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RESEARCH ARTICLE

Liming for the management of submerged aquatic weeds in rice

P. Prameela*, Savitha Antony and S.G. Gowtham

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ABSTRACT

Submerged aquatic flora are problem weeds, not only in aquatic bodies but also in wetland rice. An experiment was conducted at Kerala Agricultural University to assess the efficacy of different liming materials to manage submerged aquatic weeds in an eco-friendly manner. Preliminary studies were conducted in tanks containing *Hydrilla* spp., *Najas* spp. and *Utricularia* spp. Quicklime was effective among the three liming materials tested, while calcium carbonate and dolomite were ineffective. The increase in dose of quick lime from 2, 4, 6, 8 and 10 g/L of water in the tank resulted in a significant and rapid decline in chlorophyll content of weeds. Complete mortality of weeds occurred within four weeks of liming. In rice fields with acid soil, more than 80% weed control was observed with application of quicklime 300g/m^2 or above, which resulted in rice grain yield comparable to hand weeded plot. Rapid fluctuations in various water quality parameters were observed, including pH, electrical conductivity (EC), acidity, alkalinity, carbonate, bicarbonate, nitrate, and hardness; but the values stabilized two weeks after application. The study revealed that the application of quicklime serves as an effective method for managing submerged freshwater aquatic weeds in rice.

Keywords: Quicklime, *Hydrilla*, *Utricularia*, *Najas*, Rice, Submerged aquatic weeds, Water quality

INTRODUCTION

In India, the proliferation of submerged aquatic weeds poses a major challenge in freshwater ecosystems including rivers, canals, ponds, and irrigation systems (Sushilkumar 2011, Kawade *et al.* 2023). Weeds including *Cabomba furcata*, *Lymnophylla heterophylla*, *Hydrilla verticillata*, *Najas* spp., and *Utricularia* spp. obstruct water flow, reduce water availability, and disturb ecological balance. Infestation in the Chambal irrigation canals reduced water flow by 40–50% (Holm *et al.* 1991). The aquatic weeds were dominant in rice fields, in the initial stages of crop growth, when rice in cultivated under intensive wet tillage (puddling) conditions mainly in lowland and medium lowland areas where water from ponds were continuously available (Rao *et al.* 2017). In rice fields of Kerala, where such conditions exist, *Najas* spp. and *Utricularia* spp. are often problem weeds in transplanted rice, due to the availability of conducive light and space during the early growth phase (AICRP 2020). Physical removal, though commonly practiced, is often ineffective due to rapid regeneration of biomass. Chemical methods including bispyribac-sodium, glyphosate, 2,4-D, penoxsulam, and endothall have been evaluated with varying efficacy elsewhere (Durborow 2014). Endothall reduced *Cabomba* spp. biomass by 67% within four weeks at 5 mg/L (Hofstra *et al.* 2021). However, herbicides are not registered, currently, in India for submerged aquatic weed management.

As alternatives to synthetic herbicides, liming agents such as calcium hydroxide [$Ca(OH)_2$] and quicklime (CaO) have been reported effective by altering water pH and nutrient availability. Murphy and Prepas (1990) demonstrated that $Ca(OH)_2$ 250 mg/L reduced chlorophyll from 0.75 mg/L to <0.25 mg/L in hard water lakes, outperforming $CaCO_3$. Similarly, Zhang and Prepas (1996) reported >50% reduction in chlorophyll within 20 days at 25–87 mg/L $Ca(OH)_2$. In mesocosm and canal studies, Chambers *et al.* (2001) observed suppression of *Potamogeton pectinatus* with 200–210 mg/L $Ca(OH)_2$, while Reedyk *et al.* (2001) documented ~80% biomass reduction of *Ceratophyllum demersum* and *Potamogeton* spp. at 74–107 mg/L $Ca(OH)_2$. These findings emphasise the potential of liming materials as viable tools for submerged aquatic weed management. Thus, this experiment was conducted with an objective to assess the efficacy of using different liming materials to manage submerged aquatic weeds in the rice ecosystem of Kerala, India.

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MATERIALS AND METHODS

The experiments were conducted during the period from 2020 to 2024 at the College of Agriculture, Thrissur, Kerala and farmers' field at various locations. The experiment consisted of two tank studies and multi-location field experiments. Pilot tank studies were conducted to identify the effective liming material, dose and impact on water quality, in tanks of 50 L capacity. After placing a bottom layer of 3 kg soil, the tanks were filled with 30 L of fresh water and a uniform quantity of fresh weeds weighing 300g was placed in each tank. To identify the effective liming material for controlling submerged weeds, varied doses of three liming materials such as quick lime (CaO), calcium carbonate ($CaCO_3$) and dolomite ($CaCO_3$ and $MgCO_3$) at varied doses ranging from 0.5 g/ L to 20 g/ L of water in the tank were administered. The neutralizing values of these amendments were 125, 100 and 95, respectively.

Standardisation of dose of quicklime

As quicklime was the only effective liming material, the second tank study was conducted to standardize the dose of quicklime. The treatments consisted of 2, 4, 6, 8, and 10 g of CaO per liter of water in the tank. Untreated tanks with weed (UTC+W) and without weed (UTC-W) were also maintained for effective comparison. The complete randomized block design was used with three replications.

The pH and electrical conductivity (EC) of water were assessed at 2 hours after application (HAA) and at, 1, 7, 15, 21 and 30 days after application (DAA). Other water quality parameters like carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), total alkalinity, total hardness, acidity were estimated at 15 days interval, and nitrate, phosphate, calcium, magnesium, iron and manganese were estimated at 30 DAA

The extent of weed control was recorded based on visual assessment at 14, 21, and 30 DAA and expressed as percentage control (**Figure 1**). The percentage control of weeds, chlorophyll degradation, and a combination of both these parameters were used for assessing weed control efficiency. Regrowth of weeds was observed at 30 DAA. Phytotoxicity rating was given based on the standard scoring of 0-5 scale (0 - no control, 1 - slight control, 2 - moderate control, 3 - good control, 4 – very good control, 5 - complete control) (Thomas and Abraham 2007). The data were statistically analyzed using ANOVA, and the significant differences between treatments were studied using TUKEY's test.

The field experiments were conducted at three locations (Alathur, Pattambi and Pukottukavu) in Palakkad district of Kerala. The submerged aquatic weed infestations in transplanted rice occurred at 25-30 day after rice establishment. *Najas* spp, and *Utricularia* spp. were the dominant weeds and all other weeds of rice were absent. Treatments were applied in plots of 5 x 4m. The average rice stand was 20-25 hills/m^2. The variety of rice was Uma (medium duration variety, 125-130 days). The soil pH of experimental sites ranged from 5.06 - 5.78. Quick lime 120, 180, 240, 300 to 420 g/m^2 was broadcasted, as per the treatments tested. The dosages starting from 120 g/m^2 were tested since the infestations were observed even in fields applied with recommended doses of 600 kg/ha (60 g/m^2) lime (KAU 2024). The doses were fixed based on FAO recommendations for pond liming (2000-4000 kg/ha) (FAO 2022). Change in soil pH at 10 days after application (DAA), percent weed control and rice grain yield were recorded.

RESULTS AND DISCUSSION

Comparative efficacy of liming materials

The quick lime alone was effective against the submerged weeds. Calcite and dolomite did not cause any phytotoxic effect and failed to control submerged weeds which might be due to the fact that the reaction between calcite and dolomite with water is an endothermic process. In addition, the reaction of calcium carbonate and magnesium carbonate with water is very slow. Calcium carbonate is insoluble in water and exhibits solubility in CO_2 saturated water, producing calcium bicarbonate, a weak base that dissolves in water. This could be the reason for its less detrimental effect on weeds. Similar is the case with dolomite also which yields bicarbonates of magnesium and calcium which yields weak base on its dissolution in CO_2 saturated water. However, when CaO reacts with water, it undergoes an exothermic process, producing $Ca(OH)_2$ which is a strong base which resulted in cell damage of submerged weeds followed by decay.

By 14 days after application percent weed control ranged from 80% even when CaO 2g/L was applied, to more than 90% with higher rates. By 21 DAA complete control was observed at all doses except the lower dose of 2g/L where it took a longer period of 30 days (**Figure 1**). This is clear from the observations on chlorophyll content (**Figure 2**) where the initial content was 1.67 mg/L. Notable decline in chlorophyll content was observed immediately after application. Chlorophyll content decreased to 0.08 mg/g by 7 days due to the highly corrosive action of calcium oxide in water. More than

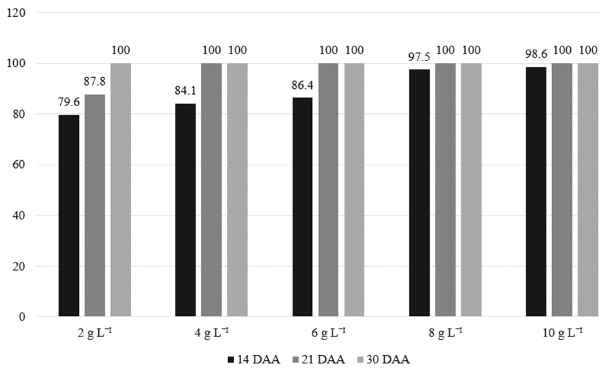

Figure 1. Percentage control of weeds, based on visual phytotoxicity and chlorophyll content, with the application of different doses of quicklime (CaO)

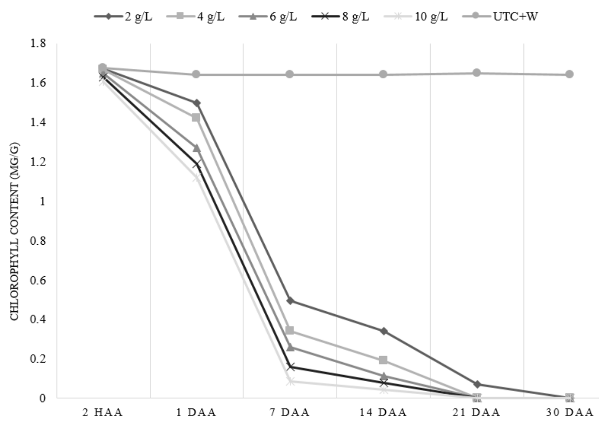

Figure 2. Total chlorophyll content of weeds as affected by different doses of quicklime (CaO)

50% reduction in chlorophyll content was observed at higher doses after 14 days of liming. By 30 days, complete chlorophyll degradation and weed control was observed in all the quicklime applied tanks.

The degradation of chlorophyll content of weeds occurred due to the vigorous exothermic reaction between calcium oxide and water. When calcium oxide reacts with water, it produces a solution of calcium hydroxide, which is a strong base, leading to cell damage. The addition of quicklime alters the inorganic carbon chemistry within soft water systems, limiting the availability of free CO_2 for the photosynthesis of submerged aquatic macrophytes (James 2011). Pond liming has the potential to shift the equilibrium of inorganic carbon towards bicarbonate dominance by transiently increasing the pH of soft water.

In addition to altering CO_2 chemistry, the rise in pH hindered oxygen within mesophyll cells and decreased the activity of ribulose-1,5-bisphosphate carboxylase (RuBP), consequently affecting photosynthesis and photorespiration of plant cells (Servaites and Ogren 1977). The complete weed control with quicklime application in all the tanks by 30 days can be attributed to the above reasons. Weeds in the untreated tanks exhibited consistent chlorophyll content, and their growth continued unabated.

Water quality parameters like pH, EC, carbonates, bicarbonates, alkalinity, total hardness, calcium, increased with increasing dose of quicklime. The values remained higher than the initial and the contents decreased over time (up to 30 days). The content nitrate, total nitrogen, phosphates, magnesium, iron, and manganese decreased with increasing dose of quicklime.

Significant increase in pH and EC was noticed after quicklime application (**Table 1** and **2**). pH increased till 2nd day in all the treatments, ranging from 10.57 to 11.44. There was a drastic increase in EC up to 14 days ranging from 0.66 dS/m to 3.56 dS/m. However, the pH and EC values remained higher than the untreated check in the range of 8.82 to 9.0 and 0.56 dS/m to 1.83 dS/m throughout the post-treatment period (30 days).

The trend in decrease of pH is the effect of organic matter content, Cation Exchange Capacity (CEC) and buffering capacity of the soil. As suggested by Panda *et al.* (2012), the pH of the solution depends on the CEC and buffering capacity of the soil and organic matter. Soil organic matter contains reactive carboxylic and phenolic groups that behaves as weak acids and they dissociate releasing H^+ ions which could increase the acidity of the solution. Liming could facilitate easy degradation of organic matter releasing organic acids, phenols, and H^+ ions.

Table 1. Effect of different quicklime doses on pH of water at different days after application (DAA)

Treatment	2 HAA	1 DAA	7 DAA	14 DAA	21 DAA	30 DAA
Quicklime 2 g/L	9.66^{d}	10.57^{d}	9.62^{e}	9.31^{e}	9.12^{c}	8.82^{d}
Quicklime 4 g/L	9.80^{cd}	10.88^{c}	9.83^{d}	9.57^{d}	9.18^{c}	8.95^{cd}
Quicklime 6 g/L	9.90^{c}	11.08^{b}	10.31^{c}	10.04^{c}	9.48^{b}	9.06^{c}
Quicklime 8 g/L	10.22^{b}	11.30^{a}	10.92^{b}	10.65^{b}	9.99^{a}	9.37^{b}
Quicklime 10 g/L	10.50^{a}	11.44^{a}	11.24^{a}	10.95^{a}	10.18^{a}	9.71^{a}
Untreated tanks with weeds	7.42^{e}	7.45^{e}	7.51^{f}	7.51^{f}	7.59^{d}	7.61^{e}
Untreated tanks without weeds	7.30^{e}	7.33^{e}	7.36^{f}	7.34^{f}	7.37^{e}	7.36^{f}

HAA - hours after application

Carbonates, bicarbonates, alkalinity, total hardness increased by 15 days, thereafter gradually decreased (**Figure 3**). Bicarbonates, total hardness, and alkalinity content ranged from 1.33 meq/L to 5.0 meq/L, 154.67 meq/L to 348.67 meq/L and 70 mg/L to 226.66 mg/L, respectively by 30 days. It can be attributed to the buffering capacity of water and the reaction of quicklime in water. The hydroxide ions (OH^-) formed in the solution cause immediate increase in pH and EC of water and rapidly react with CO_2, forming carbonates and bicarbonates. This resulted in increase in the alkalinity and total hardness. However, with time, due to gradual release of CO_2 from the solution, the carbonates and bicarbonates reached equilibrium in water and thereby alkalinity and total hardness got decreased by 30 days of lime application.

By 30 days after liming, nutrient content in water decreased with the increasing dose of quicklime (**Table 3**). Nitrate content decreased from initial value of 4.70 mg/L to 2.92 mg/L and 1.04 mg/L. This might be due to denitrification losses. Under high pH and alkalinity, the nitrate will be converted to nitrogen gas while ammonium (NH_4^+) will get reduced to ammonia (NH_3) which will be lost through volatilization.

Similarly, total nitrogen decreased from 6.60 mg/L to 1.19 mg/L and phosphate from 59.28 mg/L to 6.75 mg/L. Phosphorus precipitated as calcium phosphate and thereby decreased the phosphate concentration in solution. Magnesium, iron, and manganese content of water decreased by 27, 39, and 39%, respectively after 30 days in higher doses of quicklime application (10 g/L). Deb *et al*. (2012) reported that the availability of iron and manganese reduced at higher pH as the oxidized forms of iron (Fe^{3+}) and manganese (Mn^{3+}) are less soluble. The higher pH of the soil solution facilitated the oxidation of iron and manganese which are less soluble causing decreased availability of these metal cations.

Table 2. Effect of quicklime doses on EC of water at different days after application (DAA)

Treatment	2 HAA	1 DAA	7 DAA	14 DAA	21 DAA	30 DAA
Quicklime 2 g/L	0.25^{d}	0.52^{d}	0.54^{e}	0.66^{d}	0.62^{d}	0.56^{e}
Quicklime 4 g/L	0.27^{cd}	0.66^{cd}	0.80^{d}	0.77^{d}	0.71^{cd}	0.65^{d}
Quicklime 6 g/L	0.29^{bc}	0.79^{c}	1.24^{c}	1.40^{c}	0.82^{c}	0.84^{c}
Quicklime 8 g/L	0.32^{b}	1.21^{b}	2.36^{b}	2.03^{b}	1.36^{b}	0.93^{b}
Quicklime 10 g/L	0.65^{a}	2.03^{a}	2.63^{a}	3.56^{a}	2.93^{a}	1.83^{a}
Untreated tanks with weeds	0.13^{e}	0.14^{e}	0.13^{f}	0.14^{e}	0.14^{e}	0.14^{f}
Untreated tanks without weeds	0.12^{e}	0.13^{e}	0.12^{f}	0.13^{e}	0.13^{e}	0.13^{f}

HAA - hours after application, untreated tanks with weeds (UTC+W) and without weeds (UTC-W)

Table 3. Effect of different doses of quicklime on water quality parameters (mg/L) at 30 days after liming

Treatment	Nitrate	Magnesium	Iron	Manganese	Total nitrogen	Phosphate
Quicklime 2 g/L	2.92^{b}	3.00^{a}	0.247^{ab}	0.219^{a}	3.89^{b}	59.28^{a}
Quicklime 4 g/L	2.40^{c}	2.83^{b}	0.223^{bc}	0.175^{b}	3.15^{c}	44.04^{b}
Quicklime 6 g/L	1.77^{d}	2.62^{c}	0.210^{cd}	0.146^{bc}	2.26^{d}	30.48^{c}
Quicklime 8 g/L	1.35^{de}	2.49^{c}	0.197^{cd}	0.123^{cd}	1.69^{e}	18.63^{cd}
Quicklime 10 g/L	1.04^{ef}	2.28^{d}	0.163^{e}	0.105^{d}	1.19^{f}	6.75^{d}
Untreated tanks with weeds	3.76^{a}	3.12^{a}	0.273^{a}	0.25^{a}	5.10^{a}	71.16^{a}
Untreated tanks without weeds	0.62^{f}	1.10^{e}	0.197^{cd}	0.058^{e}	2.41^{d}	25.41^{c}
Pre-treatment values	4.70	3.55	0.38	0.43	6.60	81.33

Table 4. The extent of *Najas* spp. and *Utricularia* spp. control as affected by broadcasting of different doses of quicklime in wetland transplanted rice

Treatment	Extent of control (%)				
	Location- Alathur *Season* – I crop *Weed- Najas*	*Location*- Pattambi *Season* – II crop *Weed- Najas*	*Location*- Pattambi *Season* – II crop *Weed- Utricularia*	*Location*- Pukottukavu *Season* – II crop *Weed- Utricularia*	Pooled
Broadcasted quicklime 420 g/m^2	76.67	93.33	90.00	83.33	86.67
Broadcasted quicklime 300 g/m^2	73.33	86.67	83.33	80.00	81.11
Broadcasted quicklime 240 g/m^2	56.67	66.67	63.33	56.67	62.22
Broadcasted quicklime 180 g/m^2	23.33	33.33	30.00	33.33	28.89
Broadcasted quicklime 120 g/m^2	16.67	20.00	13.33	23.33	16.67
Untreated	-	-	-	-	
LSD(p=0.05)	5.95	11.66	10.31	10.60	

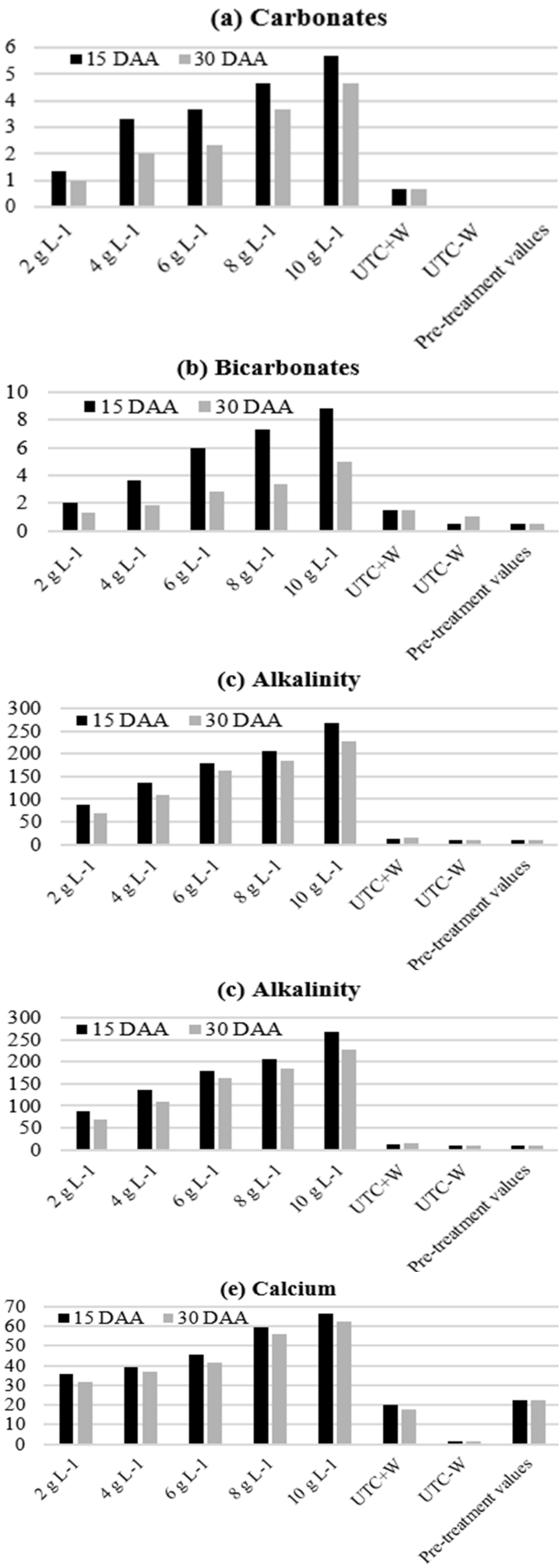

Figure 3. Variations in (a) carbonates, (b) bicarbonates, (c) alkalinity, and (d) total hardness and calcium (e) after 15 and 30 days after application of quicklime at different doses. (UTC+W = untreated tanks with weeds; UTC-W = untreated tanks without weeds)

The drastic reduction in nutrient contents can also be explained based on the coagulation and flocculation property of liming materials. Generally, the efficiency of a coagulant is pH dependent. Alkalinity plays a crucial role in supplying anions like hydroxide for the formation of insoluble compounds, facilitating their precipitation. In the current study, the application of quicklime at a higher dose led to twelvefold increase in alkalinity and pH by 2.0 units, persisting even one month after application. In addition to the pH dependent reduction in zeta potential (Lu and Gao 2010), the hydroxide ions formed after CaO application might have reacted with mineral ions and resulted in the formation of insoluble compounds like magnesium hydroxide, iron hydroxide, and manganese hydroxide which favoured the precipitation of these nutrients into the soil sediments.

Among various submerged aquatic weeds, *Najas* spp. and *Utricularia* spp. infestations are reported in rice fields with poor drainage. The trials were conducted in the *Najas* spp. and *Utricularia* spp. infested fields at three locations during 2021-2024. *Najas* spp. was the dominant weed. Infestation was observed at 25-30 day after rice transplanting and the average rice population was 20-25 hills/m^2.

More than 80 per cent weed control was observed when quick lime was applied at the rate of 300 g/m^2 and higher dosage rate (**Table 4**). There was no phytotoxicity to rice even at higher doses of lime. At 10 DAA, the soil pH ranged from 7.01-7.20 at higher doses (420 g/m^2) (**Table 6**). A higher and near neutral soil pH was observed in all the lime applied fields which were at par and significantly higher than the untreated check. There was no significant reduction in rice grain yield due to weed infestation (**Table 5**). This study demonstrated that quicklime (CaO) is a highly effective liming material for the eco-friendly management of submerged aquatic weeds such as *Hydrilla*, *Najas*, and *Utricularia*. Unlike calcium carbonate and dolomite, quicklime significantly reduced chlorophyll content and led to complete weed mortality within four weeks under controlled conditions.

It can be concluded that the infestation of submerged aquatic weeds like *Najas* and *Utricularia* in transplanted paddy, can be satisfactorily managed, in acidic soils, by localized application of quick lime 240-300 g/m^2 and thus, quicklime may serve as a promising and sustainable alternative for integrated weed management in aquatic and wetland transplanted rice ecosystems.

Table 5. Transplanted rice grain yield (t/ha) in submerged aquatic weeds (*Najas* spp. *and Utricularia* spp.) infested fields as affected by broadcasting of different doses of quicklime

Treatment	*Location*- Alathur *Season* – I crop *Weed- Najas*	**Location*- Pattambi *Season* – II crop *Weed- Najas*	**Location*- Pattambi *Season* – II crop *Weed- Utricularia*	*Location*- Pukottukavu *Season* – II crop *Weed- Utricularia*
Broadcasted quicklime 420 g/m^2	4.72	3.69	3.69	4.26
Broadcasted quicklime 300 g/m^2	4.51	3.48	3.48	4.47
Broadcasted quicklime 240 g/m^2	4.87	3.25	3.25	4.58
Broadcasted quicklime 180 g/m^2	4.22	3.57	3.57	4.87
Broadcasted quicklime 120 g/m^2	4.57	3.41	3.41	4.19
Untreated	4.33	3.39	3.39	4.47
LSD(p=0.05)	0.77	0.61	0.61	0.77

**Najas* spp. and *Utricularia* spp. were observed in the same field

Table 6. Change in soil pH 10 days after application of different doses of quicklime

Treatment	*Location*- Alathur *Season* – I crop *Weed- Najas*	**Location*- Pattambi *Season* – II crop *Weed- Najas*	**Location*- Pattambi *Season* – II crop *Weed- Utricularia*	*Location*- Pukottukavu *Season* – II crop *Weed- Utricularia*
Broadcasted quicklime 420 g/m^2	7.20	7.12	7.12	7.01
Broadcasted quicklime 300 g/m^2	6.47	7.64	7.64	6.71
Broadcasted quicklime 240 g/m^2	6.48	7.19	7.19	6.25
Broadcasted quicklime 180 g/m^2	6.57	6.34	6.34	6.07
Broadcasted quicklime 120 g/m^2	6.20	6.07	6.07	5.75
Untreated	5.78	5.54	5.54	5.06
LSD(p=0.05)	1.14	1.19	1.19	1.11

**Najas* and *Utricularia* were observed in the same field

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RESEARCH ARTICLE

Weed management efficacy of herbicide mixtures in transplanted rice under varied nutrient levels

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ABSTRACT

A field experiment was carried out at S.V. Agricultural College Farm, Tirupati, Andhra Pradesh, India during *Kharif* seasons of 2022-23 and 2023-24 to determine weed management efficacy of herbicide mixtures in transplanted rice under varied nutrient levels and to identify the best option to realize higher rice productivity. Among three tested nutrient levels, 100% recommended dose of fertilizer (RDF) recorded the lowest weed density and biomass with higher weed control efficacy. Amongst weed management treatments, hand weeding twice at 20 and 40 days after transplanting (DAT) recorded significantly lower density and biomass of all weed categories and higher weed control efficiency, followed by pre-emergence application (PE) of triafamone + ethoxysulfuron (ready-mix) 67.5 g/ha followed by (*fb*) post-emergence application (PoE) of halosulfuron-methyl 67.7 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) at 20 DAT, which was statistically comparable to bensulfuron-methyl + pretilachlor (ready-mix) 660 g/ha PE *fb* hand weeding at 40 DAT. The use of 150% RDF resulted in higher rice grain yield, straw yield, net returns and benefit cost ratio. Hand weeding twice at 20 and 40 DAT was statistically equivalent to triafamone + ethoxysulfuron (ready-mix) 67.5 g/ha PE *fb* halosulfuron-methyl 67.7 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) PoE at 20 DAT.

Keywords: Bensulfuron-methyl + pretilachlor, Halosulfuron-methyl + fenoxaprop-p-ethyl, Triafamone + ethoxysulfuron, Nutrient levels, Transplanted rice, Weed management

INTRODUCTION

Rice (*Oryza sativa* L.) is the world's most significant cereal crop, providing a staple food for 70% of the world's population and playing a critical part in global economic and social stability. Rice is grown on 47.8 million hectares in India, with a total production of 206.7 million tons and a productivity of 4.3 t/ha in 2023 (FAOSTAT 2025). One of the most common methods of establishing rice in an irrigated environment is by transplanting in puddle soil. This method is very important for enhancing the productivity of the rice.

In order to achieve a sustainable rice production, proper nutrient management is also important. The use of chemical fertilizer is the better approach to slow the rate of nutrient mining from soil. Blanket fertilizer application contributes to excess or insufficient nutrient balance in rice soils for realizing crop yield potential. Nutrient deficit is caused by poor fertilizer use, timing and manner of application, weed infestation, and crop weed competition (Swain *et al.* 2023).

Weeds are the key impediment in realizing optimal crop productivity (Rao 2022). Weed-related yield loss varies greatly according to the nature, extent and degree of weed problems, as well as the ecosystem in which the rice crop is cultivated (Rao *et al.* 2017). Manual weeding is exceedingly difficult and uneconomical during the cropping season due to continuous rains, scarcity, and high worker wages during peak weeding operations, particularly in the crop's early stages. Farmers seek a low-cost weed management technique for broad-spectrum weed control and higher rice yield. Thus, herbicides have emerged as a valuable and dependable weed management technique and ready-mix herbicides are available to manage mixed weed flora. Hence, this study was conducted with an objective to determine weed management efficacy of herbicide mixtures in transplanted rice under varied nutrient levels to

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identify the best option to realize higher transplanted rice productivity.

MATERIAL AND METHODS

A field experiment was conducted at S.V. Agricultural College's wet land farm in Tirupati during the *Kharif* seasons of 2022-23 and 2023-24. The soil had a sandy clay loam texture, a neutral reaction, low electrical conductivity, low organic carbon, low available nitrogen, medium available phosphorus and potassium. The experiment was laid up in split-plot design, with three nutritional levels *viz.*, 100% recommended dose of fertilizer (RDF), 125% RDF and 150% RDF under main plots and six weed management practices assigned to sub plots *viz.*, pre-emergence application (PE) of pretilachlor 750 g/ha followed by (*fb*) post-emergence application (PoE) of bispyribac-sodium 25 g/ha + pyrazosulfuron-ethyl 25 g/ha (tank-mix) at 20 days after transplanting (DAT), penoxsulam + butachlor 820 g/ha (ready-mix) PE *fb* bispyribac-sodium 25 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) PoE at 20 DAT, triafamone + ethoxysulfuron (ready mix) 67.5 g/ha PE *fb* halosulfuron-methyl 67.7 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) PoE at 20 DAT, bensulfuron methyl + pretilachlor (ready-mix) 660 g/ha PE *fb* hand weeding at 40 DAT, hand weeding twice at 20 and 40 DAT and unweeded check. The recommended fertilizer dose (RDF) for rice crops in southern agroclimatic zone of Andhra Pradesh is 120 N, 60 kg P, and 60 kg K/ha. The rice variety "*NLR-34449*" was used. Twenty-seven-day-old seedlings were transplanted at a spacing of 20 x 10 cm, two seedlings per hill. Nutrients were applied in accordance with the treatments in the form of urea, single superphosphate and muriate of potash. Nitrogen was applied in three stages: the initial, tillering and panicle initiation. The entire amount of phosphorus was supplied at the time of transplanting, whereas potassium was applied in two parts, half at the time of transplanting and the other half during the panicle initiation stage.

The needed amounts of PE and PoE herbicides were administered at one and 20 DAT, respectively, using 500 L/ha water and a battery-operated backpack sprayer fitted with a flat fan nozzle. The data collected on various crop factors during the study was statistically evaluated using the analysis of variance approach proposed by Panse and Sukhatme (1985). Statistical significance was determined using the F test at the 5% level of probability and treatment averages were compared using the crucial difference method. Weed density and biomass data was collected following standard recommended procedures. To standardize the distribution of weeds, the data was transformed using square roots. The weed control efficiency was computed using a standard formula and then transformed angularly.

RESULTS AND DISCUSSION

Weed growth

The predominant weed species noticed in the experimental transplanted rice field during both the years of study were: *Cynodon dactylon*, *Echinochloa colonum* and *Panicum repens* among grasses, *Cyperus iria* and *Cyperus rotundus* were the two dominant sedges and *Ammania baccifera*, *Bergia ammannioides*, *Commelina benghalensis*, *Eclipta alba* and *Marsilea quadrifolia* were broad-leaved weeds.

Nutrient levels and weed management approaches had a substantial impact on weed density and biomass, as well as improved weed control efficiency (**Table 1**). In terms of nutrient levels, using 100% RDF resulted in lower density and biomass of all categories of weeds, as well as increased weed control efficiency. The next best nutrient level was 125% RDF. Optimum nutrition availability may have fostered good crop growth, resulting in lower weed density and biomass, and hence improved weed control efficiency. This could be owing to a lack of nutrients, which resulted in poor weed growth as reported by Kumari *et al.* (2021). The highest density and biomass of all weed categories, as well as lowest weed control efficacy, were observed with 150% RDF across both years of study owing to higher growth and development of all weed categories at higher level of nutrients.

Significantly lower density and biomass of grasses, sedges, broad-leaved weeds and total weeds as well as higher weed control efficiency was recorded with hand weeding twice at 20 and 40 DAT than rest of the weed management treatments. Among the herbicide treatments, the lowest weed density and biomass of all categories of weeds and higher weed control efficiency was recorded with triafamone + ethoxysulfuron (ready-mix) 67.5 g/ha PE *fb* halosulfuron-methyl 67.7 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) PoE at 20 DAT, which was statistically at par with bensulfuron-methyl + pretilachlor (ready-mix) 660 g/ha PE *fb* hand weeding at 40 DAT. Effective management of all categories of weeds during the critical stages with hand weeding might have reduced the weed density at later stages of the crop growth and similarly sequential application of pre-and post-emergence herbicides might have killed the germinated weeds from weed seed bank resulting in lower number of weeds and higher weed control efficiency in the herbicide treated plots confirming the findings of Mir *et al.* (2023) and Shah *et al.* (2023). The next best weed management practice in recording lower weed density and biomass as well as higher weed control efficiency was penoxsulam + butachlor (ready-mix) 820 g/ha PE *fb* bispyribac-sodium 25 g/ha + fenoxaprop-p-ethyl (tank-mix) 60 g/ha PoE at 20 DAT, which was however statistically comparable with pretilachlor 750 g/ha PE *fb* bispyribac-sodium 25 g/ha + pyrazosulfuron-ethyl (tank-mix) 25 g/ha PoE at 20 DAT. Effective control of all categories of weeds at critical period of crop-weed competition resulted lower density and biomass and higher weed control efficiency. Pre-emergence application of ready-mix herbicides, *viz.* penoxsulam + butachlor, triafamone + ethoxysulfuron and bensulfuron-methyl + pretilachlor, which are selective, translocated broad-spectrum herbicides, effectively controlled all categories of weeds with their respective mode of action at early stages of crop growth. Post-emergence application of tank-mix herbicides halosulfuron-methyl + fenoxaprop-p-ethyl effectively reduced the later emerged weeds compared to bispyribac-sodium+ fenoxaprop-p-ethyl (tank-mix) and bispyribac-sodium + pyrazosulfuron-ethyl (tank-mix). Significantly higher density and biomass of weeds lower weed control efficiency were recorded with unweeded check due to continuous germination and development of all category weeds resulting in heavy wed infestation as no weed management practice was carried out from transplanting of rice to harvesting.

