier findings (Gnanasoundari and Somasundaram 2014, Pazhanisamy *et al.* 2020). The highest weed density and lowest WCE were recorded in unweeded control.

Azolla 250 kg/ha on 3 DAT *fb* cono-weeding on 35 DAT recorded the lowest weed index (1.21%), followed by cono-weeding on 15 and 35 DAT with 5.21%, and rice bran at 2 t/ha on 3 DAT *fb* cono-weeding on 35 DAT with 9.16% (**Table 1**), confirming findings of Fernando and Alawathugoda (2024) with *Azolla pinnata*.

Effect on transplanted rice growth and yield

Among different treatments, hand weeding twice at 15 and 35 DAT being on par with *Azolla* at 250 kg/ha on 3 DAT *fb* cono-weeding on 35 DAT recorded significantly higher, *viz.* transplanted rice plant height and dry matter production, number of productive tillers, filled grains and grain yield (**Table 2**). Rathod and Somasundaram (2017) and Bhargavi *et al.* (2023) noted that effective weed management practices directly improve crop growth and biomass production in transplanted rice by reducing weed interference. Effective weed control at the earlier stages of crop growth due to better suppression of weeds by the wide coverage of the field with *Azolla* and the late emerging weeds during the critical stage of crop growth by cono weeding jointly resulted in better weed control, thus finally resulting in better crop growth and yield (Pandey *et al.* 2008 and Marzouk *et al.* 2023). A negative linear relationship between grain yield of transplanted rice and weed biomass at the critical growth stage (**Figure 1**) was observed confirming findings of Pooja and Saravanane (2021).

Table 1. Effect of different non-chemical weed management treatments on total weed density, total weed biomass, weed control efficiency (WCE) and weed index in transplanted rice

Treatment	Total weed density (no./m^2)		Total weed biomass (g/m^2)		WCE (%)		Weed index
	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT	
Unweeded control	10.75 (115.00)	11.75 (137.67)	12.43 (154.09)	13.80 (189.98)	0.00	0.00	58.98
Hand weeding twice on 15 and 35 DAT	4.25 (17.67)	5.61 (31.00)	4.34 (18.60)	5.97 (35.19)	87.86	81.44	0.00
Cono-weeding on 15 and 35 DAT	5.11 (25.67)	6.10 (36.67)	5.31 (27.74)	6.50 (41.73)	81.95	77.99	5.21
Mulching with rice straw at 2 t/ha on 3 DAT followed by (*fb*) cono-weeding on 35 DAT	6.33 (39.67)	7.45 (55.00)	6.96 (48.00)	8.20 (66.72)	68.80	64.85	18.28
Mulching with rice husk at 2 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	6.72 (44.67)	7.69 (58.67)	7.39 (54.18)	8.59 (73.33)	64.85	61.41	21.99
Mulching with rice husk ash at 2 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	7.52 (56.00)	8.44 (70.67)	8.53 (72.24)	9.65 (92.57)	53.12	51.17	36.40
Mulching with rice bran at 2 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	5.72 (32.33)	6.76 (45.33)	6.13 (37.27)	7.23 (51.95)	75.73	72.73	9.16
Azolla 250 kg/ha on 3 DAT *fb* cono-weeding on 35 DAT	4.59 (20.67)	5.79 (33.00)	4.54 (20.27)	6.15 (37.29)	86.79	80.31	1.21
Mulching with neem leaves at 3 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	7.08 (49.67)	8.03 (64.00)	7.87 (61.56)	9.08 (81.92)	60.03	56.83	27.41
Mulching with *Pongamia* leaves at 3 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	7.33 (53.33)	8.26 (67.67)	8.31 (68.62)	9.37 (87.29)	55.42	53.98	31.00
Mulching with mango leaves at 3 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	5.87 (34.33)	7.08 (49.67)	6.37 (40.12)	7.62 (57.61)	73.92	69.59	12.61
Mulching with sapota leaves at 3 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	7.58 (57.00)	8.57 (73.00)	8.68 (75.04)	9.84 (96.36)	51.23	49.17	39.34
LSD (p=0.05)	0.46	0.32	0.49	0.35	-	-	-

DAT: Days after transplanting, Values in parenthesis are original and outside are transformed $\sqrt{(x + 0.5)}$)

Table 2. Effect of different non-chemical weed management practices on transplanted rice growth, yield parameters, yield and economics of transplanted rice

Treatment	Plant height (cm)	DMP (t/ha)	Productive tiller/m^2	No. of filled grains/ panicle	Grain yield (t/ha)	Total cost of cultivation (x10^3 ₹/ha)	Gross income (x10^3 ₹/ha)	Net income (x10^3 ₹/ha)	B:C
Unweeded control	74.13	6.83	185.2	94.14	2.57	49.36	58.86	9.50	1.19
Hand weeding twice on 15 and 35 DAT	103.87	11.73	347.2	113.29	6.28	65.20	140.35	75.14	2.15
Cono-weeding on 15 and 35 DAT	96.11	10.96	318.2	109.84	5.95	58.24	133.20	74.96	2.29
Mulching with rice straw at 2 t/ha on 3 DAT followed by (*fb*) cono-weeding on 35 DAT	83.83	9.61	271.6	104.69	5.13	55.50	114.98	59.48	2.07
Mulching with rice husk at 2 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	82.93	9.07	264.3	104.22	4.90	55.50	109.91	54.40	1.98
Mulching with rice husk ash at 2 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	74.97	7.26	201.8	98.35	3.99	55.50	90.24	34.73	1.63
Mulching with rice bran at 2 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	89.80	10.37	298.4	108.82	5.70	63.50	127.68	64.17	2.01
Azolla 250 kg/ha on 3 DAT *fb* cono-weeding on 35 DAT	99.73	11.46	330.4	115.10	6.20	59.75	138.65	78.89	2.32
Mulching with neem leaves at 3 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	77.37	8.44	231.4	102.43	4.56	53.50	102.32	48.82	1.91
Mulching with *Pongamia* leaves at 3 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	76.00	7.73	228.1	101.12	4.33	53.50	97.47	43.96	1.82
Mulching with mango leaves at 3 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	88.47	9.99	294.7	107.68	5.49	53.50	122.66	69.15	2.29
Mulching with sapota leaves at 3 t/ha on 3 DAT *fb* cono-weeding on 35 DAT	74.53	6.94	197.8	96.52	3.81	53.50	86.33	32.82	1.61
LSD (p=0.05)	6.18	0.51	16.73	4.03	0.25	-	-	-	-

DAT: Days after transplanting

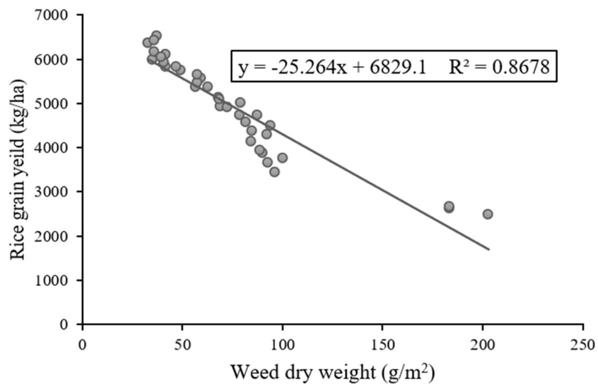

Figure 1. The relationship between transplanted rice grain yield and total weed biomass at harvest

Economics

The highest gross return, net return and B:C ratio was recorded with *Azolla* 250 kg/ha on 3 DAT *fb* cono-weeding on 35 DAT. The cono-weeding on 15 and 35 DAT recorded next highest net returns and B:C ratio which was higher than that recorded with hand weeding on 15 and 35 DAT as labour usage in hand weeding increased the cost of cultivation and reduced the returns. The lowest transplanted rice grain yield resulted in least gross return, net returns and B: C ratio in unweeded control confirming findings of Yadav *et al.* (2023).

Conclusion

Effective and economical weed management in transplanted rice can be achieved with application of *Azolla* at 250 kg/ha on 3 DAT followed by cono-weeding on 35 DAT as it recorded rice grain yield comparable to hand weeding twice at 15 and 35 DAT, with higher economic returns, especially in regions facing labour scarcity.

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RESEARCH NOTE

Farmer perception and on-farm assessment of pretilachlor + florpyrauxifen-benzyl efficacy in managing weeds in direct wet-seeded rice

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ABSTRACT

Weed infestation is a major constraint in direct wet-seeded rice (*Oryza sativa* L.) (WSR), particularly during the early stage of rice growth. The present study was undertaken to understand the farmer perception and assess the on-farm efficacy of early post-emergence herbicide application (EPoE) of pretilachlor + florpyrauxifen-benzyl to manage early season weeds in direct wet-seeded rice. The study was conducted during the *Kharif* season of 2023 in farmers' fields in Alappuzha and Kottayam districts, Kerala, India. A survey of 110 farmers and 60 dealers was carried out using a structured questionnaire to evaluate the awareness, adoption, satisfaction and market perception on weed management in WSR, by index-based analysis. The dominant weed flora in the study area was: grasses, *Echinochloa colona* (L.) Link and *Echinochloa crus-galli* (L.) P. Beauv.; sedge, *Cyperus difformis* L., and broad-leaved weed, *Monochoria vaginalis* (Burm. f.) C. Presl.. The pretilachlor + florpyrauxifen-benzyl 620+20/ha (pre-mix) applied at 8–10 days after sowing (DAS), when weeds at the 2–3 leaf stage, was observed to provide effective early season control of dominant grass weeds and moderate control of sedges and broad-leaved weeds. Survey results indicated moderate awareness and adoption levels of improved weed management options among farmers, largely influenced by labour scarcity and the need for timely weed control in WSR. Dealer perception reflected increasing interest in pre-emergence weed management options, emphasizing the need for their field demonstrations and technical guidance. The study concludes that pretilachlor + florpyrauxifen-benzyl EPoE can play a significant role in managing early emerging weeds in WSR and improved extension support is essential to enhance farmer adoption of improved weed management options under Kerala conditions.

Keywords: Adoption Index, Direct wet-seeded, Farmer Perception, Pretilachlor + florpyrauxifen-benzyl, Herbicide, Weed Flora, Weed management

Direct-seeded rice (*Oryza sativa* L.) is gaining importance in India due to labour scarcity, rising cultivation costs and the need for timely crop establishment (Yaduraj *et al.* 2021). However, weed infestation remains a major constraint in direct-seeded rice systems, particularly during early crop growth stages when the crop is highly vulnerable to competition (Rao *et al.* 2017, Yaduraj *et al.* 2021, Shekhawat *et al.* 2022). The absence of standing water during establishment favours the emergence of diverse weed flora, including grass weeds, sedges and broad-leaved weeds, leading to significant yield losses if not managed effectively (Rao *et al.* 2007).

Early season weed control is critical for the successful adoption of direct-seeded rice (Dass *et al.* 2017). Pre-emergence herbicides are widely recommended for suppressing weeds during the initial stages of crop establishment and reducing dependence on manual weeding, which is often constrained by labour unavailability. Several pre-emergence herbicides have been reported to be effective against dominant weed species in rice ecosystems; however, their performance and acceptance vary across regions due to differences in weed flora, cropping practices and farmer awareness.

In Kerala, the information on the field-level performance of early post-emergence herbicide application in direct wet-seeded rice and farmer perception on it is limited. Most of the emphasis was on experimental evaluations at research stations, while evidence from farmer fields and perception-based assessments remains scarce. This gap restricts the identification of location-specific weed management options and their adoption strategies. Thus, a study was undertaken to generate region-specific insights that can support improved weed management and promote informed adoption of early post-emergence herbicide in direct-seeded rice systems.

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The objective of this on-farm study in farmers' fields was to understand farmers' perception and assess field-level performance of pretilachlor + florpyrauxifen-benzyl EPoE for early-season weed management in direct wet-seeded rice in Kerala.

The study was conducted during the kharif season from June to October 2025 in two major rice-growing districts of Kerala, namely Alappuzha and Kottayam. A total of 110 WSR farmers were selected from the two districts (52 from Alappuzha and 58 from Kottayam) based on their willingness to participate in the study. In addition, 60 agricultural input dealers operating in the study area were surveyed during the same period, from June to October 2025, to assess market-level perceptions.

The assessment focused on the on-farm performance of early post-emergence application of Pretilachlor + florpyrauxifen-benzyl (pre-mix), which was approved for weed management in WSR. The herbicide was applied by 110 participating direct-seeded rice farmers at the label-recommended dose of 620+20/ha (pre-mix) within 8–10 days after sowing in their respective fields across selected villages of Alappuzha and Kottayam districts of Kerala. The on-farm performance assessment was based on field observations from these 110 farmer fields. Observations were made during early crop establishment to identify dominant weed flora and to assess perceived weed suppression.

Field observations were carried out using a structured visual assessment method in the direct wet-seeded rice fields of participating farmers. Each field was visited during the early crop establishment stage (within 20–30 days after sowing). Weed species present were identified visually, and dominant weeds were recorded based on their frequency of occurrence across fields. Weed flora were grouped into grasses, sedges, and broad-leaved weeds.

Frequency of occurrence of weed species was determined based on their presence across the observed farmer fields. For each weed species, the number of fields in which the species was observed during early crop establishment (20–30 days after sowing) was recorded. Frequency of occurrence was expressed qualitatively as high, moderate, or low based on the proportion of fields in which the weed species occurred. Weed species present in more than 50% of the observed fields were classified as having high frequency of occurrence, those present in 25–50% of fields were classified as moderate, and those occurring in less than 25% of fields were classified as low.

The efficacy of the early post-emergence herbicide was assessed qualitatively through visual estimation of weed suppression in comparison with untreated patches or adjacent fields managed under farmers' usual practices. Weed control effectiveness was categorized as good, moderate, or low based on the overall reduction in weed density and vigour observed during field visits.

Dominant grass weeds, sedges and broad-leaved weeds were identified based on their frequency of occurrence. Perceived weed suppression was categorized qualitatively based on visual assessment during the early growth stages of the crop as: good (>70% weed suppression), moderate (40–70% weed suppression), and low (<40% weed suppression), relative to untreated or conventionally managed fields.

A structured questionnaire was used to collect data from farmers on awareness, adoption, and satisfaction related to the use of early post-emergence herbicide in direct wet-seeded rice. Dealer surveys were conducted using a structured questionnaire to understand perceptions regarding demand trends, farmer enquiries and market potential. Responses were recorded using a five-point Likert scale, where 1 = very low, 2 = low, 3 = moderate, 4 = high, and 5 = very high

Farmer awareness and adoption regarding the use of the early post-emergence herbicide: pretilachlor + florpyrauxifen-benzyl (pre-mix) were assessed using structured questionnaire responses. The percentage of farmers aware of or adopting the herbicide was calculated by dividing the number of farmers responding positively by the total number of respondents (n = 110) and multiplying by 100. Awareness Index and Adoption Index were computed by expressing the obtained percentage scores as index values, where the percentage value directly represented the index score.

Farmer satisfaction and dealer perception were assessed using a five-point Likert scale, where 1 = very low, 2 = low, 3 = moderate, 4 = high, and 5 = very high. Mean score for each parameter was calculated as the average of individual respondent scores.

Satisfaction Index (SI, %) was calculated using the formula: SI (%) = (Obtained score / Maximum possible score) × 100 where the maximum possible score was calculated as 5 × 110 (five being the highest Likert score and 110 being the total number of farmers).

Similarly, dealer perception index (DPI, %) was calculated as: DPI (%) = (Obtained score / Maximum possible score) × 100 where the maximum possible score was 5 × 60 (five being the highest Likert score and 60 being the total number of dealers surveyed). Awareness, adoption, satisfaction and dealer perception indices were computed to interpret the survey data. The indices were calculated using standard formulae by expressing the obtained scores as a percentage of the maximum possible score. Descriptive analysis was employed to summarize the results.

The weed flora observed in direct wet-seeded rice fields of the study area included grass weeds: *Echinochloa colona*, *Echinochloa crus-galli*, *Leptochloa chinensis* and *Ischaemum rugosum*; sedges: *Cyperus difformis* and *Fimbristylis miliacea*; and broad-leaved weeds: *Monochoria vaginalis* and *Ludwigia parviflora*. Among these, *Echinochloa colona*, *E. crus-galli*, *Cyperus difformis* and *Monochoria vaginalis* were the predominant weed species during the early crop growth stage (**Table 1**). Grass weeds were the most prevalent group during early crop establishment, which is typical of direct-seeded rice systems under tropical conditions. Field observations indicated that early post-emergence application of the label-recommended dose of pretilachlor + florpyrauxifen-benzyl 620 + 20/ha (pre-mix), 8–10 days after sowing (DAS), resulted in effective early-season suppression of dominant grass weeds resulted in effective early season control of dominant grass weeds with moderate control efficacy on sedges and broad-leaved weeds.

The survey indicated that awareness and adoption indices were of a moderate level of familiarity and use of early post-emergence herbicides in wet direct-seeded rice cultivation (**Table 2**). Labour scarcity and challenges associated with timely manual weeding were identified as major factors influencing adoption. Farmers practicing wet direct-seeded rice increasingly perceived early post-emergence herbicides as a viable option to manage early weed pressure and reduce dependence on manual labour.

Farmer satisfaction index values indicated higher satisfaction regarding usage of application and labour-saving benefits of the early post-emergence herbicide, while comparatively lower satisfaction was reported with respect to cost effectiveness (**Table 2**). Thus, while farmers recognize the operational advantages of pre-emergence weed management, the economic considerations are influencing adoption decisions.

Mean score was calculated based on a five-point Likert scale (1 = very low, 2 = low, 3 = moderate, 4 = high, 5 = very high). Percentage and index values were calculated as (mean score / 5) × 100. For awareness and adoption, percentage represents the proportion of farmers responding positively, and the corresponding index value expresses the standardized score.

Dealer perception index results indicated increasing farmer enquiry and interest in pre-emergence weed management options for wet direct-seeded rice (**Table 2**). Dealers emphasized the need for field demonstrations and technical guidance to enhance farmer confidence and promote appropriate use of herbicides. The overall field observations and survey findings highlight the importance of early post-emergence herbicides as a component of early weed management in wet direct-seeded rice systems under Kerala conditions.

Conclusion

The on-farm assessment indicated that the pretilachlor + florpyrauxifen-benzyl 620+20/ha (pre-mix) applied at 8–10 days after sowing (DAS) has the potential for early-season weeds management in direct wet-seeded rice in Kerala, as it effectively managed dominant grass weeds, while survey-based indices reflected moderate awareness and adoption among farmers. Higher satisfaction of the farmers due to labour-saving benefits highlights the relevance of weed management with early post-

Table 1. The dominant weeds observed in farmers direct wet-seeded rice fields and their early-season control by tested herbicide

Weed group	Weed species	Visually assessed dominance of weed	Visually assessed early-season weed control
Grass	*Echinochloa colona*	High	Good
Grass	*Echinochloa crus-galli*	High	Good
Sedge	*Cyperus difformis*	Moderate	Moderate
Broad-leaved weed	*Monochoria vaginalis*	Moderate	Moderate

Table 2. Farmer awareness, adoption, satisfaction and dealer perception indices regarding the early post-emergence application of pretilachlor + florpyrauxifen-benzyl (pre-mix) in direct wet-seeded rice

Category	Parameter	n	Mean core	Percentage (%) and index value (%)
Farmer awareness & adoption	Awareness	110	3.5	70.9
	Adoption	110	2.9	58.2
Farmer satisfaction	Ease of application	110	4.1	82.0
	Weed suppression	110	3.8	76.0
	Labour saving	110	4.3	86.0
	Cost effectiveness	110	3.4	68.0
	Overall satisfaction	110	3.9	78.0
Dealer perception	Farmer enquiry	60	4.0	80.0
	Demand trend	60	3.8	76.0
	Repeat purchase potential	60	3.9	78.0
	Need for demonstrations	60	4.4	88.0

emergence application of herbicides to address labour constraints in direct wet-seeded rice system. Dealer perception further indicated increasing interest of the farmers to use early post-emergent herbicides and the need for location specific demonstrations and technical guidance on proper use of herbicides in WSR, by the scientists and agriculture department staff, to enhance farmer confidence.

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RESEARCH NOTE

Effect of land configuration and herbicides on weed management in early maturing pigeonpea

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ABSTRACT

A field experiment was conducted in the *Kharif* season of 2024 at Kota, Rajasthan with an objective to evaluate suitable land configuration and herbicidal weed management practices to effectively and economically manage weeds and achieve higher grain yield and net returns in early maturing pigeonpea cultivation. Among the land configurations, the raised bed land configuration with straw mulch was highly effective in suppressing weed emergence, reducing weed biomass, improving weed control efficiency (54%) and attaining higher pigeonpea growth and yield. The raised bed with straw mulch recorded the higher number of pods/plant, seeds per pod, seed yield and stover yield when compared to flatbed and raised bed methods. Among the herbicidal treatments, the post-emergence application (PoE) of propaquizafop-ethyl 2.5% + imazethapyr 3.75% ME (propaquizafop-ethyl + imazethapyr) (ready-mix) 125 g/ha at 20 days after seeding (DAS) recorded lowest weed density, weed biomass, nutrient (NPK) depletion by weeds and higher pigeonpea seed yield due to effective weed management than control and pendimethalin + imazethapyr. The next best treatment was pre-emergence application (PE) of pendimethalin 30% EC + imazethapyr 2% EC (pendimethalin + imazethapyr) (ready-mix) 800 g/ha. The integration of raised bed with straw mulch and propaquizafop-ethyl + imazethapyr (ready-mix) 125 g/ha PoE at 20 DAS significantly reduced weed-crop competition and nutrient loss due to weeds and enhanced early maturing pigeonpea productivity.