Rice grain yield and yield attributes

Number of rice panicles/m², number of rice grains/panicle, 1000 rice grain weight, rice grain and straw yield of transplanted rice were significantly influenced by nutrient levels and weed management practices (**Table 2**). Among different nutrient levels tested, higher number of panicles/m², number of grains / panicle, rice grain and straw yield were recorded with 150% RDF, which was significantly superior to 125% RDF with significant disparity. This might be attributable to the fact that adequate nutrition availability which enabled substantial proportion of tillers becoming effective tillers due to better accumulation of photosynthates, resulting in the generation of more number of panicles/m² confirming the findings of Adilakshmi *et al.* (2022). In terms of 1000 grain weight, there was no significant difference between the nutrient levels listed above due to enhanced production and translocation of

Table 1. Density and biomass of weeds and weed control efficiency at harvest as influenced by nutrient levels and weed management treatments in transplanted rice (average of two years)

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)				Weed control efficiency (%)
	Grasses	Sedges	BLWs	Total	Grasses	Sedges	BLWs	Total	
Nutrient levels									
100% RDF	4.90 (23.94)	4.84 (23.52)	4.30 (18.17)	8.07 (65.62)	3.97 (15.54)	4.72 (22.40)	4.56 (20.53)	7.62 (28.47)	50.49 (59.26)
125% RDF	5.20 (27.26)	5.21 (27.57)	4.61 (21.13)	8.64 (75.96)	4.50 (20.21)	5.12 (26.54)	5.05 (25.39)	8.43 (72.14)	44.73 (49.74)
150% RDF	5.58 (31.55)	5.53 (31.49)	4.96 (24.76)	9.24 (87.81)	4.91 (24.26)	5.47 (30.70)	5.42 (29.43)	9.09 (84.38)	37.25 (41.21)
LSD (p=0.05)	0.28	0.28	0.25	0.50	0.27	0.30	0.30	0.53	3.68
Weed management treatment									
Pretilachlor 750 g/ha PE *fb* bispyribac-sodium 25 g/ha + pyrazosulfuron-ethyl 25 g/ha (tank-mix) PoE at 20 DAT	5.63 (31.18)	5.49 (29.67)	4.78 (22.43)	9.15 (83.27)	4.91 (23.62)	5.50 (29.79)	5.41 (28.87)	9.09 (82.29)	40.77 (42.67)
Penoxsulam + butachlor 820 g/ha (ready-mix) PE *fb* bispyribac-sodium 25 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) PoE at 20 DAT	5.43 (29.07)	5.25 (27.09)	4.62 (20.92)	8.80 (77.08)	4.72 (21.87)	5.17 (26.30)	5.23 (26.98)	8.68 (75.15)	43.63 (47.64)
Triafamone + ethoxysulfuron 67.5 g/ha (ready-mix) PE *fb* halosulfuron-methyl 67.7 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) PoE at 20 DAT	4.75 (22.12)	4.58 (20.51)	4.24 (17.55)	7.78 (60.19)	4.06 (16.09)	4.49 (19.73)	4.65 (21.20)	7.57 (57.02)	50.96 (60.28)
Bensulfuron-methyl + pretilachlor 660 g/ha (ready-mix) PE *fb* hand weeding at 40 DAT	4.91 (23.69)	4.82 (22.73)	4.33 (18.30)	8.07 (64.72)	4.28 (17.99)	4.73 (21.94)	4.83 (22.98)	7.95 (62.91)	48.58 (56.17)
Hand weeding twice at 20 and 40 DAT	4.14 (16.76)	4.05 (16.02)	3.97 (15.30)	6.95 (48.08)	3.46 (11.55)	3.95 (15.23)	4.15 (16.80)	6.62 (43.58)	56.68 (69.64)
Unweeded check	6.51 (42.68)	6.99 (49.14)	5.81 (33.63)	11.14 (125.45)	5.34 (28.90)	6.79 (46.28)	5.79 (33.88)	10.35 (109.05)	24.30 (24.02)
LSD (p=0.05)	0.30	0.31	0.23	0.43	0.28	0.28	0.28	0.52	3.19

Data in parentheses are original values, which are transformed to $\sqrt{x+0.5}$ and analysed statistically; PE = pre-emergence application; PoE = post-emergence application; *fb*= followed by; DAT = days after transplanting; BLWs = broad-leaved weeds photosynthates at higher nutrient levels, which facilitated improved grain filling and hence increased 1000 grain weight. Application of 100% RDF recorded the lowest number of panicles/m², number of grains/panicle and 1000 grain weight, rice grain and straw yield, which was significantly lower than rest of the nutrient levels during both the consecutive years of study as well in pooled mean. This might be due to less availability of nutrients.

Amongst weed management treatments, significantly more number of panicles/m², number of grains/panicle, 1000 grain weight, rice grain and straw yield were observed with hand weeding twice at 20 and 40 DAT, which was at par with triafamone + ethoxysulfuron (ready-mix) 67.5 g/ha PE *fb* halosulfuron-methyl 67.7 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) PoE at 20 DAT due to maintenance of weed free environment throughout the crop growth period leading to increased availability of growth resources resulting in more total number of tillers/m², which inurn lead to the production of higher number of productive tillers/m² and rice grain yield because of maintenance of better source sink relationship in these treatments (Jaswal and Singh 2019, Jaiswal and Gupta 2020 and Mohapatra *et al.* 2021). The next best weed management treatment in recording higher rice yield parameters, grain and straw yield was bensulfuron-methyl + pretilachlor (ready-mix) 660 g/ha PE *fb* hand weeding at 40 DAT, which was followed by penoxsulam + butachlor (ready-mix) 820 g/ha PE *fb* bispyribac-sodium 25 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) PoE at 20 DAT and pretilachlor 750 g/ha PE *fb* bispyribac-sodium 25 g/ha + pyrazosulfuron-ethyl 25 g/ha (tank-mix) PoE at 20 DAT. This might be due to better translocation of photosynthates from source to rice grains. Significantly lower number of panicles/m², number of grains/panicle, 1000 grain weight, grain and straw yield were observed with unweeded check due to severe competition from uncontrolled weeds at critical stages resulting in lesser availability of growth resources, which in turn ended up with lower number of rice yield parameters.

Economics

Net returns and benefit-cost ratio of transplanted rice was significantly influenced due to nutrient levels and weed management practices (**Table 2**). Application of 150% RDF resulted in higher benefit-cost ratio, which was significantly higher than rest of the nutrient levels. The next best nutrient level in recording higher benefit-cost ratio was 125% RDF. This might be attributed to higher grain yield due to précised application of nutrients at different stages of crop growth confirming the findings of Kumari *et al.* (2021). The lowest benefit-cost ratio was recorded with 100% RDF. Among

Table 2. Yield attributes, yield and economics of transplanted rice as influenced by nutrient levels and weed management treatments

Treatment	No. of panicle/m^2			No. of grains/panicle^2			1000 grain weight (g)			Grain yield (kg/ha)	Straw yield (kg/ha)	Net returns (₹/ha)	B:C ratio
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled				
Nutrient levels													
100% RDF	244	229	236	109	101	105	14.0	13.3	13.7	4729	5397	49791	1.96
125% RDF	275	260	268	126	118	122	14.9	14.0	14.4	5172	6008	57262	2.08
150% RDF	311	296	304	140	132	136	15.3	14.5	14.9	5671	6416	65661	2.20
LSD (p=0.05)	26	24	25	11	10	11	0.7	0.6	0.6	285	340	6281	0.10
Weed management treatment													
Pretilachlor 750 g/ha PE *fb* bispyribac-sodium 25 g/ha + pyrazosulfuron-ethyl 25 g/ha (tank-mix) PoE at 20 DAT	241	226	234	106	98	102	14.0	13.2	13.6	4355	5244	42957	1.86
Penoxsulam + butachlor 820 g/ha (ready-mix) PE *fb* bispyribac-sodium 25 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) PoE at 20 DAT	265	250	258	120	112	116	14.5	13.7	14.1	5307	5697	60536	2.18
Triafamone + ethoxysulfuron 67.5 g/ha (ready-mix) PE *fb* halosulfuron-methyl 67.7 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) PoE at 20 DAT	312	297	305	147	139	143	15.5	14.7	15.1	6156	6909	75109	2.37
Bensulfuron-methyl + pretilachlor 660 g/ha (ready-mix) PE *fb* hand weeding at 40 DAT	288	273	281	135	127	131	15.0	14.2	14.6	5731	6280	66593	2.22
Hand weeding twice at 20 and 40 DAT	331	316	324	153	145	149	16.0	15.2	15.6	6259	7162	74631	2.29
Unweeded check	224	209	216	90	82	86	13.4	12.5	12.9	3335	4351	25602	1.56
LSD (p=0.05)	21	22	21	8	9	8	0.9	0.8	0.9	290	295	5660	0.10

PE = pre-emergence application; PoE = post-emergence application; *fb*= followed by; DAT = days after transplanting different weed management treatments, significantly higher net returns and higher benefit-cost ratio were observed with triafamone + ethoxysulfuron (ready-mix) 67.5 g/ha PE *fb* halosulfuron-methyl 67.7 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) PoE at 20 DAT, which was statistically comparable with HW twice at 20 and 40 DAT. Higher net returns with herbicides was due to higher grain and straw yield coupled with reduced cost of cultivation as reported by Mohapathra *et al.* (2021) and Jaiswal and Gupta (2020). The next best weed management practices in recording higher net returns and higher benefit-cost ratio were bensulfuron-methyl + pretilachlor (ready-mix) 660 g/ha PE *fb* HW at 40 DAT, which was followed by penoxsulam + butachlor (ready-mix) 820 g/ha PE *fb* bispyribac-sodium 25 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) PoE at 20 DAT and pretilachlor 750 g/ha PE *fb* bispyribac-sodium 25 g/ha + pyrazosulfuron-ethyl (tank-mix) 25 g/ha PoE at 20 DAT with significant differences among them. Significantly lower net returns and benefit-cost ratio were observed with unweeded check due to higher density of uncontrolled weeds.

It can be concluded that 100% RDF and triafamone + ethoxysulfuron (ready-mix) 67.5 g/ha PE *fb* halosulfuron-methyl 67.7 g/ha + fenoxaprop-p-ethyl 60 g/ha (tank-mix) PoE at 20 DAT usage results in lower weed density and biomass, higher weed control efficiency, higher rice yield attributes, higher rice grain yield of transplanted rice and higher net returns.

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RESEARCH ARTICLE

Efficacy of sequential herbicide applications in managing diverse weed flora and improving the productivity of transplanted rice

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ABSTRACT

A research experiment was conducted in 2020 and 2021 at the Kalyani D-Block Farm, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal, India to assess the performance of sequential herbicide applications in managing diverse weed flora and improving the productivity of transplanted rice. The experiment was laid out in a randomized block design with four replications. Nine treatments, with various combinations of pre-emergence and post-emergence herbicides with different modes of action, were evaluated. The pre-emergence application (PE) of pretilachlor 50% EC (pretilachlor) 0.70 kg/ha followed by (*fb*) cono-weeder operation was most effective in suppressing both grasses and broad-leaved weeds, recording highest weed control efficiency and rice grain yield. It was statistically comparable to the sequential application of pretilachlor 0.70 kg/ha PE *fb* post-emergence application (PoE) of bispyribac-Na 25 g/ha at 25 DAT. Both treatments have significantly enhanced rice plant growth attributes viz., plant height, biomass and improved nutrient uptake. Thus, pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE offers an efficient, profitable and sustainable weed management solution for transplanted rice.

Keywords: Bispyribac-sodium, Nutrient uptake, Pretilachlor, Sequential herbicides, Transplanted rice, Weed control efficiency

INTRODUCTION

Rice (*Oryza sativa* L.) is a world's most important cereal crop feeding over half of the global population and contributing 31% to India's total food consumption (Dhillon *et al.* 2018, Jahan *et al.* 2020). In India, it is cultivated on about 44 million hectares, producing 124 million tonnes annually, which represents roughly 21.5% of global production (DES 2024). To meet the projected demand of 197.4 million tonnes by 2050 for 1.64 billion people, production must rise despite constraints on land, water, labour, and agrochemicals (Ahmad *et al.* 2021). The weed infestation often poses a serious threat to crop productivity (Rao 2022). Weeds vigorously compete with rice for nutrients, light, and space, causing significant yield losses and serving as alternate hosts for pests and diseases (Hussain *et al.* 2021). Puddle-transplanted rice offers several agronomic benefits, such as effective weed suppression through standing water, minimized percolation losses, and improved nutrient availability (Choudhary *et al.* 2021). Despite these benefits, rice fields are commonly infested with diverse weed species, including annual grasses, broad-leaved weeds, and sedges, making effective weed control a persistent challenge (Choudhary and Dixit 2018).

Manual weeding, although traditionally considered the most reliable method, has become less feasible in recent years due to rising labour costs and shortages (Kaur *et al.* 2016). Hence, herbicides have emerged as an efficient and practical solution for weed control, reducing the need for intensive manual labour. They are particularly useful for managing weed species which are morphologically similar with the crop, where manual removal is difficult (Rao *et al.* 2017). Pre-emergence application (PE) of herbicides controls mainly early emergent weeds, whereas later emerging weeds are controlled by post-emergence application (PoE) of herbicides. Relying solely on one herbicide or repeatedly using the same mode of action can lead to the evolution of herbicide resistance in weeds and hence, using several herbicides with different modes of action applied sequentially can provide broader weed control and help delay resistance evolution (Mahajan and Chauhan 2015). Such integrated approaches are effective in

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minimizing yield losses, as it enhance overall efficacy and ensure broader weed control (Shah *et al.* 2023). Thus, a field study was conducted at Bidhan Chandra Krishi Viswavidyalaya, to assess the performance of sequential herbicide applications in managing diverse weed flora to improve productivity of transplanted rice in the subtropical region.

MATERIALS AND METHODS

The field study was carried out during the *Kharif* seasons of 2020 and 2021 at the research farm of Bidhan Chandra Krishi Viswavidyalaya (BCKV), Kalyani, India. The experimental site lies at 18.1243° N latitude and 84.5447° E longitude, with an average elevation of 257 m above sea level. The area receives about 1150 mm of annual rainfall, with approximately 85% occurring during the south-west monsoon. The climate of the region is subtropical, marked by hot summers and relatively mild winters. The average minimum temperature in January is around 22.7°C, while May records the highest average temperature of about 43°C. The experimental field had clay loam soil, composed of 32.8% clay, 21.7% silt, and 45.5% sand. The soil pH ranged from 6.8 to 7.2, indicating a neutral reaction, and contained a moderate level of organic carbon (0.46%). The study was carried out using the rice variety '*IET 4786'* (Shatabdi), with a planting geometry of 20 cm × 10 cm. The experiment was arranged in a randomized complete block design (RCBD) consisting of nine treatment combinations with four replications **(Table 1**). The treatments were oxadiargyl 80% WP (oxadiargyl) 0.1 kg/ha PE followed by *(fb)* 2,4-D 0.5 kg/ha PoE 25 days after transplanting (DAT); pretilachlor 0.70 kg/ha PE; pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 10% SC (bispyribac-Na) 25 g/ha at 25 DAT; pretilachlor 0.70 kg/ha PE *fb* cyhalofop-butyl 5.1% + penoxsulam 1.02% OD (RM) (cyhalofop-butyl + penoxsulam) 112.5 + 22.5 g/ha PoE at 25 DAT; oxadiargyl 0.1 kg/ha *fb* passing of cono-weeder at 25 DAT; pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder at 25 DAT; pretilachlor 0.70 kg/ha PE *fb* triafamone + ethoxysulfuron 44.0+22.5 g/ha PoE at 25 DAT; hand weeding twice at 20 and 40 DAT and weedy check. Each plot was 5 m × 4 m in size. Herbicide treatments were applied using a knapsack sprayer fitted with a flat-fan nozzle, delivering 500 L/ha of spray solution. Fertilizers were supplied at 80:40:40 kg N, P, and K per hectare using urea (N) and muriate of potash (K). Phosphorus and potassium were applied at transplanting, while nitrogen was split into three doses before transplanting, and at 30 and 60 DAT. The observations on weeds were recorded at 30 and 45 DAT. Weed density and biomass were measured with a 50 cm × 50 cm quadrat placed randomly at three spots per plot. Samples were sun-dried, then oven-dried at 65°C until constant weight, and expressed as weed biomass (g/m²). Weed control efficiency (WCE) was estimated from weed biomass measurements to evaluate the performance of various herbicide treatments. The formula used for WCE is as follows:

$$\text{WCE (\%)} = \left(\frac{\text{WDc} - \text{WDt}}{\text{WDC}}\right) \text{x } 100$$

Where, WD_c = Weed dry matter accumulation recorded in the untreated control plot and WD_t = Weed dry matter production was measured in the plots receiving herbicide treatments.

To homogenize the variance, weed density and biomass data were transformed using the square root formula $\sqrt{x+0.5}$. Grain yield, recorded in kg per plot, was converted to kg/ha and then expressed in t/ha. The data were statistically analysed through analysis of variance (ANOVA) appropriate for the experimental design, and treatment differences were tested using the F-test at a 5% significance level (Gomez and Gomez 1984). Since the year-to-year variation was minimal and not statistically significant in most of the parameters, the data from both years were combined and presented as pooled results.

A linear regression line is commonly used to the model relationship between variables of interest, where 'y' denotes the dependent variable and 'x' represents the independent variable (Garai *et al.*, 2023). The equation includes two key parameters: 'b' (the regression coefficient or slope) and 'c' (the intercept), both of which are estimated through regression analysis. The goodness of fit of the model is often assessed using the coefficient of determination (R^2), This represents the share of total variation in the dependent variable that can be accounted for by the independent variable. The R^2 value ranges between 0 and 1, where values closer to 1 indicate a stronger model fit to the data.

RESULTS AND DISCUSSION

Effect on weeds

The dominant grasses observed during the experiment were: *Cynodon dactylon, Echinochloa colona, Panicum repens*; and the broad-leaved weeds were: *Ludwigia parviflora*, *Alternanthera philoxeroides, Malva neglecta* and *Eclipta alba*. The major sedges were *Cyperus iria* and *Fimbristylis miliacea*. During the experimental period, broad-leaved weeds were the most dominant, followed by grasses and sedges (**Table 1**). At 30 and 45 days after transplanting (DAT), pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder recorded the minimum density of *Cynodon dactylon* and *Echinochloa colona* and was statistically superior over other treatments (**Table 1**). The distribution of E. *colona* in the order of decreasing density in response to herbicides application was: pretilachlor PE *fb* bispyribac-Na PoE > pretilachlor PE *fb* triafamone + ethoxysulfuron PoE > pretilachlor PE *fb* cyhalofop-butyl + penoxsulam PE > hand weeding twice at 20 and 40 DAT, with percentage share of 16.23%, 23.07%, 44.05%, and 54.67% of total weed density, respectively. *Ludwigia parviflora* was observed only with pretilachlor 0.70 kg/ha as PE *fb* passing of conoweeder and weedy check. *Eclipta alba* was the most abundant weed species, showing the highest density in untreated control plots, followed by plots treated with pretilachlor 0.70 kg/ha, hand weeding twice at 20 and 40 DAT, oxadiargyl 0.1 kg/ha as PE *fb* 2,4-D 0.5 kg/ha POE and oxadiargyl 0.1 kg/ha as PE *fb* passing of conoweeder. The pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder and pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha POE recorded the lowest density of *Eclipta alba*. Rishi *et al.* (2016) reported that the sequential application of pendimethalin PE *fb* bispyribac-Na PoE significantly lowered the density of *Eclipta alba* and *Panicum repens* compared to sole applications of pendimethalin PE, butachlor PE, oxadiargyl PE, ethoxysulfuron PoE, bispyribac-sodium PoE, and the untreated control at 30 and 45 DAT in rice.

The density of *Cyprus iria* was highest in weedy check, followed by pretilachlor 0.70 kg/ha PE, oxadiargyl 0.1 kg/ha as PE *fb* passing of conoweeder, oxadiargyl 0.1 kg/ha PE *fb* 2,4-D 0.5 kg/ha PoE and hand weeding twice at 20 and 40 DAT. Pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder resulted in best control of *Panicum repens*. *Malva neglecta* density was least with pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha POE, while highest with pretilachlor 0.70 kg/ha PE. *Fimbristylis miliacea* was observed only with pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder and its highest density was found in weedy check. The efficacy of pretilachlor in effectively managing grasses like *Echinochloa* spp. was previously observed widely across South Asia (Singh *et al.* 2015, Chatterjee *et al.* 2021, Shah *et al.*

Table 1. Effect of weed management treatments on the weed density in transplanted rice at 30 DAT (2 years pooled data)

Treatment	Weed density (no./ m^2)									
	Grasses			Broad-leaved weeds					Sedges	
	Cynodon dactylon	*Echinochloa colona*	*Panicum repens*	*Ludwigia parviflora*	*Alternanthera philoxeroides*	*Malva neglecta*	*Eclipta alba*	Other BLW	*Cyperus iria*	*Fimbristylis miliacea*
Oxadiargyl 0.1 kg/ha PE *fb* 2,4-D 0.5 kg/ha PoE	1.62 (2.14)	2.12 (3.98)	1.92 (3.20)	1.27 (1.11)	1.32 (1.26)	1.60 (2.07)	1.76 (2.61)	1.66 (2.25)	1.62 (2.12)	1.50 (1.75)
Pretilachlor 0.70 kg/ha PE	1.70 (2.39)	2.26 (4.63)	2.17 (4.23)	1.31 (1.23)	1.39 (1.43)	1.65 (2.23)	1.82 (2.80)	1.79 (2.71)	1.75 (2.57)	1.55 (1.89)
Pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha POE	1.18 (0.89)	1.55 (1.91)	1.48 (1.68)	1.04 (0.58)	1.03 (0.57)	1.10 (0.71)	1.54 (1.86)	1.47 (1.66)	1.46 (1.63)	1.21 (0.96)
Pretilachlor 0.70 kg/ha PE *fb* cyhalofop-butyl 112.5 + penoxsulam 22.5 g/ha (RM) as PoE	1.48 (1.71)	1.83 (2.86)	1.74 (2.52)	1.23 (1.03)	1.14 (0.81)	1.27 (1.12)	1.67 (2.28)	1.66 (2.25)	1.57 (1.96)	1.37 (1.37)
Oxadiargyl 0.1 kg/ha as PE *fb* passing of conoweeder	1.63 (2.16)	2.20 (4.33)	2.06 (3.75)	1.34 (1.30)	1.30 (1.20)	1.60 (2.07)	1.76 (2.60)	1.77 (2.63)	1.68 (2.33)	1.51 (1.77)
Pretilachlor 0.70 kg/ha as PE *fb* passing of conoweeder	1.10 (0.72)	1.45 (1.60)	1.37 (1.37)	0.97 (0.45)	0.94 (0.38)	1.13 (0.78)	1.35 (1.33)	1.28 (1.14)	1.34 (1.29)	1.13 (0.78)
Pretilachlor 0.70 kg/ha PE *fb* triafamone+ ethoxysulfuron (44.0+22.5 g/ha) PoE	1.24 (1.03)	1.61 (2.08)	1.60 (2.06)	1.11 (0.74)	1.15 (0.82)	1.27 (1.12)	1.49 (1.73)	1.54 (1.88)	1.50 (1.76)	1.30 (1.19)
Hand weeding twice at 20 and 40 DAT	1.53 (1.83)	2.01 (3.53)	1.74 (2.54)	1.43 (1.55)	1.40 (1.46)	1.49 (1.72)	1.82 (2.80)	1.83 (2.84)	1.60 (2.06)	1.45 (1.62)
Weedy check (control)	2.52 (5.86)	3.62 (12.58)	3.39 (10.97)	1.99 (3.46)	2.48 (5.68)	2.59 (6.19)	2.80 (7.33)	2.98 (8.36)	2.38 (5.15)	1.92 (3.18)
LSD (p=0.05)	0.14	0.56	0.58	0.11	0.15	0.31	0.42	0.27	0.26	0.19

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

2025). Most of the pre-emergence herbicides are less effective against sedges, particularly those that spread through rhizomes and stolons rather than cell division, which limits their control efficiency (Rao *et al.* 2007, Singh and Singh 2012, Singh *et al.* 2015, Chatterjee *et al.* 2021, Shah *et al.* 2025). Their relatively low persistence capability under hot and humid conditions further reduces their ability to suppress weeds at later growth stages (Saha *et al.* 2021). In contrast, post-emergence application of bispyribac-Na, either alone or in combination with pyrazosulfuron, has shown strong efficacy against grassy weeds, broad-leaved weeds and sedges, particularly *Cyperus iria*, the predominant sedge species in the area (Jat and Singh 2021, Saha *et al.* 2021). Similarly, Mitra *et al.* (2022) also reported the highest reduction in weed biomass at both 35 and 55 DAT with sequential use of pendimethalin as PE followed by bispyribac + pyrazosulfuron as PoE.

Pretilachlor 0.70 kg/ha PE *fb* conoweeder recorded the lowest weed density and biomass, with highest weed control efficiency followed by pretilachlor *fb* bispyribac-Na and pretilachlor *fb* triafamone + ethoxysulfuron (**Table 2** and **3**) confirming Meena *et al.* (2019), Menon (2019) and Arthanari (2023). Pretilachlor and oxadiargyl alone were less effective than the other herbicides, but all herbicide applications showed superior performance compared to the weedy check in both years. Lower weed densities were due to effective sequential application, where PE herbicides suppressed early weeds and PoE herbicides, particularly bispyribac-Na, managed later emerged weeds. Pretilachlor alone was less effective (62.05% reduction), indicating that single herbicide applications are inadequate for broad-spectrum weed control. Sequential use of pretilachlor *fb* bispyribac-Na effectively managed mixed weed flora in transplanted rice with pretilachlor controlling grasses and some broad-leaved weeds and bispyribac-Na suppressing sedges, broad-leaved, and late emerging weeds. Combining PE and PoE herbicides, whether in sequence or compatible mixes with different modes of action, provided superior weed suppression.

Pretilachlor *fb* bispyribac-sodium showed high efficacy due to their complementary mode of actions. Pretilachlor, a chloroacetamide herbicide, inhibits very long chain fatty acid biosynthesis in target weeds by blocking the Acetyl-CoA carboxylase (ACCase) enzyme, disrupting cell membrane formation and other lipid structures essential for growth, leading to plant death (Shilpakar *et al.* 2020). It primarily targets grassy weeds in rice and is absorbed through roots or foliage, translocating

Table 2. Effect of weed management treatments on the weed density in transplanted rice at 45 DAT (2 years pooled data)

Treatment	Weed density (no./ m^2)									
	Grasses			Broad-leaved weeds					Sedges	
	Cynodon dactylon	*Echinochloa colona*	*Panicum repens*	*Ludwigia parviflora*	*Alternanthera philoxeroides*	*Malva neglecta*	*Eclipta alba*	Other BLW	*Cyrus iria*	*Fimbristylis miliacea*
Oxadiargyl 0.1 kg/ha PE *fb* 2,4-D 0.5 kg/ha PoE	1.82 (2.81)	2.99 (8.43)	2.21 (4.38)	1.67 (2.29)	1.57 (1.96)	1.99 (3.47)	2.17 (4.19)	1.99 (3.45)	1.73 (2.48)	1.54 (1.86)
Pretilachlor 0.70 kg/ha PE	1.93 (3.23)	3.24 (9.97)	2.54 (5.94)	1.70 (2.39)	1.61 (2.11)	1.97 (3.39)	2.17 (4.22)	2.09 (3.85)	1.86 (2.97)	1.60 (2.06)
Pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha POE	1.49 (1.72)	2.44 (5.45)	1.82 (2.82)	1.32 (1.24)	1.13 (0.79)	1.47 (1.68)	1.94 (3.26)	1.81 (2.77)	1.51 (1.79)	1.26 (1.10)
Pretilachlor 0.70 kg/ha PE *fb* cyhalofop-butyl 112.5 + penoxsulam 22.5 g/ha (RM) as PoE	1.77 (2.62)	2.70 (6.81)	1.90 (3.12)	1.50 (1.76)	1.32 (1.26)	1.77 (2.65)	2.07 (3.80)	1.97 (3.38)	1.67 (2.30)	1.43 (1.55)
Oxadiargyl 0.1 kg/ha as PE *fb* passing of conoweeder	1.92 (3.17)	3.04 (8.74)	2.34 (4.98)	1.70 (2.39)	1.64 (2.18)	1.91 (3.15)	2.14 (4.08)	2.08 (3.81)	1.78 (2.66)	1.56 (1.94)
Pretilachlor 0.70 kg/ha as PE *fb* passing of conoweeder	1.36 (1.35)	2.24 (4.51)	1.65 (2.22)	1.34 (1.29)	1.05 (0.59)	1.27 (1.12)	1.75 (2.57)	1.52 (1.81)	1.43 (1.54)	1.20 (0.94)
Pretilachlor 0.70 kg/ha PE *fb* triafamone+ ethoxysulfuron (44.0+22.5 g/ha) PoE	1.55 (1.91)	2.55 (6.03)	1.83 (2.84)	1.49 (1.71)	1.25 (1.06)	1.69 (2.37)	1.90 (3.12)	1.87 (3.01)	1.57 (1.96)	1.33 (1.27)
Hand weeding twice at 20 and 40 DAT	1.79 (2.70)	2.87 (7.72)	1.98 (3.43)	1.70 (2.39)	1.57 (1.97)	1.89 (3.09)	2.17 (4.22)	2.03 (3.63)	1.69 (2.37)	1.50 (1.74)
Weedy check (control)	2.87 (7.77)	5.17 (26.26)	4.03 (15.72)	2.89 (7.85)	2.74 (7.00)	2.92 (8.01)	3.43 (11.26)	3.67 (12.95)	2.54 (5.96)	2.08 (3.82)
LSD (p=0.05)	0.22	0.93	0.64	0.27	0.18	0.31	0.46	0.34	0.27	0.19

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

throughout the plant. On the other hand, bispyribac-Na inhibits branched-chain amino acid biosynthesis in target weeds by blocking the Aceto- Lactate-Synthetase (ALS) enzyme, effectively controlling a broad spectrum of weeds with a favourable eco-toxicological profile. Chaudhury and Dixit (2024) reported earlier the greater efficacy of bispyribac-Na against *Echinochloa crusgalli* when applied at 25 DAT. Similarly, pretilachlor *fb* triafamone + ethoxysulfuron was effective against grasses and sedges as observed earlier by Yadav *et al.* (2019). Additionally, sequential application of pretilachlor *fb* 2,4-D also effective in controlling broad-leaved weeds. Penoxsulam was also effective in suppressing both grasses and sedges up to 60 DAT (Jehangir *et al.* 2022).

Effect on transplanted rice

The pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder improved rice growth, yield attributes (**Figure 2**) and nutrient uptake (**Table 4**). This combination achieved the maximum grain yield, which was approximately 2.18 times greater than the yield under the weedy check. Other combinations, such as pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE and pretilachlor 0.70 kg/ha PE *fb* triafamone+ ethoxysulfuron (44.0+22.5 g/ha) PoE were also found to be effective in improving rice growth, yield attributes and nutrient uptake confirming the findings of Mukherjee (2020) and Shah *et al.* (2023). These results highlight the role of herbicides as an important component of integrated weed management for reducing weed competition and create suitable conditions for crop development, which in turns enhance rice productivity.

Improved yield attributes under these treatments, due to lower weed pressure, facilitated greater dry matter accumulation and nutrient absorption, thereby enhancing photosynthate availability for grain formation (Mukherjee 2020). This combined PE and POE approach collectively contributed to the improved crop growth conditions and nutrient uptake, ultimately leading to enhanced grain yield by 61.20% to 123.64%. Similar observations were made by Kaur and Singh (2015), Saha *et al.* (2021) and Mitra *et al.* (2022). The minimum yield was recorded in the weedy check treatment, primarily due to severe competition for nutrients, light, and moisture (Choudhary *et al.* 2021, 2024).

Rice yield losses from weed interference varied between 1% and 58.39% (**Figure 2**), with the highest reduction of 58.39% observed in the weedy check. Pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder recorded lower yield loss of 1% followed by pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE with 4.29% yield loss due to uncontrolled weeds.

Rice grain yield was found to be significant negative linear correlation with weed density and biomass (**Figure 1**). Regression analysis showed that for weed biomass, $y = -0.0669x + 5.92$ ($R^2 = 0.81$), each unit increase reduced yield by 0.066 t/ha, explaining 81% of yield variation. For weed density, $y = -0.0542x + 6.36$ ($R^2 = 0.89$), each unit increase lowered yield by 0.054 t/ha, accounting for 89% of

Table 3. Effect of weed management treatments on the total weed density, biomass, WCE and nutrient removal by weeds in transplanted rice (pooled data of two years)

Treatment	Total Weed density (no./m^2) (30 DAT)	Total Weed density (no./ m^2) (45 DAT)	Total Weed biomass (g/ m^2) (30 DAT)	Total Weed biomass (g/ m^2) (45 DAT)	WCE (%) (30 DAT)	WCE (%) (45 DAT)	Removal of nutrients by weeds (kg/ha)			Removal of total nutrient by weeds (kg/ha)
							N	P	K	
Oxadiargyl 0.1 kg/ha PE *fb* 2,4-D 0.5 kg/ha PoE	22.46	35.31	10.62	12.28	79.34	76.01	2.39	0.38	2.32	5.09
Pretilachlor 0.70 kg/ha as PE	26.08	40.13	12.29	14.78	72.64	71.13	2.76	0.39	2.69	5.84
Pretilachlor 0.70 kg/ha as PE *fb* bispyribac-Na 25 g/ha as POE	12.44	22.60	5.18	6.41	89.29	87.48	1.16	0.18	1.14	2.48
Pretilachlor 0.70 kg/ha as PE *fb* cyhalofop-butyl 112.5 + penoxsulam 22.5 g/ha (RM) as PoE	17.90	29.23	8.08	9.82	82.59	80.82	1.82	0.28	1.77	3.87
Oxadiargyl 0.1 kg/ha as PE *fb* passing of conoweeder	24.13	37.09	11.70	13.21	74.52	74.19	2.63	0.41	2.56	5.60
Pretilachlor 0.70 kg/ha as PE *fb* passing of conoweeder	9.83	17.94	4.11	5.58	90.78	89.10	0.93	0.14	0.90	1.97
Pretilachlor 0.70 kg/ha as PE *fb* triafamone + ethoxysulfuron 44.0 + 22.5 g/ha PoE	14.40	25.27	6.52	8.17	86.02	84.04	1.49	0.23	1.43	3.15
Hand weeding twice at 20 and 40 DAT	21.88	3.24	9.82	1.97	80.37	96.15	2.21	0.34	2.15	4.70
Weedy check (control)	68.73	106.59	48.71	51.19	0.00	0.00	10.84	1.72	10.56	23.12
LSD (p=0.05)	2.93	3.80	1.81	1.95	7.56	6.80	0.30	0.05	0.30	0.65

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

Table 4. Effect of weed management treatments on growth parameters, nutrient uptake and yield of transplanted rice (pooled data of two years)

Treatment	Plant height (30 DAT)	Plant height (45 DAT)	Plant dry matter (30DAT)	Plant dry matter (45 DAT)	Nutrient uptake by rice			Total uptake by rice (kg/ha)
					N	P	K	
Oxadiargyl 0.1 kg/ha PE *fb* 2,4-D 0.5 kg/ha PoE	70.49	85.53	90.93	356.22	115.64	16.13	187.29	319.06
Pretilachlor 0.70 kg/ha PE	75.28	86.97	80.72	338.31	108.19	15.09	175.26	298.54
Pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE	78.81	93.65	107.43	391.74	138.37	19.18	217.33	374.88
Pretilachlor 0.70 kg/ha PE *fb* cyhalofop-butyl 112.5 + penoxsulam 22.5 g/ha (RM) as PoE	73.08	88.14	97.50	402.09	125.23	17.45	201.84	344.52
Oxadiargyl 0.1 kg/ha as PE *fb* passing of conoweeder	69.00	84.03	89.56	354.06	110.67	15.42	178.44	304.53
Pretilachlor 0.70 kg/ha as PE *fb* passing of conoweeder	81.82	96.97	113.61	398.77	144.72	20.06	227.34	392.12
Pretilachlor 0.70 kg/ha PE *fb* triafamone+ ethoxysulfuron (44.0+22.5 g/ha) PoE	75.27	90.13	101.14	384.24	131.60	18.30	209.72	359.62
Hand weeding twice at 20 and 40 DAT	71.53	86.86	92.76	389.82	121.49	16.96	197.66	336.11
Weedy check (control)	60.55	73.73	71.75	298.55	74.17	10.52	130.28	214.97
LSD (p=0.05)	8.08	7.28	8.44	28.17	13.03	1.80	21.16	35.99

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

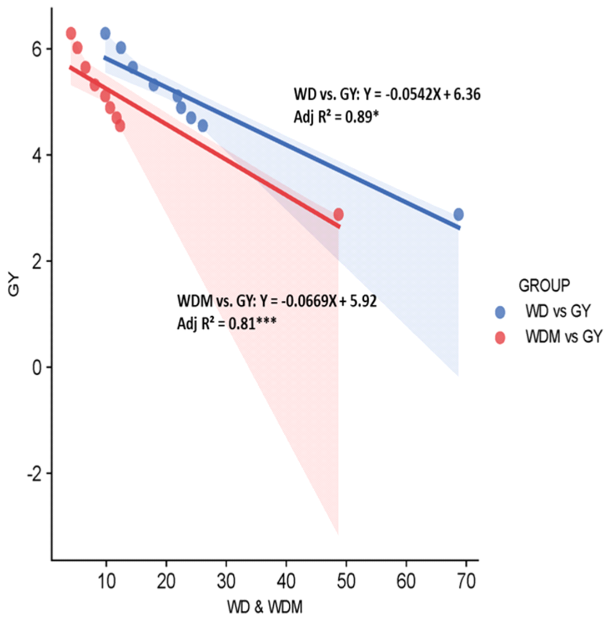

Figure 1. Linear regression model between weed density (WD), weed biomass (WDM), and grain yield (GY) by considering GY as dependent variable.

*Significant at $p<0.05$, **Significant at $p<0.01$, *** Significant at $p<0.001$.

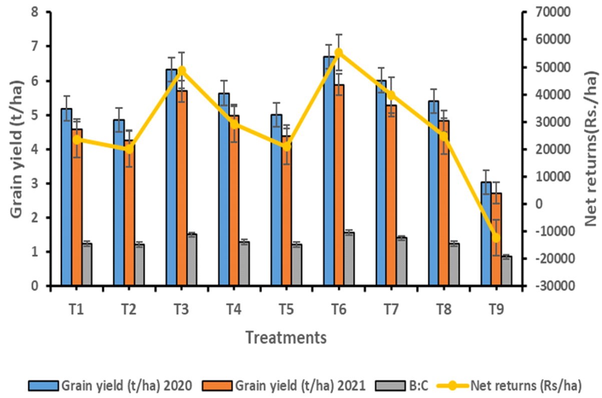

Figure 2. Significance chart for weed management treatments on transplanted rice grain yield, net returns and benefit cost ratio

*Oxadiargyl 0.1 kg/ha as PE *fb* 2,4-D 0.5 kg/ha at 25 DAT POE (T_1); pretilachlor 0.70 kg/ha PE (T_2); pretilachlor 0.70 kg/ha as PE *fb* bispyribac-Na 25 g/ha PoE 25 DAT (T_3); pretilachlor 0.70 kg/ha PE *fb* cyhalofop-butyl + penoxsulam 112.5 + 22.5 g/ha (RM) POE 25 DAT (T_4); oxadiargyl 0.1 kg/ha PE *fb* passing of conoweeder at 25 DAT (T_5); pretilachlor 0.70 kg/ha PE *fb* passing of cono-weeder at 25 DAT (T_6); pretilachlor 0.70 kg/ha PE *fb* triafamone + ethoxysulfuron 44.0+22.5 g/ha POE 25 DAT (T_7), hand weeding twice at 20 and 40 DAT (T_8) and weedy check (T_9)

variation. These findings emphasize the crucial role of effective weed management in achieving maximum rice yield.