Keywords: Early maturing pigeonpea, Land configuration, raised bed, Mulching, Pendimethalin + imazethapyr, Propaquizafop-ethyl + imazethapyr, Weed management

Pulses are rich source of protein, fibre, B-vitamins, isoflavones, and essential minerals like iron, calcium, and zinc. In Indian agriculture, it ranks just after cereals and oilseeds. India leads globally in pigeonpea (75%), chickpea (65%), and lentil (23%) production (FAO 2024). Pulses are mostly cultivated in rainfed, low-input areas prone to drought. India produced 27.69 million tonnes of pulses in 31.03 million ha. (Directorate of Economics and Statistics 2022). India is currently importing 2.5 million tons of pulses annually (Directorate of Pulses Development 2024). The per capita availability of pulses has dropped from 60 g/day (1951) to 44 g/day (2020), below the WHO recommendation of 80 g/day (Tiwari *et al.* 2022). The pulses production must grow by 2.14% annually to meet the projected demand of 39 million tonnes by 2050 (IIPR 2015).

Among the pulses, pigeonpea (*Cajanus cajan* (L.) Millsp.), commonly known as tur, arhar or red gram, is extensively consumed as part of the daily diet in many regions, especially in India. The crop serves food, fodder, fuel, and supports lac production. It is a short-day, photoperiod-sensitive legume with varied maturity (120–180 days) (Hussain *et al.* 2022), suitable for different agroclimatic conditions and is mostly cultivated in *Kharif* season. Pigeonpea is intercropped with cereals, pulses, and long-duration crops. It ranks fifth globally among pulses, second only to chickpea in India. India produces 3.52 million tons of pigeonpea from 4.20 million ha (FAO 2024). In India it is mainly cultivated in Maharashtra, MP, Karnataka, UP, Gujarat, Telangana and Andhra Pradesh. The yield of pigeonpea is severely affected due to weeds, the appropriate weed management strategy in early maturing pigeonpea along with proper land configuration methods is needed.

Conservation agriculture (CA) minimal tillage, residue retention, and crop diversification-offers a sustainable pigeonpea production. Permanent raised beds improve water use efficiency, reduce input costs, and support mechanization (Lichter *et al.* 2008). Mulching with straw helps conserve soil moisture, suppress weeds, and prevent erosion, especially when combined with reduced tillage (Busari *et al.* 2015).

Weeds are a major constraint, especially in the early growth phase (6–8 weeks), reducing pigeonpea

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yield by 20 to 80% (Talnikar *et al.* 2008, Rao and Chauhan 2015). Manual weeding, though effective, is costly and hence, herbicides are a practical solution (Rao *et al.* 2020). The pre-emergence application (PE) of pendimethalin, is commonly used but may cause resistance over time. The post-emergence application (PoE) of propaquizafop + imazethapyr provides broad spectrum weed control as imazethapyr is systemic and controls broad-leaved and grass weeds (Dixit and Varshney 2007), while propaquizafop targets grass weeds by translocation to growing points (Rao *et al.* 2018). This combination is highly effective in rainfed conditions. Thus, an experiment was conducted with an objective to evaluate suitable land configuration and herbicidal weed management treatments to effectively and economically manage weeds and achieve higher grain yield and net returns in early maturing pigeonpea cultivation.

The field study was conducted at Agricultural Research Station, Ummedganj, Kota, Agriculture University, Kota, during *Kharif* 2024. The experimental soil was clay loam, with a pH of 7.76, medium in organic carbon (0.45%), low in available nitrogen (220.4 kg/ha), medium in phosphorus availability (27.5 kg/ha), and high in potassium content (390 kg/ha). The factorial experiment was carried out using randomised block design (FRBD). The treatments comprise of two factors *i.e.,* land configuration and weed management treatments. In factor one there were three land configurations i.e., flat bed, raised bed, and raised bed with straw mulch and in factor two, there were three weed management treatments, *i.e.* control, pendimethalin 30% EC + imazethapyr 2% EC (pendimethalin + imazethapyr) (pre-mix) 800 g/ha PE, and propaquizafop ethyl 2.5% + imazethapyr 3.75% ME (propaquizafop-ethyl + imazethapyr) (pre-mix)125 g/ ha PoE at 20 days after sowing (DAS). Total nine treatment combinations were replicated thrice. The field preparation was done including one ploughing with a tractor-drawn disc plough, followed by two harrowing and planking to achieve a fine tilth. The field was levelled using a leveller prior to layout. Raised beds were prepared using a tractor-operated bed maker, with each bed 90 cm wide and separated by 30 cm furrows. The pigeonpea variety IPA 15-06 was sown at a seed rate of 20 kg/ha on 08.07.2025. Straw mulch, composed of pigeonpea stalks, was applied uniformly to designated plots to form a protective soil cover. Herbicides were applied as per treatment in earmarked plots of the experiment. Pendimethalin + imazethapyr was applied just after sowing of pigeonpea crop and propaquizafop-ethyl + imazethapyr was applied at 20 DAS. The herbicides were sprayed using knapsack sprayer using flat fan nozzle using 500 litre water/ha as per treatments in earmarked plots. A uniform basal dose of nitrogen and phosphorus (20:60 kg/ha) was applied at sowing using urea (46% N) and single super phosphate (16% P_2O_5). As pigeonpea is a legume, all fertilizer was applied at the time of sowing in furrows 8–12 cm deep. Sowing was carried out using a tractor-drawn seed drill, keeping a row spacing of 60 cm and sowing depth of 2–3 cm. Data were recorded on weed density of monocots, dicots, and sedges using a 0.5 m² quadrat placed randomly at four locations per plot, with density presented as number/m². Weed biomass was measured by oven-drying the collected samples at 70–75°C and expressed as kg/ha. Observation on phyto-toxicity on the pigeonpea crop on leaf i.e. wilting, vein clearing, necrosis, epinasty and hyponasty were made at 3, 5, 7, 10 days after herbicide application using the standard scale (0-10) using (Rao 2000). Representative samples of weed dry matter were taken from each plot at harvest were grounded and subjected to chemical analysis for N, P and K concentration with standard methods and expressed in per cent. Nutrient uptake (kg/ha) by weeds was calculated at harvest by formula given below.

$$\text{N/P/K uptake (kg/ha)} = \frac{\text{Nutrient concentration (\%) x Weed dry matter (kg/ha)}}{100}$$

The pods of the five randomly selected plants from each plot at harvest were counted and the average was expressed as number of pods/plant and the produce of seed + straw from each net plot area after complete sun drying was weighed for recording biological yield and expressed as (kg/ha), after threshing and winnowing, the weight of seed from each net plot area was recorded as kg/plot and was converted to kg/ha and the stover yield was obtained by subtracting the seed yield from biological yield per net plot and then converted in terms of kg/ha. Economics of different treatments were worked out in terms of net returns (Rs./ha) by subtracting the cost of treatment and the cost of cultivation from gross income obtained. Cost of cultivation and net profit were calculated on the basis of prevailing prices of produce and inputs. The B:C ratio was calculated by dividing net returns with cost of cultivation for each treatment to see the economic viability of treatments. The experimental data were subjected to statistical analysis, and wherever treatment effects were significant, F-tests and critical differences (CD) at 5% probability level were calculated and presented accordingly.

Effect on weeds

The experimental field was infested with a diverse weed flora comprising monocot, dicot, and sedge weed species, with monocot weeds being the most predominant, followed by dicots and sedges. The minimum weed density and biomass and maximum weed control efficiency (54.0%) at 60 DAS was observed in pigeonpea grown on raised beds with straw mulch over flatbed and raised bed (**Table 1**). This enhanced weed suppression under raised beds with mulch could be attributed to vigorous crop growth, reduced inter-row weed colonization space, and improved nutrient and moisture availability for the crop, which collectively contributed to a less favourable environment for weed proliferation. Similar observations were reported by Badvel *et al.* (2024).

All herbicidal weed management treatments were found significantly effective in reducing weed density and biomass accumulation, thereby resulting in higher weed control efficiency compared to the control plots. Among the treatments, propaquizafop-ethyl + imazethapyr (ready-mix) 125 g/ha at 20 DAS recorded minimum weed density and biomass both at 60 DAS and at harvest, and subsequently recorded the maximum weed control efficiency (78.7 and 62.0%, respectively) when compared to both pendimethalin + imazethapyr (ready-mix) 800 g/ha and the untreated control. Notably, both herbicidal options showed comparable performance in reducing overall weed density and biomass. These results are in line with the findings of Goud and Patil (2014), who concluded that a pre-emergence herbicide followed by a post-emergence application provided effective and sustained weed control in pigeonpea. Throughout the study period, no signs of phytotoxicity (wilting, vein clearing, necrosis, epinasty, and hyponasty) were observed in any treatment.

Effect on nutrient content and uptake by weeds

Nitrogen (N), phosphorus (P) and potassium (K) content in weeds were not affected significantly by application of weed management and land configurations treatments. However, N, P and K depletion by weeds was significantly influenced by different land configurations treatments. The maximum N, P and K uptake by weeds (19.7, 9.78 and 12.1 kg/ha, respectively) was observed under flatbed, while the minimum and significantly lower nutrient depletion was recorded with the raised bed + straw mulch treatment (14.1, 7.06 and 8.30 kg/ha, respectively). In case of weed management, the minimum and significantly lower depletion of nitrogen (12.2 kg/ha), phosphorus (6.22 kg/ha) and potassium (7.05 kg/ha) by weeds was observed with the post-emergence application of propaquizafop-ethyl + imazethapyr (ready-mix) 125 g/ha at 20 DAS, followed by pendimethalin + imazethapyr (ready-mix) 800 g/ha and control (**Table 5**). This reduction in N, P and K depletion by weeds under raised bed + mulch and propaquizafop-ethyl + imazethapyr (ready-mix) may be attributed to reduced weed growth, weed biomass, thereby limiting the competition for nutrients due to improved crop stand and soil conditions, which likely limited nutrient availability to weeds as reported by Singh *et al.* (2020).