Significantly highest net returns (₹ 55,289/ha) and B:C ratio (1.57) were achieved with pretilachlor 0.70 kg/ha PE followed by conoweeder, which was statistically similar to pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha (₹ 48647 and 1.51), based on pooled data (**Figure 2**). Similar results were reported by Mohapatra *et al.* (2021).

Conclusion

It was concluded that pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE was most efficient in achieving maximum rice yield due to an effective, economic and broad-spectrum weed management in transplanted rice in West Bengal. Pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder was found to be equally effective in lowering weed density, biomass and increasing transplanted rice grain yield.

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RESEARCH ARTICLE

Black rice cultivars as a component of integrated weed management in direct-seeded rice at Nagaland

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ABSTRACT

Black rice also known **"***Chakhao*" in Manipuri language is unique due to its purplish black colour because of its high anthocyanin content and its multiple health benefits. Weeds are of major concern as they compete severely with black rice and to minimize adverse impact of weeds on black rice, integration of different weed management strategies including competitive cultivars and herbicides are required as components of weed management. Hence a study was conducted with an objective to identify effective integrated weed management method to manage weeds and improve productivity of black rice. The highest growth, yield attributes and yield of black rice was recorded with hand weeding (HW) twice at 15 and 30 days after seeding (DAS) and was closely followed by pre-emergence application (PE) of pretilachlor 1.0 kg/ha followed by (*fb*) HW at 40 DAS. Among cultivars, Chakhao poireiton and Wairi chakhao recorded maximum and minimum growth, yield attributes and yield, respectively. The lowest weed density, biomass and nutrient depletion was observed with hand weeding twice at 15 and 30 DAS and cultivar Chakhao poireiton which also recorded the highest cost of cultivation and gross returns during both the years.

Keywords: Bispyribac-sodium, Black rice, Hand weeding, Pretilachlor, Weeds and Integrated Weed management

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most significant cereal crops worldwide with 90% of the world's rice cultivation occurring in Asia (Lei and Yuan 2019). Rice is providing nourishment to more than half of the world population and is known as one of the significant crops (Bin and Zhang 2023). Worldwide demand for rice is expected to increase by more than 40% by 2050 to meet the requirements of the growing population (Mohammed *et al.* 2021, Rao 2022). Black rice, also known as forbidden rice, is drawing attention in recent times for to its nutraceutical properties like antioxidant, fiber, vitamins, anticarcinogenic and mineral content (Kushwaha *et al.* 2016). Among the different rice establishment methods, the success of upland direct-seeded rice (DSR) is significantly hampered by weed competition since weeds are denser in this system as compared to a transplanting, because of the lack of standing water during the initial stages (Rao *et al.* 2007). Therefore, management of weeds is of outmost importance to achieve higher outcome in direct-seeded rice (Rao and Matsumoto 2017) as weeds cause around 67% loss in yield of DSR (Kashyap *et al.* 2019). Weeds are very diverse and complex in the rice field and it is advisable to integrate different weed management practices instead of using a single management practice (Rao *et al.* 2014, 2020). Competitive cultivars of rice are characterized with higher early vigour, increased leaf area, biomass accumulation, increased ground cover by canopy, more tillering, increased height and early maturity (Ramesh *et al.* 2017, Dhillon *et al.* 2021). Additionally, different weed competitive abilities differ with the varied cultivars of rice based on their diverse morphological traits and it becomes crucial to grow cultivars that can have a smothering effect on weeds to reduce the negative effect on the main crop (Ramesh *et al.* 2017). Thus, inclusion of weed suppressing cultivars as a component of integrated weed management (IWM) strategies is of prime importance to maximize the crop yields. Hence a study was conducted with an objective to identify effective integrated weed management method, with rice cultivars and herbicides as components, to manage weeds and improve productivity of black rice.

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MATERIALS AND METHODS

The present study was conducted in the experimental field of School of Agricultural Sciences

(SAS), Medziphema Campus, Nagaland University during the *Kharif* season of 2021 and 2022. It lies in humid sub- tropical region with average rainfall ranging from 2000-2500 mm yearly. The mean summer ranging from 21ºC to 32 ºC and during winter temperature rarely goes below 8ºC due to high atmospheric humidity. Weather condition in the experimental farm varied throughout the growing duration. Total rainfall during the cropping season (from July to December) in 2021 and 2022 was 829.9 mm and 1070.8 mm respectively. The average maximum temperature in both years was recorded in August at 34.4°C and 34.1°C, and the lowest temperature was recorded in December at 11.4°C and 12.0°C respectively. The initial nutrient content of soil was analysed in the experimental field which resulted that the soil was highly acidic (pH 4.75) with high carbon content (1.52%) low levels of available Nitrogen, high level of phosphorous and medium potassium (250.55, 34.88, 148.21 kg/ha) respectively. The treatments were laid out in Split Plot Design (SPD) with four integrated weed management in the main plot *viz.* weedy check (control), hand weeding (HW) twice at 15 and 30 days after seeding (DAS), by pre-emergence application (PE) of pretilachlor 1.0 kg/ha followed by (*fb*) HW at 40 DAS and pretilachlor 1.0 kg/ha PE *fb* post-emergence application (PoE) of bispyribac-sodium 25 g/ha at 20 DAS; while four cultivars, *viz.* Chakhao poireiton, Chakhao amubi, Wairi chakhao and Khurukhul chakhao were assined in the sub-plots. Each of the experimental plot size was 4 × 3m. The seed rate of 80 kg/ha was used. Rice seed was directly sown maintaining a row-to-row distance of 20 cm and 10 cm for plant to plant. Irrespective of the treatments Farm Yard Manure (10 t /ha) was applied evenly on the entire field during its preparation. Fertilizers (Nitrogen, Phosphorous and Potassium) in the form of urea, SSP and MOP were applied uniformly in each plot. Urea was applied in split doses before sowing and at tillering stage while full doses of SSP and MOP were applied before sowing as basal application. Further, for observations on weeds studies, *viz.* weed density and weed biomass, 1 m^2 quadrat was randomly placed in each plot and observations were recorded using standard recommended procedures. Weed density and weed biomass square root transformed respectively for uniform results for statistical analysis of the data. Growth parameters, yield, economics and nutrient depletion were also recorded. The 5 % level probability of critical differences was used to compare significant differences between the treatment means.

RESULTS AND DISCUSSION

Effect on weeds

The tested weed management treatments significantly controlled the grasses, sedges and broad-leaved weeds at 40 DAS (**Table 1**). Pooled data from the two years experiment revealed minimum weed density and biomass with hand weeding twice at 15 and 30 DAS and it was closely followed by pretilachlor 1.0 kg/ha PE *fb* HW at 40 DAS which was at par with pretilachlor 1.0 kg/ha PE *fb* bispyribac-sodium 25 g/ha PoE at 20 DAS confirming the findings of Karthika *et al.* (2019). The maximum weed density and biomass was observed in weedy check, where weeds dominated the crops in utilizing all the required nutrients, light, moisture as also observed by Parihar *et al.* (2020).

Pooled data of observation at 40 DAS on weeds density and biomass also showed variations with different cultivars studied. Among the four cultivars,

Table 1. Effect of integrated weed management treatments with black rice cultivars as a component on weed density (no./m^2) weed biomass (g/m^2) at 40 days after sowing (DAS) (pooled data two years)

Treatment	Grasses		Sedges		Broad-leaved weed	
	Weed density	Weed biomass	Weed density	Weed biomass	Weed density	Weed biomass
Weed management						
Weedy check (control)	11.92(143.5)	7.45(55.7)	7.80(60.7)	7.46(55.6)	9.47(90.2)	8.03(64.8)
Hand weeding twice at15 and 30 DAS	6.20(41.0)	4.68(22.9)	4.48(20.2)	4.07(16.5)	5.46(31.2)	4.54(21.1)
Pretilachlor 1.0 kg/ha PE *fb* HW at 40 DAS	8.66(76.8)	6.05(36.9)	6.01(36.3)	5.82(34.1)	7.07(51.3)	5.58(32.0)
Pretilachlor 1.0 kg/ha PE *fb* bispyribac-sodium 25g/ha PoE at 20 DAS	8.78(78.3)	6.15(37.9)	6.31(39.8)	6.14(37.8)	7.00(50.3)	5.40(29.8)
LSD (p=0.05)	0.61	0.41	0.29	0.31	0.40	0.33
Cultivar						
Chakhao poireiton	7.33(60.3)	5.13(28.06)	5.39(30.50)	5.20(28.49)	5.67(34.83)	4.58(22.85)
Chakhao amubi	8.55(77.8)	5.94(35.90)	5.99(37.17)	5.72(33.97)	6.91(49.67)	5.67(33.57)
Wairi chakhao	10.45(113.3)	6.98(49.37)	6.91(48.83)	6.57(44.37)	8.78(78.67)	7.14(52.33)
Khurukhul chakhao	9.23(88.2)	6.28(39.97)	6.29(40.50)	5.99(37.08)	7.65(59.83)	6.16(38.97)
LSD (p=0.05)	0.68	0.45	0.38	0.38	0.38	0.30

Original values were subjected to square root transformation. Figures in parentheses are the original value; *PE- Pre emergence application, PoE- Post emergence application, DAS- days after sowing; *fb* - followed by

Cultivar Chakhao poireiton recorded lowest weed density and biomass which was followed with Chakhao amubi. The maximum weed density and biomass at 40 DAS was associated with rice cultivar Wairi chakhao.

Effect on growth and yield attributes

The two years pooled data of rice growth at 90 DAS and at rice harvest revealed maximum plant height, dry matter accumulation, The rice growth rate (CGR) and grain yield was highest with hand weeding twice at 15 and 30 DAS and it was closely followed with pretilachlor 1.0 kg/ha PE *fb* HW at 40 DAS (**Table 2**). This could be attributed to effective weed suppression by those treatments reducing intra and inter competition and favor on the growth and development of crop for various growth-related factors (Ahmed *et al.* 2020). The weedy check recorded the significantly lowest rice growth, yield attributes and yield due to severe weed competition throughout the growing period (Nazir *et al.* 2020).

Further, different cultivars also showed variations in growth and yield parameters at 90 DAS where highest plant height, dry matter and CGR was recorded with Chakhao poireiton and was statistically at par with Chakhao amubi. However, highest grain yield was observed with rice cultivar Chakhao poireiton. The lower growth parameters were recorded with rice cultivar Wairi chakhao, during both the years, which was statically at par with Khurukhul chakhao. The observed variation among different rice cultivars might be attributed to their varietal origin and environmental conditions during the growing season that could have impacted the overall differences among the cultivars as reported earlier by Kujur *et al.* (2017).

Effect on nutrient depletion

The treatment combinations of integrated weed management and different cultivars from the pooled data of two years revealed differences in nutrient depletion by weeds where minimum depletion of all the three nutrients (nitrogen, phosphorous and potassium) was with hand weeding twice at 15 and 30 DAS and with cultivar Chakhao poireiton (**Table 3**). This may have been due to timely control of weeds during the critical stages that created a favorable condition for the rice to use applied nutrients leading to prolific rice growth while keeping the weed growth under control (Sanodiya and Singh 2021). The treatment combination of weedy check with cultivar Wairi chakhao resulted in maximum depletion of the nutrients by weeds as uncontrolled weed growth led to higher weed density and biomass and greater competition with rice for nutrients (Sharma *et al.* 2018).

Economics

The highest cost of cultivation was incurred with hand weeding twice at 15 and 30 DAS (**Table 3**), due to higher requirement of labours for manual weeding and higher labor wages that increased labour cost for hand weeding (Yogananda *et al.* 2017). This was followed by pretilachlor 1.0 kg/ ha PE *fb* HW at 40 DAS. The highest gross return was observed with hand weeding at 15 and 30 DAS. Similar findings were reported by Gangireddy *et al.* (2019). The highest net returns were recorded with the above treatments in combination with the rice variety Chakhao poireiton. Among the cultivars, all four cultivars incurred the same cost of cultivation while Chakhao poireiton recorded maximum gross and net returns.

Correlation analysis

Table 2. Effect of integrated weed management treatments with black rice cultivars as component on growth parameters yield of black rice

Treatment	Plant height at 90 DAS			Dry matter accumulation (g/m^2) at 90 DAS			CGR at 60-90 DAS			Grain yield (kg/ha)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Weed management												
Weedy check (control)	76.44	78.17	77.31	12.18	12.29	12.24	11.97	12.12	12.05	1067	1086	1077
Hand weeding twice 15 and 30 DAS	100.21	101.99	101.10	19.45	19.82	19.64	19.97	20.48	20.23	1870	1873	1871
Pretilachlor 1.0 kg/ha PE *fb* HW at 40 DAS	92.74	93.79	93.26	16.05	16.41	16.23	15.99	16.45	16.22	1686	1693	1690
Pretilachlor 1.0 kg/ha PE *fb* bispyribac sodium 25g/ha PoE at 20 DAS	86.05	87.76	86.91	13.78	13.91	13.85	13.47	13.64	13.56	1268	1272	1270
LSD (p=0.05)	4.49	4.69	2.89	0.79	1.10	0.60	0.86	1.70	0.85	93.21	111.27	64.62
Cultivar												
Chakhao Poireiton	91.69	92.97	92.33	17.03	17.19	17.11	17.42	17.65	17.54	1553	1561	1557
Chakhao Amubi	89.43	91.46	90.45	15.87	16.14	16.01	16.03	16.36	16.20	1508	1520	1514
Wairi Chakhao	86.08	87.11	86.59	13.74	13.99	13.86	13.39	13.71	13.55	1389	1397	1393
Khurukhul Chakhao	88.25	90.18	89.21	14.82	15.12	14.97	14.57	14.98	14.77	1440	1446	1443
LSD (p=0.05)	3.80	4.16	2.75	0.78	0.66	0.50	1.27	1.12	0.83	62.52	62.64	43.11

*PE: pre-emergence application; PoE: post-emergence application; DAS: days after sowing; *fb:* followed by; CGR: crop growth rate

Table 3. Effect of integrated weed management treatments on nutrient depletion by weeds and economics of direct-seeded black rice

Treatment	Nitrogen (kg/ha)			Phosphorous (kg/ha)			Potassium (kg/ha)			Cost of cultivation (x10^3 Rs/ha)			Gross returns (x10^3 Rs/ha)			Net returns (x10^3 Rs/ha)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
W1C1	23.93	19.93	21.93	15.57	13.45	14.51	42.49	37.20	39.85	36.04	36.04	36.04	93.85	94.92	94.39	57.81	58.88	58.35
W_1C_2	29.20	34.02	31.61	18.87	20.43	19.65	53.40	55.63	54.51	36.04	36.04	36.04	91.76	94.07	92.92	55.72	58.03	56.88
W_1C_3	36.13	35.90	36.02	25.22	24.98	25.10	69.71	68.45	69.08	36.04	36.04	36.04	82.14	84.06	83.10	46.10	48.02	47.06
W_1C_4	34.13	33.90	34.02	20.28	22.08	21.18	57.32	60.32	58.82	36.04	36.04	36.04	85.78	86.82	86.30	49.74	50.78	50.26
W_2C_1	2.57	2.55	2.56	0.93	0.86	0.89	1.78	1.66	1.72	48.04	48.04	48.04	161.05	161.44	161.25	113.01	113.40	113.20
W_2C_2	4.35	4.00	4.17	1.46	1.43	1.44	2.89	2.70	2.80	48.04	48.04	48.04	155.97	156.15	156.06	107.93	108.11	108.02
W_2C_3	7.68	5.97	6.83	3.03	2.63	2.83	6.41	5.28	5.84	48.04	48.04	48.04	147.36	147.72	147.54	99.32	99.68	99.50
W_2C_4	4.77	5.04	4.90	1.88	1.92	1.90	3.80	3.85	3.83	48.04	48.04	48.04	150.07	150.58	150.32	102.03	102.54	102.28
W_3C_1	6.58	7.17	6.87	2.17	2.35	2.26	11.22	12.52	11.87	41.44	41.44	41.44	143.52	143.99	143.76	102.08	10.25	102.31
W_3C_2	9.23	8.65	8.94	3.30	2.89	3.10	16.16	14.67	15.41	41.44	41.44	41.44	141.57	142.63	142.10	100.13	101.19	100.66
W_3C_3	12.03	13.30	12.67	5.27	4.98	5.13	23.49	23.14	23.32	41.44	41.44	41.44	132.64	133.15	132.89	91.20	91.71	91.45
W_3C_4	11.73	10.55	11.14	4.34	3.68	4.01	20.69	18.23	19.46	41.44	41.44	41.44	136.81	137.06	136.94	95.37	95.62	95.50
W_4C_1	7.32	8.68	8.00	4.33	4.94	4.63	11.53	13.63	12.58	37.53	37.53	37.53	113.21	113.88	113.55	75.68	76.35	76.02
W_4C_2	10.36	11.22	10.79	6.27	6.64	6.45	16.33	17.26	16.80	37.53	37.53	37.53	107.72	108.26	107.99	70.19	70.73	70.46
W_4C_3	17.36	14.12	15.74	11.07	9.05	10.06	28.47	23.78	26.13	37.53	37.53	37.53	95.87	96.05	95.96	58.34	58.52	58.43
W_4C_4	11.74	12.84	12.29	7.31	7.34	7.32	18.69	19.72	19.21	37.53	37.53	37.53	102.36	102.58	102.47	64.83	65.05	64.94
LSD (p=0.05) (WxC)	3.23	4.62	2.74	1.33	2.58	1.41	3.73	6.63	3.71	-	-	-	-	-	-	-	-	-
LSD (p=0.05) (CxW)	3.74	5.67	4.41	1.55	2.96	2.21	4.46	7.99	5.95	-	-	-	-	-	-	-	-	-

*****W_1=Weedy check (Control), W_2=Hand weeding twice at 15 and 30 DAS, W_3=pretilachlor 1.0 kg/ha PE *fb* HW at 40 DAS, W_4=pretilachlor 1.0 kg/ha PE *fb* bispyribac-sodium 25 g/ha PoE at 20 DAS, C_1=Chakhao poireiton, C_2=Chakhao amubi, C_3=Wairi chakhao, C_4= Khurukhul chakhao; *PE- pre-emergence application, PoE- post-emergence application, DAS- days after sowing, *fb* - followed by

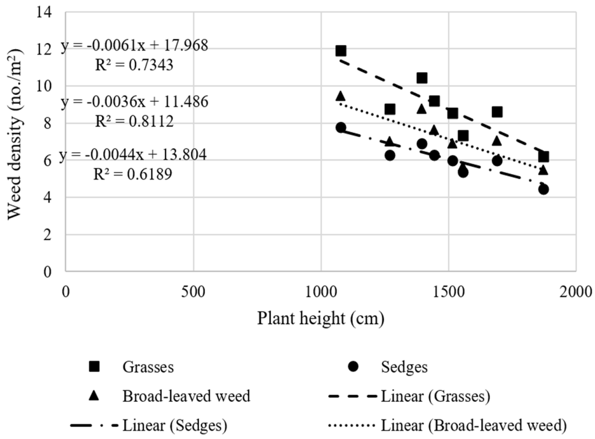

Figure 1. Relationship between rice plant height (cm) and weed density (no./m^2)

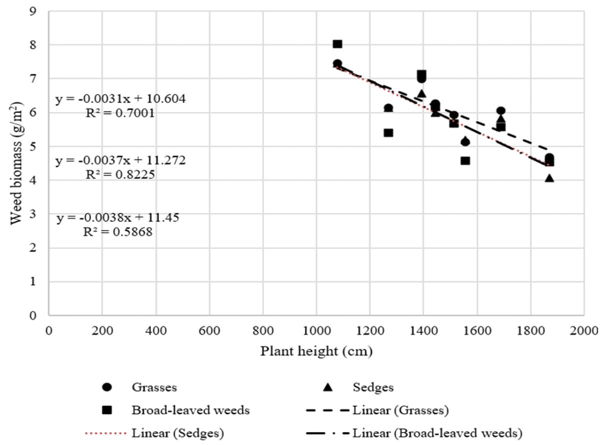

Figure 2. Relationship between rice plant height (cm) and weed biomass (g/m^2)

There was a negative correlation between rice plant height and weed density. The coefficient of negative correlation between rice plant height and weed density and biomass indicates that weeds negatively impacted the crop growth and eventually reduced the yield (**Figure 1** and **2**)

Conclusion

During both the years, hand weeding twice at 15 and 30 DAS was effective in managing weeds but keeping in view of the continuous increased labour cost for hand weeding, it would be advantageous growing of black rice cultivar Chakhao poireiton with pretilachlor 1.0 kg/ha PE *fb* HW at 40 DAS for effectively and economically managing weeds in direct-seeded rice with higher rice yield and farmers income under Nagaland conditions.

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RESEARCH ARTICLE

Management of weeds with varying quantities of rice residues and split application of nitrogen in zero till wheat

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ABSTRACT

A field study was carried out during the *Rabi* seasons of 2023-24 and 2024-25 at the Instructional Farm of Uttar Banga Krishi Viswavidyalaya, Coochbehar, West Bengal to evaluate the efficacy of varying rice residue quantity as mulch, and splitting of nitrogen (N) for better weed control and higher yields in zero till wheat. The experiment was laid out in a split plot design with three replications. Four main plot treatments consisted of preceding rice harvested at different heights from ground leaving varying quantities of rice residues after rice harvest *i.e.*, R_0 – rice harvested at ground level (no residue retention); R_1 – rice harvested at 20 cm from ground level; R_2 – rice harvested at 40 cm from ground level and R_3 – rice harvested at 60 cm from ground level. Due to the harvest of rice at various heights, the retained rice residue quantity varied under each main plot and the residue quantity estimated based on rice biomass retained was 1.7, 3.0 and 4.0 t/ha under R_1; R_2 and R_3, respectively. The applied nitrogen dose was uniform at 150 kg/ha; however, the amount of nitrogen applied in each of the three splits of nitrogen application varied and four different splits of nitrogen were allocated under each main plot as sub-plot treatments, *viz.* N_1 – 33+33+33%, N_2 - 20+40+40%, N_3 - 40+40+20%, N_4 - 40+20+40%, each at basal, crown root initiation (CRI) and at active tillering stage, respectively. The wheat variety DBW 187 was used in the experiment. The rice residue retention had a noticeable impact on early soil moisture conservation and weed growth suppression in zero tillage wheat. The higher residue levels (keeping the rice straw by harvesting at 60 cm from ground level) effectively reduced weed pressure as evident by lower weed density and biomass with increased weed control efficiency (WCE) (73-81%). Thus, preceding rice crop residues had a great impact in supressing weeds under zero till wheat. The nitrogen split application, with varying nitrogen dose at each split, didn't have a significant impact on weed density and biomass. The nitrogen application in three equal splits at basal, CRI and active tillering stage resulted in significantly higher wheat grain yield.

Keywords: Mulching, Nitrogen, Rice residue retention, Weed management, Wheat, Zero tillage

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a staple cereal crop that plays a vital role in feeding a large portion of the global population. Globally, India ranks third in terms of wheat production, following China and the European Union. During 2024-25, wheat output reached a record high of 117.51 million tons from 32.76 million hectares, with a national average productivity of 3.6 t/ha (Anonymous 2025). However, weeds pose a significant challenge to wheat cultivation as they compete for essential resources such as nutrients, moisture, sunlight and space. Weed infestation itself is a major biotic factor limiting wheat production in the country (Chhokhar *et al.* 2009, Ramesh *et al.* 2017). It has been estimated that weeds can lead to a reduction in wheat yield ranging from 10% to 60%, depending on the severity, type, and duration of the infestation (Jat *et al.* 2003, Rao and Chauhan 2015, Singh *et al.* 2015). Zero tillage wheat cultivation is a promising technology through which sustainable production can be addressed. Residue management is one of the important aspects of zero tillage technology which has direct relation with weed infestation. Retaining crop residues on the soil surface offers several benefits in addition to weed control, such as enhancing soil health, conserving moisture, improving soil fertility, and contributing positively to the environment. Shifting from conventional intensive tillage to reduced or zero-tillage practices brings about notable changes in weed dynamics, the effectiveness of herbicides, and the recruitment of weed seeds (Singh 2014, Fracchiolla *et al.* 2018). Currently, weed management largely depends on herbicides usage; however, the continuous and heavy reliance on herbicides have accelerated the evolution of herbicide-resistant weed species, posing a significant environmental threat. To address this issue and to improve wheat yields under

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zero-tillage conditions, there is a need to devise and adapt innovative weed management strategies. These strategies should aim to keep weed populations below the level where they significantly compete with crops, thereby reducing dependence on herbicides and mitigating resistance development. In this context, long-term field studies are crucial for assessing the effectiveness of rice residue management as a component of integrated weed control strategies in the rice-wheat cropping system. The quantity of residue retained on the soil surface plays a vital role in its potential to suppress weeds in wheat (Sindhu 2017) with a higher residue load could reduce weed seed germination by 30.5% (Sharma and Singh 2010) and a lower residue (2.5 t/ha) inadequacy in providing satisfactory weed control (Chhokar *et al*. 2009). The retention of rice residue at 30 cm with balanced nutrition improved productivity with better weed control and soil health in zero till wheat (Reddy *et al.* 2025). These findings highlight the necessity of optimizing residue levels to achieve effective suppression of weeds primarily through physical barriers or allelopathic effects.

Under varying residue load, nitrogen management is very crucial to achieve optimum growth and yields from the crop and to discourage weed growth. Wheat crop responds to higher rates of nitrogen and it was found that the crop responded significantly up to 150 kg/ha of nitrogen both under conventional and zero tillage practices in the eastern sub-Himalayan plains of West Bengal (Mondal *et al.* 2018, Mitra *et al*. 2023a, Mitra *et al*. 2023b). However, splitting of nitrogen in various stages synchronising with crop growth may ensure a steady and synchronized nutrient supply that favours crop growth over weeds (Singh *et al*. 2015). The information is scanty on the combined effect of residue load and nitrogen splitting on weed growth of wheat grown under zero till practice. Thus, the current study was aimed to evaluate the efficacy of varying rice residue quantity retention and splitting of nitrogen (N) for better weed control and higher yields in zero till wheat under rice-wheat systems.

MATERIALS AND METHODS

The field experiment was carried out during the winter (*Rabi*) seasons of 2023–24 and 2024–25 at the Instructional Farm of Uttar Banga Krishi Viswavidyalaya in Pundibari, Coochbehar, West Bengal situated at a latitude of 26°24’02.2"N, longitude of 89°23’21.7"E with an elevation of 43 meters above mean sea level (msl). The experiment was laid out in a split plot design, consisted of preceding rice harvested at different heights from ground, with varying quantities of rice residues left after rice harvest, in the main plot. The preceding rice crop variety was MTU 1153 (115-120 days duration) which was harvested manually at different heights with the help of sickle in each main plot and accordingly differential residues were left after harvest *i.e*., R_0 –rice harvested at ground level (no residue retention), R_1 – rice harvested at 20 cm from ground level; R_2 - rice harvested at 40 cm from ground level, and R_3 – rice harvested at 60 cm from ground level. Due to harvest of rice at various heights, the rice residue quantity varied under each main plot and the residue quantity was estimated (based on dry biomass) as 1.7, 3.0 and 4.0 t/ha under R_1, R_2 and R_3, respectively. The nitrogen dose was kept uniform at 150 kg/ha; however, the amount of nitrogen applied in each of the three splits of nitrogen application was varied and four different splits of nitrogen were allocated under each main plot as sub-plot treatments *viz*., N_1 – three equal splits at basal (33%), crown root initiation (CRI) (33%) and active tillering stage (33%), N_2 – 20% N at basal + 40% N at CRI + 40% N at active tillering stage, N_3 – 40% N at basal + 40% N at CRI + 20% N at active tillering stage, and N_4 – 40% N at basal + 20% N at CRI + 40% N at active tillering stage. The wheat variety DBW 187 was used in the experiment. The crop was sown in between two rice (preceding crop) rows with zero till drill with a seed rate of 100 kg/ha at 20 cm rows apart during November 20 in both the years. The full doses of phosphorus (60 kg/ha) and potassium (40 kg/ha) were applied as basal with respective nitrogen doses based on treatments at the time of sowing. The irrigations (5 cm) were provided through check basin method. The nitrogen fertilizer was also applied after first irrigation at CRI [20 days after seeding (DAS)] and second irrigation at active tillering (38 DAS) apart from the basal application as per treatments.

The data on weed density and biomass was recorded from each treatment at 20 and 40 DAS from four randomly selected spots using a quadrat of 50 x 50 cm size. For taking biomass, weeds were removed from the ground level from the selected spots (two quadrats at 20 DAS and rest two quadrats at 40 DAS) and were sun dried for three days and kept in an oven at 65°C till constant weight obtained. To control weeds at later stages, a post-emergence application was made of metribuzin + clodinafop-propargyl 0.60 kg/ha at 6 weeks after seeding, after taking all the weed samples at 40 DAS. Weed data were subjected to square root transformation ($\sqrt{x+0.5}$) to normalize the distribution (Gomez and Gomez 1984). The indices like weed control efficiency (WCE) and weed persistence index (WPI), relative density (RD) were calculated at 20 and 40 DAS using the following formulae:

$$\text{WCE (\%)} = \frac{WDC-WDT}{WDC} \times 100 \text{ (Mani } et\ al.\text{ 1973)}$$

Where, WDC: Weed density (number/m^2) in control (un-weeded) plot, WDT: Weed density (number/m^2) in treated plot.

$$\text{WPI} = \frac{\frac{Weed\ population}{in\ control\ plot}}{\frac{Weed\ population}{in\ treated\ plot}} \times \frac{\frac{Weed\ dry\ weight}{in\ treated\ plot}}{\frac{Weed\ dry\ weight}{in\ control\ plot}} \text{ (Mishra and Mishra 1997)}$$

$$\text{Relative Density} = \frac{Density\ of\ the\ species}{Total\ density\ of\ all\ species} \times 100$$

The data were analysed statistically by using split plot design. Standard error of means (SEm ±) and critical difference (CD) was evaluated at 5% level of significance.

RESULTS AND DISCUSSION

Effect on weeds

The experimental field was dominated by grasses (60-80%) at 20 DAS while broad-leaved weeds were predominant at 40 DAS. The major grassy weeds found in the experimental plots were *Cynodon dactylon*, *Setaria glauca* and *Digitaria sanguinalis* and amongst broad-leaved weeds, *Polygonum pensylvenicum*, *Polygonum orientale*, *Polygonum persicaria*, *Stellaria media*, *Oldenlandia diffusa* and *Spilanthes paniculate* were predominant as reported by Mitra *et al.* (2019). It was noted that the sedges were not so prevalent in the experimental plots in both the years. At 20 DAS, the grasses predominated and were the early fast-growing colonizers aggressively competing with wheat for light and nutrients. But at 40 DAS, their population decreased possibly due to better canopy closure. On the contrary, broad-leaved weed population increased at 40 DAS as higher residue load treatments (R_2 and R_3) reduced grasses at 20 DAS as compared to lower residue loads (R_0 and R_1) as straw mulch physically blocked the weed emergence and reduced light availability. Sharma *et al.* (2023) reported the dominance of grassy and broad-leaved weeds in zero tillage wheat with or without residue retention. Residue load had less consistent effects on sedge population possibly due their lower numbers. However, by 40 DAS, the density of broad-leaved weeds increased under different residue loads possibly due to moist soil and residue establishing niches. In zero tillage wheat, residue load may be a factor in weed control and weed seed bank exhaustion (Sharma *et al.* 2023). Concerning various nitrogen splits, it was generally observed that higher initial nitrogen applications frequently resulted in higher grass weed densities since nitrogen availability accelerated grassy weeds growth. While broad-leaved weeds flourished in areas where more nitrogen was initially administered, sedges displayed inconsistent reactions. Khan *et al.* (2017) reported lesser weeds in wheat with three nitrogen split application.

Weed density and biomass were significantly lower (**Table 1** and **2**) and weed control efficiency (**Figure 1a**) was higher with increasing levels of rice residue retention during both the years at 20 and 40 DAS. R_0 (no residue) had the highest density and biomass of grassy weeds in 20 DAS, while R_3 (highest residue retention) showed the lowest grass weed density and biomass. The trend continued at 40 DAS also with gradual suppression of weeds across higher residue levels.

However, residue retention did not show any significant effect on sedge weed density and biomass as sedges population was very minimal during both the years at 20 and 40 DAS. The rice residue retention showed significant difference in broad-leaved weed density and biomass. In general, broad-leaved weeds were slightly decreased with increased residue quantity but not fully suppressed as retained rice residues acted as a physical barrier and light filter inhibiting weed density. Suppression was more evident in early stages (20 DAS); higher moisture and residue decomposition might be favouring the later flushes of broad-leaved weeds. Surface placement of rice residues created unfavourable growing conditions for weed seed germination, leading to a noticeable reduction in weeds biomass (Rahman *et al.* 2005). Beyond physically hindering weed emergence, surface residues also helped to reduce the weed seedbank through increased seed predation. Additionally, rice straw had allelopathic compounds such as gallic acid and *p*-hydroxybenzoic acid, which were known to inhibit the germination and early growth of weed species in wheat fields (Bhandari and Guru 2017, Sharma *et al.* 2004, Dhyani *et al.* 2010).

The weed density was modest in the treatments where nitrogen was applied in three equal splits. Weed density, especially of grasses, tended to be higher with more nitrogen quantity in the early split application (**Table 1**). However, the effect was largely non-significant indicates that nitrogen splitting had no direct influence on changing the weeds density.