Effect on early maturing pigeonpea

Number of pods/plant was significantly influenced by land configuration and weed

Table 1. Effect of land configuration and weed management treatments on weed density*, weed biomass* and weed control efficiency at 60 DAS

Treatment	Weed density (no./m^2)				Weed biomass (kg/ha)				WCE (%)
	Monocot	Dicot	Sedge	Total	Monocot	Dicot	Sedge	Total	
Land configuration									
Flat bed	6.10 (40.1)	5.08 (29.2)	3.90 (17.9)	8.87 (87.2)	20.4 (429)	22.3 (503)	8.27 (68.6)	31.4 (1001)	28.3
Raised bed	5.27 (31.9)	4.95 (25.7)	3.78 (15.5)	8.16 (73.1)	19.6 (391)	21.2 (455)	7.95 (63.3)	29.9 (909)	41.6
Raised bed + straw mulch	4.23 (20.5)	3.90 (17.5)	2.81 (8.61)	6.34 (46.6)	16.9 (287)	18.0 (326)	6.89 (47.8)	25.6 (660)	54.0
LSD (p=0.05)	0.89	0.72	0.65	0.64	0.98	1.23	0.56	1.08	7.95
Weed management									
Control	7.34 (55.7)	6.44 (42.3)	5.13 (27.2)	11.1 (125)	22.1 (501)	22.5 (513)	8.62 (74.2)	32.8 (1089)	-
Pendimethalin + imazethapyr (ready-mix) 800 g/ha PE	5.18 (26.8)	4.75 (22.4)	3.29 (10.7)	7.74 (60.0)	18.1 (327)	20.7 (431)	7.66 (58.7)	28.5 (817)	45.1
Propaquizafop-ethyl + imazethapyr (ready-mix) 125 g/ha PoE at 20 DAS	3.07 (10.1)	2.74 (7.61)	2.06 (4.06)	4.54 (21.7)	16.6 (278)	18.3 (340)	6.82 (46.8)	25.7 (664)	78.7
LSD (p=0.05)	0.89	0.72	0.65	0.64	0.98	1.23	0.56	1.08	7.95

*Values are subjected to $\sqrt{x+0.5}$ transformed. Values in parentheses are original values.,
PE: pre-emergence application; PoE: post-emergence application; DAS: days after seeding; WCE: Weed control efficiency

management options which also affected the early maturing pigeonpea yield (**Table 4**). The maximum number of pods/plant (159.9), seed yield (1.52 t/ha) and stover yield (4.88 t/ha) were recorded in raised bed with straw mulch and found superior over the raised bed and flatbed land configuration. The pigeonpea yield increased because of increased pods/plant, this is due to the cumulative action of soil moisture, soil microbial population, aeration and nutrients in optimum quantity under raised bed with straw mulch, and raised bed compared to flatbed as observed earlier by Pandey *et al* (2014), Mankar *et al.* (2013). Among the weed management options, the maximum number of pods/plant, seed yield and stover yield were recorded with propaquizafop-ethyl + imazethapyr (ready-mix) 125 g/ha which was superior over rest of the weed management options. The stover yield was statistically at par with pendimethalin + imazethapyr (ready-mix) 800 g/ha (**Table 2**). The minimum seed yield was in a control plot due to severe weed competition faced by the crop. The maximum seed yield was obtained from the combination of raised bed + straw mulch and propaquizafop-ethyl + imazethapyr 125 g/ha at 20 DAS. Raised bed + straw mulch resulted in statistically similar yield to flatbed planting along with propaquizafop-ethyl + imazethapyr (ready-mix) 125 g/ha at 20 DAS and thus underscoring the importance of raised bed + straw mulching for weed control and improved crop performance. (**Table 3**).

Table 3 Interaction effect of land configuration and weed management on seed yield (t/ha) of pigeonpea

Treatments (land configuration/weed management) *	Flat bed	Raised bed	Raised bed + straw mulch
Control	1.10	1.12	1.41
Pendimethalin + imazethapyr (ready-mix) 800 g/ha PE	1.19	1.47	1.50
Propaquizafop-ethyl + imazethapyr (ready-mix) 125 g/ha PoE at 20 DAS	1.37	1.54	1.64
LSD (p=0.05)		0.13	

PE: pre-emergence application; PoE: post-emergence application; DAS: days after seeding

Table 4 Interaction effect of land configuration and weed management on net returns (₹/ha)

Treatments (land configuration/weed management) *	Flat bed	Raised bed	Raised bed + straw mulch
Control	59876	59778	81541
Pendimethalin + imazethapyr (ready-mix) 800 g/ha	60369	81746	84313
Propaquizafop-ethyl + imazethapyr (ready-mix) 125 g/ha at 20 DAS	75733	88586	95711
LSD (p=0.05)		9957	

PE: pre-emergence application; PoE: post-emergence application; DAS: days after seeding

Table 2. Effect of land configuration and weed management treatments on yield and economics of pigeonpea

Treatment	Pods/plant (no.)	Seed yield (t/ha)	Stover yield (t/ha)	Net return ($x10^3$ Rs/ha)	B:C ratio
Land configuration					
Flat bed	94.4	1.219	4.13	65.93	2.17
Raised bed	110.6	1.375	4.43	77.47	2.50
Raised bed + straw mulch	159.9	1.519	4.88	87.77	2.76
LSD (p=0.05)	11.4	0.07	0.28	5.81	0.18
Weed management					
Control	97.8	1.212	4.13	66.97	2.33
Pendimethalin + imazethapyr (ready-mix) 800 g/ha PE	124.9	1.386	4.56	77.69	2.46
Propaquizafop-ethyl + imazethapyr (ready-mix) 125 g/ha PoE at 20 DAS	142.2	1.515	4.75	86.50	2.65
LSD (p=0.05)	11.4	0.07	0.28	5.81	0.18

*PE: pre-emergence application; PoE: post-emergence application; DAS: days after seeding

Table 5. Effect of land configuration and weed management treatments on nutrient content and uptake by weeds at pigeonpea harvest

Treatment	Nutrient content (%)			Nutrient uptake (kg/ha)		
	N	P	K	N	P	K
Land configuration						
Flat bed	2.57	1.28	1.55	19.7	9.78	12.1
Raised bed	2.50	1.27	1.46	17.4	8.75	10.2
Raised bed + straw mulch	2.49	1.24	1.45	14.1	7.06	8.3
LSD (p=0.05)	NS	NS	NS	2.17	1.01	1.85
Weed management						
Control	2.56	1.29	1.54	22.4	11.22	13.6
Pendimethalin + imazethapyr (ready-mix) 800 g/ha PE	2.54	1.26	1.51	16.5	8.15	9.85
Propaquizafop-ethyl + imazethapyr (ready-mix) 125 g/ha PoE at 20 DAS	2.46	1.25	1.42	12.2	6.22	7.05
LSD (p=0.05)	NS	NS	NS	2.17	1.01	1.85

*PE: pre-emergence application; PoE: post-emergence application; DAS: days after seeding

Economics

The net returns and benefit: cost ratio of pigeonpea were significantly influenced by the land configuration methods (**Table 2**). The raised bed + straw mulch recorded the maximum net returns and B:C ratio over the raised bed and flatbed configurations, the enhanced profitability was attributed to increased seed and stover yields, which resulted in maximum net returns (₹ 87,773/ha) and B:C ratio (2.76) as reported by Garud *et al*. (2018). With respect to weed management strategies, the application of propaquizafop-ethyl + imazethapyr 125 g/ha at 20 DAS resulted in the highest cost of cultivation, yet it also delivered superior economic returns and B:C ratio, followed by pendimethalin + imazethapyr (ready-mix). The increased profitability with propaquizafop-ethyl + imazethapyr was due to the improved seed and stalk yield, which resulted in higher net returns and B:C ratio. Similar trends were reported by Padmaja *et al.* (2013) and Singh *et al*. (2020). The maximum net return (₹ 95,711/ha) was recorded with the combination of raised bed + straw mulch and propaquizafop-ethyl + imazethapyr 125 g/ha at 20 DAS (**Table 4**).

It can be concluded that the sowing of pigeonpea on raised bed with straw mulch was most productive and profitable land configuration while among weed management options, propaquizafop-ethyl + imazethapyr 125 g/ha PoE at 20 DAS was most profitable with higher net returns and B:C ratio.

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RESEARCH NOTE

Herbicide application using unmanned aerial vehicle in groundnut

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ABSTRACT

A field experiment was conducted during *Rabi*, 2024-25 at S.V. Agricultural College Farm, Tirupati campus of Acharya N.G. Ranga Agricultural University, Andhra Pradesh to evaluate and compare the efficacy of pre- and post-emergence herbicides applied through unmanned aerial vehicle (UAV) and knapsack sprayer for weed management in *Rabi* groundnut. Among different weed management treatments tested, pre-emergence application (PE) of pendimethalin 1kg/ha with UAV at 50 L/ha of spray fluid significantly reduced total weed density and biomass with higher weed control efficiency and resulted in increased groundnut yield attributes and yield. It was statistically comparable with same herbicide application with knapsack sprayer at 500 L/ha. The highest benefit-cost ratio was observed with pendimethalin 1.0 kg/ha PE with UAV using 50 L/ha of spray fluid indicating that usage of unmanned aerial vehicle for herbicide spraying has potential as an alternative to conventional knapsack sprayer for herbicide application in groundnut.

Keywords: Groundnut, Spraying technique, Unmanned aerial vehicle, Weed management

Groundnut (*Arachis hypogaea* L.) is a vital crop in India due to its nutritional, economic and ecological significance. Despite its importance, groundnut productivity is often constrained by several factors, among which weed infestation remains as one of the major yield limiting factor. The yield loss due to weeds in groundnut was reported to be 30 to 80% (Priya *et al.* 2013, Rao and Chauhan 2015, Kumari 2017). Groundnut is highly susceptible to weed infestation because of its slow growth during initial stages up to 40 days after sowing (DAS), short plant stature and underground pod-bearing habit. Weeds interfere with pegging, pod development and harvesting of groundnut, besides competing for essential growth resources. Therefore, effective weed control is the foremost critical production factor in groundnut cultivation (Choudhary *et al.* 2022). Ttraditionally, knapsack sprayers are widely used in small holdings for herbicide application, which requires high spray volumes of 500 L/ha, making them less suitable for dryland situations due to shortage of water in the water bodies for spraying. In addition, it is time-consuming and physically demanding, which limits their efficiency on larger farms and also poses significant health hazards to the humans who are involved in spraying operations.

In this context, unmanned aerial vehicle (UAV) or drones have emerged as a promising alternative for pesticide and herbicide application in agriculture (Gatkal *et al.* 2025). Drones are capable in navigating challenging terrains and inaccessible zones ensuring comprehensive coverage (Wang *et al.* 2020), reducing application time by 99% (Ahmad *et al.* 2020) and reducing labour requirement by 85% compared to manual method (Partel *et al.* 2021). UAV spray was evaluated in summer cotton (Vimalraj et al. 2025) and direct-seeded rice (Karthickraja et al. 2024) to effectively manage the diverse weed flora and enhance crop yield. However, the use of UAV for herbicide application, especially in crops like groundnut, is still in its nascent stage and their impact on weed control remains largely unexplored. Herbicidal applications in groundnut are still carried out using knapsack sprayers, which demand high spray volume of 500 L/ha, whereas UAVs operate with significantly lower spray volume of 25 L/ha (Jeevan *et al.* 2023). There is an urgent need for scientific evaluation to establish standard operating procedures for drone application of herbicides in India. In this context, a field study was conducted to evaluate the efficacy of pre- and post-emergence herbicides application using drones in *Rabi* groundnut.