Table 1. The density of grasses, sedges and broad-leaved weeds as influenced by varying rice residue quantity and nitrogen splitting in zero tilled wheat

Treatment	Grasses (no./m^2)				Sedges (no./m^2)				Broad-leaved (no./m^2)			
	20 DAS		40 DAS		20 DAS		40 DAS		20 DAS		40 DAS	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Residue loads												
R_0 (No above ground residue)	9.49 (89.56)	6.78 (45.50)	9.86 (96.75)	7.78 (60.00)	0.71 (0.00)	1.32 (1.25)	2.17 (4.19)	1.30 (1.19)	4.53 (20.00)	4.25 (17.56)	6.07 (36.37)	5.43 (28.94)
R_1 (Preceding rice harvested at 20 cm from ground)	7.45 (55.06)	5.32 (27.81)	6.68 (44.12)	5.12 (25.69)	1.48 (1.69)	1.25 (1.06)	2.26 (4.62)	1.56 (1.94)	4.16 (16.81)	3.68 (13.06)	4.69 (21.50)	4.27 (17.75)
R_2 (Preceding rice harvested at 40 cm from ground)	6.52 (42.00)	4.87 (23.19)	5.48 (29.50)	4.39 (18.75)	0.90 (0.31)	1.25 (1.06)	1.90 (3.12)	1.17 (0.87)	4.03 (15.75)	3.61 (12.56)	4.39 (18.81)	4.13 (16.56)
R_3 (Preceding rice harvested at 60 cm from ground)	4.60 (20.62)	3.33 (10.62)	3.69 (13.12)	2.87 (7.75)	1.12 (0.75)	0.93 (0.37)	1.79 (2.69)	1.17 (0.87)	3.64 (12.75)	3.30 (10.37)	4.00 (15.50)	3.63 (12.69)
LSD (p=0.05)	0.99	1.03	0.95	0.89	0.22	NS	NS	NS	NS	0.58	0.45	0.63
N Splitting												
N_1 (33%+33%+33%)	7.54 (56.31)	5.33 (27.87)	7.01 (48.62)	5.36 (28.19)	1.12 (0.75)	1.17 (0.87)	2.22 (4.44)	1.25 (1.06)	4.41 (18.94)	3.94 (15)	5.11 (25.62)	4.37 (18.62)
N_2 (20%+40%+40%)	6.41 (40.62)	4.68 (21.44)	6.47 (41.37)	5.36 (28.19)	1.14 (0.81)	1.25 (1.06)	2.05 (3.69)	1.25 (1.06)	3.61 (12.50)	3.30 (10.37)	4.57 (20.37)	4.53 (20.06)
N_3 (40%+40%+20%)	7.52 (56.06)	5.60 (30.81)	7.04 (49)	5.67 (31.69)	1.09 (0.69)	1.25 (1.06)	1.94 (3.25)	1.35 (1.31)	4.38 (18.69)	4.00 (15.50)	5.14 (25.87)	4.60 (20.62)
N_4 (40%+20%+40%)	7.40 (54.25)	5.24 (27)	6.71 (44.50)	4.96 (24.13)	1.00 (0.50)	1.12 (0.75)	1.94 (3.25)	1.39 (1.44)	3.96 (15.19)	3.63 (12.69)	4.56 (20.31)	4.14 (16.62)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	0.54	0.46	NS	NS

LSD- Least significant difference at 5%; DAS - Days after sowing; NS – Non-Significant; Figures in the parentheses are original values; Data subjected to square root transformation

Table 2. The biomass of grasses, sedges and broad-leaved weeds as influenced by various rice residue load and nitrogen splitting in zero tilled wheat

Treatment	Grasses (g/m^2)				Sedges (g/m^2)				Broad-leaved (g/m^2)			
	20 DAS		40 DAS		20 DAS		40 DAS		20 DAS		40 DAS	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Residue loads												
R_0 (No above ground residue)	3.74 (13.48)	2.88 (7.77)	4.49 (19.66)	3.55 (12.09)	0.71 (0.00)	0.92 (0.34)	1.48 (1.68)	1.03 (0.57)	3.43 (11.27)	3.01 (8.54)	5.89 (34.21)	5.27 (27.23)
R_1 (Preceding Rice harvested at 20 cm from ground)	3.17 (9.56)	2.46 (5.54)	3.35 (10.71)	2.31 (4.84)	1.01 (0.53)	0.92 (0.34)	1.51 (1.79)	1.17 (0.88)	2.61 (6.29)	2.62 (6.36)	4.54 (20.12)	3.93 (14.91)
R_2 (Preceding Rice harvested at 40 cm from ground)	2.63 (6.43)	2.10 (3.91)	2.83 (7.53)	2.10 (3.92)	0.79 (0.13)	0.89 (0.29)	1.44 (1.57)	1.00 (0.51)	2.23 (4.48)	2.60 (6.24)	4.04 (15.84)	3.97 (15.27)
R_3 (Preceding Rice harvested at 60 cm from ground)	2.01 (3.54)	1.62 (2.11)	1.93 (3.24)	1.47 (1.66)	0.90 (0.31)	0.80 (0.14)	1.30 (1.19)	0.94 (0.38)	2.26 (4.59)	2.20 (4.35)	3.79 (13.84)	3.52 (11.87)
LSD (p=0.05)	0.15	0.35	0.11	0.16	NS	NS	NS	NS	0.19	0.25	0.22	0.16
N Splitting												
N_1 (33%+33%+33%)	3.04 (8.77)	2.30 (4.81)	3.35 (10.72)	2.48 (5.67)	0.88 (0.28)	0.89 (0.29)	1.53 (1.83)	1.01 (0.53)	2.76 (7.12)	2.83 (7.49)	4.88 (23.31)	4.16 (16.78)
N_2 (20%+40%+40%)	2.65 (6.53)	1.99 (3.45)	3.17 (9.52)	2.47 (5.62)	0.87 (0.25)	0.91 (0.32)	1.35 (1.33)	1.01 (0.52)	2.36 (5.09)	2.27 (4.67)	4.33 (18.23)	4.38 (18.69)
N_3 (40%+40%+20%)	3.07 (8.92)	2.49 (5.68)	3.43 (11.24)	2.62 (6.37)	0.85 (0.23)	0.88 (0.28)	1.48 (1.69)	1.07 (0.65)	2.93 (8.07)	2.83 (7.49)	4.93 (23.83)	4.41 (18.99)
N_4 (40%+20%+40%)	3.05 (8.80)	2.43 (5.41)	3.19 (9.66)	2.32 (4.86)	0.84 (0.21)	0.85 (0.23)	1.37 (1.38)	1.07 (0.65)	2.62 (6.34)	2.52 (5.84)	4.37 (18.64)	3.91 (14.82)
LSD (p=0.05)	0.17	0.22	0.16	0.14	NS	NS	NS	NS	0.13	0.21	0.20	0.12

LSD- Least significant difference at 5%; DAS - Days after sowing; NS – Non-Significant; Figures in the parentheses are original values; Data subjected to square root transformation

Additionally, higher quantity of nitrogen in the initial split part would initially favour broad-leaved weeds, N split of 40+20+20% and 40+40+20% recording relatively higher weed biomass.

Among the nitrogen treatments, N_2 (20+40+40%) consistently showed lower weed density and biomass of grasses, sedges and broad-leaved weeds. This could be due to improved crop vigour under optimal nitrogen availability enhancing the competitive ability of wheat, leading to faster growth and reduced weed proliferation as reported by Chauhan *et al.* (2012). Whereas, N_3 (40+40+20%) recorded lower WCE due to higher weed density *vis-a-vis* dry weight facilitated by higher dose of nitrogen application at early stages. The initial higher nitrogen rates provided increased nutrition to weeds which promoted weed growth and thus increased the values of weed dry matter. These results were in line of conformity with Ghuman *et al.* (2019).

Amongst different treatment combinations, higher WCE was recorded in the treatment combinations where preceding rice crop was harvested at 60 cm height from ground level (keeping higher residue load) along with nitrogen splitting at 20+40+40% at basal, CRI and active tillering stage, respectively (73 and 81%) (**Figure 1a**). As higher residue load supressed the weeds in an efficient way by acting as physical barrier, it improved the WCE. The variation in WCE suggested that lower nitrogen application at early stages was effective, but its overall influence in weed control was secondary to residue management. WCE values under various treatment combinations reflected that management decisions were primarily be focussed on residue level while nitrogen distribution could support crop growth without much alterations in weed pressure. However, higher values of weed persistence index (WPI) under higher residue load also suggestive of higher weed persistence particularly at later growth stages even under high residue load (**Figure 1b**). The monitoring and follow up management supposed to be crucial even under higher residue cover.

Effect on wheat

Different levels of rice residue retention through harvesting preceding rice at different heights did not result in significant differences in wheat grain yield across both the years of the study even though higher residue load had a better control of weeds. It was rather evident that neither complete removal nor excessive retention of residues was beneficial for wheat production in this region (**Table 3**). Instead, a moderate residue level was found to be optimal, as it created a suitable micro environment for wheat development and appreciable weed control. This moderate amount of residue (rice straw harvested at 40 cm above ground level) was not only easier to manage but also its enhanced soil conditions by improving moisture retention and nutrient availability, ultimately supporting better yields under zero-tillage systems. These observations were consistent with the findings of Sirazuddin *et al.* (2019).

Among the different splits of nitrogen, significantly higher grain yield was recorded with evenly distributed nitrogen application (N_1-33+33+33%). The production of higher number of effective tillers, appropriate N utilisation, the beneficial effects of nitrogen application during the peak vegetative growing period, an improvement in yield-contributing characteristics, and the arresting volatilisation or leaching down of N under three uniform splits could all contribute to the increase in grain yield under the aforementioned treatment.

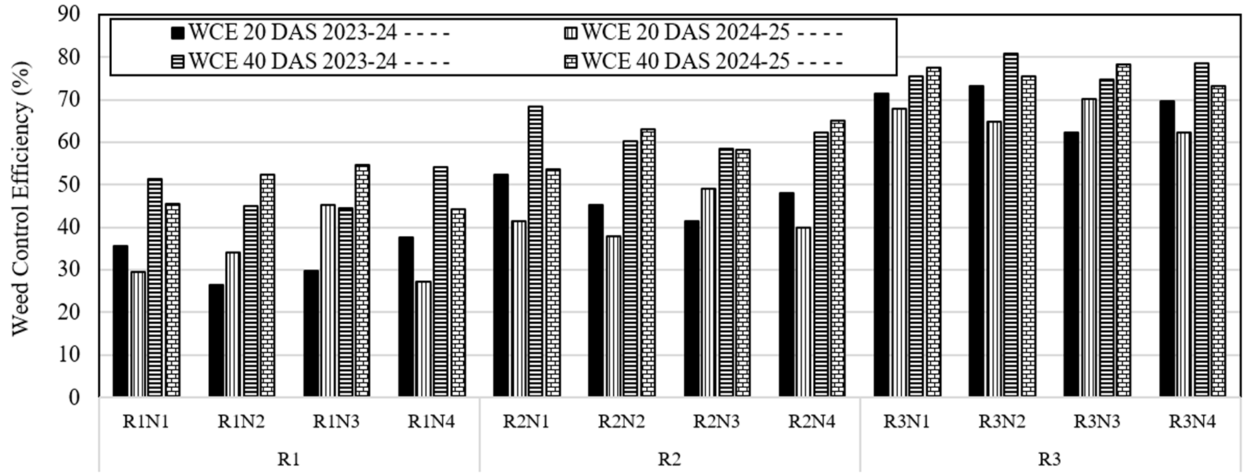

Figure 1(a). Weed control efficiency (WCE) as influenced by various rice residue load and nitrogen splitting in zero tilled wheat

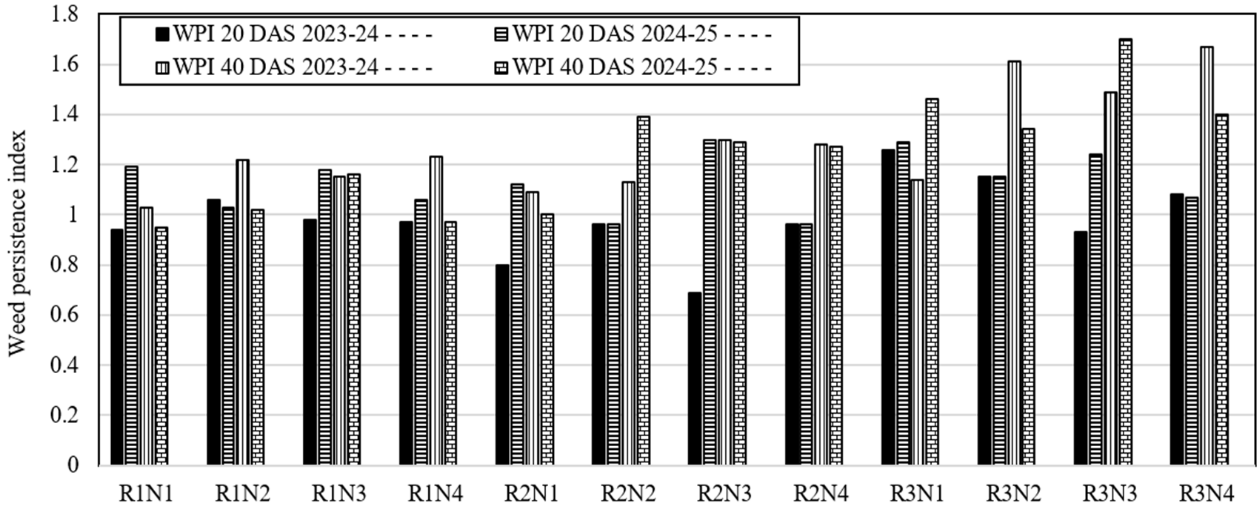

Figure 1(b). Weed persistence index as influenced by various rice residue load and nitrogen splitting in zero tilled wheat

Table 3. Grain yield of zero till wheat as influenced by various rice residue load and N splits

Residue load / Nutrient options	Grain yield (t/ha) in 2023-2024					Grain yield (t/ha) in 2024-2025				
	R_0 (no residue)	R_1 (rice harvest at 20 cm)	R_2 (rice harvest at 40 cm)	R_3 (rice harvest at 60 cm)	Mean	R_0 (no residue)	R_1 (rice harvest at 20 cm)	R_2 (rice harvest at 40 cm)	R_3 (rice harvest at 60 cm)	Mean
N_1 (33%+33%+33%)	5.79	6.04	6.08	6.22	6.03	5.36	5.49	5.54	4.96	5.34
N_2 (20%+40%+40%)	4.12	4.75	4.89	4.59	4.59	4.42	4.50	4.20	4.15	4.32
N_3 (40%+40%+20%)	5.36	5.14	5.76	5.15	5.35	5.22	4.97	5.15	4.74	5.02
N_4 (40%+20%+40%)	4.73	5.06	5.27	4.39	4.86	4.82	4.60	4.29	4.65	4.59
Mean	5.00	5.25	5.50	5.09		4.96	4.89	4.79	4.63	
	R	N	R x N	N x R		R	N	R x N	N x R	
LSD(p=0.05)	NS	0.27	NS	NS		NS	0.23	NS	NS	

LSD- Least significant difference at 5%; NS - Non-Significant

These results were in conformity with the findings of Mitra *et al.* (2023a), Sangin *et al.* (2024) and Tripathi *et al.* (2015).

It can be concluded that weeds in zero till wheat could effectively be supressed by harvesting preceding rice at 40-60 cm above ground level, thus keeping a moderate rice residue load of 3-4 t/ha. Higher nitrogen application at early stages tended to increase weed density, grasses in particular. The three equal splits of nitrogen application at basal, CRI and active tillering stage brought about better weed suppression along with higher grain yield in zero till wheat.

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RESEARCH ARTICLE

Bixlozone + metribuzin (pre-mix) - a recent herbicide combination for managing herbicide resistant *Phalaris minor* and other weeds in wheat in North-West India

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ABSTRACT

The assessment of the efficacy of premix herbicides that combine two different modes of action is crucial for achieving effective and broad-spectrum weed management in wheat, in view of the growing concern over development of herbicide resistance by weeds. A field experiment was conducted for two-years during *Rabi* 2021-22 and 2022-23, at Punjab Agricultural University, Ludhiana, India using a randomized complete block design with three replicates. The objective of the study was to assess the efficacy of pre-mix herbicide combination of bixlozone 50% + metribuzin 10% WG (bixlozone + metribuzin) on herbicide resistant *Phalaris minor* and other weeds in wheat. The pre-mix of bixlozone + metribuzin at 600-750 g/ha with safener cloquintocet at 1000 mL/ha applied at one day before first irrigation [28-30 days after seeding (DAS)] recorded a reduction of 93.5-97.6% and 95.5-98.7% of *P. minor*, 100% of *M. denticulata* and 62.2-100% and 100% of *R. dentatus* biomass at 60 days after application (DAA) in 2021-22 and 2022-23, respectively. Moreover, this herbicide combination improved wheat grain yield by 24.4-22.1% in 2021-22 and 29.4-26.7% in 2022-23 compared to the weedy check. Thus, bixlozone + metribuzin (pre-mix) at 600-750 g/ha with safener cloquintocet at 1000 mL/ha applied at one day before first irrigation (28-30 DAS) provided effective control of diverse weed flora including herbicide resistant *Phalaris minor* and significantly improved the productivity of wheat in Punjab.

Keywords: Bixlozone, Bixlozone + metribuzin, Herbicide resistance, Metribuzin, *Phalaris minor*, Weed management

INTRODUCTION

With the increasing world population, the demand for food is rising and enhancing crop productivity has become more critical than ever (Saha *et al.* 2024). Weeds remain among the most persistent and damaging constraints in agricultural fields, posing a serious challenge to crop establishment and productivity (Rao 2022, Zhou *et al.* 2025). Their interference significantly hampers plant growth and yield potential (Paul *et al.* 2025). In north-west India, poor weed control has been a major factor responsible for the considerable gap between potential and actual wheat yields (Soni *et al.* 2023). On an average, insufficient weed management is estimated to cause around 35% yield losses in wheat annually (Bekele *et al.* 2006). Herbicide usage has played a significant role in boosting crop productivity in agricultural systems (Costa *et al.* 2025). Nevertheless, excessive reliance on herbicides has led to several issues that warrant serious attention (Feng *et al.* 2025). The prolonged and repeated application of herbicides belonging to the same chemical class in these areas has led to the emergence of herbicide-resistant biotypes (Chhokar *et al.* 2025).

A total of 83 weeds in wheat fields has evolved resistance to at least one herbicide (Kumar *et al.* 2023). These resistant weeds have evolved against 21 of the 31 recognized sites of action for herbicides (Singh *et al.* 2021). In India, herbicide resistance in *Phalaris minor* Retz. has emerged as a serious sustainability challenge, threatening the rice-wheat cropping system (RWCS) in the north-western Indo-Gangetic Plains (IGP) (Singh *et al.* 2021). Apart from its resemblance to wheat in early growth stages, its early seed shedding (before crop harvest), non-synchronous maturity, and ability to germinate in multiple flushes makes it particularly troublesome to control (Rana and Rana 2015). Farmers initially relied on isoproturon in the 1980s for its control. However, prolonged dependence on this single herbicide, coupled with monocropping, led to the evolution of isoproturon resistant *P. minor* by 1992-93, marking the first recorded herbicide resistant weed report in

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India (Malik and Singh 1995). By 1993, herbicide resistant *P. minor* had spread to around 0.8-1.0 mha in NW-India, with Haryana being the most affected state (0.56-0.6 mha), followed by Punjab (0.3 mha) (Franke 2002).

To address *P. minor* resistance, other alternative herbicides such as sulfosulfuron, clodinafop, fenoxaprop were recommended (Yadav and Malik 2005). However, within 10-15 years, the efficacy of alternative herbicides too declined, prompting farmers to increase application rates and/or resort to repeated sprays to achieve satisfactory weed control (Bhullar *et al.* 2014). *P. minor* has developed multiple herbicides resistance against different modes of action (Singh 2007, Chhokar and Sharma 2008, Punia *et al.* 2017), such as isoproturon (Singh *et al.* 1998), fenoxaprop-p-ethyl (Abbas *et al.* 2016). Several researchers have undertaken field surveys to examine herbicide usage patterns and spray techniques against resistant *P. minor*, but these efforts have largely been random and yielded inconclusive results (Bhullar *et al.* 2014).

Thus, there is an immediate necessity to introduce herbicides with modes of action distinct from currently used herbicides for managing herbicides resistant *P. minor*. Additionally, the use of herbicide mixtures, either as tank mixes or premixes combining two different mechanisms of action, can help prevent or slow down the development of resistance in weed populations. The deployment of broad-spectrum herbicides would also aid in tackling the challenge posed by diverse weed flora. The new formulation, bixlozone 50% + metribuzin 10% WG (bixlozone + metribuzin), fits this requirement, offering a novel mode of action along with broad-spectrum weed control. Bixlozone, a recently developed oxazole-based herbicide, inhibits the enzyme 1-deoxy-D-xylulose-5-phosphate synthase (DOXP), which disrupts the isoprenoid production at an early stage of the methylerythritol phosphate pathway, thereby providing effective control over both grass and broadleaf weeds (Goggin *et al.* 2025). It also has low volatility and unintended impacts on non-target plants. The second component, metribuzin, an effective post-emergence triazine group herbicide with the mode of action of photosynthesis inhibition is often applied to restrict the broadleaved and annual grass weeds in wheat (Javaid *et al.* 2022). In this context, a field experiment was carried out to determine the efficacy of two-way premix herbicide, combining DOXP and PSII inhibition, under subtropical conditions in India. This study was aimed to evaluate the efficacy and identify effective application rates of the bixlozone + metribuzin (pre-mix) for managing herbicide resistant *P. minor* and other associated weeds in wheat.

MATERIAL AND METHODS

During the *Rabi* seasons of 2021-22 and 2022-23, a field experiment was conducted at the Research Farm, Department of Agronomy, Punjab Agricultural University (PAU), Ludhiana, Punjab, India. It is situated in the northwestern Indo-Gangetic Plains within a subtropical climatic zone. This region is characterized by a semi-arid, subtropical climate, featuring hot, dry summers followed by a humid monsoon period. The winter season starts mildly and becomes colder in December to January. The area typically receives 500 to 750 mm of rainfall annually, with nearly 75% of it occurring during the southwest monsoon. The soil at the test site is loamy sand in texture, with a neutral pH (7.1) and low electrical conductivity (0.14 dS/m). The organic carbon content is low (0.36%), while the soil is low in $KMnO_4$-N (219.4 kg/ha), high in Olsen P (31.2 kg/ha) and high in NH_4OAc-K (361 kg/ha).

The treatments in the field experiment consisted of bixlozone + metribuzin at 500+100, 625+125, 750+150 g/ha with safener cloquintocet at 1000 mL/ha, bixlozone 40 SC (bixlozone) at 750 g/ha with cloquintocet at 1000 mL/ha, metribuzin 70 WP (metribuzin) at 150 g/ha with cloquintocet at 1000 mL/ha, metribuzin 210 g/ha, clodinafop-propargyl 12% + metribuzin 42% WG (clodinafop-propargyl + metribuzin) at 210+60 g/ha with surfactant at 1250 mL/ha, weed free and weedy check. The field experiment was laid out in a randomized complete block design with three replicates. Wheat cv. *Unnat PBW 343* was sown on November 17, 2021 and November 14, 2022, at a seed rate of 100 kg/ha with 20 cm row spacing. Each plot measured 5.0 m × 5.0 m (25 m^2). Herbicides were sprayed using a knapsack sprayer with a flat fan nozzle on December 14, 2021 and December 14, 2022, during the first and second year, respectively, one day before first irrigation to crop at 28 days after seeding (DAS) in 2021-22 and 30 DAS in 2022-23 using volume of water 500 L/ha except metribuzin 150 g/ha with cloquintocet at 1000 mL/ha, metribuzin 210 g/ha, clodinafop-propargyl + metribuzin 210 + 60 g/ha with surfactant at 1250 mL/ha as these were applied as post emergence (35 DAS). In the weed-free plots, weeds were manually removed using khurpa. All standard cultivation practices were followed for raising the crop, except for weed management interventions. Fertilization was done at the rate of 125 kg N and 62 kg P/ha.

Recommended plant protection measures were taken against insect pests and diseases to ensure a healthy crop. Manual harvesting of crop was carried out on April 19 2022, and April 22, 2023, respectively.

The data on weeds was recorded with a quadrat (50 cm × 50 cm) from two different locations in each plot at 15, 30, 45 and 60 days after application (DAA) of pre-mix herbicide combination. Bio-efficacy in terms of weed control was recorded by taking observations of weed density and biomass. Species-wise weed density was recorded at 15, 30, 45 and 60 DAA. The biomass of weed species was observed at 60 DAA. To analyse and interpret weed density and biomass, the average of both quadrats was converted into no./m^2 and g/m^2, respectively. Weed control efficiency was calculated based on weed biomass using the formula suggested by Mani *et al.* (1973), as shown below:

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

where, WBc is the weed biomass in untreated control and WBt is the weed biomass in treated plot.

The recorded data were analyzed using CPCS-1 software (version 3.2.3) developed by Cheema and Singh (1991). Differences among treatment means were tested for significance through Fisher's Least Significant Difference (LSD) procedure at a 5% probability level (p=0.05) as outlined by Cochran and Cox (1957). To achieve normality in weed data distribution, square root transformation was performed before statistical analysis.

RESULTS AND DISCUSSION

Effect on weeds

During both the years of field study, the experimental site was predominant with weed flora of grasses like *P. minor* and broad-leaved weeds like *Medicago denticulata* and *Rumex dentatus etc.*

At 15, 30, 45 and 60 DAA, bixlozone + metribuzin 750-900 g/ha with cloquintocet at 1000 mL/ha recorded statistically at par density of *P. minor* and were significantly lower than all other herbicidal treatments (**Table 1-2**). Bixlozone + metribuzin 750 g/ha with cloquintocet at 1000 mL/ha resulted in reduction in the *P. minor* density of 97.1, 97.7, 97.9 and 98.1% in 2021-22 and 100, 96.7, 97.7 and 98.1% in 2022-23 at 15, 30, 45 and 60 DAA, respectively over weedy check. Moreover, bixlozone + metribuzin 600-900 g/ha with cloquintocet at 1000 mL/ha and clodinafop-propargyl + metribuzin 270 g/ha with surfactant at 1250 mL/ha recorded statistically at par density of *M. denticulata* and *R. dentatus* at 15, 30, 45 and 60 DAA and significantly lower than all other herbicide treatments except in 2021-22 at 45 and 60 DAA. During both years of study, at 15 and 30 DAA

Table 1. Effect of herbicide treatments on weed density(no./m^2) at 15 and 30 days after herbicide application in wheat

Treatment	Dose (g/ha)	Grass				Broad-leaved weeds							
		P. minor				*M. denticulata*				*R. dentatus*			
		15 DAA		30 DAA		15 DAA		30 DAA		15 DAA		30 DAA	
		2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Bixlozone + metribuzin with cloquintocet at 1000 mL/ha	600	1.63 (2)	1.37 (1)	2.02 (3)	1.60 (2)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Bixlozone + metribuzin with cloquintocet at 1000 mL/ha	750	1.24 (1)	1.10 (0)	1.41 (1)	1.20 (1)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Bixlozone + metribuzin with cloquintocet at 1000 mL/ha	900	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)	1.33 (1)	1.00 (0)
Bixlozone with cloquintocet at 1000 mL/ha	750	2.51 (5)	2.51 (5)	2.76 (7)	3.15 (9)	2.85 (7)	2.85 (7)	2.95 (8)	3.21 (9)	2.45 (5)	2.44 (5)	1.00 (0)	2.62 (6)
Metribuzin with cloquintocet at 1000 mL/ha	150	3.16 (9)	1.86 (2)	3.55 (12)	3.04 (8)	2.40 (5)	1.46 (1)	2.44 (5)	2.44 (5)	2.16 (4)	1.38 (1)	2.24 (4)	1.65 (2)
Metribuzin	210	2.02 (3)	3.15 (9)	2.23 (4)	3.86 (14)	1.37 (1)	2.38 (4)	1.53 (1)	3.26 (9)	1.20 (1)	2.12 (3)	1.00 (0)	2.62 (6)
Clodinafop propargyl + metribuzin with surfactant at 1250 mL/ha	270	1.78 (2)	1.49 (1)	2.12 (4)	1.69 (2)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (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)
Weedy check	-	6.01 (35)	3.93 (14)	6.73 (44)	5.44 (30)	2.77 (7)	2.92 (7)	2.89 (7)	3.30 (10)	2.87 (7)	2.88 (7)	3.31 (10)	2.98 (8)
LSD (p=0.05)		0.30	0.19	0.48	0.29	0.35	0.35	0.22	0.47	0.08	0.28	0.37	0.43

*Figures in parentheses are original means. Data were subjected to square root transformation and in 2022-23 at 45 and 60 DAA, bixlozone + metribuzin 600 g/ha recorded complete (100%) control of *M. denticulata* and *R. dentatus* density over weedy check. In 2021-22, at 30 DAA, bixlozone 750 g/ha with cloquintocet at 1000 mL/ha and metribuzin 210 g/ha recorded statistically at par density of *R. dentatus* with bixlozone + metribuzin 600 g/ha with cloquintocet at 1000 mL/ha. Similarly, metribuzin 150 g/ha with cloquintocet at 1000 mL/ha recorded statistically at par density of *P. minor* (at 45 and 60 DAA) and *R. dentatus* (at 45 DAA) with bixlozone + metribuzin 750 g/ha with cloquintocet at 1000 mL/ha. Due to a different mode of action (DOXP inhibitor), bixlozone could be an effective herbicide for the control of herbicide-resistant weeds in wheat fields (Wu *et al.* 2022). As a synthetic organic compound from the triazine group, metribuzin is widely used as a pre- and post-emergence herbicide to control grass and broad-leaved weeds in wheat with the mode of action of photosynthesis inhibition (Rubio *et al.* 2014). The synergistic effect of both the combined molecules might have inhibited the growth of newly germinated weed seeds or seedlings. Therefore, during the initial periods of crop growth, total weed density was significantly less. Bixlozone + metribuzin was found to be phyto-toxic to wheat crop after application and resulted in drooping of leaves and yellowing and bleaching of the crop but wheat recovered within 15-25 days.

Bixlozone + metribuzin 750-900 g/ha with cloquintocet at 1000 mL/ha recorded statistically similar biomass of *P. minor* and were significantly lower than all other herbicide treatments except metribuzin with cloquintocet 150 g/ha during 2021-22. Bixlozone + metribuzin 750 g/ha with cloquintocet at 1000 mL/ha recorded 97.6% in 2021-22 and 98.7% in 2022-23 reduction of *P. minor* biomass at 60 DAA, respectively over the weedy check. Moreover, bixlozone + metribuzin 600-900 g/ha with cloquintocet at 1000 mL/ha and clodinafop-propargyl + metribuzin 270 g/ha with surfactant at 1250 mL/ha recorded statistically at par biomass of *M. denticulata* and *R. dentatus* at 60 DAA and significantly lower than all other herbicide treatments except *R. dentatus* in 2021. Bixlozone + metribuzin at 600 g/ha recorded cent percent (100%) reduction in biomass of *M. denticulata* and *R. dentatus* over weedy check except *R. dentatus* biomass during 2021-22. In 2021-22, metribuzin 150 g/ha with cloquintocet at 1000 mL/ha recorded statistically at par biomass of *P. minor* with bixlozone + metribuzin 750 g/ha with cloquintocet at 1000 mL/ha (**Table 3**). This might be due to the fact that combined formulation of two herbicides known for controlling grass and broad-leaved weeds provided effective control of all the weeds leading to lower weed biomass. These results confirm the findings of Malik *et al.* (2013) and Sudha *et al.* (2016), who reported that application of pre-mix herbicides significantly

Table 2. Effect of different herbicide treatments on weed density (no./m^2) at 45 and 60 days after herbicide application in wheat

Treatment	Dose (g/ha)	Grass				Broad-leaved weeds							
		P. minor				*M. denticulata*				*R. dentatus*			
		45 DAA		60 DAA		45 DAA		60 DAA		45 DAA		60 DAA	
		2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Bixlozone + metribuzin with cloquintocet at 1000 mL/ha	600	2.06 (3)	1.69 (2)	2.14 (4)	1.94 (3)	1.77 (2)	1.00 (0)	1.81 (2)	1.00 (0)	2.43 (5)	1.00 (0)	2.07 (3)	1.00 (0)
Bixlozone + metribuzin with cloquintocet at 1000 mL/ha	750	1.49 (1)	1.29 (1)	1.51 (1)	1.36 (1)	1.24 (1)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Bixlozone + metribuzin with cloquintocet at 1000 mL/ha	900	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)
Bixlozone with cloquintocet at 1000 mL/ha	750	2.38 (5)	3.35 (10)	2.44 (5)	3.95 (14)	2.23 (4)	3.73 (13)	3.02 (8)	3.98 (15)	1.58 (2)	3.86 (14)	1.67 (2)	2.98 (8)
Metribuzin with cloquintocet at 1000 mL/ha	150	1.00 (0)	1.67 (2)	1.00 (0)	2.43 (6)	1.72 (2)	1.88 (3)	1.63 (2)	2.92 (9)	1.19 (1)	1.90 (3)	1.38 (1)	2.07 (4)
Metribuzin	210	2.20 (4)	2.44 (5)	2.51 (5)	3.86 (14)	1.90 (3)	2.64 (6)	1.72 (2)	4.03 (16)	2.19 (4)	2.85 (7)	1.73 (2)	3.64 (12)
Clodinafop propargyl + metribuzin with surfactant at 1250 mL/ha	270	2.17 (4)	1.85 (2)	2.21 (4)	2.04 (3)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (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)
Weedy check	-	7.00 (48)	6.63 (44)	7.39 (54)	7.29 (52)	3.15 (9)	3.39 (11)	4.26 (17)	4.24 (17)	3.31 (10)	3.10 (9)	3.91 (14)	3.60 (12)
LSD(p=0.05)		0.53	0.35	0.56	0.47	0.38	0.27	0.22	0.81	0.51	0.29	0.29	0.53

*Figures in parentheses are original means. Data were subjected to square root transformation reduced the biomass of grass and broad-leaved weeds in wheat. As weed seedlings emerge, their meristematic tissues come into contact with the herbicide, absorb it, and subsequently exhibit phytotoxic symptoms, leading to suppressed growth and reduced biomass (Onwuchekwa-Henry *et al.* 2023).

At 60 DAA, the highest control efficiency of *P. minor* (93.5-100% in 2021 and 94.9-100% in 2022-23), *M. denticulata* (100% in both years) and *R. dentatus* (62.2-100% in 2021-22 and 100% in 2022-23) was recorded with bixlozone + metribuzin 600-900 g/ha with cloquintocet at 1000 mL/ha which were similar to the weed control efficiency achieved with clodinafop-propargyl + metribuzin 270 g/ha with surfactant at 1250 mL/ha for *P. minor* (92.7% in 2021-22 and 94.3% in 2022-23), *M. denticulata* (100% in both years) and *R. dentatus* (100% in 2022-23 only) (**Figure 1**). The suppression of weed growth, resulting from the application of various herbicides, likely contributed to reduced weed proliferation and increased mortality, as outlined earlier. These factors collectively appear to be the primary reasons for the lower weed biomass accumulation, which in turn led to higher weed control efficiency (Yadav *et al.* 2021). The herbicide mixture strategy would not only offer broad-spectrum weed control but also help delay the development of herbicide resistance in weeds, manage existing herbicide resistance issues (Lakra *et al.* 2022).

Effect on wheat

Wheat grain yield in various treatments ranged from 4.30 t/ha to 6.06 t/ha in 2021-22 and 4.15 t/ha to 5.54 t/ha in 2022-23. Bixlozone + metribuzin 600-750 g/ha with cloquintocet at 1000 mL/ha and clodinafop-propargyl + metribuzin 270 g/ha with surfactant at 1250 mL/ha recorded at par grain yield of wheat and was significantly higher than all other herbicide treatments. The bixlozone + metribuzin 600 g/ha with cloquintocet at 1000 mL/ha resulted in 24.4% and 29.4% higher wheat grain yield than weedy check (**Table 3**). The reduction in weed biomass under herbicide treatments may be ascribed to the better development of plant reproductive structures and greater translocation of photosynthates towards the sink, resulting from effective weed suppression and minimized competition for vital resources such as moisture, nutrients, space, and light, which ultimately enhanced crop productivity (Kumar *et al.* 2017).

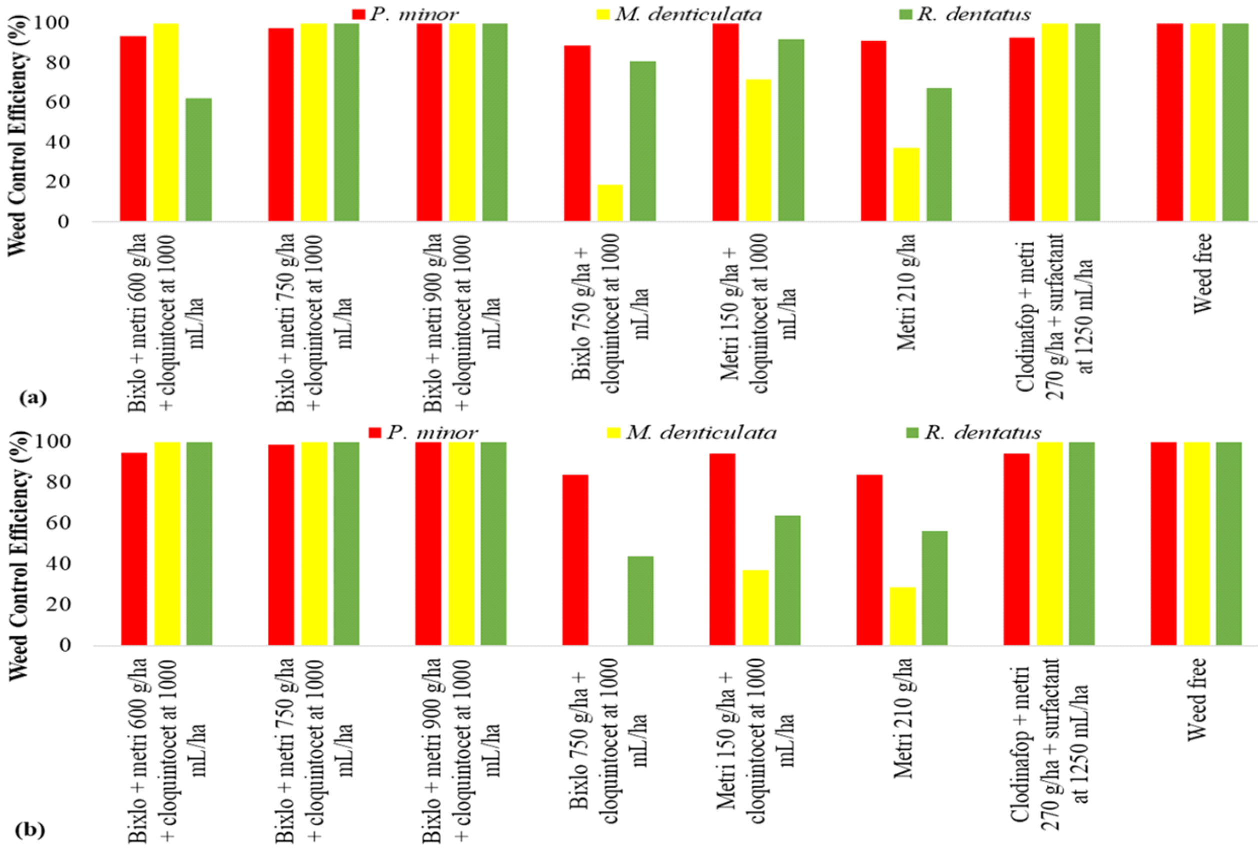

Figure 1. Weed control efficiency (%) of herbicide treatments in wheat at 60 DAA (a) 2021-22 (b) 2022-23

Table 3. Effect of different herbicide treatments on weed biomass (g/m²) at 60 DAA and grain yield in wheat during *Rabi* 2021-22 and 2022-23

Treatment	Dose (g/ha)	Grass *P. minor*		Broad-leaved weeds *M. denticulata*		Broad-leaved weeds *R. dentatus*		Wheat grain yield (t/ha)	
		2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Bixlozone + metribuzin with cloquintocet at 1000 mL/ha	600	2.99(8)	2.89(7)	1.00(0)	1.00(0)	3.85(14)	1.00(0)	5.35	5.37
Bixlozone + metribuzin with cloquintocet at 1000 mL/ha	750	1.90(3)	1.75(2)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	5.25	5.26
Bixlozone + metribuzin with cloquintocet at 1000 mL/ha	900	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	4.96	4.72
Bixlozone with cloquintocet at 1000 mL/ha	750	3.84(14)	5.00(25)	5.16(26)	5.91(35)	2.72(7)	6.10(36)	4.53	4.93
Metribuzin with cloquintocet at 1000 mL/ha	150	1.00(0)	3.11(9)	3.11(9)	4.82(22)	1.67(3)	4.89(23)	4.86	5.07
Metribuzin	210	3.46(11)	5.1(25)	4.49(20)	5.15(25)	3.64(12)	5.36(28)	4.71	4.82
Clodinafop propargyl + metribuzin with surfactant at 1250 mL/ha	270	3.11(9)	3.07(9)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	5.30	5.26
Weed free	-	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	6.06	5.54
Weedy check	-	11.15(124)	12.56(157)	5.70(32)	5.99(35)	6.19(37)	8.07(64)	4.30	4.15
LSD(p=0.05)		0.99	0.94	0.66	0.47	0.63	0.48	0.23	0.16

*Figures in parentheses are original means. Data were subjected to square root transformation, DAA = Days after application

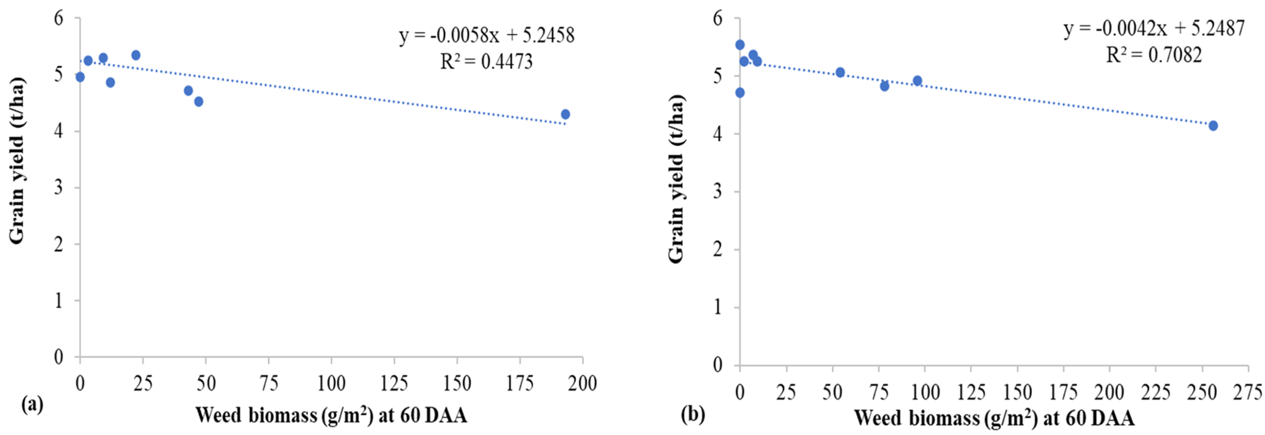

Figure 2. The relationship of the wheat grain yield (t/ha) with weed biomass (g/m²) at 60 DAA (a) 2021-22 (b) 2022-23

The linear regression analysis illustrates the relationship between total weed biomass at 60 DAA and grain yield of wheat (**Figure 2**). A strong negative linear correlation was observed, with R^2 values of 0.4473 and 0.7082 at 60 DAA for 2021-22 and 2022-23, respectively. This indicates that weed biomass accounted for 45% of the yield variation in 2021-22 and 71% in 2022-23. As total weed biomass increased, there was a corresponding decrease in wheat grain yield. The findings highlight a significant influence of weed control treatments on both weed biomass at 60 DAA and grain yield.

Based on a two-year study, it is concluded that early post-emergence application at 28-30 DAS (one day before first irrigation) of bixlozone + metribuzin 600-750 g/ha with safener cloquintocet at 1000 mL/ha provided effective control of herbicide resistant *P. minor* and associated broad-leaved weeds in wheat.

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RESEARCH ARTICLE

Metribuzin + clodinafop-propargyl (ready-mix) efficacy in managing weeds in wheat and assessment of its residues in the soil and wheat at harvest

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ABSTRACT

Indiscriminate use of herbicides may raise human and animal health and environmental concerns due to residues on consumables and soil. Hence, field experiments were conducted during rabi season of 2021-22 and 2022-23 at PAU Ludhiana and KVK Sri Muktsar Sahib, Punjab, India. The objectives were to assess efficacy of metribuzin + clodinafop-propargyl (ready-mix) in managing weeds in wheat and quantify its residues retained in soil and in wheat produce. It involved spray of metribuzin and clodinafop-propargyl (ready-mix) at rates of 275, 220 and 165 g/ha along with unsprayed for weed management in surface seeded wheat. Metribuzin and clodinafop-propargyl at 275 and 220 g/ha significantly lowered weed density and biomass and improved wheat grain yield compared to its lowest dose of 165 g/ha and unsprayed control. Metribuzin and clodinafop-propargyl residues in soil and crop produce were assessed at harvest time and it was observed that their residue levels were below detectable limits (<0.01 µg/g) and below the maximum residue limit fixed by Food Safety and Standards Authority of India (FSSAI), indicating metribuzin + clodinafop-propargyl safety to use as an herbicide in wheat production and consumption of wheat produced after its usage.

Keywords: Herbicide residues, Metribuzin + clodinafop-propargyl, Wheat, Weed management

INTRODUCTION

Weeds are among the most important biological constraints that can adversely affect wheat productivity (Rao *et al.* 2014, Yadav and Brar 2025). Mechanical and chemical methods are most commonly used to manage weeds but of these methods, herbicides are most preferred method of weed control due to fast action, selectivity, lesser cost and drudgery (Singh *et al.* 2008, Singh and Chhina 2025). *Phalaris minor* is among the most problematic weeds and difficult to control as it mimics wheat. *Phalaris minor* has potential to cause yield reduction to the extent of 100% (Chhokar and Malik 2002). Metribuzin + clodinafop-propargyl (ready-mix) is an effective broad-spectrum herbicide especially against herbicide resistant *Phalaris minor* (Abbas *et al.* 2016, Singh *et al.* 2015). But using herbicide with similar modes of action year after year has resulted in development of multiple herbicide resistance in *Phalaris minor* (Bhullar *et al.* 2014, Kaur *et al.* 2015) in north-west part of India. Apart from this, there are environmental, and health concerns associated with herbicide use in wheat as it may leave its residues which may be harmful for human and animal health as they both are end users of crop produce i.e. grains and straw (Sondhia and Mishra 2005, Thakur *et al.* 2019). Keeping this in view, a study was conducted to evaluate metribuzin + clodinafop-propargyl (ready-mix) efficacy in managing weeds in wheat and to quantify its residues in the soil and in wheat produce, at wheat harvest.

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MATERIALS AND METHODS

Experiments were conducted at Punjab Agricultural University (PAU) Ludhiana (Latitude: 30° 53’ N, Longitude: 75° 47’ E) and Krishi Vigyan Kendra (KVK) Sri Muktsar Sahib (SMS) (Latitude: 30° 26’ N, Longitude: 74° 30’ E). At PAU, soil was sandy loam in nature (sand: 68, silt:16 and clay: 16%) with 0.38% organic carbon, situated in sub-humid climate with total rainfall for 2021-22 and 2022-23 from 44th SMW (Standard Meteorological Week) to 16th SMW were 158 and 113 mm, respectively. In contrast, KVK soil was characterised as sandy clay loam (sand: 54, silt:12 and clay 34%) with organic carbon of 0.60%, located in semi-arid region with 92 and 83 mm of total rainfall, respectively for the corresponding period.

At PAU, sowing of wheat variety, PBW 766 was done on 10th November, 2021 and 2nd November, 2022 during first and second year, respectively. Similarly, at KVK, sowing of same variety was done on 16th and 17th November during 2021 and 2022 respectively. Post-emergence application (PoE) of active in-gradient of metribuzin 42% + clodinafop-propargyl 12% (ready-mix) at 275 g/ha, 220 g/ha and 165 g/ha was done on 2-3 days after first post emergence irrigation in surface seeded wheat. An unsprayed control was maintained. Wheat was raised as per standard procedure and harvesting was done on 12th April, 2022 in the first year and 17th April, 2023 in second year at PAU. At KVK, it was harvested on 18th April 2022 and 22nd April 2023.The data on weed density was collected 60 days after seeding (DAS) and on biomass, 90 DAS of wheat following standard procedures.

Statistical analysis

Analysis of variance (ANOVA) was performed to see effect of metribuzin + clodinafop-propargyl at different doses on weeds and wheat yield. Weed data was subjected to square root transformation ($\sqrt{x+1}$) to homogenize the distribution. Pooled analysis of two years data for each location was performed as experimental error for two years was homogenous according to the Bartlett's test of homogeneity of variance. To determine significant differences between means, the Fisher's least significant difference (LSD) test was employed at a 5% probability level.

Assessment of residues of herbicides in soil and wheat at harvest

Sample collection

From all the experiments during both years, the soil samples (taken from a depth of 0-15 cm), along with the grain and straw samples, were collected at harvest and were immediately stored at -4ºC in a deep freezer to prevent any degradation of herbicide residues.

Extraction of herbicide residues

Metribuzin was extracted from soil / wheat grain / straw using ultrasonic assisted extraction technique. Soil/wheat grain/straw (10 g) sample was ultrasonicated with 60 mL of acetone (2 cycles of 30 ml each) in ultrasonic bath (40 kHz, 20 W) maintained at 40±2°C for 3 minutes. The supernatant was collected, filtered and for quantification of metribuzin residues from soil, filtrate was evaporated to dryness using rotary vacuum evaporator and redissolved in 2 mL HPLC grade acetonitrile. For quantification of metribuzin from wheat grain and straw, filtrate was concentrated to 5 mL using rotary vacuum evaporator and concentrated extract was loaded on column packed with silica gel. The column was eluted with 60 mL acetone:hexane (8:2). Eluent was evaporated to dryness and the residues were then reconstituted in 2 mL of acetonitrile and quantified using HPLC.

Clodinafop-propargyl was extracted from soil, wheat grain and straw using matrix solid-phase dispersion (MSPD) technique. The procedure was carried out in a glass column packed with silica gel, activated sodium sulphate and charcoal. A 10 g sample of soil/wheat grain was blended with 5 g of silica (60-200 mesh, pre-activated at 200°C for 8 hours) for 7 minutes. This mixture was then transferred to the glass column containing 2g sodium sulphate and 3 mg of charcoal. The column was eluted with 70 mL of ethyl acetate:hexane (8:2) and the collected eluent was evaporated using a rotary vacuum evaporator. The residue was reconstituted in 2 mL of acetonitrile and quantified using HPLC. Wheat straw (10 g) was shaken overnight with 80 mL ethyl acetate for extraction of clodinafop-propargyl. The contents were filtered and concentrated to 5 mL using rotary vacuum evaporator. For cleanup, concentrated extract was loaded on column packed with silica gel, activated sodium sulphate, charcoal and eluted with ethyl acetate:hexane (8:2). Eluents were evaporated, reconstituted in acetonitrile (2 mL) and quantified using HPLC.

Quantification of herbicide residues

The residues of herbicides at harvest were quantified using high-performance liquid chromatography (HPLC) with UV detector. C_{18} column (5 µm; 4.6 × 250 mm) was used for the separation of the herbicides. Acetonitrile: water (80:20) was used as a mobile phase at a flow rate of 0.8 ml/min. The detector wavelength was set at 297 and 240 nm for metribuzin and clodinafop-propargyl, respectively. The retention time of metribuzin and clodinafop-propargyl were 4.467 and 7.700 minutes, respectively (**Figures 1a** and **2a**).

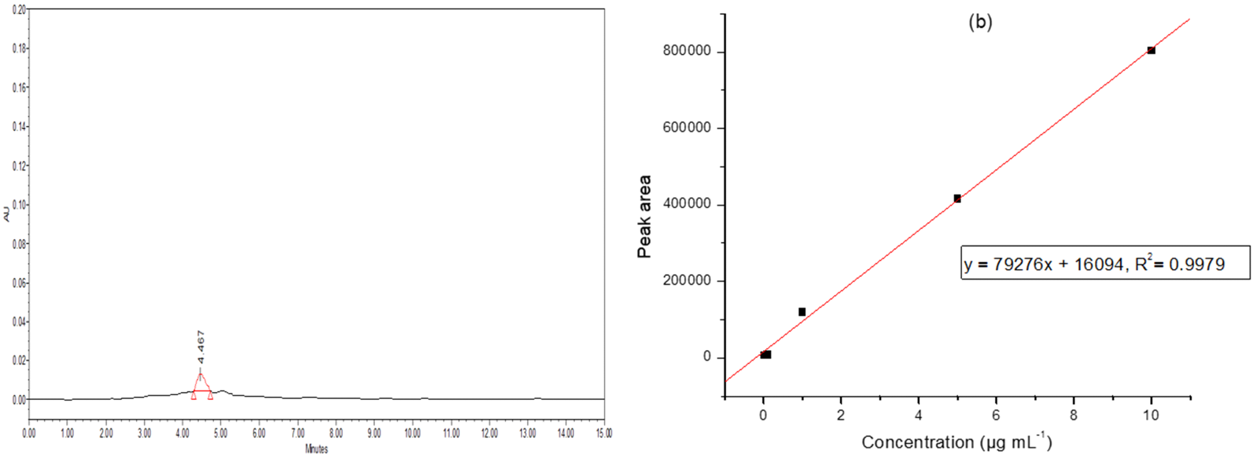

Figure 1(a). HPLC chromatogram of metribuzin (0.1 μg/mL) (b) Calibration curve of metribuzin

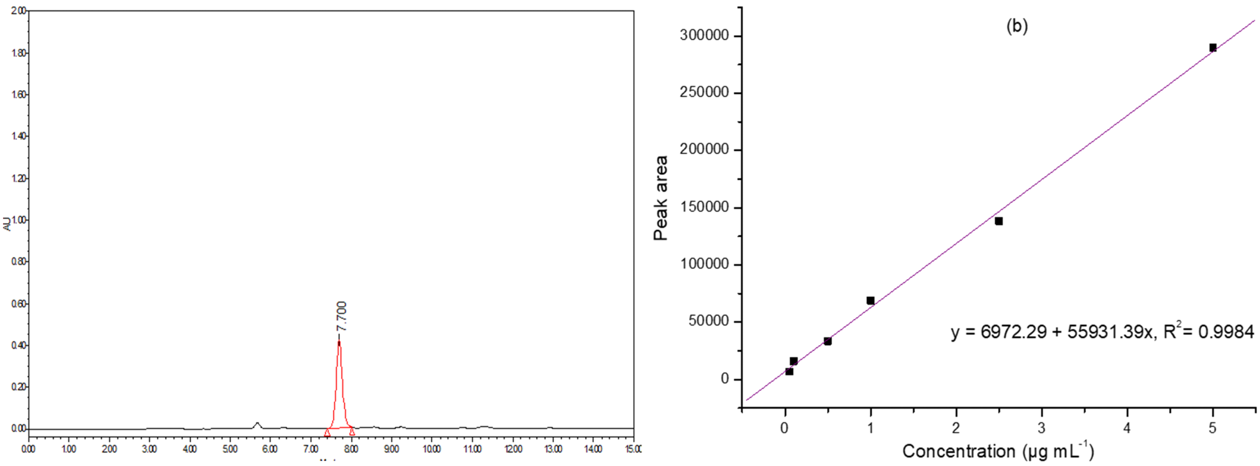

Figure 2(a). HPLC chromatogram of clodinafop-propargyl (0.1 μg/mL) (b) Calibration curve of clodinafop-propargyl

Estimation of metribuzin and clodinafop-propargyl herbicide residues

Method validation

The calibration curves of metribuzin and clodinafop-propargyl were linear with correlation coefficient R^2>0.99 (**Figure 1b** and **2b**). The limit of detection (LOD) and limit of quantitation (LOQ) for both metribuzin and clodinafop-propargyl were 0.003 and 0.01 μg/g, respectively. The mean percent recoveries of metribuzin from soil, wheat grain and wheat straw samples at fortification levels of 0.5, 0.1 and 0.01 μg/g ranged from 82.5 ± 2.21 to 94.3 ± 2.78, 78.4±1.72 to 87.4±3.88 and 74.5±2.50 to 84.5±1.56, respectively. The mean percent recoveries of clodinafop-propargyl from soil, wheat grain and wheat straw samples at fortification levels of 0.5, 0.1 and 0.01 μg/g ranged from 83.1 ± 3.45 to 93.7 ± 2.09, 79.1 ± 2.87 to 89.1 ± 1.65 and 76.8 ± 1.66 to 84.3 ± 2.83%, respectively (**Table 2**). Inter day precision (percent RSD_R) and intraday precision (percent RSD_r) of herbicides were assessed by repeating experiment three times a day and on three different days, respectively and were <10 percent in all matrices.

RESULTS AND DISCUSSION

Effect on weed density, biomass and wheat yield

Phalaris minor, Rumex dentatus, Medicago denticulata and *Coronopus didymus* were major weeds in experimental field, at both locations and sum total of all four weeds consisted of total weed density and biomass. Weed density and biomass showed differential response to metribuzin + clodinafop-propargyl at different doses. Metribuzin + clodinafop-propargyl at 275, 220 and 165 g/ha recorded 81, 76, 52% lower total weed density at PAU and 79,76 and 40% lower at KVK, respectively **(Table 1).** Similarly, total weed biomass was significantly lower with metribuzin + clodinafop-propargyl irrespective of dose than unsprayed control. Reductions compared to the weedy check were 70%, 68%, and 32% at the PAU location, and 72%, 68%, and 23% at the KVK location. Singh *et al.* (2015) also reported lower weed biomass with clodinafop-propargyl + metribuzin compared to weedy check. Metribuzin + clodinafop-propargyl at 275 g/ha recorded the highest wheat grain yield which was at par with next higher dose of 220 g/ha at both the locations, but both were significantly better than that of the lowest dose of 165 g/ha and untreated control. Nanher *et al.* (2015) also reported similar grain yield at both lower and higher doses of metribuzin + clodinafop-propargyl, and better than weedy check. Qazizada *et al.* (2022) also reported higher grain yield with herbicide use as compared to unsprayed check. Higher weed biomass and density were inversely related with the lower grain yield and vice versa. Our results are in conformity with that of Kaur *et al.* (2025) who observed inverse relationship between yield and weed biomass. Vigorous weed growth, resulting in severe competition with the wheat crop for nutrients, light, water, and space caused a 22% yield reduction at PAU and a 16% reduction at KVK compared to the with metribuzin + clodinafop-propargyl at 275 g ai/ha (**Table 1**). Similar trend was observed with straw yield. Minimum straw yield was observed in untreated spray, which was significantly lower than metribuzin + clodinafop-propargyl at all doses at both the locations.

Harvest time residues of metribuzin and clodinafop-propargyl in soil and wheat grain and straw

Residues of metribuzin and clodinafop-propargyl were below the detectable limits (<0.01 µg/g) at harvest in soil, wheat grain, and wheat straw (**Figures 3-4**) across all tested application rates (275, 220, and 165 g/ha) at both locations during both years. Consequently, the residues were significantly below the maximum residue limits (MRLs) set by the Food Safety and Standards Authority of India (FSSAI 2011).

Residues below detectable limits can be attributed to the substantial time interval of over three-and-a-half months between herbicide application and crop harvest at PAU and KVK during both the years. The half-life of clodinafop-propargyl varies from 1.9 to 3.1 days (EFSA 2020) and of metribuzin from 15.2 to 46.6 days (EFSA 2006) in soil. In our study, the time between was sufficient to degrade these herbicides, by the time of crop harvest during both years and at both locations. The residues

Table 1. Effect of metribuzin + clodinafop-propargyl on total weed density, total weed biomass and grain and straw yield at two locations (pooled data of 2 years)

Treatment	Total weed density (no./m^2) 60 DAS		Total weed biomass (g/m^2) 90 DAS		Grain yield (t/ha)		Straw yield (t/ha)	
	PAU	KVK	PAU	KVK	PAU	KVK	PAU	KVK
Unspayed control	9.18(83.4)	7.36(53.3)	10.81(116.1)	8.24(66.9)	4.13	4.37	6.12	6.48
Metribuzin + clodinafop- propargyl (ready-mix) 165 g/ha	6.38(40.4)	5.72(32.0)	7.58(56.9)	6.48(41.3)	4.73	4.78	6.79	6.94
Metribuzin + clodinafop- propargyl (ready-mix) 220 g/ha	4.45(19.6)	3.69(13.0)	5.22(26.9)	4.17(16.8)	5.20	5.09	7.38	7.38
Metribuzin + clodinafop- propargyl (ready-mix) 275 g/ha	4.04(16.1)	3.43(11.1)	5.02(25.0)	3.93(15.0)	5.32	5.19	7.54	7.53
LSD(p=0.05)	0.31	0.17	0.31	0.18	0.14	0.15	0.17	0.18

Weed data subjected to square root transformation ($\sqrt{x+1}$); Figures in parentheses are original values; PAU: Punjab Agricultural University, Ludhiana; KVK: Krishi Vigyan Kendra, Sri Muktsar Sahib; DAS: days after seeding

Table 2. Mean percent recoveries of metribuzin and clodinafop-propargyl from soil, wheat grain and straw

Herbicide	Matrix	Recovery (%)		
		0.5 µg/g	0.1 µg/g	0.01 µg/g
Metribuzin	Soil	94.3 ± 2.78	90.9 ± 1.77	82.5 ± 2.21
	Wheat grain	87.4 ± 3.88	83.9 ± 1.98	78.4 ± 1.72
	Wheat straw	84.5 ± 1.56	80.2 ± 1.22	74.5 ± 2.50
Clodinafop-propargyl	Soil	93.7 ± 2.09	89.7 ± 2.02	83.1 ± 3.45
	Wheat grain	89.1 ± 1.65	84.0 ± 2.33	79.1 ± 2.87
	Wheat straw	84.3 ± 2.83	80.9 ± 1.21	76.8 ± 1.66

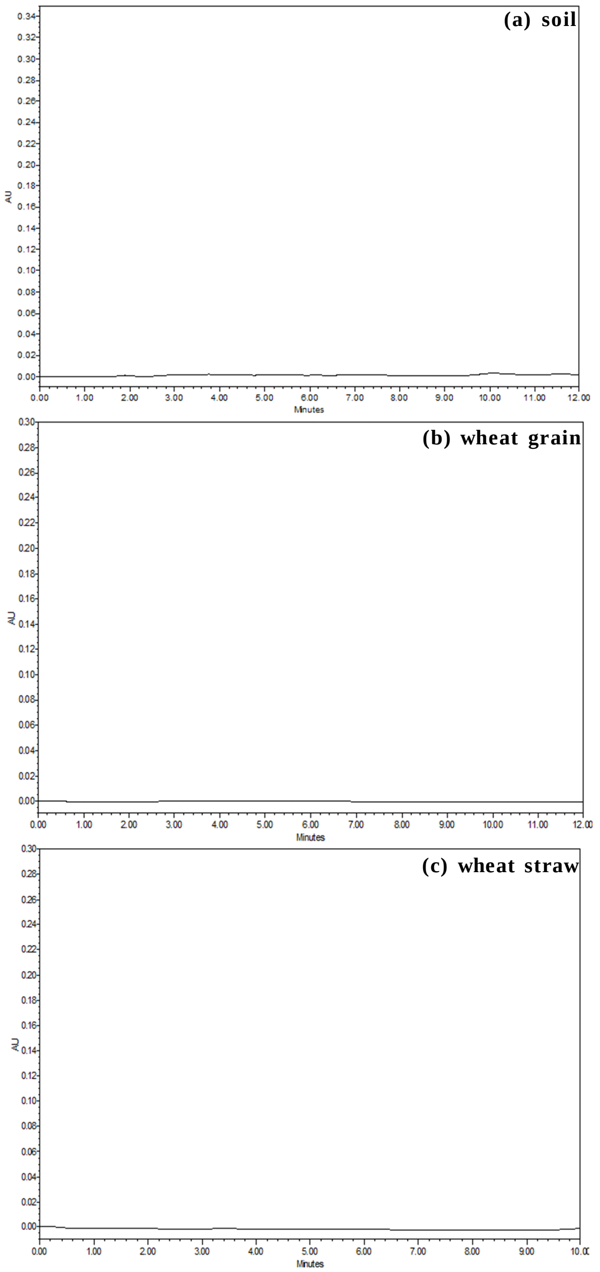

Figure 3. Chromatograms of metribuzin in (a) soil (b) wheat grain (c) wheat straw at wheat harvest

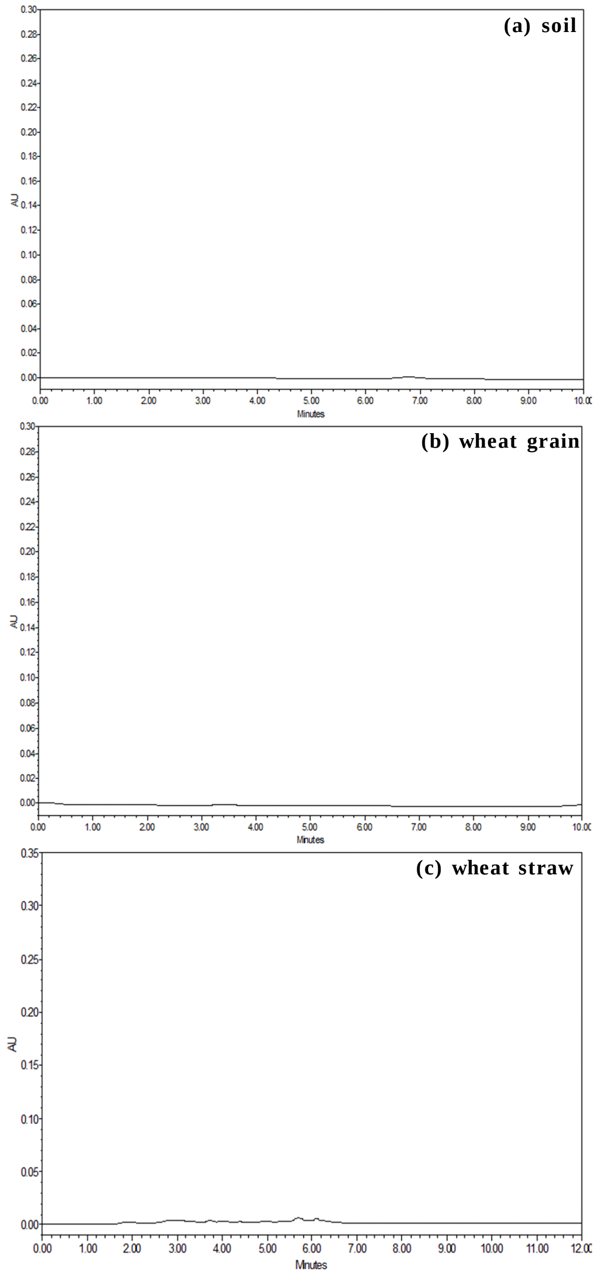

Figure 4. Chromatograms of clodinafop-propargyl in (a) soil (b) wheat grain (c) wheat straw at wheat harvest

of pendimethalin, imazethapyr, and carfentrazone-ethyl in soil (Walia *et al.* 2021), metsulfuron-methyl in wheat grain and straw (Thakur *et al*. 2019) and clodinafop-propargyl in wheat (Singh *et al.* 2004, Sondhia and Mishra 2005) were reported earlier to be below detectable limits when applied at recommended and lower doses.

It can be concluded that the use of metribuzin + clodinafop-propargyl (ready-mix) is safe for effective weed management in wheat, as its residues were below detectable limits (<0.01 µ/g) and below the maximum residue limit fixed by FSSAI, both in the soil or in wheat produce.

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RESEARCH ARTICLE

Non-chemical weed management in sweet corn-fennel cropping system

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ABSTRACT

The area and demand of organic agriculture is increasing in Gujarat state and other states in India. The management of weeds is the most serious constraint in organic crop production systems. The integration of various non-chemical weed management practices provides effective weed control for realizing higher crop production. Hence a study was conducted to identify the effective non-chemical approaches for weed management in sweet corn-fennel cropping system. A field experiment was conducted during *Kharif* 2023 and *Rabi* 2023-24 on loamy sand soil at the farm of AICRP-Weed Management, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat. The non-chemical weed management treatments that were effective in manaing weeds include: soil solarization followed by (*fb*) hand weeding (HW) + straw mulch 5 t/ha at 20 DAS + HW at 40 DAS in sweet corn; and hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 50 and 75 DAS in fennel. These were at par with soil solarization *fb* plastic mulch at sowing *fb* HW at 40 DAS in sweet corn and plastic mulch at sowing *fb* HW at 50 and 75 DAS in fennel. The effective treatments recorded lower weed density and biomass, higher growth and yield attributes, higher sweet corn equivalent green cob, gross returns and benefit cost ratio as compared to other treatments.

Keywords: Cropping system, Fennel, Non-chemical approach, Sweet corn, Weed management

INTRODUCTION

Sweet corn (*Zea mays* L. var. saccharata Sturt) is popular among producers and grown in large area. Sweet corn with enhanced sugar content, is gaining popularity in commercial establishments like hotels, malls and stores. Sweet corn is being used in soups, sweets, jams and has many more uses. Similarly, among seed spices, fennel (*Foeniculum vulgare* Mill.) is one of the major seed spices belonging to the family Apiaceae. In both the crops, weed control is challenging constraint as weeds compete for essential resources such as nutrients, water, sunlight, and space and critically contribute to low crop yields. The intensity of weeds and damage due to weeds is related to the type of weeds, species and density of weeds in a crop. A reduction of 50% fennel yield (Gohil *et al.* 2015) and 40-42% green cob yield of sweet corn (Sunitha *et al.* 2010) were reported due to uncontrolled weeds.

Various methods are employed to manage the weeds during growing season of both the crops (Sunitha *et al.* 2010, Patel *et al.* 2019). Chemical method of weed control is cheaper as well as feasible for timely control of weeds (Meena and Mehta 2009, Dobariya *et al.* 2014) but it is not acceptable in organic farming system hence, alternative methods are used to manage the weeds The options for organic weed management include mechanical weeding, cover cropping, crop rotation, modified sowing and planting methods, organic residue mulching, green manuring, reduced or zero tillage, soil solarization, hand weeding, intercropping etc.

Application of straw mulch showed favourable effect on growth parameters and yield of crop as compared to no mulch which might be explained by early emergence, quick establishment of crop and higher interception of light (Patel *et al.* 2019). Moreover, soil under mulch remains loose, friable and well-aerated therefore, roots have access to adequate oxygen and enhance the microbial activity in the soil. Soil solarization is a non-chemical disinfestation practice that involves covering the ground with a transparent polyethylene cover to maintain soil moisture and trap solar energy which reduces weed growth, increases soil temperature and leading to enhancement of crop yield and improve quality of the produce (Setyowati *et al.* 2017). Hoeing is the most efficient method for weed control in all crops, sowing methods and growth conditions and mechanical weeding can provide effective weed management even when other methods are not possible. Stale seedbed is based on the principle of flushing out germinating weed seeds before sowing of the crop.

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This study was conducted to identify the effective non-chemical approach for weed management in sweet corn-fennel cropping system.

MATERIALS AND METHODS

Field experiment was carried out during *Kharif* -2023 and *Rabi* 2023-24 on loamy sand soil at the farm of AICRP-Weed Management, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat. The experiment was laid out in randomized complete block design with three replications and eight treatments. The treatments in sweet corn, during *Kharif* season, include: soil solarization followed by (*fb*) hand weeding (HW) + straw mulch 5 t/ha at 20 days after seeding (DAS) + HW at 40 DAS, soil solarization *fb* plastic mulch at sowing *fb* HW at 40 DAS, stale seed bed preparation *fb* plastic mulch at sowing *fb* HW at 40 DAS, stale seed bed preparation *fb* hand weeding + straw mulch 5 t/ha at 20 DAS *fb* hand weeding at 40 DAS, sunnhemp between rows as smothering crop and used as mulch at 30 DAS with tillage *fb* HW at 40 DAS, inter cultivation (IC) + HW + straw mulch 5 t/ha at 20 DAS *fb* HW at 40 DAS, IC + HW twice at 20 and 40 DAS and weedy check. The treatments in fennel, during *Rabi* season, include: hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 50 and 75 DAS; Plastic mulch at sowing *fb* HW at 50 and 75 DAS; Stale seed bed preparation *fb* plastic mulch at sowing *fb* HW at 75 DAS; Stale seed bed preparation *fb* hand weeding + straw mulch 5 t/ha at 20 DAS *fb* hand weeding at 50 and 75 DAS; Sunnhemp between rows as smothering crop and used as mulch at 30 DAS with tillage *fb* HW at 50 and 75 DAS; IC + HW + straw mulch 5 t/ha at 20 DAS *fb* HW at 50 and 75 DAS; IC + HW at 20, 40 and 60 DAS *fb* earthing-up at 75 DAS and weedy check tested in *rabi* fennel. The recommended seed rate of 16 kg/ha of sweet corn cv. "madhuram" was sown keeping the distance of 45 cm row spacing by manually in previously open furrows with the help of Kudali during *Kharif* season on 28.06.2023. Whereas, fennel cv. "*Gujarat Fennel 12*" was sown keeping the seed rate of 4.0 kg/ha with the spacing of 45 cm during *Rabi* season on 21.11.2023. All other recommended package of practices were adopted to raise the crop. Weed parameters recorded using randomly placed 0.25 m^2 quadrat from net plot area of each treatment and converted into one m^2 area. At 75 DAS, hand weeding was done in respective treatment after recording the weed density in fennel. Data on various observations *viz.*, in sweet corn plant height, green cob yield, green fodder yield while in fennel plant stand, plant height, number of umbels, seed yield and stalk yield recorded during the experimental period was statistically analysed as per the standard procedure and weed data were transformed by square root transformation ($\sqrt{x+1}$) and transformed data were subjected to ANOVA analysis (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

In the experimental field of sweet corn, the major monocot weeds were: *Dactyloctenium aegyptium, Digitaria sanguinalis, Eleusine indica, Commelina benghalensis and Setaria glauca*. *Oldenlandia umbellata, Digera arvensis, Phyllanthus niruri* and *Mollugo nudicaulis* were the dominant dicot weeds in the field. In *rabi* fennel *Dactyloctenium aegyptium, Setaria glauca*, *Eleusine indica* and *Digitaria sanguinalis* were monocot weeds and *Digera arvensis*, *Phyllanthus niruri*, *Chenopodium album* and *Oldenlandia umbellata* were dominant dicot weeds.

Effect on weeds in sweet corn

The weed density and dry biomass at 30 DAS was lower under soil solarization *fb* hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 40 DAS, stale seed bed preparation *fb* hand weeding + straw mulch 5 t/ha at 20 DAS *fb* hand weeding at 40 DAS and IC + HW + straw mulch 5 t/ha at 20 DAS *fb* HW at 40 DAS (**Table 1**). While at 60 DAS and at harvest, significantly lower weed density and dry biomass were noticed under soil solarization *fb* plastic mulch at sowing *fb* HW at 40 DAS, soil solarization *fb* hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 40 DAS and stale seed bed preparation *fb* plastic mulch at sowing *fb* HW at 40 DAS. Effectiveness of soil solarization might be due to ensnared sunlight energy elevates the soil temperature to kill the germinating and germinated weeds as well as the seeds near the soil surface (Arora and Tomar 2012, Kumar *et al*. 2022).

Effect on sweet corn

Sweet corn plant stands at 15 DAS (no./m row length) showed non-significant difference amongst different weed management treatments**.** At 60 DAS, significantly higher plant height was measured under soil solarization *fb* hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 40 DAS but it was at par with soil solarization *fb* plastic mulch at sowing *fb* HW at 40 DAS at 30 DAS. Sweet corn green cob yield under the weed management practices was significant influenced. The soil solarization *fb* hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 40 DAS recorded significantly higher green cob yield and green fodder yield and it was at par with soil solarization *fb* plastic mulch at sowing *fb* HW at 40 DAS at 30 DAS confirming findings of Choudhary *et al*. (2021). Among all the treatments, weedy check registered significantly the lowest green cob yield and green fodder yield (**Table 3**). All the weed management treatments recorded significantly higher green fodder yield as compared to weedy check.

Effect on weeds in fennel

The lower weed density and dry biomass was noticed under soil solarization *fb* hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 50 and 75 DAS, soil solarization *fb* plastic mulch at sowing *fb* HW at 50 and 75 DAS, stale seed bed preparation *fb* plastic mulch at sowing *fb* HW at 75 DAS and stale seed bed preparation *fb* hand weeding + straw mulch 5 t/ha at 20 DAS *fb* hand weeding at 50 and 75 DAS as compared to others at all the growth stages in fennel (**Table 2**). Decrease in the density and dry biomass of weeds by 93% due to soil solarization in fennel at harvest was noticed by Campiglia *et al*. (2000). Similarly, stale seedbed technique also reduced the density and dry biomass of weeds as early germinated weed flush prior to sowing of crop were destroyed from the respective plots.