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A field experiment was conducted during *Rabi* 2024-25 at dryland farm of ANGRAU-S.V. Agricultural College, Tirupati, Andhra Pradesh. The soil was sandy loam in texture, neutral in reaction, low in organic carbon and available nitrogen, high in available phosphorus and medium in available potassium. Healthy and sound groundnut kernel of test variety '*Visishta*' were sown on 26 December 2024 at a spacing of 22.5 cm × 10 cm using a seed rate of 140 kg/ha. The experiment was laid out in randomized block design with eight weed management treatments replicated thrice. The pre-emergence application (PE) of pendimethalin 1.0 kg/ha with unmanned aerial vehicle (UAV) using 25 and 50 L/ha of spray fluid and post-emergence application (PoE) of imazethapyr + propaquizafop (ready-mix) 125 g/ha with UAV using 25 and 50 L/ha spray fluid, application of above herbicides with conventional knapsack sprayer using 500 L/ha spray fluid, hand weeding twice at 20 and 40 days after sowing (DAS) and unweeded check. The soils of the experimental site was sandy loam in texture, neutral in soil reaction (6.9), low in organic carbon(0.28%) and available nitrogen (215 kg/ha), high in available phosphorus (21 kg/ha) and medium in available potassium(250 kg/ha).The drone used for the experiment was ANGRAU-Pushpak-03, which is a hexacopter agricultural drone with a 12 L tank capacity developed by Acharya N.G. Ranga Agricultural University for aerial spraying of pesticides approved by DGCA. It is pressure-based UAV with 4 flat-fan nozzles fitted with nozzle model - 110015 VP and a swath width of 3 meters and nozzle discharge rate is 0.42 to 0.45 L/m operated by certified drone pilot. The UAV consisting of 2 units of batteries each 16,000 mAH capacity. Prior to herbicide application, UAV was calibrated to ensure accurate and uniform delivery of the spray fluid as per the treatments by measuring the droplet size. A detailed geo-referenced map of the treatment plots was developed to ensure accurate application of spray fluid. The mean diameter of spray droplets in UAV and Knapsack sprayer was 390.3 and 412.4 micrometers, respectively. The UAV was operated at a constant height of 1 meter above the soil/crop canopy with a flight speed of 5 m/s for 25 L/ha and 2.5 m/s for 50 L/ha of spray fluid to ensure uniform coverage. For pre-emergence herbicide application, weather conditions recorded were 77 % relative humidity, 2.5 km/hr wind speed and 25.5 °C temperature with soil moisture content at field capacity. For post-emergence herbicide application, the relative humidity, wind speed and temperature were 73 %, 0.6 km/hr and 22.5 °C respectively. Knapsack sprayer was fitted with standard flat fan nozzle and was calibrated before PE and PoE herbicide application by adjusting nozzle discharge and walking speed. Pre-emergence herbicidal application of pendimethalin was done at 1 DAS while post-emergence herbicidal application of imazethapyr + propaquizafop (ready-mix) was done at 20 DAS. Gross plot area for UAV and knapsack sprayer was 5.4 m × 14 m and 5.4 m × 4 m, respectively by maintaining buffer zone of 2 m around the UAV plot. Recommended fertilizer dose of 20 kg N, 40 kg P and 50 kg K/ha were applied through urea, single super phosphate and muriate of potash, respectively to all plots as basal while 10 kg of N was applied in form of urea at 25 DAS as topdressing. The rest of the package of practices was adopted as per Acharya N.G. Ranga Agricultural University recommendations. Unweeded check plots were allowed to remain infested with weeds throughout the crop duration. Category wise weed density and biomass was recorded at harvest by using 0.25 m^2 quadrant. The data on weed density and biomass was subjected to square root transformation ($\sqrt{x+0.5}$) before statistical analysis. Weed control efficiency of different weed management practices were calculated based on the following formula.

$$WCE = \frac{DM_C - DM_T}{DM_C} \times 100$$

where,

WCE = Weed control efficiency (%)

DM_C = Dry matter of weeds in the un-weeded check (control)

DM_T = Dry matter of weeds in the treatment imposed plot.

The crop was harvested on 17 April 2025. Net returns were arrived by deducting the cost of cultivation from gross returns for each treatment. The hiring charges for UAV is Rs750/ha.

The predominant weed species observed were *Boerhavia erecta* L. (45.0%), *Cyperus rotundus* L. (15.0%), *Celosia argentea* L. (11.0%), *Euphorbia hirta* L. (10.0%), *Dactyloctenium aegyptium* (L.) Willd. (9.0%), *Ageratum conyzoides* L. (5.0%) and other minor weeds (5.0%) in unweeded check plots at harvest. All the weed management practices significantly influenced the weed growth and yield of *Rabi* groundnut. The lowest density and biomass of weeds as well as higher weed control efficiency (WCE) were recorded with hand weeding twice at 20 and 40 DAS which was significantly lower than rest of the weed management treatments due to effective removal of weeds by the laborers. Pendimethalin 1 kg/ha PE with UAV at 50 L/ha of spray fluid recorded significantly lower weed density and biomass, which was however comparable with application of same herbicide with knapsack sprayer at 500 L/ha of spray fluid (**Table 1**). The improved weed control with pendimethalin 1.0 kg/ha applied using UAV with 50 L/ha of spray fluid can be attributed due to better spray coverage and more effective deposition of the herbicide per unit surface area of soil and pendimethalin inhibited the mitotic activity by disrupting microtubule assembly and ultimately led to cessation of cell division in target weeds. These results are in conformity with the findings of Madhusree *et al.* (2024) in greengram. Additionally, there was no significant difference in weed control due to post-emergence herbicides application using knapsack sprayer and UAV (Naveen *et al.* 2023).

Weed management treatments significantly influenced yield attributes, yield and economics of *rabi* groundnut (**Table 2**). The highest groundnut yield attributes and yield was recorded with hand weeding twice at 20 and 40 DAS, which was significantly higher than rest of the weed management treatments. Among two different methods of herbicide application, pendimethalin 1.0 kg/ha using UAV at 50L/ha spray fluid recorded taller plants, increased number of filled pods/plant and 100-pod weight and higher groundnut pod yield. However, it was statistically at par with application of the same herbicide with knapsack sprayer at 500 L/ha of spray fluid. Yield loss due to weeds in unweeded check was 41.71% compared to pendimethalin pre-emergence application with UAV using 50 L/ha of spray fluid.

Table 1. Weed density, weed biomass and weed control efficiency at harvest as influenced by pre- and post-emergence herbicides application using unmanned aerial vehicle (UAV) and knapsack sprayer in *rabi* groundnut

Weed management practices	Weed density (no./m^2)				Weed biomass (g/m^2)				WCE (%)
	Grasses	Sedges	BLWs	Total weeds	Grasses	Sedges	BLWs	Total weeds	
Pre-emergence application (PE) of pendimethalin 1.0 kg/ha with UAV at 25 L/ha spray fluid	2.67 (6.67)	6.77 (45.33)	4.34 (18.33)	8.42 (70.33)	1.59 (2.02)	7.10 (50.05)	2.69 (6.73)	7.70 (58.79)	61.16
Pendimethalin 1.0 kg/ha PE with UAV at 50 L/ha spray fluid	2.27 (4.67)	5.96 (35.00)	3.76 (13.67)	7.34 (53.33)	1.37 (1.37)	6.52 (42.10)	2.23 (4.47)	6.95 (47.94)	68.33
Post-emergence application (PoE) propaquizafop + imazethapyr 125 g/ha with UAV at 25 L/ha of spray fluid	3.08 (9.00)	5.43 (29.00)	11.52 (132.33)	13.06 (170.33)	1.79 (2.70)	5.64 (31.36)	6.70 (44.50)	8.89 (78.56)	48.10
Propaquizafop + imazethapyr 125 g/ha PoE with UAV at 50 L/ha of spray fluid	3.03 (8.67)	5.40 (28.67)	11.46 (131.00)	12.99 (168.33)	1.77 (2.63)	5.54 (30.24)	6.51 (41.91)	8.68 (74.77)	50.60
Pendimethalin 1.0 kg/ha PE with knapsack sprayer at 500 L/ha spray fluid	2.35 (5.00)	6.15 (37.33)	3.85 (14.33)	7.56 (56.67)	1.42 (1.51)	6.55 (42.45)	2.33 (4.93)	7.02 (48.88)	67.71
Propaquizafop + imazethapyr 125 g/ha PoE with knapsack sprayer at 500 L/ha spray fluid	2.97 (8.33)	5.30 (27.67)	11.44 (130.67)	12.92 (166.67)	1.73 (2.49)	5.33 (27.91)	6.43 (40.94)	8.47 (71.33)	52.88
Hand weeding twice at 20 and 40 days after seeding	1.46 (1.67)	2.73 (7.00)	2.86 (7.67)	4.10 (16.33)	1.26 (1.10)	3.61 (12.54)	1.51 (1.79)	3.99 (15.43)	89.81
Unweeded check	4.45 (19.33)	9.22 (84.67)	19.49 (380.00)	22.00 (484.00)	2.01 (3.56)	7.66 (58.24)	9.48 (89.58)	12.32 (151.37)	-
LSD (p=0.05)	0.20	0.43	0.85	0.69	0.10	0.54	0.49	0.65	-

BLWs: Broad-leaved weeds WCE: Weed control efficiency

Table 2. Yield attributes, yield and economics of *Rabi* groundnut as influenced by pre- and post-emergence herbicides application using unmanned aerial vehicle (UAV) and knapsack sprayer

Weed management practices	Plant height (cm)	No. of filled pods/ plant	100 pod weight (g)	Pod yield (t/ha)	Haulm yield (t/ha)	Net returns (x 10^3/ha)	Benefit-cost ratio
Pre-emergence application (PE) of pendimethalin 1 kg/ha with UAV at 25 L/ha spray fluid	28.45	22.47	124.21	3.04	4.17	80.41	2.32
Pendimethalin 1 kg/ha PE with UAV at 50 L/ha spray fluid	32.01	24.40	135.00	3.50	4.61	100.66	2.63
Post-emergence application (PoE) propaquizafop + imazethapyr 125 g/ha with UAV at 25 L/ha of spray fluid	23.78	16.73	110.98	2.57	3.70	58.19	1.95
Propaquizafop + imazethapyr 125 g/ha PoEwith UAV at 50 L/ha of spray fluid	24.57	17.47	112.67	2.67	3.75	61.90	1.99
Pendimethalin 1 kg/ha PE with knapsack sprayer at 500 L/ha spray fluid	31.97	24.27	133.65	3.34	4.57	94.03	2.55
Propaquizafop + imazethapyr 125 g/ha PoE with knapsack sprayer at 500 L/ha spray fluid	24.90	18.00	113.37	2.70	3.79	63.99	2.04
Hand weeding twice at 20 and 40 days after seeding	35.23	29.66	144.13	3.80	4.99	98.99	2.28
Unweeded check	21.00	12.80	98.65	2.04	3.12	37.64	1.65
LSD (p=0.05)	2.13	1.40	8.05	2.87	3.36	6.20	0.20

The increased groundnut yield due to herbicide spray either by UAV or knapsack sprayer can be attributed due to weed-free environment during critical period of crop weed competition and thereby increased the development of groundnut pods as reported by Madhusree *et al*. (2024) with UAV usage to spray pendimethalin 50 L/ha of spray fluid in greengram and by Chen *et al*. (2019) in wheat. The highest net return was obtained with pendimethalin 1.0 kg/ha with UAV at 50 L/ha of spray fluid, which was however comparable to hand weeding twice at 20 and 40 DAS, which in turn was comparable to spraying of same herbicide with knapsack sprayer 500 L/ha of spray fluid. The highest benefit-cost ratio was obtained with UAV spray of pendimethalin 1.0 kg/ha using 50 L/ha spray fluid which was at par with application of same herbicide with knapsack sprayer using 500L/ha spray fluid. The highest weed density and biomass with lower pod and haulm yield were recorded with unweeded check due to heavy weed infestation.