Table 1. Density and dry biomass of weeds as influenced by different treatments in sweet corn of sweet corn-fennel cropping system

Treatment	Weed density (no./m^2)			Weed dry biomass (g/m^2)		
	At 30 DAS	At 60 DAS	At harvest	At 30 DAS	At 60 DAS	At harvest
Soil solarization *fb* hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 40 DAS	1.00 (0.00)	4.20 (17.0)	4.49 (19.3)	1.00 (0.00)	2.74 (6.55)	5.70 (31.9)
Soil solarization *fb* plastic mulch at sowing *fb* HW at 40 DAS	3.40 (10.7)	3.58 (12.0)	4.01 (15.3)	1.99 (2.96)	2.66 (6.06)	5.31 (27.4)
Stale seed bed preparation *fb* plastic mulch at sowing *fb* HW at 40 DAS	3.85 (14.0)	3.95 (14.7)	4.24 (17.3)	2.44 (4.95)	2.89 (7.38)	5.46 (28.9)
Stale seed bed preparation *fb* hand weeding + straw mulch 5 t/ha at 20 DAS *fb* hand weeding at 40 DAS	1.00 (0.00)	8.44 (70.7)	6.74 (45.3)	1.00 (0.00)	4.49 (19.2)	8.23 (67.2)
Sunnhemp between rows as smothering crop and used as mulch at 30 DAS with tillage *fb* HW at 40 DAS	6.57 (42.7)	12.6 (157)	8.29 (69.3)	3.68 (12.6)	7.24 (52.1)	10.5 (109)
IC + HW + straw mulch 5 t/ha at 20 DAS *fb* HW at 40 DAS	1.00 (0.00)	10.7 (115)	6.29 (38.7)	1.00 (0.00)	3.99 (15.6)	7.84 (62.1)
IC + HW at 20 and 40 DAS	5.12 (25.3)	11.2 (125)	10.1 (101)	1.71 (1.93)	5.12 (25.2)	10.9 (118)
Weedy check	20.7 (429)	17.6 (313)	11.4 (129)	7.80 (60.2)	16.5 (274)	23.4 (551)
LSD (p=0.05)	0.99	1.94	1.59	0.49	1.94	1.98

Data subjected to ($\sqrt{x+1}$) transformation. Figures in parentheses are means of original values. DAS – days after seeding; *fb* - followed by; HW – hand weeding; IC - intercultivation

Table 2. Density and dry biomass of weed as influenced by different treatments in fennel under sweet corn-fennel cropping system

Treatment	Weed density (no./m^2)			Weed dry biomass (g/m^2)		
	At 30 DAS	At 75 DAS	At harvest	At 30 DAS	At 75 DAS	At harvest
Hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 50 and 75 DAS	1.00 (0.00)	3.11 (8.67)	3.41 (10.7)	1.00 (0.00)	2.19 (3.82)	2.58 (5.79)
Plastic mulch at sowing *fb* HW at 50 and 75 DAS	1.00 (0.00)	3.58 (12.0)	4.94 (23.7)	1.00 (0.00)	2.24 (4.04)	3.22 (9.56)
Stale seed bed preparation *fb* plastic mulch at sowing fb HW at 75 DAS	1.00 (0.00)	5.76 (33.3)	3.37 (10.7)	1.00 (0.00)	5.82 (33.0)	2.64 (6.00)
Stale seed bed preparation *fb* hand weeding + straw mulch 5 t/ha at 20 DAS *fb* hand weeding at 50 and 75 DAS	1.00 (0.00)	6.29 (38.7)	3.72 (13.0)	1.00 (0.00)	2.77 (6.94)	2.67 (6.16)
Sunnhemp between rows as smothering crop and used as mulch at 30 DAS with tillage *fb* HW at 50 and 75 DAS	11.5 (133)	5.20 (26.7)	7.10 (50.7)	5.26 (26.7)	3.02 (8.32)	5.71 (31.9)
IC + HW + straw mulch 5 t/ha at 20 DAS *fb* HW at 50 and 75 DAS	4.06 (16.0)	5.30 (28.0)	4.26 (17.3)	1.41 (1.02)	3.15 (9.04)	3.12 (8.81)
IC + HW at 20, 40 and 60 DAS *fb* earthing-up at 75 DAS	6.30 (40.0)	1.00 (0.00)	5.07 (24.7)	1.71 (1.94)	1.00 (0.00)	3.75 (13.4)
Weedy check	21.2 (450)	13.8 (191)	11.6 (136)	9.59 (91.8)	16.3 (265)	17.2 (297)
LSD (p=0.05)	1.66	1.75	1.68	0.75	1.16	1.62

Data subjected to ($\sqrt{x+1}$) transformation. Figures in parentheses are means of original values. DAS – days after seeding; *fb* - followed by; HW – hand weeding; IC - intercultivation

Effect on fennel

The fennel plant stand at 15 DAS (no./m row length) was statistically similar under different weed management treatments**.** Fennel plant height at 75 DAS was significantly higher soil solarization *fb* hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 50 and 75 DAS while at harvest, fennel plant height was highest with stale seed bed preparation *fb* hand weeding + straw mulch 5 t/ha at 20 DAS *fb* hand weeding at 50 and 75 DAS (**Table 4**). Significantly lowest fennel plant height, seed and stalk yield was recorded with weedy check at 75 DAS and at harvest. All the weed management treatments remained at par with each other and recorded significantly higher number umbels/m row length, seed and stalk yield as compared to weed check. Among all the treatments, soil solarization *fb* hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 50 and 75 DAS recorded significantly higher seed and stalk yield and it was at par with stale seed bed preparation *fb* hand weeding + straw mulch 5 t/ha at 20 DAS *fb* hand weeding at 50 and 75 DAS, IC + HW + straw mulch 5 t/ha at 20 DAS *fb* HW at 50 and 75 DAS, stale seed bed preparation *fb* plastic mulch at sowing *fb* HW at 75 DAS and IC + HW at 20, 40 and 60 DAS *fb* earthing-up at 75 DAS. These findings are in agreement with those of Patel *et al*. (2018). Campiglia *et al*. (2000) observed that yield of fennel was improved up to 91% following solarization with clear polyethylene mulch compared with the un-mulched control.

Sweet corn equivalent yield

The highest system productivity reduction of 65.6% was noticed under weedy check in the sweet corn-fennel cropping sequence (**Table 5**).

The least reduction in yield due to weed competition, highest sweet corn equivalent green cob, green fodder yield, gross returns, net returns and benefit cost ratio was observed higher with soil solarization *fb* hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 40 DAS in sweet corn and same

Table 3. Effect of different treatments on growth and yield of sweet corn under sweet corn-fennel cropping system

Treatment	Plant stands at 15 DAS (no./net plot)	Plant height (cm)		Green cob yield (t/ha)	Green fodder yield (t/ha)
		30 DAS	60 DAS		
Soil solarization *fb* hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 40 DAS	166	88.1	199	19.0	20.1
Soil solarization *fb* plastic mulch at sowing *fb* HW at 40 DAS	165	86.6	191	17.4	15.2
Stale seed bed preparation *fb* plastic mulch at sowing *fb* HW at 40 DAS	162	69.4	172	13.1	13.5
Stale seed bed preparation *fb* hand weeding + straw mulch 5 t/ha at 20 DAS *fb* hand weeding at 40 DAS	164	65.8	189	14.6	15.7
Sunnhemp between rows as smothering crop and used as mulch at 30 DAS with tillage *fb* HW at 40 DAS	165	73.4	170	14.4	15.4
IC + HW + straw mulch 5 t/ha at 20 DAS *fb* HW at 40 DAS	165	66.1	187	14.6	15.7
IC + HW at 20 and 40 DAS	165	65.5	172	11.6	12.6
Weedy check	163	59.6	163	7.67	7.63
LSD (p=0.05)	NS	12.6	NS	3.86	3.02

DAS – days after seeding; *fb* - followed by; HW – hand weeding; IC - intercultivation

Table 4. Effect of different treatments on growth and yield of fennel under sweet corn-fennel cropping system

Treatment	Plant stands at 15 DAS (no./m row length)	Plant height (cm)		No. of umbels (no./m row length)	Seed yield (t/ha)
		75 DAS	At harvest		
Hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 50 and 75 DAS	13.8	147.7	190.7	53.7	1.56
Plastic mulch at sowing *fb* HW at 50 and 75 DAS	13.6	129.3	191.3	53.7	1.33
Stale seed bed preparation *fb* plastic mulch at sowing *fb* HW at 75 DAS	13.4	131.7	187.3	51.0	1.48
Stale seed bed preparation *fb* hand weeding + straw mulch 5 t/ha at 20 DAS *fb* hand weeding at 50 and 75 DAS	13.7	143.7	192.7	51.8	1.46
Sunnhemp between rows as smothering crop and used as mulch at 30 DAS with tillage *fb* HW at 50 and 75 DAS	13.2	124.3	178.3	53.7	1.17
IC + HW + straw mulch 5 t/ha at 20 DAS *fb* HW at 50 and 75 DAS	13.4	143.3	181.3	52.0	1.53
IC + HW at 20, 40 and 60 DAS *fb* earthing-up at 75 DAS	13.5	134.3	183.3	52.1	1.46
Weedy check	13.4	96.0	162.3	17.9	0.36
LSD (p=0.05)	NS	13.0	14.0	12.5	0.15

DAS – days after seeding; *fb* - followed by; HW – hand weeding; IC – inter cultivation

Table 5. System productivity of sweet corn-fennel cropping system under organic farming (Sweet corn equivalent)

Treatment		Green cob equivalent yield (t/ha)	Green fodder equivalent yield (t/ha)	Additional cost over control (Rs./ha)	Total cost of cultivation (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C
Sweet corn	Fennel							
Soil solarization *fb* hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 40 DAS	Hand weeding + straw mulch 5 t/ha at 20 DAS + HW at 50 and 75 DAS	29.40	22.3	102505	273746	485600	211854	1.77
Soil solarization *fb* plastic mulch at sowing *fb* HW at 40 DAS	Plastic mulch at sowing *fb* HW at 50 and 75 DAS	26.30	17.3	144200	318499	429100	110601	1.35
Stale seed bed preparation *fb* plastic mulch at sowing *fb* HW at 40 DAS	Stale seed bed preparation *fb* plastic mulch at sowing *fb* HW at 75 DAS	23.00	15.6	90370	260721	376200	115479	1.44
Stale seed bed preparation *fb* hand weeding + straw mulch 5 t/ha at 20 DAS *fb* hand weeding at 40 DAS	Stale seed bed preparation *fb* hand weeding + straw mulch 5 t/ha at 20 DAS *fb* hand weeding at 50 and 75 DAS	24.30	17.8	58320	226320	400100	173780	1.77
Sunnhemp between rows as smothering crop and used as mulch at 30 DAS with tillage *fb* HW at 40 DAS	Sunnhemp between rows as smothering crop and used as mulch at 30 DAS with tillage *fb* HW at 50 and 75 DAS	22.20	16.9	52640	220225	366800	146575	1.67
IC + HW + straw mulch 5 t/ha at 20 DAS *fb* HW at 40 DAS	IC + HW + straw mulch 5 t/ha at 20 DAS *fb* HW at 50 and 75 DAS	24.80	17.8	65530	234060	407600	173540	1.74
IC + HW at 20 and 40 DAS	IC + HW at 20, 40 and 60 DAS *fb* earthing-up at 75 DAS	21.30	14.6	49280	216619	348700	132081	1.61
Weedy check	Weedy check	10.10	6.4	0	163724	164300	576	1.00

DAS – days after seeding; *fb* - followed by; HW – hand weeding; IC - intercultivation

components of IWM as in sweet corn except for HW at 50 and 75 DAS in fennel (**Table 5**). Next best IWM strategy was soil solarization *fb* plastic mulch at sowing *fb* HW at 40 DAS in sweet corn and HW at 50 and 75 DAS in fennel.

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RESEARCH ARTICLE

Effect of herbicides on weed control, yield and profitability of summer greengram under conservation agriculture

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ABSTRACT

Weeds pose a major challenge to the adoption of conservation agriculture (CA), where reduced tillage and crop residues can limit the effectiveness of pre-emergence herbicides, highlighting the need to evaluate herbicides post-emergence application (PoE) option for summer greengram. A two-year field study was undertaken with an objective to assess the effect of eleven weed control treatments on weed density, crop productivity, and profitability of summer greengram under CA. The weed control efficiency declined over time from 30 to 50 days after sowing (DAS) due to weed biomass buildup. Among tested treatments, imazethapyr + imazamox 70 g/ha PoE at 20 DAS caused the best weed suppression, higher (nearly double) greengram seed yield, economic return, and benefit-cost ratio (2.08–2.53), compared to untreated control. The quizalofop was effective against grassy weeds, while higher rates of imazethapyr and sodium- acifluorfen + clodinafop showed limited efficacy. It is concluded that imazethapyr + imazamox at 70 g/ha PoE is the most effective and economical solution to manage weeds in summer greengram under CA.

Keywords: Conservation agriculture, Imazethapyr + imazamox, Post-emergence herbicides, Weed management, Summer greengram

INTRODUCTION

The global population is projected to reach 9.7 billion by 2050, resulting in a 50% increase in food demand compared to 2012 (FAO 2017). The agricultural intensification using high-yielding varieties, irrigation, fertilizers, and agrochemicals remains essential. However, there is a growing shift towards sustainable practices that address environmental concerns, reduce costs, enhance stress resilience, and limit agrochemical use. Ensuring future agricultural sustainability now poses an even greater challenge than increasing productivity. The rice–wheat cropping system (RWCS), spanning ~13.5 million hectares in the Indo-Gangetic Plains, relies heavily on conventional practices that have led to overuse of natural resources and declining soil health (Jat *et al.* 2014; Reddy *et al.* 2025). Repeated tillage depletes soil organic matter and carbon, degrading soil structure and reducing productivity (Kumar *et al.* 2023). These negative impacts highlight the need for sustainable alternatives like conservation agriculture (CA), which focuses on minimal soil disturbance, crop diversification, and residue retention. The CA improves soil physical, chemical, and biological properties, enhancing productivity, profitability, and environmental sustainability (Choudhary *et al.* 2024a, b).

The development of short-duration, photo-insensitive, high-yielding, and disease-resistant greengram varieties has enabled their integration into the RWCS under CA, improving system productivity, profitability, and soil health (Singh *et al.* 2017). However, weed infestation remains a major challenge in CA, often causing greater yield losses than other biotic stresses, with greengram yield reductions reported up to 100% (Choudhary *et al.* 2024b). While various weed management practices such as tillage, competitive cultivars, residue mulching (Choudhary *et al.* 2020), and precise nutrient and water use can help (Parihar *et al.* 2016), CA's reliance on crop residues can delay weed emergence and also complicate late-stage control. Due to rising labour costs and limited availability, non-chemical methods are declining in preference, making herbicides increasingly vital (Rao 2022). Effective, safe herbicide options are essential for weed control, cost reduction, and the broader adoption of CA (Choudhary *et al.* 2012).

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Effective weed management in CA requires the right herbicide applied at the correct time and dose, alongside proper crop practices. Pre-emergence (PE) herbicides often bind to crop residues, reducing their efficacy (Sahu *et al.* 2023). In such cases, post-emergence (PoE) herbicides become crucial, offering a low-cost, broad-spectrum alternative vital for CA adoption. However, systematic studies on PoE herbicides in greengram are limited, hindering its integration into the rice–wheat–greengram system. Research on PoE herbicide efficacy is essential to optimize weed control, boost productivity, and support sustainable adoption of greengram in CA-based systems. Thus, a study was conducted with an objective to identiffy effective post-emergent herbicides to manage weeds, improve crop productivity, and profitability of summer greengram under conservation agriculture.

MATERIALS AND METHODS

A field experiment was conducted during the summers of 2017 and 2018 on deep black vertisol at ICAR - Directorate of Weed Research, Jabalpur, India (23°132 N, 79°592 E; 388 m AMSL), within a long-term CA block established in 2012. The site has a subtropical climate with 1386 mm average annual rainfall, 80% of which occurs from June to September. Temperatures range from 4–7°C in January to 42–45°C in May. The soil had medium organic carbon content (0.54%), neutral pH (7.20), low $KMnO_4$ oxidizable nitrogen (245 kg/ha), medium 0.5N $NaHCO_3$-extractable phosphorus (16.9 kg/ha), and high 1N NH_4OAc-exchangeable potassium (350 g/ha), with a clay loam texture in the top 0–20 cm. A randomized complete block design (RCBD) with three replications was used. Wheat residues (~4 t/ha) were retained after its harvest, and glyphosate (1.0 kg/ha) was applied to control existing weeds. Greengram variety 'Samrat' was drilled two days later into the untilled soil, followed by sprinkler irrigation. The experiment layout was marked 16 days after sowing. Eleven treatments were tested including: post-emergence application (PoE) of imazethapyr 80 g/ha and 100 g/ha; quizalofop 60 g/ha and 75 g/ha, imazethapyr + imazamox 56 g/ha and 70 g/ha, sodium-acifluorfen + clodinafop at 196 g/ha and 245 g/ha, oxyfluorfen 150 g/ha; hand weeding at 25 days after sowing (DAS) and weedy check. Herbicides were applied at 20 DAS using a solar-powered knapsack sprayer (375 L/ha at 350 kPa). Gross plot size was 5 × 5 m (net plot size of 3.8 × 4.2 m) with 1.0 m spacing between plots. Greengram seeds (25 kg/ha), treated with carbendazim (3 g/kg), were sown at 30 × 10 cm spacing and 5 cm depth using a zero-till seed-cum-ferti drill (Happy Seeder), with a basal dose of 20:60 kg/ha N and P_2O_5 using di-ammonium phosphate.

At flowering, leaf area index (LAI) and plant biomass were recorded. Leaf area of five plants per plot was measured using a LI-3100 meter, and LAI was calculated. Plants were then oven-dried at 65 ± 2°C to a constant weight to determine biomass and extrapolated to m² based on plant density. Weed counts were taken at 30 and 50 DAS using two 0.5 × 0.5 m quadrats per plot. Weeds were classified as grasses, broad-leaved weeds (BLWs), and sedges. Above-ground weed parts were collected, cleaned, and oven-dried at 65 ± 2°C for 72 h to estimate weed biomass. The weed control efficiency was calculated from weed biomass. The Shapiro–Wilk test indicated that the data deviated from normality; therefore, a square root transformation ($\sqrt{x+0.5}$) was performed to achieve normalization. Phyto-toxicity was visually rated 1 to 9 days after herbicide application (DAHA) on a 0–10 phyto-toxicity rating scale, where 0 indicates no injury and 10 indicates complete destruction of the plant.

At physiological maturity, greengram was manually harvested. Yield attributes were recorded from five plants at five locations per plot and averaged. Seeds and haulm from the net plot were threshed separately to determine yield, with seed moisture adjusted to 11%. The cost of cultivation included expenses for seeds, zero-till sowing, fertilizers, irrigation, agrochemicals (including weed control), harvesting, and threshing. Gross returns were based on market prices, and the benefit-cost ratio (B: C) was calculated as gross returns divided by total cost. Treatment effects were analyzed using ANOVA in SAS 9.3 under the general linear model (GLM) for RCBD. Mean differences were tested using LSD at a 5% significance level (p/ =/ 0.05). As year effects were significant, results were presented separately for each year.

RESULTS AND DISCUSSION

The study area comprised the major grassy weeds jungle rice [*Echinochloa colona* (L.) Link], bermuda grass [*Cynodon dactylon* L.], viper grass [*Dinebra retroflexa* (Vahl) Panz.], hairy crabgrass [*Digitaria sanguinalis* (L.) Scop.] and yellow watercrown grass [*Paspalidium flavidum* (Retz.) A. Camus]. The major BLWs were false daisy [*Eclipta alba* (L.) Hassk.], gooseberry [*Physalis minima* L.], benghal dayflower [*Commelina benghalensis* (L.)], sessile joyweed [*Alternanthera sessilis* (L.) R. Br. Ex

DC], giant pigweed [*Trianthema portulacastrum* (L.)], green amaranth [*Amaranthus viridis* (L.)], Asiatic dayflower [*Commelina communis* (L.)] and bur clover [*Medicago polymorpha* (L.)]. purple nutsedge [*Cyperus rotundus* (L.)] was the only sedge species identified in the study area.

Effect on weeds at 30 and 50 DAS

Weed density and biomass in greengram under CA were significantly affected (p=0.05) by weed management treatments (**Tables 1-4**). Grassy weeds such as *E. colona, C. dactylon,* and *D. retroflexa* were more prevalent in 2018 than in 2017, whereas *P. flavidum* density remained relatively stable. The highest densities of grassy weeds were observed in un-weeded control plots, while the lowest were recorded with hand weeding at 25 DAS followed by quizalofop 60 and 75 g/ha. In contrast, imazethapyr 80 and 100 g/ha and sodium-acifluorfen + clodinafop 196 g/ha were less effective, particularly at later crop stages. *D. sanguinalis* and *C. dactylon* densities tended to be higher under lower herbicide doses. *Paspalidium flavidum* was significantly suppressed in all treated plots. *Dinebra retroflexa* and *C. rotundus* were poorly controlled by lower herbicide rates, with the latter appearing prominently in 2018 but absent in hand-weeded plots in 2017.

Un-weeded control plots exhibited the highest density of BLWs across both years and sampling times, with overall weed densities generally higher in 2018, except for *E. alba*. *M. polymorpha* was absent in 2017 (**Table 1**). *Physalis minima* density peaked at 30 DAS in plots treated with sodium-acifluorfen + clodinafop 196 g/ha and 245 g/ha and low-dose imazethapyr 80 g/ha, and remained high at 50 DAS under imazethapyr 80 g/ha and 100 g/ha and oxyfluorfen 150 g/ha. The lowest BLW densities were observed in hand-weeded plots and those treated with the higher dose of imazethapyr + imazamox 70 g/ha.

Eclipta alba density was not influenced by year but was higher at 30 DAS under imazethapyr + imazamox, both doses of sodium-acifluorfen + clodinafop, and the lower dose of imazethapyr. By 50 DAS, the highest density was recorded with oxyfluorfen 150 g/ha, followed by the lower dose of sodium-acifluorfen + clodinafop and imazethapyr + imazamox. *Amaranthus viridis* was effectively suppressed by all treatments except quizalofop and was eventually controlled by crop competition. *Commelina communis* was poorly managed under low-dose sodium acifluorfen + clodinafop and imazethapyr + imazamox. *Medicago polymorpha* density increased in plots treated with these

Table 1. Density and biomass of grassy weeds at 30 days after seeding (DAS) as influenced by post-emergence herbicides in greengram under conservation agriculture (2017 and 2018)

Treatment	Dose (g/ha)	*E. colona*		*C. dactylon*		*P. flavidum*		*D. retroflexa*	
		2017	2018	2017	2018	2017	2018	2017	2018
Weed density (no./m²)									
Imazethapyr	80	1.2(1.0)*	2.2(4.3)	0.9(0.3)	1.5(1.7)	1.1(0.7)	1.2(1.0)	1.1(0.7)	1.2(1.0)
Imazethapyr	100	0.9(0.3)	1.7(2.3)	0.7(0.0)	1.2(1.0)	1.1(0.7)	0.9(0.3)	1.1(0.7)	1.1(0.7)
Quizalofop	60	0.7(0.0)	1.1(0.7)	0.9(0.3)	1.2(1.0)	0.9(0.3)	0.9(0.3)	0.9(0.3)	0.9(0.3)
Quizalofop	75	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.9(0.3)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)
Imazethapyr + imazamox	56	1.3(1.3)	1.5(1.7)	1.2(1.0)	1.3(1.3)	1.2(0.7)	1.2(1.0)	1.2(1.0)	1.4(1.7)
Imazethapyr + imazamox	70	1.2(1.0)	1.3(1.3)	0.9(0.3)	0.9(0.3)	1.1(0.3)	0.9(0.3)	1.1(0.7)	1.2(1.0)
Sodium-acifluorfen + clodinafop	196	1.5(1.7)	1.7(2.3)	1.2(1.0)	1.4(1.7)	0.9(0.7)	1.2(1.0)	0.9(0.3)	1.1(0.7)
Sodium-acifluorfen + clodinafop	245	1.1(0.7)	1.3(1.3)	1.1(0.7)	1.1(0.7)	1.1(0.7)	1.1(0.7)	1.1(0.7)	1.1(0.7)
Oxyfluorfen	150	0.9(0.3)	1.1(0.7)	1.1(0.7)	1.2(1.0)	1.1(0.0)	0.7(0.0)	1.1(0.7)	1.1(0.7)
Hand weeding at 25 DAS	-	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.9(0.3)	0.7(0.0)	0.7(0.0)	0.7(0.0)	1.2(1.0)
Control	-	2.0(3.3)	2.7(6.7)	1.5(1.7)	1.9(3.0)	1.7(3.0)	1.9(3.0)	1.7(2.3)	1.9(3.0)
LSD (p=0.05)		0.39	0.47	0.39	0.46	0.42	0.51	0.43	0.64
Weed biomass (g/m²)									
Imazethapyr	80	1.2(1.2)	1.7(2.5)	0.8(0.1)	1.0(0.5)	0.8(0.2)	0.8(0.2)	0.9(0.4)	0.8(0.1)
Imazethapyr	100	0.9(0.5)	1.4(1.5)	0.7(0.0)	0.9(0.2)	0.8(0.2)	0.8(0.2)	0.9(0.3)	0.8(0.1)
Quizalofop	60	0.7(0.0)	1.0(0.5)	0.7(0.0)	0.9(0.3)	0.7(0.0)	0.8(0.1)	0.7(0.0)	0.7(0.0)
Quizalofop	75	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.8(0.1)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)
Imazethapyr + imazamox	56	1.4(1.5)	1.3(1.3)	0.9(0.3)	1.0(0.4)	0.8(0.2)	0.8(0.2)	1.0(0.5)	0.9(0.3)
Imazethapyr + imazamox	70	1.1(0.7)	1.2(0.9)	0.8(0.2)	0.8(0.1)	0.8(0.1)	0.8(0.1)	1.0(0.5)	0.8(0.1)
Sodium-acifluorfen + clodinafop	196	1.5(1.7)	1.4(1.6)	1.3(1.2)	1.0(0.6)	1.1(0.7)	0.9(0.2)	0.8(0.2)	0.8(0.1)
Sodium-acifluorfen + clodinafop	245	1.1(0.7)	1.2(0.7)	0.9(0.3)	0.9(0.2)	0.8(0.2)	0.8(0.1)	0.9(0.4)	0.8(0.1)
Oxyfluorfen	150	0.9(0.4)	0.9(0.3)	0.9(0.3)	0.9(0.2)	0.7(0.0)	0.7(0.0)	0.9(0.3)	0.8(0.1)
Hand weeding at 25 DAS	-	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.8(0.2)
Control	-	1.7(2.5)	2.0(3.5)	1.5(1.8)	1.1(0.8)	1.7(2.3)	1.2(0.8)	1.6(2.2)	1.0(0.5)
LSD (p=0.05)		0.41	0.30	0.16	0.18	0.20	0.15	0.25	0.14

*Figures in parentheses are original value

herbicides, particularly at lower application rates (**Table 2**).

At 50 DAS, *E. geniculata* density was highest under oxyfluorfen 150 g/ha, followed by imazethapyr + imazamox 56 g/ha, while other herbicides provided only moderate control compared to hand weeding (**Table 3**). *Alternanthera sessilis* was more prevalent under imazethapyr 80 g/ha and 100 g/ha and at low doses of sodium-acifluorfen + clodinafop. *Trianthema portulacastrum* density increased under both doses of sodium-acifluorfen + clodinafop, imazethapyr + imazamox, and oxyfluorfen. *Commelina communis* showed higher density with low doses of sodium acifluorfen + clodinafop, imazethapyr, and imazethapyr + imazamox, but was better suppressed at higher doses. *Medicago polymorpha* density was elevated under sodium acifluorfen + clodinafop and imazethapyr + imazamox, particularly at lower rates. No sedges were observed at 30 DAS. Weed biomass patterns closely reflected density trends across both sampling times and years (**Table 4**).

Table 2. Density and biomass of broad-leaved weeds at 30 days after seeding (DAS) as influenced by post-emergence herbicides in greengram under conservation agriculture (2017 and 2018)

Treatment	Dose (g/ha)	*P. minima*		*E. alba*		*A. sessilis*		*A. viridis*		*C. communis*		*M. polymorpha*	
		2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Weed density (no./m²)													
Imazethapyr	80	1.1	1.2	0.7	0.9	1.3	1.7	0.7	0.9	1.2	1.7	1.2	1.2
		(0.7)*	(1.0)	(0.0)	(0.3)	(1.3)	(2.3)	(0.0)	(0.3)	(1.0)	(2.3)	(1.0)	(1.0)
Imazethapyr	100	0.9	0.9	0.9	0.9	1.1	1.2	0.7	0.9	1.1	1.3	1.1	1.1
		(0.3)	(0.3)	(0.3)	(0.3)	(0.7)	(1.0)	(0.0)	(0.3)	(0.7)	(1.3)	(0.7)	(0.7)
Quizalofop	60	2.1	2.1	2.1	1.8	2.4	2.4	1.9	1.8	2.1	2.2	2.0	3.4
		(4.0)	(4.0)	(4.0)	(2.7)	(5.3)	(5.3)	(3.3)	(2.7)	(4.0)	(4.3)	(3.3)	(11.0)
Quizalofop	75	1.9	1.9	2.1	1.7	2.4	2.4	1.7	1.7	2.0	2.0	1.9	3.3
		(3.0)	(3.0)	(4.0)	(2.3)	(5.3)	(5.3)	(2.3)	(2.3)	(3.7)	(3.7)	(3.0)	(10.3)
Imazethapyr + imazamox	56	0.7	1.0	1.3	1.3	1.3	1.7	1.1	1.1	1.2	1.3	1.3	2.0
		(0.0)	(0.7)	(1.3)	(1.3)	(1.3)	(2.3)	(0.7)	(0.7)	(1.0)	(1.3)	(1.3)	(3.3)
Imazethapyr + imazamox	70	0.7	0.9	1.1	1.1	1.1	1.3	0.9	0.9	0.9	1.1	1.1	1.5
		(0.0)	(0.3)	(0.7)	(0.7)	(0.7)	(1.3)	(0.3)	(0.3)	(0.3)	(0.7)	(0.7)	(1.7)
Sodium-acifluorfen + clodinafop	196	1.2	1.3	0.9	0.9	1.5	1.8	1.1	1.1	1.1	1.7	1.3	2.3
		(1.0)	(1.3)	(0.3)	(0.3)	(1.7)	(2.7)	(0.7)	(0.7)	(0.7)	(2.3)	(1.3)	(4.7)
Sodium-acifluorfen + clodinafop	245	0.9	1.2	0.9	0.9	1.3	1.6	0.9	0.9	0.9	1.2	1.1	1.8
		(0.3)	(1.0)	(0.3)	(0.3)	(1.3)	(2.0)	(0.3)	(0.3)	(0.3)	(1.0)	(0.7)	(2.7)
Oxyfluorfen	150	0.9	0.9	0.7	0.7	1.3	1.3	0.9	0.9	0.9	1.1	1.1	1.1
		(0.3)	(0.3)	(0.0)	(0.0)	(1.3)	(1.3)	(0.3)	(0.3)	(0.3)	(0.7)	(0.7)	(0.7)
Hand weeding at 25 DAS	-	0.7	0.7	0.7	0.7	0.7	1.0	0.7	0.7	0.7	0.7	0.7	1.2
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.7)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(1.0)
Control	-	2.3	2.5	1.9	1.7	2.6	2.5	1.0	1.9	2.1	2.4	2.0	3.9
		(4.7)	(5.7)	(3.0)	(2.3)	(6.3)	(6.0)	(3.0)	(3.0)	(4.0)	(5.3)	(3.3)	(15.0)
LSD (p=0.05)		0.50	0.64	0.40	0.03	0.30	0.50	0.39	0.42	0.53	0.48	0.45	0.50
Weed biomass (g/m²)													
Imazethapyr	80	0.9	0.9	0.7	0.8	1.0	1.1	0.7	0.8	0.9	0.9	0.8	0.9
		(0.4)	(0.3)	(0.0)	(0.1)	(0.6)	(0.7)	(0.0)	(0.1)	(0.3)	(0.3)	(0.2)	(0.2)
Imazethapyr	100	0.8	0.8	0.8	0.8	0.8	0.9	0.7	0.8	0.8	0.8	0.8	0.8
		(0.2)	(0.1)	(0.1)	(0.1)	(0.2)	(0.3)	(0.0)	(0.1)	(0.2)	(0.2)	(0.1)	(0.1)
Quizalofop	60	1.4	1.1	1.2	1.1	1.2	1.3	0.9	1.1	1.2	1.0	1.0	1.4
		(1.4)	(0.8)	(1.0)	(0.6)	(1.0)	(1.1)	(0.3)	(0.6)	(0.9)	(0.5)	(0.5)	(1.4)
Quizalofop	75	1.3	1.1	1.2	0.9	1.2	1.2	0.8	1.0	1.1	1.0	0.9	1.3
		(1.2)	(0.8)	(0.8)	(0.4)	(0.9)	(1.0)	(0.1)	(0.5)	(0.8)	(0.4)	(0.3)	(1.3)
Imazethapyr + imazamox	56	0.7	0.8	0.9	0.9	0.9	1.0	0.8	0.8	0.9	0.8	0.8	1.1
		(0.0)	(0.2)	(0.3)	(0.3)	(0.4)	(0.6)	(0.1)	(0.2)	(0.3)	(0.2)	(0.1)	(0.7)
Imazethapyr + imazamox	70	0.7	0.8	0.8	0.8	0.8	0.9	0.7	0.8	0.8	0.8	0.8	1.0
		(0.0)	(0.1)	(0.1)	(0.1)	(0.2)	(0.3)	(0.0)	(0.1)	(0.1)	(0.1)	(0.1)	(0.4)
Sodium-acifluorfen + clodinafop	196	0.9	1.0	0.8	0.8	1.0	1.0	0.8	0.9	0.8	0.9	0.8	1.1
		(0.4)	(0.4)	(0.1)	(0.1)	(0.4)	(0.5)	(0.1)	(0.2)	(0.2)	(0.3)	(0.1)	(0.8)
Sodium-acifluorfen + clodinafop	245	0.8	0.9	0.8	0.8	0.9	1.0	0.7	0.8	0.8	0.8	0.8	1.0
		(0.1)	(0.3)	(0.1)	(0.1)	(0.4)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.5)
Oxyfluorfen	150	0.8	0.8	0.7	0.7	0.9	0.9	0.7	0.8	0.8	0.8	0.8	0.8
		(0.1)	(0.1)	(0.0)	(0.0)	(0.3)	(0.3)	(0.0)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
Hand weeding at 25 DAS	-	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.2)
Control	-	1.5	1.2	1.1	1.0	1.5	1.2	1.0	1.1	1.3	1.3	0.9	1.5
		(1.7)	(1.0)	(0.7)	(0.6)	(1.8)	(1.0)	(0.6)	(0.6)	(1.3)	(0.7)	(0.4)	(1.8)
LSD (p=0.05)		0.25	0.23	0.13	0.11	0.11	0.16	0.08	0.14	0.17	0.09	0.08	0.17

*Figures in parentheses are original value

Effect on group-wise weeds at 30 and 50 DAS

The density and biomass of weeds were significantly (p<0.05) influenced by weed management treatments during both the years (**Table 5**). Un-weeded control plots exhibited higher densities of grassy weeds at 30 DAS and 50 DAS. The lowest density of grassy weeds was recorded with hand weeding at 25 DAS followed by quizalofop at 75 g/ha. Among the different herbicides, quizalofop 75 g/ha consistently provided effective control of grassy weeds during both sampling times and years, followed by quizalofop 60 g/ha. At 50 DAS, higher densities were observed with sodium acifluorfen + clodinafop 196 g/ha, imazethapyr + imazamox 56 g/

Table 3. Grasses and sedges density and biomass at 50 days after seeding (DAS) as influenced by post-emergence herbicides in greengram under conservation agriculture (2017 and 2018)