Thus, pendimethalin 1.0 kg/ha PE applied with UAV using 50 L/ha of spray fluid was found to be an economically viable weed management option for obtaining broad-spectrum weed control and enhancing yield of *rabi* groundnut on sandy loam soil.

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RESEARCH NOTE

Growth and yield of fennel as influenced by weed control measures and nutrient management

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ABSTRACT

A field experiment was conducted, to study the effect of by weed control measures and nutrient management on growth and yield of fennel, at Instructional Farm, College of Agriculture, Bikaner during the *Rabi* season of 2021-22. There were 16 treatment combinations with four nutrient managements: control, 75% recommended dose of fertilizers (RDF), 100% RDF and 125% RDF and four weed control measures: weed free, pre-emergence application (PE) of pendimethalin 0.75 kg/ha, post-emergence application (PoE) of oxyfluorfen 50 g/ha at 25 DAS and weedy check. A factorial randomized design with three replications was used. The reduction in weed density, biomass and increase in fennel growth and yield were significantly higher with pendimethalin 0.75 kg/ha PE than with oxyfluorfen50 g/ha PoE. Weed-free recorded the highest fennel seed yield, biological yield and net returns while pendimethalin0.75 kg/ha PE recorded the highest B: C ratio. Among nutrient levels, 100% RDF recorded the highest fennel seed yield, biological yield and net returns.

Keywords: Economics, Fennel, Nutrient management, Pendimethalin, Weed management

Fennel (*Foeniculum vulgare* Mill.) a significant seed spice crop belongs to the Umbelliferae (Apiaceae) family. The genus name "Foeniculum" originates from the Latin word *foenum*, meaning "hay," which refers to the plant's feathery foliage. Botanically, fennel is a robust, aromatic annual herb. Its seeds are nutritionally valuable, containing 9.5% protein, 10% fat, 42.3% carbohydrates, 18.5% fiber, and 13.4% mineral content (Bhunia *et al.* 2005). India is the leading country in the production, consumption and export of fennel which is commonly known as "*Saunf*" and also referred by various regional names across different parts of the country (Ashok Kumar *et al.* 2017). Major producer states of India are Gujarat, Rajasthan, Karnataka, and Andhra Pradesh. Among these, Gujarat dominates the national fennel output contributing approximately 82% of the total production. Regarding its climatic preferences, fennel is a cool-season crop. Considering the importance of fennel its average productivity is very low. The major reasons for low fennel productivity is due to inadequate availability and adoption of nutrient management and agronomic practices to control heavy weed infestation.

Fennel typically exhibits slow initial growth and takes a longer time to germinate, making it highly susceptible to weed infestation during the early stages of development (Gohil *et al.* 2015). If not managed promptly, weeds can significantly hinder crop growth and may lead to yield losses as high as 91.4% (Mali and Suwalka 1987). Furthermore, weed competition can adversely impact the quality of essential oils in fennel (Abdallah *et al.* 2021). Maintaining a weed-free fennel field typically requires 3 to 4 rounds of manual weeding to attain higher fennel productivity (Parthasarathy *et al.* 2008). Mechanical and cultural methods of weed control are often less effective and more costly, especially during labor shortages or when labor costs are high (Rao 2022). In contrast, weed control using herbicides is generally more effective, economical and reliable. Herbicides have been shown to provide substantial increases in seed yield ranging from 43.2% to 86.9% and typically offer a three to fourfold return on investment compared to other weed control practices (Patel *et al.* 2017).

Efficient and balanced fertilizer application plays a crucial role in promoting proper plant growth, development and achieving higher yields (Waskela *et al.* 2017). Since, fennel is a commercial spice crop, its yield as well as quality is important and both can be achieved only by adoption of proper nutrient management and effective and economical weed management at the critical stages of crop weed competition. Thus, this study was undertaken to

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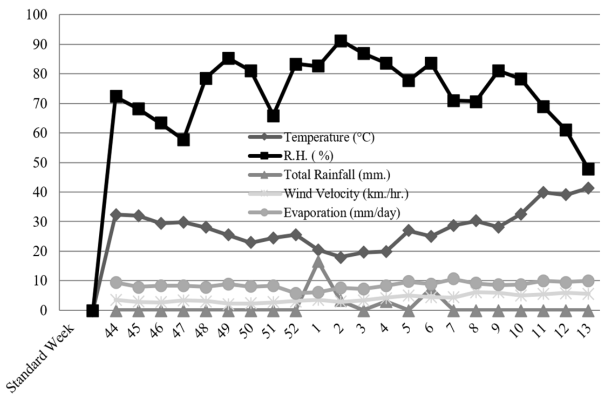
identify the most effective weed management option and optimal nutrient management practice for enhancing the productivity of fennel.

The field study was carried out during the *Rabi* season of 2021–22 at the Instructional Farm of the College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan. The experimental site is located at 28.01° N latitude, 73.22° E longitude, with an elevation of 234.70 meters above mean sea level. According to the 'Agro-ecological Region Map' developed by the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) location lies in Agro-ecological Region 2 (M_9E_1) which is part of the Hot Arid Eco-region. This area is characterized by deep sandy to coarse loamy desert soils, poor water-holding capacity and a hot, arid climate that receives 350–600 mm of annual rainfall. Based on agro-climatic classifications, Bikaner falls within Zone I-C (Hyper Arid Partially Irrigated Western Plain Zone) under the National Agricultural Research Project (NARP) and Zone XIV (Western Dry Region) as per the Planning Commission of India. The soil at the site was loamy sand in texture with a pH of 8.5, organic carbon content of 0.18%, low available nitrogen (121.4 kg/ha), medium phosphorus (19.08 kg/ha) and low potassium (191.42 kg/ha). A factorial randomized block design (FRBD) with three replications was used. There were 16 treatment combinations with four nutrient managements treatments: control (no fertilizers or FYM), 75% recommended dose of fertilizers (RDF), 100% RDF and 125% RDF and four weed control treatments: weed free, pre-emergence application (PE) of pendimethalin 0.75 kg/ha, post-emergence application (PoE) of oxyfluorfen 50 g/ha at 25 DAS and weedy check. Weed-free plots were maintained by hand weeding thrice. The fennel cultivar '*RF 141*' was sown following the recommended package of practices. Sowing was done on 31 October 2021 using a *Deshi plough* at spacing of 50 x 20 cm with a seed rate of 8 kg/ha and a sowing depth of 2–3 cm. Fertilizers were applied as per the treatments. Recommended dose of fertilizer for fennel crop 90 N kg/ha and 40 P_2O_5 kg/ha were used. Urea and SSP were used as sources of nutrients N and P, respectively and applied as per treatment details. Half of the nitrogen dose along with the full doses of phosphorus and potassium were incorporated as basal application. The remaining nitrogen was supplied as urea in two equal splits with irrigation. Herbicide applications and hand weeding were executed according to the treatment structure. Herbicides were applied with a knapsack sprayer and manual weeding was carried out as per the treatment. Standard plant protection measures were adopted to ensure a healthy crop. At physiological maturity, the crop from the net plot area was harvested manually on 1 April 2022.

Plant population at harvest was recorded from the net plot area and converted to a per-hectare basis using the appropriate multiplication factor. For growth observations, five plants were randomly selected and permanently tagged in each plot. Plant height was measured at harvest from the base to the tip of the main shoot using a meter scale and the mean height was computed. The same tagged plants were used to record the number of branches per plant at harvest and their average values were calculated. Dry matter accumulation was assessed at 50 DAS and at harvest by sampling five randomly selected plants from each plot. After removing the root portion the samples were air-dried and then oven-dried at 70°C to constant weight the values were expressed in g/m{ ^{2}. Crop growth rate (CGR) was estimated following Radford (1967) as the increase in dry matter per unit area per unit time using periodic dry matter records. Relative growth rate (RGR) was computed according to Radford (1967) as the increase in dry matter per unit of existing biomass per unit time.

Weed density and weed dry weight (weed biomass) was measured form each plot at 50 DAS and at harvest using 1m^2 quadrat. The collected weed data were subjected to square root transformation before statistical analysis. In order to evaluate the efficacy of various weed control treatments, the weed control efficiency and weed index were calculated using standard formulae.

Biological yield was recorded as the weight of thoroughly sun-dried harvested produce from each plot prior to threshing and expressed in kg/ha. Seed yield was obtained by sun-drying, threshing and



#Data taken from Agro-meteorological Observatory, ARS, SKRAU, Beechwal, Bikaner

Figure 1. Weekly Meteorological data of Bikaner for the *Rabi* 2021-22

cleaning the produce from the net plot area after which the seed weight was measured in kg per plot and converted to kg/ha. The ratio of economic yield (seed yield) to biological yield was worked out and expressed in percentage (Singh and Stoskopf, 1971).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \text{ X } 100$$

Economic analysis included estimation of net returns (Rs/ha) and the benefit–cost (B: C) ratio based on prevailing market prices. The data were analyzed statistically using Fisher's method of analysis of variance (ANOVA) as described by Fisher (1950).

Effect on weeds

The weed control treatments varied in their effect on weed density and biomass. Weed-free was maintained without weeds and weedy check had the highest weed density and biomass at both 50 DAS and at harvest (**Table 1**). Among the herbicides, pendimethalin 0.75 kg/ha PE and oxyfluorfen 50 g/ha PoE at 25 DAS were effective reducing weed density at 50 DAS and harvest over the weedy check. They recorded highest weed control efficiency and the lowest weed index (**Table 2**). The reduction in weed index (%) can be attributed to decreased crop-weed competition for essential resources such as light, nutrients and space which allowed the crop to more efficiently utilize available resources. This enhanced resource use efficiency ultimately contributed to improved crop growth and yield. Similar observations were reported by Kaur *et al.* (2022), Meena *et al.* (2013) and Gohil *et al.* (2015).

Effect on fennel

The weed control measure treatments differed significantly in their effect on plant population, plant height, number of branches per plant and dry matter accumulation, CGR and RGR (**Table 3**). Weed free recorded the maximum plant population, plant height, number of branches per plant, dry matter accumulation, CGR and RGR, which were 36.98, 33.32, 86.92, 32.48, 31.90 and 6.58% percent increase over weedy check, respectively at harvest. Pendimethalin 0.75 kg/ha PE was next best treatment which was equally effective in enhancing these characters of fennel. Improvement in growth attributes by pendimethalin at 0.75 kg /ha (PE) were increased by 32.06, 31.26, 67.43, 29.10, 28.48 and 5.8% over weedy check, respectively at harvest. Because there was less competition for plant growth inputs when there are lesser weeds and less weed biomass, crop plants produce more dry matter and develop to a greater height when weed control treatments were implemented as reported by Nagar *et al.* (2009) and Kumar *et al.* (2021) in fennel. Thus, sufficient availability of light, space as well as better soil and nutritional environment along with improvement in physiological and morphological characters of the plant in rhizosphere might have improved the photosynthetic efficiency, which led to more dry matter accumulation under effective treatments. In contrast, continuous growth of weeds throughout the crop season in weedy check decreased the fennel growth due to high weed-crop competition. Hand weeding done with hoeing, as in weed free, also improved the physical condition of the soil by increasing its friability, aeration and it is an effective method to prevent weeds from producing seeds that might helps in establishment and proliferation of roots and ultimately the plant growth confirming the findings of Bagri *et al.* (2014) in fenugreek.