Treatment	Dose (g/ha)	Grasses										Sedge	
		E. colona		*C. dactylon*		*D. sanguinalis*		*P. flavidum*		*D. retroflexa*		*C. rotundus*	
		2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Weed density (no./m²)													
Imazethapyr	80	1.8	3.0	1.3	1.7	1.7	1.6	1.5	1.8	1.7	1.9	0.9	1.2
		(2.7)*	(8.7)	(1.3)	(2.3)	(2.3)	(2.0)	(1.7)	(2.7)	(2.3)	(3.0)	(0.3)	(1.0)
Imazethapyr	100	1.2	2.2	1.1	1.2	1.3	1.2	1.1	1.3	1.5	1.3	0.7	0.9
		(1.0)	(4.3)	(0.7)	(1.0)	(1.3)	(1.0)	(0.7)	(1.3)	(1.7)	(1.3)	(0.0)	(0.3)
Quizalofop	60	0.9	1.3	0.9	1.4	1.2	1.2	1.1	1.3	1.1	1.2	1.8	2.0
		(0.3)	(1.3)	(0.3)	(1.7)	(1.0)	(1.0)	(0.7)	(1.3)	(0.7)	(1.0)	(2.7)	(3.3)
Quizalofop	75	0.7	0.9	0.7	0.7	0.9	0.9	0.7	0.9	0.9	1.1	1.7	1.8
		(0.0)	(0.3)	(0.0)	(0.0)	(0.3)	(0.3)	(0.0)	(0.3)	(0.3)	(0.7)	(2.3)	(2.7)
Imazethapyr + imazamox	56	1.7	2.1	1.3	1.7	1.2	1.3	1.6	1.6	1.9	2.1	1.2	1.3
		(2.3)	(4.0)	(1.3)	(2.3)	(1.0)	(1.3)	(2.0)	(2.0)	(3.0)	(4.0)	(1.0)	(1.3)
Imazethapyr + imazamox	70	1.5	1.8	1.1	1.3	1.1	1.0	1.2	1.2	1.3	1.5	0.9	1.1
		(1.7)	(2.7)	(0.7)	(1.3)	(0.7)	(0.7)	(1.0)	(1.0)	(1.3)	(1.7)	(0.3)	(0.7)
Sodium-acifluorfen +	196	1.9	2.0	1.8	2.0	1.5	1.5	1.7	1.9	1.9	1.9	1.9	1.7
clodinafop		(3.0)	(3.7)	(2.7)	(3.3)	(1.7)	(1.7)	(2.3)	(3.0)	(3.0)	(3.0)	(3.0)	(2.3)
Sodium-acifluorfen +	245	1.7	1.8	1.5	1.7	0.9	1.3	1.1	1.5	2.0	1.7	1.5	1.3
clodinafop		(2.3)	(2.7)	(1.7)	(2.3)	(0.3)	(1.3)	(0.7)	(1.7)	(3.3)	(2.3)	(1.7)	(1.3)
Oxyfluorfen	150	1.6	1.8	1.3	1.7	1.3	1.7	1.9	2.0	1.8	1.9	1.1	1.5
		(2.0)	(2.7)	(1.3)	(2.7)	(1.3)	(2.3)	(3.0)	(3.7)	(2.7)	(3.0)	(0.7)	(1.7)
Hand weeding at 25 DAS	-	0.7	1.1	0.7	0.9	0.7	0.9	0.7	1.3	0.7	1.3	0.7	1.7
		(0.0)	(0.7)	(0.0)	(0.3)	(0.0)	(0.3)	(0.0)	(1.3)	(0.0)	(1.3)	(0.0)	(2.3)
Control	-	3.0	3.2	2.3	2.5	3.0	2.1	2.1	2.9	2.4	2.4	2.0	2.2
		(8.7)	(9.7)	(5.0)	(5.7)	(8.3)	(4.0)	(4.0)	(8.0)	(5.3)	(5.3)	(3.7)	(4.3)
LSD (p=0.05)		0.43	0.50	0.43	0.54	0.40	0.49	0.43	0.53	0.40	0.55	0.30	0.40
Weed biomass (g/m²)													
Imazethapyr	80	1.6	2.1	1.4	1.5	1.4	1.4	0.9	1.3	1.3	1.5	0.9	0.9
		(2.0)	(3.8)	(1.6)	(1.6)	(1.4)	(1.5)	(0.4)	(1.2)	(1.3)	(1.7)	(0.3)	(0.3)
Imazethapyr	100	1.1	1.6	1.1	1.1	1.2	1.1	0.8	1.1	1.3	1.1	0.7	0.8
		(0.8)	(2.2)	(0.9)	(0.8)	(1.0)	(0.8)	(0.1)	(0.8)	(1.1)	(0.7)	(0.0)	(0.1)
Quizalofop	60	0.9	1.1	0.9	1.2	1.1	1.1	0.8	1.1	1.0	1.0	1.7	1.1
		(0.3)	(0.8)	(0.4)	(1.1)	(0.7)	(0.7)	(0.1)	(0.8)	(0.5)	(0.6)	(2.5)	(0.8)
Quizalofop	75	0.7	0.9	0.7	0.7	0.8	0.8	0.7	0.8	0.8	1.0	1.6	1.1
		(0.0)	(0.4)	(0.0)	(0.0)	(0.2)	(0.3)	(0.0)	(0.2)	(0.2)	(0.5)	(2.2)	(0.7)
Imazethapyr + imazamox	56	1.2	1.6	1.2	1.4	1.1	1.3	0.9	1.2	1.3	1.7	1.2	0.9
		(1.0)	(2.0)	(0.9)	(1.5)	(0.7)	(1.1)	(0.4)	(0.9)	(1.1)	(2.3)	(0.9)	(0.3)
Imazethapyr + imazamox	70	1.1	1.4	1.0	1.2	0.9	0.9	0.8	1.0	1.0	1.3	0.8	0.8
		(0.8)	(1.5)	(0.5)	(1.0)	(0.3)	(0.5)	(0.2)	(0.4)	(0.6)	(1.1)	(0.2)	(0.2)
Sodium-acifluorfen +	196	1.5	1.5	1.6	1.5	1.2	1.3	1.0	1.3	1.4	1.4	1.8	1.0
clodinafop		(1.6)	(1.9)	(2.1)	(1.8)	(1.0)	(1.3)	(0.4)	(1.1)	(1.5)	(1.6)	(2.8)	(0.5)
Sodium-acifluorfen +	245	1.4	1.3	1.3	1.3	0.8	1.2	0.8	1.1	1.4	1.3	1.5	0.9
clodinafop		(1.4)	(1.2)	(1.3)	(1.3)	(0.2)	(1.0)	(0.2)	(0.7)	(1.6)	(1.3)	(1.8)	(0.4)
Oxyfluorfen	150	1.4	1.6	1.3	1.4	1.1	1.5	1.0	1.3	1.4	1.4	1.1	1.0
		(1.5)	(1.9)	(1.2)	(1.5)	(0.6)	(1.6)	(0.6)	(1.1)	(1.6)	(1.6)	(0.8)	(0.4)
Hand weeding at 25 DAS	-	0.7	0.9	0.7	0.9	0.7	0.9	0.7	1.1	0.7	1.0	0.7	1.1
		(0.0)	(0.4)	(0.0)	(0.3)	(0.0)	(0.3)	(0.0)	(0.7)	(0.0)	(0.4)	(0.0)	(0.6)
Control	-	3.4	2.5	2.0	2.1	2.3	1.9	1.1	1.7	2.0	2.0	1.9	1.4
		(11.1)	(5.6)	(3.4)	(3.8)	(4.8)	(3.2)	(0.7)	(2.5)	(3.4)	(3.6)	(3.2)	(1.4)
LSD (p=0.05)		0.33	0.33	0.39	0.40	0.27	0.37	0.11	0.28	0.25	0.36	0.26	0.14

*Figures in parentheses are original value

ha and oxyfluorfen 150 g/ha. The other herbicides resulted in lower densities of grassy weeds, although their efficacy was compared to hand weeding and quizalofop 75 g/ha. Similar to density, the highest biomass recorded in un-weeded control plots during both sampling times and years. Lower biomass of grassy weeds was observed in plots subjected to hand weeding followed by quizalofop at 75 g/ha. The other herbicides at tested doses resulted in lower biomass of grassy weeds, although their effects were less pronounced compared to hand weeding.

Hand weeding at 25 DAS resulted in the lowest density of BLWs, followed by oxyfluorfen 150 g/ha and imazethapyr 100 g/ha. Other weed management treatments also effectively controlled BLWs, although their efficacy was comparatively lower than hand weeding. Hand weeded plots recorded the lowest biomass of BLWs followed by imazethapyr 100 g/ha and imazethapyr + imazamox 70 g/ha. The other weed management practices also significantly reduced the biomass of BLWs, although their effectiveness was lower than hand weeded plots during both years.

In 2017, at 50 DAS, sedges were absent in hand weeded plots and plots treated with imazethapyr 100 g/ha, while in 2018, the lowest density and biomass of sedges were recorded with imazethapyr 100 g/ha followed by imazethapyr + imazamox 70 g/ha. The

Table 4. Broad-leaved weeds density (no./m^2) and biomass (g/m^2) at 50 days after seeding (DAS) as influenced by post-emergence herbicides in greengram under conservation agriculture (2017 and 2018)

Treatment	Dose (g/ha)	*P. minima*		*E. alba*		*E. geniculata*		*A. sessilis*		*T. portulcastrum*		*C. communis*		*M. polymorpha*	
		2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Weed density (no./m^2)															
Imazethapyr	80	1.7 (2.3)*	2.0 (3.3)	0.9 (0.3)	1.3 (1.3)	0.7 (0.0)	0.7 (0.0)	1.7 (2.3)	1.9 (3.0)	0.9 (0.3)	1.2 (1.0)	0.9 (0.3)	1.6 (2.0)	-	2.0 (3.7)
Imazethapyr	100	1.3 (1.3)	1.7 (2.3)	0.7 (0.0)	0.9 (0.3)	0.7 (0.0)	0.7 (0.0)	1.3 (1.3)	1.7 (2.3)	0.7 (0.0)	0.9 (0.3)	0.7 (0.0)	1.1 (0.7)	-	1.6 (2.0)
Quizalofop	60	2.4 (5.3)	2.5 (5.7)	1.7 (2.3)	1.8 (2.7)	1.7 (2.3)	1.8 (2.7)	2.0 (3.3)	2.0 (3.3)	2.0 (3.3)	2.1 (4.0)	1.9 (3.0)	1.7 (2.3)	-	3.5 (12.0)
Quizalofop	75	2.3 (4.7)	2.1 (4.0)	1.5 (1.7)	1.7 (2.3)	1.5 (1.7)	1.6 (2.0)	1.7 (2.3)	1.6 (2.0)	1.8 (2.7)	1.8 (2.7)	1.7 (2.3)	1.7 (2.3)	-	3.6 (12.3)
Imazethapyr + imazamox	56	1.2 (1.0)	1.3 (1.3)	1.3 (1.3)	1.5 (1.7)	1.2 (1.0)	1.5 (1.7)	1.6 (2.0)	1.6 (2.0)	1.8 (2.7)	1.9 (3.0)	1.5 (1.7)	1.6 (2.0)	-	2.3 (5.0)
Imazethapyr + imazamox	70	1.1 (0.7)	1.1 (0.7)	1.1 (0.7)	1.1 (0.7)	0.9 (0.3)	0.9 (0.3)	1.3 (1.3)	1.2 (1.0)	1.3 (1.3)	1.3 (1.3)	0.9 (0.3)	0.9 (0.3)	-	1.8 (2.7)
Sodium-acifluorfen + clodinafop	196	1.2 (1.0)	1.3 (1.3)	1.2 (1.0)	1.5 (1.7)	1.2 (1.0)	1.2 (1.0)	1.6 (2.0)	1.8 (2.7)	1.9 (3.0)	2.0 (3.7)	1.3 (1.3)	1.8 (2.7)	-	2.4 (5.3)
Sodium-acifluorfen + clodinafop	245	0.9 (0.3)	1.1 (0.7)	1.1 (0.7)	1.2 (1.0)	0.9 (0.3)	0.9 (0.3)	1.5 (1.7)	1.5 (1.7)	1.7 (2.3)	1.6 (2.0)	0.9 (0.3)	1.5 (1.7)	-	1.9 (3.3)
Oxyfluorfen	150	1.1 (0.7)	1.6 (2.0)	1.2 (1.0)	1.7 (2.3)	0.9 (0.3)	1.7 (2.3)	1.3 (1.3)	1.8 (2.7)	1.8 (2.7)	1.8 (2.7)	1.1 (0.7)	1.6 (2.0)	-	2.0 (3.7)
Hand weeding at 25 DAS	-	0.7 (0.0)	1.3 (1.3)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	1.2 (1.0)	0.7 (0.0)	1.2 (1.0)	0.7 (0.0)	1.2 (1.0)	-	1.2 (1.0)
Control	-	1.9 (3.0)	2.4 (5.3)	1.8 (2.7)	2.0 (3.7)	1.7 (2.3)	1.9 (3.0)	2.2 (4.3)	2.3 (4.7)	2.0 (3.7)	2.5 (5.7)	2.0 (3.7)	2.1 (4.0)	-	3.9 (15.0)
LSD (p=0.05)		0.46	0.39	0.41	0.41	0.37	0.34	0.44	0.36	0.32	0.44	0.39	0.47		0.53
Weed biomass (g/m^2)															
Imazethapyr	80	1.4 (1.4)	1.6 (2.1)	0.9 (0.4)	0.9 (0.3)	0.7 (0.0)	0.7 (0.0)	2.0 (3.6)	1.3 (1.3)	0.9 (0.3)	1.0 (0.4)	0.8 (0.1)	1.1 (0.6)	-	1.2 (0.9)
Imazethapyr	100	1.2 (0.9)	1.4 (1.6)	0.7 (0.0)	0.8 (0.1)	0.7 (0.0)	0.7 (0.0)	1.6 (2.1)	1.2 (1.0)	0.7 (0.0)	0.8 (0.1)	0.7 (0.0)	0.8 (0.1)	-	1.0 (0.6)
Quizalofop	60	1.7 (2.4)	1.8 (2.8)	1.7 (2.4)	1.1 (0.7)	1.7 (2.4)	1.2 (0.9)	2.1 (3.7)	1.3 (1.3)	1.7 (2.4)	1.6 (2.0)	1.2 (0.9)	1.1 (0.6)	-	1.7 (2.4)
Quizalofop	75	1.6 (2.1)	1.7 (2.3)	1.5 (1.6)	1.0 (0.5)	1.5 (1.8)	1.1 (0.6)	1.8 (2.8)	1.1 (0.8)	1.6 (2.0)	1.3 (1.2)	1.1 (0.7)	1.1 (0.7)	-	1.7 (2.5)
Imazethapyr + imazamox	56	1.0 (0.6)	1.1 (0.8)	1.2 (1.0)	1.0 (0.4)	1.2 (0.8)	1.0 (0.5)	1.4 (1.6)	1.2 (1.0)	1.4 (1.5)	1.3 (1.3)	1.0 (0.4)	1.0 (0.6)	-	1.3 (1.1)
Imazethapyr + imazamox	70	0.9 (0.4)	1.3 (1.5)	0.9 (0.4)	0.8 (0.1)	0.8 (0.2)	0.8 (0.1)	1.3 (1.2)	1.0 (0.4)	1.1 (0.7)	1.0 (0.5)	0.8 (0.1)	0.8 (0.1)	-	1.1 (0.7)
Sodium-acifluorfen + clodinafop	196	1.0 (0.6)	1.1 (0.8)	1.1 (0.9)	1.0 (0.4)	1.2 (1.0)	0.9 (0.3)	1.7 (2.3)	1.1 (0.8)	1.5 (1.7)	1.4 (1.4)	0.9 (0.4)	1.1 (0.8)	-	1.4 (1.3)
Sodium-acifluorfen + clodinafop	245	0.8 (0.2)	1.0 (0.4)	1.1 (0.7)	0.9 (0.3)	0.9 (0.3)	0.8 (0.1)	1.6 (2.0)	1.0 (0.5)	1.4 (1.5)	1.2 (0.9)	0.8 (0.1)	1.0 (0.4)	-	1.2 (1.0)
Oxyfluorfen	150	1.0 (0.5)	1.3 (1.2)	1.2 (1.0)	1.0 (0.6)	0.9 (0.4)	1.0 (0.6)	1.4 (1.9)	1.2 (1.0)	1.6 (2.1)	1.3 (1.1)	0.8 (0.2)	1.1 (0.6)	-	1.3 (1.1)
Hand weeding at 25 DAS	-	0.7 (0.0)	1.1 (0.7)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.9 (0.4)	0.7 (0.0)	1.0 (0.5)	0.7 (0.0)	0.9 (0.3)	-	0.9 (0.3)
Control	-	1.6 (1.9)	1.7 (2.4)	1.8 (2.9)	1.3 (1.1)	1.8 (2.9)	1.2 (0.9)	2.5 (6.0)	1.8 (2.9)	1.9 (3.1)	1.8 (2.6)	1.3 (1.1)	1.5 (1.8)	-	1.7 (2.4)
LSD (p=0.05)		0.29	0.43	0.37	0.15	0.34	0.14	0.45	0.23	0.28	0.22	0.14	0.16		0.21

*Figures in parentheses are original value

weed management treatments caused reduced density and biomass of sedges (**Table 6**).

Over time, an increasing density of grasses, especially *D. sanguinalis*, *D. retroflexa*, and *C. dactylon*, was observed under ZT, indicating a change in weed flora from BLWs to grasses, and from annuals to perennials. These species, capable of vegetative reproduction, thrive in undisturbed soils and escape PE and early PoE herbicide applications due to delayed emergence under crop residues. This delay leads to late weed flushes and increased seed production, enriching the seed bank (Choudhary and Kumar 2019, Mishra *et al.* 2019). Herbicides are essential in CA, but crop residues can reduce their efficacy by intercepting the spray, limiting soil contact (Mobli *et al.* 2020). Consequently, escape weeds like *C. iria* persist. The reliance only on PE or early PoE herbicides may worsen weed problems. Effective weed control in CA is critical in the initial 2–3 years to prevent seed bank buildup. Integrated weed management, including timely herbicide application and residue management, is essential (Sims *et al.*

Table 5. Weed densities and biomass of grassy and broad-leaved weeds at 30 days after seeding (DAS) as influenced by post-emergence herbicides in greengram under conservation agriculture

Treatment	Dose (g/ha)	Weed density (no./m^2)				Weed biomass (g/m^2)			
		Grasses		Broad-leaved		Grasses		Broad-leaved	
		2017	2018	2017	2018	2017	2018	2017	2018
Imazethapyr	80	1.8(2.7)*	2.9(8.0)	2.1(4.0)	2.8(7.3)	1.5(1.8)	1.9(3.3)	1.4(1.5)	1.5(1.6)
Imazethapyr	100	1.5(1.7)	2.2(4.3)	1.8(2.7)	2.1(4.0)	1.2(0.9)	1.6(1.9)	1.1(0.8)	1.2(0.8)
Quizalofop	60	1.1(1.0)	1.6(2.3)	4.9(24.0)	5.5(30.0)	0.7(0.0)	1.2(0.9)	2.4(5.1)	2.4(5.0)
Quizalofop	75	0.7(0.0)	0.9(0.3)	4.7(21.3)	5.2(27.0)	0.7(0.0)	0.8(0.1)	2.1(4.1)	2.1(4.0)
Imazethapyr + imazamox	56	2.1(4.0)	2.5(5.7)	2.5(5.7)	3.2(9.7)	1.7(2.4)	1.6(2.2)	1.3(1.2)	1.5(1.7)
Imazethapyr + imazamox	70	1.7(2.3)	1.9(3.0)	1.6(2.7)	2.3(5.0)	1.4(1.5)	1.3(1.1)	1.0(0.6)	1.3(1.3)
Sodium-acifluorfen + clodinafop	196	2.0(3.7)	2.5(5.7)	2.5(5.7)	3.5(12.0)	2.0(3.7)	1.7(2.5)	1.4(1.4)	1.7(2.3)
Sodium-acifluorfen + clodinafop	245	1.8(2.7)	1.9(3.3)	1.9(3.3)	2.8(7.3)	1.4(1.6)	1.3(1.2)	1.1(0.8)	1.4(1.5)
Oxyfluorfen	150	1.5(1.7)	1.7(2.3)	1.8(3.0)	1.9(3.3)	1.2(1.0)	1.1(0.6)	1.0(0.6)	1.1(0.7)
Hand weeding at 25 DAS	-	0.7(0.0)	1.3(1.3)	0.7(0.0)	1.4(1.7)	0.7(0.0)	0.8(0.2)	0.7(0.0)	0.9(0.3)
Control	-	3.3(10.3)	4.0(15.7)	5.0(24.3)	6.1(37.3)	3.1(8.9)	2.5(5.6)	2.6(6.5)	2.5(5.7)
LSD (p=0.05)		0.49	0.57	0.65	0.59	0.37	0.33	0.24	0.24

*Figures in parentheses are original value

Table 6. Weed densities and biomass of grassy, broad-leaved weeds and sedges at 50 days after seeding (DAS) as influenced by post-emergence herbicides in greengram under conservation agriculture

Treatment	Dose (g/ha)	Grasses		Broad-leaved		Sedges	
		2017	2018	2017	2018	2017	2018
Weed density (no./m^2)							
Imazethapyr	80	3.3(10.3)*	4.4(18.7)	2.5(5.7)	3.8(14.3)	0.9(0.3)	1.2(1.0)
Imazethapyr	100	2.4(5.3)	3.0(9.0)	1.8(2.7)	2.9(8.0)	0.7(0.0)	0.9(0.3)
Quizalofop	60	1.8(3.0)	2.6(6.3)	4.5(19.7)	5.8(32.7)	1.8(2.7)	2.0(3.3)
Quizalofop	75	1.1(0.7)	1.4(1.7)	4.0(15.3)	5.3(27.7)	1.7(2.3)	1.8(2.7)
Imazethapyr + imazamox	56	3.2(9.7)	(3.813.7)	3.2(9.7)	4.1(16.7)	1.2(1.0)	1.3(1.3)
Imazethapyr + imazamox	70	2.4(5.3)	2.8(7.3)	2.3(4.7)	2.7(7.0)	0.9(0.3)	1.1(0.7)
Sodium-acifluorfen + clodinafop	196	3.6(12.7)	3.9(14.7)	3.1(9.3)	4.3(18.3)	1.9(3.0)	1.7(2.3)
Sodium-acifluorfen + clodinafop	245	3.0(8.3)	3.3(10.3)	2.5(5.7)	3.3(10.7)	1.5(1.7)	1.3(1.3)
Oxyfluorfen	150	3.3(10.3)	3.9(14.3)	2.7(6.7)	4.3(17.7)	1.1(0.7)	1.5(1.7)
Hand weeding at 25 DAS	-	0.7(0.0)	2.1(4.0)	0.7(0.0)	2.4(5.3)	0.7(0.0)	1.7(2.3)
Control	-	5.6(31.3)	5.8(32.7)	4.5(19.7)	6.5(41.3)	2.0(3.7)	2.2(4.3)
LSD (p=0.05)		0.50	0.55	0.40	0.48	0.30	0.40
Weed biomass (g/m^2)							
Imazethapyr	80	2.7(6.7)	3.2(9.9)	2.5(5.8)	(5.7)	0.9(0.3)	0.9(0.3)
Imazethapyr	100	2.1(4.0)	2.4(5.3)	1.9(3.0)	(3.5)	0.7(0.0)	0.8(0.1)
Quizalofop	60	1.6(2.1)	2.1(4.0)	3.8(14.3)	(10.7)	1.7(2.5)	1.1(0.8)
Quizalofop	75	1.0(0.5)	1.3(1.4)	3.4(11.0)	(8.6)	1.6(2.2)	1.1(0.7)
Imazethapyr + imazamox	56	2.1(4.1)	2.9(7.8)	2.5(6.0)	(5.7)	1.2(0.9)	0.9(0.3)
Imazethapyr + imazamox	70	1.7(2.4)	2.2(4.4)	1.9(3.0)	(3.5)	0.8(0.2)	0.8(0.2)
Sodium-acifluorfen + clodinafop	196	2.7(6.7)	2.8(7.6)	2.7(6.8)	(5.9)	1.8(2.8)	1.0(0.5)
Sodium-acifluorfen + clodinafop	245	2.3(4.7)	2.4(5.4)	2.3(4.8)	(3.7)	1.5(1.8)	0.9(0.4)
Oxyfluorfen	150	2.5(5.6)	2.9(7.7)	2.6(6.1)	(6.0)	1.1(0.8)	1.0(0.4)
Hand weeding at 25 DAS	-	0.7(0.0)	1.6(2.1)	0.7(0.0)	(2.1)	0.7(0.0)	1.1(0.6)
Control	-	4.9(23.4)	4.4(18.6)	4.3(17.9)	(14.2)	1.9(3.2)	1.4(1.4)
LSD (p=0.05)		0.41	0.40	0.32	0.38	0.26	0.14

*Figures in parentheses are original value

2018). Uniform crop residue placement with sufficient thickness (≥4 t/ha) suppresses weeds by blocking light and altering soil microclimate, with possible allelopathic effects. The effectiveness of mulch also depends on residue type and decomposition rate, which can affect soil fertility and weed emergence (Choudhary and Bhagawati 2019).

Effect on weed biomass and weed control efficiency

At both 30 DAS and 50 DAS, hand weeding recorded the lowest weed biomass and highest WCE (95.9–100% and 86–100%, respectively) (**Table 7**). As the crop matured, weed biomass increased, reducing WCE. Under CA, minimal soil disturbance leaves weed seeds near the surface, where they can germinate in favourable conditions, though they are prone to predation. Some seeds exhibit delayed germination or emerge in multiple flushes, especially small-sized seeds that respond rapidly to surface conditions and crop residues (Marble 2015, Choudhary 2016).

Phytotoxicity rating

Oxyfluorfen 150 g/ha showed the highest phytotoxicity (rating 4.7) at 4 DAHA, which diminished completely by the 9th DAHA (**Figure 1**). Sodium-acifluorfen + clodinafop 245 g/ha and 196 g/ha showed moderate phytotoxicity (up to 3.0), and imazethapyr + imazamox 70 g/ha and 56 g/ha showed mild effects (up to 1.5), both resolving by the 7th and 5th DAHA, respectively. Other herbicides were safe for greengram.

Greengram growth and yield attributes

Hand weeding recorded the highest LAI, total biomass and greengram haulm yield and seed yield followed by imazethapyr + imazamox at 70 g/ha (**Table 8**). Yield attributes were also highest in hand-weeded plots. Weed management improved pod number and seeds/pod, depending on herbicide and dose. The hand weeding and selective herbicides like imazethapyr + imazamox improved greengram plant branching, pod formation, haulm yield and seed yield.

Table 7. Total weed biomass and weed control efficiency at 30 and 50 days after seeding (DAS) as influenced by post-emergence herbicides in greengram under conservation agriculture

Treatment	Dose (g/ha)	Total weed biomass (g/m^2) 30 DAS 2017	30 DAS 2018	50 DAS 2017	50 DAS 2018	Weed control efficiency (%) 30 DAS 2017	30 DAS 2018	50 DAS 2017	50 DAS 2018
Imazethapyr	80	1.9(3.3)*	2.3(4.9)	3.6(12.8)	4.0(15.8)	78.4	56.7	70.9	53.8
Imazethapyr	100	1.5(1.7)	1.8(2.8)	2.7(7.0)	3.1(8.9)	88.6	75.7	84.0	73.9
Quizalofop	60	2.4(5.1)	2.5(5.9)	4.4(18.9)	4.0(15.4)	67.0	47.5	57.2	54.9
Quizalofop	75	2.1(4.1)	2.1(4.1)	3.8(13.7)	3.3(10.6)	73.3	63.9	69.1	69.1
Imazethapyr + imazamox	56	2.0(3.6)	2.1(4.0)	3.4(11.0)	3.8(13.9)	76.4	64.5	75.1	59.4
Imazethapyr + imazamox	70	1.6(2.0)	1.7(2.4)	2.4(5.5)	2.9(8.1)	86.8	78.4	87.5	76.5
Sodium-acifluorfen + clodinafop	196	2.3(5.1)	2.3(4.8)	4.1(16.3)	3.8(14.0)	67.1	58.4	63.1	58.9
Sodium-acifluorfen + clodinafop	245	1.7(2.4)	1.8(2.7)	3.4(11.2)	3.2(9.5)	84.3	76.7	74.5	72.4
Oxyfluorfen	150	1.4(1.6)	1.3(1.3)	3.6(12.4)	3.8(14.2)	89.4	88.5	72.2	58.5
Hand weeding at 25 DAS	-	0.7(0.0)	1.0(0.4)	0.7(0.0)	2.3(4.8)	100.0	95.9	100.0	86.0
Control	-	4.0(15.4)	3.4(11.3)	6.7(44.5)	5.9(34.2)	-	-	-	-
LSD (p=0.05)		0.37	0.25	0.38	0.38				

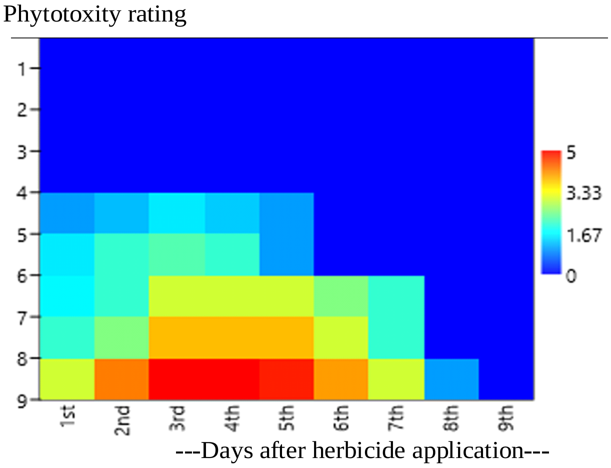
*Figures in parentheses are original value

Table 8. Greengram growth, yield and economics as influenced by post-emergence herbicides under conservation agriculture

Treatment	Dose (g/ha)	Leaf area index 2017	Leaf area index 2018	Total plant biomass (g/m^2) 2017	Total plant biomass (g/m^2) 2018	Pods (no./plant) 2017	Pods (no./plant) 2018	Seeds (no./pod) 2017	Seeds (no./pod) 2018	Seed yield (kg/ha) 2017	Seed yield (kg/ha) 2018	Haulm yield (kg/ha) 2017	Haulm yield (kg/ha) 2018	Net returns ($x10^3$ Rs/ha) 2017	Net returns ($x10^3$ Rs/ha) 2018	B: C 2017	B: C 2018
Imazethapyr	80	3.25	3.16	232.8	225.7	16.9	20.4	10.6	10.8	983	931	1390	1955	26.02	22.85	1.91	1.66
Imazethapyr	100	3.30	3.24	234.2	226.3	19.3	21.7	11.5	11.4	1041	1008	1477	2218	28.52	26.57	2.01	1.81
Quizalofop	60	3.05	3.00	217.1	209.9	14.6	17.9	9.5	9.2	810	787	1267	1972	17.36	15.77	1.47	1.34
Quizalofop	75	3.23	3.16	231.4	222.6	15.8	19.0	10.0	9.8	850	829	1293	2155	18.7	17.20	1.48	1.37
Imazethapyr + imazamox	56	3.39	3.33	240.8	234.9	20.1	23.5	11.7	11.3	1170	1133	1543	2493	34.50	32.80	2.29	2.08
Imazethapyr + imazamox	70	3.41	3.35	242.3	236.3	20.2	23.4	12.0	11.7	1193	1167	1727	2567	35.59	34.12	2.32	2.12
Sodium-acifluorfen + clodinafop	196	3.15	3.08	223.5	216.8	13.9	17.5	9.2	9.4	800	802	1205	1849	16.89	16.31	1.45	1.36
Sodium-acifluorfen + clodinafop	245	3.31	3.25	234.0	228.6	17.2	20.5	11.2	10.9	1007	978	1387	1750	26.16	23.63	1.86	1.66
Oxyfluorfen	150	3.01	2.91	214.0	207.7	13.2	16.3	8.6	8.3	712	698	1193	1174	13.16	10.57	1.29	1.12
Hand weeding at 25 DAS	-	3.49	3.41	247.1	239.2	19.7	24.4	11.9	11.8	1243	1202	1727	2644	33.22	31.23	1.94	1.78
Control	-	2.63	2.56	186.9	180.0	11.0	15.0	8.1	8.1	400	390	1093	988	0.25	-2.36	0.68	0.56
LSD (p=0.05)		0.15	0.16	9.40	8.86	1.73	1.62	0.53	0.46	72.2	70.1	102	141.2	3.24	3.37	0.14	0.14

*Figures in parentheses are original value

Post-emergent herbicide	Dose (g/ha)
Imazethapyr	80
Imazethapyr	100
Quizalofop	60
Quizalofop	75
Imazethapyr + imazamox	56
Imazethapyr + imazamox	70
Sodium-acifluorfen + clodinafop	196
Sodium-acifluorfen + clodinafop	245
Oxyfluorfen	150



The intense colour of the row shows more phytotoxicity ratings, and fading of the colour means getting recoveries.

Figure 1. Phytotoxicity rating as influenced by post-emergence herbicides in greengram under conservation agriculture (mean of two years)

Herbicides like imazethapyr, imazethapyr + imazamox, and acifluorfen + clodinafop effectively suppressed grasses and BLWs, improving yield. Hand weeding eliminated weeds entirely, creating optimal conditions for growth. These findings align with Singh *et al.* (2017) highlighting the importance of early and effective weed control for maximizing yield in greengram. The PoE herbicides provided effective weed control, improving crop yield by enhancing branching and pod formation (**Tables 5–8**). However, conventional tillage still offers favourable conditions for crop growth (Sangakkara 2004).

Economic return

The highest net returns and B: C were achieved with imazethapyr + imazamox 70 g/ha, followed by its 56 g/ha dose, with no significant difference between them (**Table 8**). Effective weed management led to higher yields, reduced costs, and better economic returns, consistent with findings in RWCS and maize-wheat systems in South Asia (Gathala *et al.* 2013, Nawaz *et al.* 2017).

Conclusion

This study highlighted the potential for enhancing greengram productivity and profitability under CA in the RWCS. Hand weeding achieved the highest seed yield (2.08–2.11 times greater than the un-weeded control) with 86–100% weed control efficiency, but it was not economically viable. In contrast, imazethapyr + imazamox at 70 g/ha offered a sustainable option, providing 76.5–86.8% weed control, nearly doubling yield (1.98–1.99 folds), and achieving a B: C of 2.08–2.53. For long-term success of CA, optimizing crop residue levels and the use of post-emergence herbicide is essential to maximize weed suppression, greengram yield, and farm profitability.

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RESEARCH ARTICLE

Evaluation of post-emergence herbicides to manage weeds in greengram of South-Eastern Rajasthan

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ABSTRACT

A field experiment was conducted during three consecutive *Kharif* seasons (2020, 2021 and 2022) at Agricultural Research Station, Kota, Rajasthan, India to identify most effective post-emergence herbicides to managing weeds and improve greengram productivity. The experiment was laid out in Randomized Block Design with three replications and eight treatments. The weed free recorded minimum weed density and biomass, higher weed control efficiency, maximum and significantly higher growth, yield attributes and yields followed by hand weeding twice. Amongst herbicides, post-emergence application (PoE) of fomesafen + fluazifop-p-butyl 220 g/ha recorded lower weed density and biomass, higher weed control efficiency, maximum and significantly higher greengram growth, yield attributes and yields being at par with propaquizafop + imazethapyr 33.3 g/ha + 50 g/ha PoE and sodium-acifluorfen + clodinafop-propargyl 140 g/ha + 70 g/ha PoE over rest of the treatments. Maximum and significantly higher net returns and B:C ratio were also recorded with propaquizafop 33.3 g/ha + imazethapyr 50 g/ha PoE which was at par with fomesafen + fluazifop-p-butyl 220 g/ha PoE and sodium-acifluorfen 140 g/ha + clodinafop-propargyl 70 g/ha PoE.

Keywords: Economics, Fomesafen + fluazifop-p-butyl, Greengram, Propaquizafop + imazethapyr, Sodium-acifluorfen + clodinafop-propargyl, Weed management

INTRODUCTION

Greengram (*Vigna radiata* L. Wilczek), is one of the most important and extensively cultivated pulse crops in arid and semi-arid regions of India. In India, during 2023-24, greengram was cultivated in an area of 51.9 lakhs hectares with 31.0 lakh tonnes production and 0.6 t/ha productivity, according to the Department of Economics and Statistics, Ministry of Agriculture & Farmers Welfare, Government of India. Rajasthan led in greengram cultivation during 2023-24 with an area of 23.64 lakhs hectares, production of 8.12 lakhs tonnes accounting for 45% of nationwide production. Greengram is a self-pollinated annual crop belongs to family Leguminosae. It is known for its nutritive value and digestibility, containing higher protein contents (28%), fat (1.3%), carbohydrate (60.4%) and reasonable number of vitamins and essential micronutrients (Akhtar *et al.* 2013). The calorific value of greengram is 334 cal/100g and chemically it contains mineral (3.5%), lysine (20.43%), methionine (0.10%), calcium 124 mg, phosphorus 3.26 mg and iron 7.3 mg. The greengram makes valuable green manures and can be used as cover crop. Apart from these, it also fixes atmospheric nitrogen of about 30-40 kg/ha as a leguminous crop and improves the soil fertility (Ghumare *et al.* 2014). Consumed in various forms such as 'dal', 'halwa' (a sweet dessert), boiled dry beans, sprouted and roasted, greengram is also a good source of riboflavin and vitamin C.

Weeds pose a serious threat to the productivity of greengram due to greater competition for nutrients, water, space and sunlight (Sahu *et al.* 2019). Weed management in greengram is a challenging factor, mainly in *Kharif* season due to unpredictability of rains, entailing to non-workable conditions of soil in rainy days and timely non-availability of labour (Leva *et al.* 2018). Weeds have competitive nature and withstand in adverse condition and weeds compete with greengram for water, nutrient, space and light causing severe yield losses, if not effectively managed during the critical period (Mishra *et al.* 2016, Bagariya *et al.* 2025). The weed infestation in greengram is severe during rainy season and as a result, the quantity and quality of the seed are reduced substantially (Shukla *et al.* 2025). Hand

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weeding is a traditional and effective method but untimely rains, unavailability of labour at peak time and increasing labour cost are the main limitations (Gupta *et al.* 2019). Weeds can also be mechanically managed but due to continuous rainfall during the season makes the manual/mechanical weeding impracticable (Shweta and Singh 2005). Mechanical practices such as hand weeding and inter–culturing is effective but unavailability of labour and incessant rains during the early crop season normally limit the weeding operations. The conventional methods of weed control are time consuming, expensive and laborious. Therefore, herbicide usage under such circumstances becomes indispensable and was found to be a cost-effective alternative (Khairnar *et al.* 2014, Bajiya *et al.* 2025). Many weed species don't germinate at the planting time and have ungerminated reserve seeds in the soil which germinate in the staggered manner in standing greengram crop. So, pre-emergence herbicides might just not be able to provide substantial weed control and are unable to take care of weeds completely until critical period. Two hand weeding or intercultural operations are to be followed at some later stage which is a costly affair. In rainy season, very narrow time range available for planting huge acreage, sometimes compel the farmers to forego the use of pre-emergence herbicides and mannual/mechanical weeding in standing crop due to financial and manpower constraints and unpredictable conditions of rain. Herbicides with broad spectrum action will control all the type of weeds effectively (Bajiya *et al.* 2025). Pre-emergence herbicides like pendimethalin and post-emergence herbicides like imazethapyr, fluzifop-p-butyl, propaquizafop, sodium-aciflourfen and fomesafen, whether used individually or in ready mix formulations, were found effective in controlling weed emergence and growth during the initial stages of greengram in the *Kharif* season. Effective herbicide use can provide a weed-free environment during the critical early growth stages of greengram, ensuring optimal crop development and ultimately enhancing greengram productivity (Bhowmick and Gupta 2005). It is crucial to develop sustainable and economically viable solutions to combat weeds in greengram. Thus, the present study was undertaken to assess the performance of post-emergence herbicides for broad-spectrum weed management and identify effective and economic option to manage weeds in *Kharif* (rainy season) greengram.