Table 1. Effect of weed control and nutrient management treatments on weed density and biomass in fennel

Treatment	Weed density (no./m^2)		Weed biomass (g/m^2)	
	At 50 DAS	At harvest	At 50 DAS	At harvest
Nutrient management				
Control	4.64(31.7)	4.16(26.8)	7.16	48.89
75% RDF	4.89(34.7)	4.50(29.8)	8.59	53.68
100 % RDF	4.96(35.6)	4.70(32.6)	9.61	59.53
125 % RDF	5.07(37.6)	4.90(35.1)	9.95	61.58
LSD (p=0.05)	0.12	0.18	1.01	4.20
Weed control measures				
Weed free	0.71(0.0)	0.71(0.0)	0.0	0.0
Pendimethalin 0.75 kg/ha PE	4.12(16.5)	3.78(14.0)	3.61	29.57
Oxyfluorfen 50 g/ha PoE at 25 DAS	4.55(20.2)	4.03(15.9)	4.38	32.98
Weedy check	10.16(102.8)	9.73(94.5)	27.31	161.14
LSD (p=0.05)	0.12	0.18	1.01	4.20

The original weed density per m^2 is shown in parenthesis. (*A square root transformation of x + 0.5 were used)*. RDF = Recommended dose of fertilizer, NS= Non – significant, DAS= Days after sowing, PE= pre-emergence application, PoE= post-emergence application

Table 2. Effect of weed control measures on weed control efficiency and weed index in fennel

Treatment	Weed control efficiency (%)		Weed index (%)
	At 50 DAS	At harvest	
Weed free	100.00	100.00	0.00
Pendimethalin at 0.75 kg/ha PE	86.87	81.78	16.89
Oxyfluorfen at 50 g/ha PoE at 25 DAS	84.03	79.67	31.50
Weedy check	0.0	0.0	92.07
LSD (p=0.05)	-	-	-

DAS= Days after sowing, PE= pre-emergence application, PoE= post-emergence application

Weed-free throughout the crop season resulted in highest number of umbel per fennel plant, umbellate per umbel, and seeds per umbel, maximum fennel biological yield and seed yield (**Table 4**). The absence of weed competition throughout the growth period allowed the crop to fully utilize nutrients, moisture and sunlight, thereby enhancing growth and yield. Among herbicides, pendimethalin 0.75 kg/ha PE proved most effective, followed closely by oxyfluorfen 50 g/ha PoE at 25 DAS. These treatments significantly improved yield components and yields compared to the weedy check where unchecked weed growth led to excessive depletion of soil nutrients and moisture by the weeds ultimately hindering crop development Thus, season-long weed control played a crucial role in enhancing fennel productivity as reported earlier by Gohil *et al.* (2015) and Choudhary *et al.* (2021).

In the present study, maximum fennel growth parameters (plant height, number of branches/plant and dry matter accumulation) were observed with 125% RDF. Crop growth parameters improved due to fulfillment of crop nutrient requirement and created good soil environment for crop growth. Reported by Waskela *et al.* (2017) and Kalasare *et al.* (2021)

Yield attributes were significantly higher with application of 100% RDF by 31.22%, 26.84%, 44.54%, 13.90% and 38.77% increase in number of umbles/plant, umblets/umble, seeds/umble, test weight and seed yield, respectively over control. 125 % RDF also resulted in equally higher increase of the fennel yield attributes and yield. The yield attributes and yield were found to be higher due to higher nutrient availability under the recommended dose of fertilizer. The longer period of the reproductive phase due to higher nutrition (N P and K) resulted into higher seed yield per hectare. The significantly highest biological yield was also recorded with 100 % RDF and the lowest, under control, respectively. The results suggest that NPK fertilization improved both direct parameters like dry matter accumulation and indirect traits such as branching and reproductive structures confirming earlier studies of Kumawat *et al.* (2015) and Kumar *et al.* (2021).

Table 3 Effect of weed control and nutrient management treatments on fennel growth parameters

Treatment	Plants population/ ha	Plant height (cm)	No. of branches	Dry matter accumulation (g/m^2)		CGR (g/m^2/day)		RGR (mg/g/day) 50 DAS – at harvest
				At 50 DAS	At harvest	0-50 DAS	50 DAS – at harvest	
Nutrient management								
Control	78061	93.45	5.56	31.29	289.49	0.63	2.58	2.44
75% RDF	80000	107.29	6.55	37.64	341.96	0.75	3.04	2.51
100 % RDF	81654	119.40	7.21	41.92	378.05	0.84	3.36	2.56
125 % RDF	82165	121.62	7.38	42.38	382.10	0.85	3.40	2.56
LSD (p=0.05)	NS	8.12	0.52	3.00	23.95	0.06	0.24	0.03
Weed control measures								
Weed free	90129	122.17	8.15	45.49	396.52	0.91	3.51	2.58
Pendimethalin 0.75 kg/ha PE	86892	120.28	7.30	40.55	377.64	0.81	3.37	2.56
Oxyfluorfen 50 g/ha PoE at 25 DAS	79062	107.70	6.90	38.03	349.73	0.76	3.12	2.52
Weedy check	65797	91.63	4.36	29.16	267.71	0.58	2.39	2.41
LSD (p=0.05)	6097	8.12	0.52	3.00	23.95	0.06	0.24	0.03

RDF = Recommended dose of fertilizer, NS= Non – significant, DAS= Days after sowing, PE= Pre-emergence, PoE= post-emergence, the figures in the parentheses were original values

Table 4 Effect of weed control and nutrient management treatments on fennel yield attributes, yield and economics

Treatment	Biological yield (kg/ha)	Seed yield (kg/ha)	Harvest index (%)	Net returns (x10^3 Rs/ha)	B: C ratio
Nutrient management					
Control	2.86	0.81	29.64	41.95	2.19
75% RDF	3.56	1.01	28.76	58.00	2.56
100 % RDF	3.98	1.13	28.61	68.71	2.78
125 % RDF	4.12	1.17	28.64	71.66	2.82
LSD (p=0.05)	0.19	0.07	NS	6.62	0.16
Weed control measures					
Weed free	4.59	1.31	28.57	76.78	2.62
Pendimethalin 750 g/ha PE	3.89	1.12	28.85	70.33	2.97
Oxyfluorfan50 g/ha PoE at 25 DAS	3.69	1.00	28.29	60.97	2.79
Weedy check	2.34	0.69	29.95	32.24	1.98
LSD (p=0.05)	0.19	0.07	NS	6.62	0.16

RDF = Recommended dose of fertilizer, NS= Non – significant, PE= Pre-emergence, PoE= Post- emergence, DAS= Days after sowing, the figures in the parentheses were original values

Economics

Significantly highest net returns and benefit: cost ratio (2.78) were recorded with 100% RDF. All weed control treatments recorded significantly higher net returns and B:C ratios compared to the weedy check, primarily due to their higher seed yields (**Table 4**). The weed-free treatment produced the highest net returns and a B: C ratio of 2.67. Pendimethalin at 0.75 kg/ha PE recorded next highest net returns with the highest B: C ratio of 2.97, due to its lower application cost. In contrast, unrestricted weed growth in the weedy check resulted in the lowest net returns and B: C ratio (1.98) confirming earlier reports by Yadav *et al.* (2016) in coriander, Choudhary *et al.* (2021) and Mamantha *et al.* (2021) in fennel.

Conclusion

It was concluded that maximum fennel growth and yield attributes, yield, net return and the highest B: C ratio due to effective management of weeds can be attained with pendimethalin 0.75 kg/ha PE and weed-free (hand weeding thrice) in fennel crop. The season-long weed-free conditions and optimal nutrient management (100% RDF) are critical for maximizing fennel productivity and profitability. However, these results are only indicative and further experimentation is required to arrive at more consistent and definite conclusions for recommendation to the farmers.

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RESEARCH NOTE

Effect of integrated weed management on weed growth and yield of onion

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ABSTRACT

A field experiment was carried out during *Rabi*, 2024-2025 at the Vegetable Research Farm, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur. The objective of the study was to identify integrated weed management option to manage weeds and attain higher onion yield. There were twelve treatments, replicated thrice in randomized block design. The major weed flora associated with onion were: *Poa annua* (37.31%) followed by *Coronopus didymus* (16.55%), miscellaneous weeds (15.76%), *Euphorbia sp*. (11.94%), *Capsella bursa-pastoris* (9.34%) and *Gallinsoga parviflora* (9.1%). The weed free, pre-emergence application (PE) of pendimethalin 1.0 kg/ha followed by (*fb*) hand weeding (HW) twice at 45 and 70 days after transplanting (DAT) onion and post-emergence application (PoE) of oxyfluorfen 0.15 kg/ha *fb* HW twice at 45 and 70 DAT, efficiently reduced the density and biomass of different weed species with higher highest weed control efficiency at 90 DAT. It is concluded that effective and economical weed management and higher onion yield can be obtained with pendimethalin 1.0 kg/ha PE *fb* HW twice at 45 and 70 DAT.

Keywords: Onion, Oxyfluorfen, Pendimethalin, Weed free, Weed control efficiency

Onion (*Allium cepa* L.), a member of the family Amaryllidaceae, is one of the important vegetable crops grown all over the globe. In India, onion is being grown on an area of 1.53 million hectares with production of 25.47 million tons and the productivity is about 16.64 tons/hectare (Anonymous 2023). Onion is more vulnerable to weed competition than many other crops because of its short statured plants, less canopy formation, limited foliage, shallow roots, slow initial crop growth and prolonged growth period. Although, hand weeding is effective but it is more labour-intensive, time-consuming and economically unviable under many circumstances. Consequently, the application of both pre-emergence and post-emergence herbicides individually or in combination, presents a viable option for farmers to minimize crop-weed competition during both early and later stages of crop growth. In many instances, farmers are unable to apply pre-emergence herbicides in a timely manner. Therefore, identifying suitable post-emergence herbicides or their combinations supplemented with hand weeding are essential for managing the complex weed flora. Thus, this study was conducted with an objective to identify integrated weed management option with post-emergence herbicides as a component to manage weeds and attain higher onion yield.

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MATERIALS AND METHODS

The soil of mid-hill conditions of Palampur was of podzolic type with pH range of 5.0-6.0. The experiment with 12 treatments was laid out in randomized block design with 3 replications. Two herbicides and their combinations tested include: pre-emergence application (PE) of pendimethalin 1.0 kg/ha, pendimethalin 1.5 kg/ha PE, pendimethalin 1.0 kg/ha PE followed by (*fb*) hand weeding (HW) at 45 days after transplanting (DAT), pendimethalin 1.0 kg/ha PE *fb* HW twice at 45 and 70 DAT, post-emergence application (PoE) of oxyfluorfen 0.15 kg/ha, oxyfluorfen 0.25 kg/ha PoE, oxyfluorfen 0.15 kg/ha PoE *fb* HW at 45 DAT, oxyfluorfen 0.15 kg/ha PoE *fb* HW twice at 45 and 70 DAT, pendimethalin 1.0 kg/ha PE *fb* oxyfluorfen 0.15 kg/ha PoE, HW twice at 45 and 70 DAT, weed free and weedy check. Pre-emergence application of pendimethalin was done two days before transplanting and the post-emergence spray of oxyfluorfen was done on December 30, 2024. Onion variety '*Palam Lohit*' was transplanted at a spacing of 15 x 10 cm on December 9, 2024. Observations on species-wise weed density, total weed biomass at 30, 60, 90, 120 days after transplanting (DAT) and at harvest were taken and weed control efficiency was also calculated for 60, 90 and 120 DAT. A quadrat of 25 x 25 cm was placed randomly at two spots in each plot and the species-wise weed count (density) was recorded and the average density was calculated as no./m^2. The crop was harvested on May 23, 2025. The data of weed density and biomass were subjected to square root transformation *i.e.* $\sqrt{(x + 0.5)}$) prior to statistical analysis.

RESULTS AND DISCUSSION

The experimental field was predominated by *Poa annua*, *Coronopus didymus*, *Euphorbia* sp., *Capsella bursa-pastoris*, *Gallinsoga parviflora* and miscellaneous weeds. All the weed management treatments resulted in significant reduction of weed flora at different stages of observation (**Table 1** and

Table 1. Effect of weed management treatments on density (no./m^2) of different weeds at 60 and 120 days after transplanting (DAT) onion

Treatment	*Poa annua*		*Coronopus didymus*		*Euphorbia* sp.		*Capsella bursa-pastoris*		*Gallinsoga parviflora*	
	60 DAT	120 DAT	60 DAT	120 DAT	60 DAT	120 DAT	60 DAT	120 DAT	60 DAT	120 DAT
Pendimethalin PE 1.0 kg/ha	12.19 (148.10)	7.99 (63.34)	7.68 (58.52)	8.59 (73.29)	7.32 (53.08)	7.32 (53.08)	6.97 (48.08)	6.90 (47.11)	6.54 (42.27)	6.97 (48.08)
Pendimethalin PE 1.5 kg/ha	11.29 (126.96)	7.32 (53.08)	6.97 (48.08)	8.30 (68.39)	6.90 (47.11)	6.96 (47.94)	6.90 (47.11)	6.54 (42.27)	6.12 (36.95)	6.54 (42.27)
Pendimethalin PE 1.0 kg/ha *fb* HW 45 DAT	6.92 (47.37)	6.12 (36.95)	5.32 (27.80)	6.29 (39.06)	4.65 (21.12)	6.34 (39.70)	5.20 (26.54)	5.15 (26.02)	5.15 (26.02)	5.87 (33.96)
Pendimethalin PE 1.0 kg/ha *fb* HW twice at 45 and 70 DAT	6.14 (37.20)	4.61 (20.75)	4.61 (20.75)	4.35 (18.42)	4.36 (18.51)	4.65 (21.12)	4.61 (20.75)	5.03 (24.8)	4.90 (23.51)	4.65 (21.12)
Oxyfluorfen PoE 0.15 kg/ha	15.83 (250.03)	15.15 (229.02)	7.92 (62.23)	8.30 (68.39)	7.68 (58.52)	8.03 (63.98)	7.32 (53.08)	7.32 (53.08)	6.90 (47.11)	7.67 (58.33)
Oxyfluorfen PoE 0.25 kg/ha	16.00 (255.5)	14.06 (197.18)	7.68 (58.52)	8.94 (79.42)	7.32 (53.08)	7.99 (63.34)	7.25 (52.06)	7.15 (50.62)	7.32 (53.08)	8.05 (64.30)
Oxyfluorfen PoE 0.15 kg/ha *fb* HW 45 DAT	5.92 (34.55)	6.76 (45.20)	4.95 (24.00)	6.29 (39.06)	4.61 (20.75)	6.29 (39.06)	4.90 (23.51)	5.58 (30.64)	5.58 (30.64)	6.14 (37.20)
Oxyfluorfen PoE 0.15 kg/ha *fb* HW twice at 45 and 70 DAT	5.89 (34.19)	5.45 (29.20)	5.15 (26.02)	5.15 (26.02)	4.36 (18.51)	4.60 (20.66)	5.15 (26.02)	4.90 (23.51)	4.65 (21.12)	4.90 (23.51)
Pendimethalin PE *fb* oxyfluorfen PoE 1.0 *fb* 0.15 kg/ha	8.51 (71.94)	6.54 (42.27)	6.00 (35.50)	7.13 (50.34)	5.70 (31.99)	7.01 (48.64)	6.54 (42.27)	5.87 (33.96)	5.92 (34.55)	6.90 (47.11)
Hand weeding (HW) twice at 45 and 70 DAT	5.67 (31.65)	5.89 (34.19)	5.20 (26.54)	5.32 (27.80)	4.06 (15.98)	5.20 (26.54)	4.06 (15.98)	4.61 (20.75)	4.95 (24.00)	4.61 (20.75)
Weed free	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)
Weedy check	19.01 (360.88)	17.04 (289.86)	12.97 (167.72)	13.26 (175.33)	9.54 (90.51)	10.35 (106.62)	9.54 (90.51)	10.08 (101.11)	7.68 (58.51)	10.22 (103.95)
LSD (p=0.05)	1.53	1.35	1.53	1.60	1.04	1.26	1.17	1.49	1.03	1.25

Value in parentheses are the means of original values, DAT= days after transplanting, PE: pre-emergence, PoE: post-emergence

Table 2. Effect of weed management treatments on total weed biomass and weed control efficiency at different stages of onion growth

Treatment	Total weed biomass (g/m^2)					Weed control efficiency (%)		
	30 DAT	60 DAT	90 DAT	120 DAT	At harvest	60 DAT	90 DAT	120 DAT
Pendimethalin PE 1.0 kg/ha	1.1(0.8)	14.2(200.9)	15.0(224.5)	14.6(213.0)	13.5(182.3)	75.90	77.55	71.70
Pendimethalin PE 1.5 kg/ha	1.1(0.8)	14.1(197.7)	14.3(204.6)	13.9(194.1)	12.8(162.3)	76.28	79.54	74.21
Pendimethalin PE 1.0 kg/ha *fb* HW 45 DAT	1.2(0.9)	7.8(60.3)	13.8(176.4)	12.9(166.9)	10.6(112.9)	92.76	82.36	77.82
Pendimethalin PE 1.0 kg/ha *fb* HW twice at 45 and 70 DAT	1.2(1.0)	7.7(58.6)	3.2(9.5)	4.8(22.9)	4.5(19.4)	92.96	99.05	96.95
Oxyfluorfen PoE 0.15 kg/ha	3.5(12.0)	25.7(662.0)	27.5(755.7)	25.7(661.0)	19.1(364.6)	20.57	24.42	12.16
Oxyfluorfen PoE 0.25 kg/ha	4.5(19.4)	24.0(574.1)	26.3(694.1)	21.9(480.7)	15.3(234.2)	31.13	30.58	36.12
Oxyfluorfen PoE 0.15 kg/ha *fb* HW 45 DAT	4.4(18.9)	8.6(74.6)	14.0(196.1)	13.8(190.8)	12.8(162.6)	91.04	80.39	74.64
Oxyfluorfen PoE 0.15 kg/ha *fb* HW twice at 45 and 70 DAT	4.2(17.6)	9.0(80.5)	5.7(32.2)	5.9(28.9)	4.9(19.1)	90.34	96.78	96.15
Pendimethalin PE *fb* oxyfluorfen PoE 1.0 *fb* 0.15 kg/ha	1.2(0.9)	10.6(109.3)	14.6(199)	13.3(175.9)	11.1(122.2)	86.88	80.09	76.63
Hand weeding (HW) twice at 45 and 70 DAT	4.5(19.6)	7.9(62.7)	5.8(33.7)	9.6(83.2)	9.1(82.9)	92.48	96.63	88.95
Weed free	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	-	-	-
Weedy check	4.1(16.6)	28.9(833.5)	31.6(999.9)	27.4(752.5)	19.9(393.5)	-	-	-
LSD (p=0.05)	0.24	1.35	1.55	1.48	1.22			

Value in parentheses are the means of original values, DAT= days after transplanting, PE: pre-emergence, PoE: post-emergence; *fb* = followed by

Table 3. Effect of weed management treatments on economics in onion

Treatment	Bulb yield (t/ha)	Gross returns (x10^3 INR/ha)	Cost of cultivation (x10^3 INR/ha)	Net returns (x10^3 INR/ha)	B:C ratio
Pendimethalin PE 1.0 kg/ha	11.59	231.88	116.45	115.43	0.99
Pendimethalin PE 1.5 kg/ha	11.94	238.78	117.93	120.85	1.02
Pendimethalin PE 1.0 kg/ha *fb* HW 45 DAT	20.45	409.00	138.73	270.26	1.95
Pendimethalin PE 1.0 kg/ha *fb* HW twice at 45 and 70 DAT	24.96	499.12	154.45	344.67	2.23
Oxyfluorfen PoE 0.15 kg/ha	5.51	110.30	107.01	3.29	0.03
Oxyfluorfen PoE 0.25 kg/ha	8.12	162.50	110.48	52.02	0.47
Oxyfluorfen PoE 0.15 kg/ha *fb* HW 45 DAT	14.75	295.06	129.42	165.64	1.28
Oxyfluorfen PoE 0.15 kg/ha *fb* HW twice at 45 and 70 DAT	20.93	418.66	147.69	270.97	1.83
Pendimethalin PE *fb* oxyfluorfen PoE 1.0 *fb* 0.15 kg/ha	16.42	328.44	125.36	203.07	1.62
Hand weeding (HW) twice at 45 and 70 DAT	20.76	415.12	145.75	269.37	1.85
Weed free	28.71	574.30	202.74	371.55	1.83
Weedy check	0.98	19.56	98.09	-	-
LSD (p=0.05)	2.71	-	-		

fb= followed by, DAT= days after transplanting, PE: pre-emergence application, PoE: post-emergence application

2). The minimum density of *Poa annua*, *Coronopus didymus*, *Euphorbia* sp., *Capsella bursa-pastoris*, *Gallinsoga parviflora* and miscellaneous weeds; maximum weed control efficiency at all the growth stages studied was recorded with weed free, pendimethalin 1.0 kg/ha PE *fb* HW twice at 45 and 70 DAT and oxyfluorfen 0.15 kg/ha PoE *fb* HW twice at 45 and 70 DAT confirming findings of Rajkumara and Palled (2009) and Vashi *et al.* 2012. The maximum onion bulb yield and benefit cost ratio was observed with weed free, which was followed by pendimethalin 1.0 kg/ha PE *fb* HW twice at 45 and 70 DAT (**Table 3**) confirming Paikra and Kumar (2025).

It is concluded that effective and economical weed management and higher onion yield can be obtained with pendimethalin 1.0 kg/ha PE *fb* HW twice at 45 and 70 DAT.

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