MATERIALS AND METHODS

A field experiment was conducted during three consecutive *Kharif* seasons (2020, 2021 and 2022) at Agricultural Research Station, Kota, Rajasthan. The experiment consisted of eight treatments including: post-emergence application (PoE) of imazethapyr 55 g/ha at 20 days after seeding (DAS); fluazifop-p-butyl 250 g/ha PoE at 20 DAS; propaquizafop 2.5% + imazethapyr 3.75% ME (propaquizafop + imazethapyr) (ready-mix) 33.3 g/ha +50 g/ha PoE at 20 DAS; sodium-acifluorfen 16.5% EC 140 g/ha + clodinafop-propargyl 8% EC (sodium-acifluorfen + clodinafop-propargyl) (ready-mix) 140 g/ha + 70 g/ha PoE at 20 DAS; fomesafen + fluazifop-p-butyl (ready-mix) 220 g/ha PoE at 20 DAS; hand weeding twice at 20 and 40 DAS; weed free and weedy check. The experiment was laid out in Randomized Block Design with three replications.

The soil of the experimental field was clay loam, slightly alkaline, medium in available N and K and low in available P and S. Greengram variety: IPM 02-03 was used with a seed rate of 20 kg/ha and row spacing of 30 cm. Recommended dose of fertilizers (20 kg N + 40 kg P/ha) were applied at the time of sowing through Single super phosphate (SSP) and urea. Post-emergence herbicides were applied at 20 DAS by using 500 l/ha of water with knapsack sprayer fitted flat fan nozzle. Weed density was recorded by using 0.25 m^2 quadrat at all growth stages in all the treatments and then converted into number of weeds/ m^2. The data on total weeds density was subjected to square root transformation to normalize their distribution (Blackman and Roberts 1950). Weed control efficiency was calculated at 30, 60 DAS and at harvest in each treatment on the basis of weed dry matter (weed biomass) based on adopted formula by Umrani and Boi (1982).

$$\text{WCE (\%)} = \frac{\text{DMC} - \text{DMT}}{\text{DMC}} \times 100$$

Where:

WCE= Weed control efficiency,

DMC = Weed dry matter in weedy check plot

DMT = Weed dry matter in treated plot

Greengram growth parameters i.e. plant height, branches/plant and yield attributes i.e. pods/plant, seeds/pod, 100 seed weight was recorded at harvest. Net returns were calculated using current input and output prices during the crop season. The benefit-cost ratio was calculated by dividing from the cost of cultivation. The data was analysed using standard ANOVA for randomized block design and the significance of differences in treatment means was compared to critical differences at the 5% level of probability. To assess the relationshp and regression coefficients between grain yield (Y) and the independent variables (X) such as branches per plant, pods per plant, seeds per pod and 100 seed weight were worked out using the procedure given by Snedecor and Cochran (1968). The regression equations were also fitted and tested for significance.

RESULTS AND DISCUSSION

Effect on weeds

The weed flora in the experimental field consisted of *Echinochloa crus-galli*, *Echinochloa colonum* and *Cynodon dactylon* among grassy weeds and *Eclipta alba*, *Commelina benghalensis*, *Amaranthus viridis*, *Trianthema portulacastrum*, *Celosia argentic*, *Capsularis silaris*, *Phyllanthus niruri*, *Corchorus olitorius*, *Alternanthera Caracas ana* among the broad-leaved weeds, *Cyperus rotundus* and *Cyperus iria* among sedges. The grassy weeds are predominant (60%), followed by sedges (25%) and broad-leaved weeds (15%).

Weed density and weed biomass at 60 DAS and at harvest were higher than at 30 DAS. At all the stages of observation, weedy check recorded significantly higher weed density and biomass than any other treatment.

Among the herbicide treatments, fomesafen + fluazifop-p-butyl 220 g/ha (ready-mix) PoE, propaquizafop 33.3 g/ha + imazethapyr (ready-mix) 50 g/ha PoE and sodium-acifluorfen 140 g/ha + clodinafop-propargyl (ready-mix) 70 g/ha PoE recorded significantly lower weed density at 30, 60 DAS and at harvest and were statistically at par with each other with respect to weed density at all the stages (**Table 1**). Similarly, weed biomass was lowest at 30 DAS with fomesafen + fluazifop-p-butyl (ready-mix) 220 g/ha PoE, among the all-herbicidal treatments. At 60 DAS, lowest weed biomass was observed with fomesafen + fluazifop-p-butyl (ready-mix) 220 g/ha PoE followed by propaquizafop 33.3 g/ha + imazethapyr (ready-mix) 50 g/ha PoE which are statistically at par with each other. At greengram harvest, fomesafen + fluazifop-p-butyl (ready-mix) 220 g/ha PoE, propaquizafop 33.3 g/ha + imazethapyr 50 g/ha (ready-mix) PoE and sodium-acifluorfen 140 g/ha + clodinafop-propargyl 70 g/ha (ready-mix) PoE were at par with each other confirming the findings of Singh *et al.* (2014). These herbicides performed better than other herbicidal treatments as the predominant weed species are susceptible to these groups of herbicides.

Maximum weed control efficiency was observed at 30 DAS with weed free check followed by hand weeding twice at 20 and 40 DAS. Fomesafen + fluazifop-p-butyl (ready-mix) 220 g/ha PoE recorded significantly higher weed control efficiency at 30, 60 DAS and at harvest. Next best treatments were propaquizafop 33.3 g/ha + imazethapyr 50 g/ha (ready- mix) PoE and sodium-acifluorfen 140 g/ha + clodinafop-propargyl 70 g/ha (ready-mix) PoE. The variation in weed biomass under various treatments is directly related to the variation in weed control efficiency and the observed highest weed control efficiency was due to the higher reduction in weeds biomass at early stages of crop growth.

Table 1. Effect of weed management treatments on weed density and biomass in greengram (pooled data of 3 years)

Treatment	Weed density (no./m^2)			Weed biomass (g/m^2)			Weed control efficiency (%)		
	At 30 DAS	At 60 DAS	At harvest	At 30 DAS	At 60 DAS	At harvest	At 30 DAS	At 60 DAS	At harvest
Weedy check	15.18 (230.66)	18.51 (342.71)	14.23 (209.82)	10.19 (103.33)	11.95 (142.33)	9.75 (94.65)	0.00	0.00	0.00
Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	100.0	100.0	100.0
Hand weeding twice at 20 and 40 DAS	3.35 (11.00)	4.06 (16.18)	3.23 (10.00)	2.67 (6.62)	4.43 (19.16)	3.04 (8.75)	93.59	86.54	90.76
Imazethapyr 55 g/ha PoE	9.40 (88.24)	12.13 (147.35)	9.02 (83.12)	6.72 (44.63)	8.51 (71.86)	5.99 (35.44)	56.81	49.51	62.56
Fluazifop-P-butyl 250 g/ha PoE	9.03 (81.07)	9.81 (117.43)	9.15 (85.34)	6.39 (40.32)	7.90 (61.87)	5.95 (34.85)	60.98	56.53	63.18
Propaquizafop 33.3 g/ha + imazethapyr (ready- mix) 50 g/ha PoE	6.85 (46.52)	9.03 (64.26)	6.57 (42.04)	4.75 (22.11)	6.77 (45.32)	4.61 (20.74)	78.60	68.16	78.09
Sodium-acifluorfen 140 g/ha + clodinafop-propargyl (ready-mix) 70 g/ha PoE	6.88 (47.54)	8.57 (73.51)	6.20 (37.53)	5.01 (24.65)	7.02 (48.81)	4.87 (23.26)	76.14	65.70	75.43
Fomesafen + fluzifop-p-butyl (ready-mix) 220 g/ha PoE	6.24 (38.71)	7.62 (59.19)	6.09 (35.52)	4.17 (16.86)	6.53 (42.11)	4.47 (19.49)	83.68	70.41	79.41
LSD (p=0.05)	0.98	1.44	1.01	0.43	0.44	0.45			

**Square root transformed values. * Figures in parentheses are original values. PoE: post-emergence application; DAS: days after seeding

Effect on greengram growth, yield attributes and yield

The highest number of branches/plant, yield attributes, higher grain yield and straw yield were recorded under weed free followed by hand weeding twice at 20 and 40 DAS. Among the herbicides; fomesafen + fluazifop-p-butyl (ready-mix) 220 g/ha PoE recorded maximum and significantly higher branches/plant, yield attributes, higher grain yield and straw yield, which was at par with propaquizafop 33.3 g/ha + imazethapyr 50 g/ha (ready- mix) PoE and sodium-acifluorfen 140 g/ha + clodinafop-propargyl 70 g/ha (ready-mix) PoE. The plant height remained similar among the treatments (**Table 2**) due to better control of all categories of weeds by these treatments that resulted in lower nutrient depletion and lesser weeds biomass and thereby increasing the nutrient uptake of crop growth and yield attributes and yield of greengram confirming the earlier findings of Naidu *et al.* (2011).

The adequate availability of light, space as well as better edaphic and nutritional environment along with improvement in physiological and morphological characters of the plant in rhizosphere led to greater photosynthetic rate, thereby more accumulation of dry matter under better treatments. Contrary to this, unrestricted weed growth throughout the crop season in weedy check plots arrested the crop

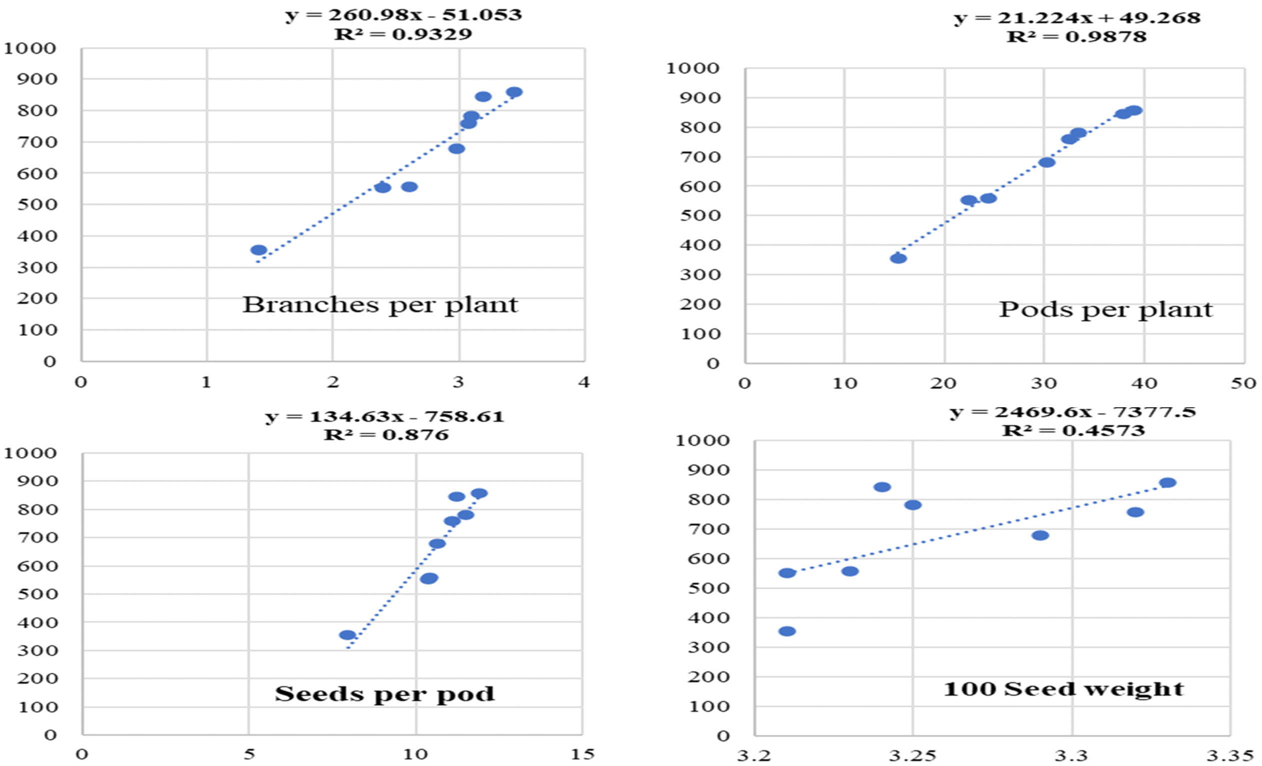

Figure 1. Relationship between branches per plant, pods per plant, seeds per pod and 100 seed weight (X) and greengram grain yield (Y)

Table 2. Effect of weed management treatments on growth, yield and economics of greengram (pooled data of 3 years)

Treatment	Plant height (cm) at harvest	Branches/ plant (no.)	Pods/ plant (no.)	Seeds/ pod (no.)	100 seed weight (g)	Grain yield (kg/ha)	Straw yield (kg/ha)	Net returns (₹/ha)	B:C ratio
Weedy check	53.44	1.41	15.30	7.95	3.21	356	531	5353	1.25
Weed free	56.49	3.44	38.93	11.88	3.33	858	1247	29541	1.87
Hand weeding twice at 20 and 40 DAS	53.80	3.19	37.92	11.23	3.24	844	1160	28505	1.84
Imazethapyr 55 g/ha PoE	53.82	2.40	22.47	10.38	3.21	553	821	17032	1.72
Fluazifop-P-butyl 250 g/ha	54.29	2.61	24.41	10.43	3.23	558	762	15818	1.62
Propaquizafop 33.3 g/ha + imazethapyr (ready-mix) 50 g/ha PoE	53.08	3.08	32.55	11.10	3.32	758	1011	32257	2.36
Sodium-acifluorfen 140 g/ha + clodinafop-propargyl (ready-mix) 70 g/ha PoE	54.32	2.98	30.28	10.63	3.29	679	1010	26562	2.13
Fomesafen + fluzifop-p-butyl (ready-mix) 220 g/ha PoE	53.33	3.10	33.43	11.50	3.25	782	1112	32572	2.28
LSD (p=0.05)	NS	0.36	3.70	1.51	NS	103	164	6873	0.27

PoE: post-emergence application; DAS: days after seeding growth due to high degree of crop-weed competition confirming the findings of Yadav *et al.* (2022) and Shilurenla *et al.* (2022).

Economics

Maximum and significantly higher net returns (Rs. 32572/ha) were recorded with fomesafen + fluazifop-p-butyl 220 g/ha PoE which was at par with propaquizafop 33.3 g/ha + imazethapyr 50 g/ha PoE and sodium-acifluorfen 140 g/ha + clodinafop-propargyl 70 g/ha PoE over rest of treatments. The B:C ratio was significantly higher with propaquizafop 33.3 g/ha + imazethapyr 50 g/ha PoE followed by fomesafen + fluazifop-p-butyl 220 g/ha PoE and sodium-acifluorfen 140 g/ha + clodinafop-propargyl 70 g/ha PoE (**Table 2**). These results are in conformity with those reported by Susmita *et al.* (2017). The higher B:C ratio achieved under superior treatments might be due to higher seed and straw yield and higher returns per rupees investment than poor yielding treatments. **.**

Regression studies

The regression coefficients (b) and regression equations were worked out to quantify the amount of change in grain yield of greengram for a unit change in growth and yield attributes of crop. It was observed that every unit increase in branches per plant, pods per plant, seeds per pod and 100 seed weight increased the grain yield of greengram by 260.98, 21.22, 134.63, and 2469.6 kg/ha, respectively in pooled analysis (**Figure 1**).

Conclusion

It may be concluded that effective and economic management of weeds with higher greengram yield and higher economic returns (benefit cost ratio) can be achieved with propaquizafop 33.3 g/ha + imazethapyr (ready-mix) 50 g/ha PoE or fomesafen + fluazifop-p-butyl (ready-mix) 220 g/ha PoE or sodium-acifluorfen 140 g/ha + clodinafop-propargyl 70 g/ha PoE at 20 DAS.

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RESEARCH ARTICLE

Impact of herbicides on weeds and productivity of clusterbean in western Rajasthan

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ABSTRACT

The clusterbean is confined mainly as rainfed crop during kharif season in Rajasthan. Clusterbean is severely infested by many broad-leaved and grassy weeds which cause considerable loss of clusterbean productivity and economic returns. A field experiment was conducted for two consecutive years *i.e. Kharif* 2021 and 2022 on sandy loam soils of Western Rajasthan to assess the effect of new herbicide molecules on weed management and productivity of clusterbean (cultivar HG 2-20). A randomized block design (RBD) with four replications was used. The post-emergence application of propaquizafop 2.5% + imazethapyr 3.75% w/w (propaquizafop + imazethapyr) 135 g/ha at 20 days after seeding recorded maximum weed control efficiency, clusterbean growth, yield attributes, seed yield, net return and B:C ratio of 2.0 and was at par with weed free.

Keywords: Clusterbean, Economics, Pendimethalin, Propaquizafop + imazethapyr, Weed management

INTRODUCTION

Clusterbean [*Cyamopsis tetragonoloba* (L.) Taub] is a drought tolerant grain legume thrives well in semiarid regions of Rajasthan. It needs abundant sunshine, moderately frequent rainfalls and well-drained soil for productive and fruitful outputs (Jain *et al*. 2019). It has significant importance as raw material in industries for making guar gum, a gel forming fiber obtained after refining the seeds. Clusterbean is also cultivated as a catch crop, green manure and vegetable crop in different parts of the country. India is the main producers of clusterbean and accounting more than 80% of global production and lead in exports of guar and its by-products (Kumar *et al*. 2013). India covers 6.82 million hectares with a production of 4.79 million tons and productivity of 0.7 t/ha (Kumar *et al.* 2024). The northwestern parts of country encompassing states of Rajasthan, Gujarat, Haryana and Punjab contribute 87 and 82% of the country's area and production, respectively. In Rajasthan, the area under clusterbean is high (2.88 m ha) due to its drought hardy nature and better performance under moisture stress compared to traditional legume crops (Anonymous 2024).

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The realized productivity of clusterbean is low as against its potential productivity as it is cultivated mainly in marginal lands and sown as catch crop. Further, weeds that infest during cropping season cause a significant reduction (47%) in productivity of the crop (Jain and Singh 2000, Bamboriya *et al*. 2024). The severity and extent of weeds density and biomass in the clusterbean varies depending crop management practices adopted (Choudhary *et al*. 2024). and it is important to identify effective and economical weed management practices. Herbicides usage to manage weeds is replacing the traditional practice of weeding i.e. manual weeding and hoeing due to scarcity of manual labour as well as high cost of labour and herbicide usage is helpful to reduce the production cost (Yadav *et al.* 2019). Thus, this study was carried out to evaluate the efficacy of new herbicides molecules and compare them with the traditional practice *i.e.* manual hoeing in clusterbean.

MATERIALS AND METHODS

The field study was carried out at Instructional Farm, College of Agriculture Sumerpur, Agriculture University Jodhpur, Rajasthan for two consecutive Kharif seasons of 2021 and 2022. The soil of the experimental field was sandy loam in texture, slightly alkaline in pH (7.80), low in organic carbon (0.26 %), low in available nitrogen (197.3 kg/ha), medium in available phosphorus (27.80 kg/ha) and high in available potassium (283.0 kg/ha). Eight weed management treatments were tested, *viz*. weedy check; pre-emergence application (PE) of pendimethalin 38.7CS (pendimethalin) 500 g/ha (currently recommended); post-emergence (PoE) of fomesafen 11.1% + fluazifop-p-butyl 11.1% SL (fomesafen + fluazifop-p-butyl) 220 g/ ha at 20 days after seeding (DAS); imazethapyr 35%+ imazamox 35 % WDG (imazethapyr + imazamox) 40 g/ha PoE at 20 days after seeding; sodium-acifluorfen 16.5% + clodinafop-propargyl 8% EC (sodium-acifluorfen + clodinafop-propargyl) 250g/ha PoE at 20 DAS; propaquizafop 2.5% + imazethapyr 3.75% w/w (propaquizafop + imazethapyr) 135 g/ha PoE at 20 DAS; imazethapyr 10% SL (imazethapyr) 40 g/ha PoE at 25 DAS and weed free check (manual weeding up to 45 DAS). The clusterbean crop variety HG 2-20 was sown manually, with the onset of monsoon, keeping the row distance of 30 cm and seed rate of 15 kg seed/ha during the first fortnight of July and harvested in first week of October in the respective years. The recommended package of practices was used for crop cultivation. The basal fertilizer dose of 20 kg/ha N and 40 kg/ha P was applied at the time of sowing. The herbicides were applied as per treatment using knapsack sprayer fitted with flat fan nozzle as per schedule including manual hoeing and weeding in respective experimental units. The weeds data was collected by randomly placing 0.25 m^2 quadrat at two places in each plot. The gross plot size was 5.0 m × 4.8 m while net plot size was 4.0 × 3.6 m. Observations were taken of weed parameters at 60 DAS and growth and yield attributes at harvest of the crop as per standard procedure.

RESULTS AND DISCUSSION

Effect on weeds

The weeds infested in the experimental plot include: *Amaranthus viridis, Euphorbia hirta, Aristida depressa, Portulaca oleracea, Digera arvensis, Cenchrus biflorus, Corchorus tridense, Commelina benghalensis, Phyllanthus niruri, Eleusine verticillata* and *Trianthema portulacastrum* among broad-leaved weeds and *Cenchrus biflorus, Eragrostis pilosa* and *Eragrostis tenella* among grassy weeds.

The pooled and individual years data of weed dry matter production (weed biomass), weed control efficiency, weed index and herbicide efficiency index showed significant variations among the treatments (**Table 1**). The mean minimum weed biomass and mean maximum weed control efficiency was recorded in weed free check while among the herbicides, propaquizafop + imazethapyr 135 g/ha PoE at 20 DAS was found superior over pendimethalin 500 g/ha and recorded higher mean herbicide efficiency index. Fomesafen +fluazifop-p-butyl (ready mix) 220 g/ha PoE at 20 DAS recorded next significant higher weed control efficiency but caused mild phytotoxicity on crop. These herbicides controlled the broad-leaved and grassy weeds better than pendimethalin applied alone and minimized the competition of weeds with crop for resources, *viz*. light, nutrients and moisture as observed by Jagdesh and Raju (2021) and Yadav *et al.* (2022).

The regular weeding as the weeds emerged in weed free resulted in practically complete absence of weeds. The weed free environment up to 40 DAS caused highest reduction of weed biomass due to prolonged effect of hoeing on controlling the weeds and enhanced crops shading effect on weeds as reported by Singh *et al.* (2016) and Patil *et al.* (2021).

Effect on crop

The average mean clusterbean plant height, and number of branches per plant, various yield

Table 1. Efficiency of weed management treatments in managing weeds in clusterbean

Treatment	Weed biomass (g/ m^2) at 60 DAS			Weed control efficiency (%) at 60 DAS			Weed index (%)			Herbicide efficiency index (%)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Weedy check	186.3	193.8	190.0	0.0	0.0	0.0	34.4	22.6	28.5	0.00	0.00	0.00
Pendimethalin 500 g/ha PE	71.2	60.8	66.0	61.5	68.4	65.0	15.0	7.2	11.1	0.90	0.86	0.88
Fomesafen+ fluazifop-p-butyl 220 g / ha PoE at 20 DAS	53.7	63.8	58.7	70.6	67.0	68.8	17.0	15.0	16.0	1.14	0.50	0.82
Imazethapyr + imazamox 40 g /ha PoE at 20 DAS	62.3	63.9	63.1	66.0	66.9	66.5	20.8	8.1	14.5	0.88	0.77	0.83
Sodium- acifluorfen + clodinafop-propargyl 250g/ha PoE at 20 DAS	67.8	67.4	67.6	63.2	65.0	64.1	23.5	15.0	19.3	0.67	0.46	0.57
Propaquizafop + imazethapyr 135g /ha PoE at 20 DAS	51.2	60.0	55.6	72.1	69.0	70.6	4.0	5.0	4.5	1.75	0.98	1.37
Imazethapyr 40 gm/ha PoE at 25 DAS	61.2	61.3	61.2	67.1	68.0	67.6	15.5	8.1	11.8	1.02	0.84	0.93
Weed free check	37.4	38.0	37.7	79.6	80.4	80.0	0.0	0.0	0.0	2.47	2.41	2.44
LSD (p=0.05)	16.7	19.7	10.9	-	-	-	-	-	-	0.67	1.31	0.62

DAS = days after seeding; PE= pre-emergence application; PoE = post-emergence application attributes, *viz.* number of pods/plant and number of seeds/pod and seed yield at harvest were highest with propaquizafop + imazethapyr 135 g/ha PoE at 20 DAS as against the currently recommended pendimethalin 500 g/ha (**Table 2**). The manual hoeing twice at 25 and 40 DAS maintained its superiority over all the treatment in respect of all crop characters. The increase in height was attributed to the weed free environment with the application of various herbicides (Yadav *et al.* 2021).

The traditional practice of weed management i.e. manual weeding twice recorded maximum yield attributes of the crop. However, the test weight was found non-significant during both the years. The weed free environment provides the crop the reater resources availability particularly nutrient, water and light at the critical crop stage due to reduced weed crop competition during critical period (Borana *et al.* 2021 and Jain and Parewa 2022). The better initial growth induced more flower and pod production with timely supply of resources might have reduced shedding of flowers and pods, which led to a positive source-sink gradient of photosynthates translocation (Yadav *et al.* 2019).

The harvest index was not influenced significantly on mean basis as well as in individual years. It might be due to lesser infestation of weeds that encourage proper translocation of photosynthates from source to sink as report by Dubey *et al.* (2018).

Economics

The highest mean gross returns were recorded with hand weeding twice at 25 and 40 DAS followed by propaquizafop + imazethapyr 135 g/ha PoE at 20 DAS and lowest gross returns was recorded in weedy check. The other herbicidal treatments also recorded a higher gross return than the weedy check.

The highest mean net return and mean benefit: cost ratio (2.00) was recorded with propaquizafop + imazethapyr 135 g/ha PoE at 20 DAS due to lower cost of cultivation and higher economic yield of clusterbean. Nearly equivalent net returns and B:C

Table.2. Effect of different weed management treatments on the growth and yield attributes of clusterbean

Treatment	Plant height (cm) at 90 DAS			No. of branches/ plant			No. of pods/ plant			No. of seeds/ pod		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Weedy check	73.2	60.5	66.9	3.9	3.2	3.5	43.5	37.2	40.3	7.8	7.4	7.6
Pendimethalin 500 g/ha PE	78.2	66.2	72.2	5.2	4.3	4.8	61.7	55.2	58.5	8.0	8.0	8.0
Fomesafen + fluazifop-p-butyl 220 g/ha PoE at 20 DAS	75.3	61.8	68.5	4.7	3.8	4.3	61.7	52.7	57.2	8.0	7.4	7.7
Imazethapyr + imazamox 40 g/ha PoE at 20 DAS	79.0	64.4	71.7	5.2	4.2	4.7	64.1	57.8	61.0	8.0	7.8	7.9
Sodium- acifluorfen + clodinafop- propargyl 250 g/ha PoE at 20 DAS	76.7	59.9	68.3	4.5	3.7	4.1	59.4	51.6	55.5	7.9	7.4	7.6
Propaquizafop + imazethapyr 135 g/ha PoE at 20 DAS	83.3	65.9	74.6	5.4	4.4	4.9	66.4	59.1	62.7	8.1	7.8	8.0
Imazethapyr 40 g/ha PoE at 25 DAS	81.4	66.4	73.9	5.2	4.4	4.8	64.0	58.1	61.0	7.8	7.9	7.9
Weed free check	84.2	75.2	79.7	5.5	4.5	5.0	66.4	59.4	62.9	8.2	8.1	8.1
LSD (p=0.05)	7.46	8.69	4.81	0.65	0.60	0.37	6.60	5.43	3.59	0.72	0.65	0.41

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

Table 3. Efficiency of different weed management treatments on productivity of clusterbean

Treatment	Test weight (g)			Seed yield (kg/ha)			Haulm yield (t/ha)			HI (%)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Weedy check	30.8	30.3	30.5	730	630	680	2.17	1.87	2.02	25.17	25.08	25.13
Pendimethalin 500 g/ha PE	32.5	31.5	32.0	980	790	880	2.54	2.06	2.30	27.84	27.66	27.75
Fomesafen + fluazifop-p-butyl 220 g/ha PoE at 20 DAS	32.1	30.8	31.4	960	730	840	2.59	1.94	2.26	27.17	27.25	27.21
Imazethapyr + imazamox 40 g/ha PoE at 20 DAS	32.7	31.3	32.0	930	780	860	2.52	2.05	2.29	26.99	27.58	27.29
Sodium- acifluorfen + clodinafop-propargyl 250 g/ha PoE at 20 DAS	31.6	30.8	31.2	910	730	820	2.51	2.00	2.26	26.60	26.61	26.61
Propaquizafop + imazethapyr 135 g/ha PoE at 20 DAS	32.5	31.5	32.0	1070	810	940	2.66	2.07	2.37	28.60	27.95	28.27
Imazethapyr 40 g/ha PoE at 25 DAS	31.7	31.0	31.3	970	780	880	2.59	2.09	2.34	27.25	27.22	27.24
Weed free check	32.5	31.8	32.1	1100	850	970	2.66	2.15	2.41	29.17	28.26	28.71
LSD (p=0.05)	NS	NS	NS	120	71	59	0.25	0.19	0.13	NS	NS	NS

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

Table 4. Efficiency of different weed management treatments on the economics of clusterbean cultivation

Treatment	Gross returns ($x10^3$ Rs/ha)			Net returns ($x10^3$ Rs/ha)			B:C ratio		
	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean
Weedy check	38.06	32.50	35.28	24.46	18.90	21.68	1.80	1.39	1.59
Pendimethalin 500 g/ha PE	50.86	40.95	45.90	34.38	24.47	29.42	2.09	1.48	1.79
Fomesafen + fluazifop-p-butyl 220 g / ha PoE at 20 DAS	50.02	37.70	43.86	33.52	21.20	27.36	2.03	1.28	1.66
Imazethapyr + imazamox 40 g /ha PoE at 20 DAS	48.46	40.56	44.51	32.85	24.95	28.90	2.10	1.60	1.85
Sodium-acifluorfen + clodinafop-propargyl 250 g/ha PoE at 20 DAS	47.32	37.70	42.51	31.95	22.33	27.14	2.08	1.45	1.77
Propaquizafop + imazethapyr 135g /ha PoE at 20 DAS	55.43	41.86	48.65	39.23	25.66	32.45	2.42	1.58	2.00
Imazethapyr 40 gm/ha PoE at 25 DAS	50.65	40.56	45.60	35.37	25.29	30.33	2.32	1.66	1.99
Weed free check	57.10	43.94	50.52	38.70	25.54	32.12	2.10	1.39	1.75

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

ratio were recorded with imazethapyr 40 g/ha PoE at 25 DAS and hand weeding twice at 25 and 40 DAS. Year to year variation in cost of cultivation, which consequently reflected the benefits were due to variability in cost of inputs and outputs. The observations of this study on economic viability and agronomic feasibility of the technology for clusterbean cultivation confirmed the findings of Jain and Jain (2025).

Based on the results of this study, it canbe concluded that propaquizafop + imazethapyr 135 g/ha PoE at 20 DAS be profitably used and recommended in clusterbean, instead of pendimethalin and hand weeding twice, as it significantly improved the weed management and increased clusterbean productivity with better economic returns. However, location specificity verification is required before recommendation.

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RESEARCH ARTICLE

Integrated weed management and productivity of mustard in coastal zone of Odisha

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ABSTRACT

A field study was carried out during 2023-2024 and 2024-2025 at Agriculture research station, Binjhagiri, Chatabar, Faculty of Agricultural Sciences, SOADU, Bhubaneswar with an objective to evaluate the effect of integrated use of closer spacing, herbicide and mulch on weed growth and yield of mustard. The soil of the experimental field was sandy loam in texture. The experiment comprised of twelve treatments, *viz.* pre-emergence application (PE) of pendimethalin at 0.75 kg/ha; mulching with rice straw 4 t/ha; mulching with biomass of *Chromolaena odorata* 20 t/ha; pendimethalin 0.75kg/ha PE followed by (*fb*) mulching with rice straw 4 t/ha; pendimethalin at 0.75kg/ha PE *fb* mulching with biomass of *C. odorata* 20 t/ha; closer spacing of mustard (30 cm x 10 cm) + pendimethalin 0.75 kg/ha PE; closer spacing + mulching with rice straw 4 t/ha; closer spacing + mulching with *C. odorata* 20 t/ha; closer spacing + pendimethalin 0.75 kg/ ha PE+ mulching with rice straw 4 t/ ha; closer spacing + pendimethalin 0.75 kg/ ha PE + mulching with *C. odorata* 20 t/ha; hand weeding twice at 20 and 40 days after seeding (DAS) and weedy check. A randomized block design with three replications was used. The hand weeding twice at 20 and 40 DAS registered significantly lower total weed density and biomass with higher values of yield attributes and yield of mustard. It was closely followed by closer spacing + pendimethalin at 0.75 kg/ha PE + mulching with rice straw 4 t/ha which recorded maximum net return and returns/rupee invested and was found to be promising for realising effective weed management, higher productivity and profitability in mustard.

Keywords: Closer crop spacing, *Chromolaena odorata*, Integrated weed management, Mulching, Mustard, Pendimethalin, Rice straw

INTRODUCTION

Mustard (*Brassica juncea* (L.) Czern.), belonging to Cruciferae or Brassicaceae family, is one of the major *Rabi* oilseed crops of India. India is one of the largest producers of mustard in the world. The oil content in mustard seeds varies from 37-49% (Bhowmik *et al.* 2014). Among numerous constraints of mustard production technology, weed infestation is one of the major causes of low mustard productivity. Weed management aims to minimize weed growth and competition and thus helping to increase crop yield and improve profitability (Rao 2022). Manual weeding is labour intensive and tiresome. The continuous use of herbicides to control weeds may be causing weeds developing resistance to herbicides used. Thus, it is essential to identify effective alternatives to use as components of integrated weed management (IWM). Mulching may be one of the important components of IWM in mustard. Using weeds that are common in the local area as a natural organic mulch to manage other weeds is an option as straw mulch helps to control weeds, improves soil moisture levels, and increases crop production (Choudhary and Bhagawati 2019). Alternative weed management methods, such as using straw (Fatima *et al.* 2020) and weed mulch (Sar *et al.* 2025) as part of integrated weed management, have proven effective in crops like sesame and mustard (Fatima and Duary 2020, Fatima *et al.* 2020, Fatima *et al.* 2021, Sar *et al.* 2025). The research to develop effective, ecologically safe, economical and practical method for managing weeds in mustard is limited. Thus, a field study was carried to study efficacy and economic feasibility of the integrated use of closer spacing, herbicide use and mulch on weed growth and yield of mustard.

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MATERIALS AND METHODS

A field experiment was conducted during *Rabi* at Agricultural Research station, Faculty of Agricultural Sciences, Siksha 'O' Anusandhan Deemed University (SOADU), Bhubaneswar during 2023-24 and 2024-25. The soil of the experimental field was sandy loam in texture. The experiment comprised of twelve treatments, *viz.* pre-emergence application (PE) of pendimethalin 0.75 kg/ha;

mulching with paddy rice straw 4 t/ha; mulching with biomass of *Chromolaena odorata* 20 t/ha; pendimethalin 0.75 kg/ha PE followed by (*fb*) mulching with rice straw 4 t/ha; pendimethalin 0.75kg/ha PE *fb* mulching with *C. odorata* 20 t/ha; closer spacing of mustard (30 x 10 cm) + pendimethalin 0.75 kg/ha PE; closer spacing + mulching with rice straw 4 t/ha; closer spacing + mulching with *C. odorata* 20 t/ha; closer spacing + pendimethalin 0.75 kg/ ha PE + mulching with rice straw 4 t/ha; closer spacing + pendimethalin 0.75 kg/ ha PE+ mulching with *C. odorata* 20 t/ha; hand weeding (HW) twice at 20 and 40 days after seeding (DAS) and weedy check. A randomized block design with three replications was used. Mustard seeds were sown on November 7, 2023-24 and 2024-25 using seed rate of 6kg /ha maintaining a spacing of 40cm x10cm. The recommended dose of fertiliser was 80:40:40 kg/ ha of N, P and K which was given in form of urea, SSP and MOP respectively. Mulching materials was applied to the respective plots as per the treatment at 10 DAS. Pendimethalin was sprayed using hand operated knapsack sprayer at 1 DAS. 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 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 attributing characters such as siliqua length, number of siliqua per plant, test weight and yield like seed yield, and stover yield was recorded and analysed. Weed control efficiency (%) was computed using the weed biomass of different category of species.

RESULT AND DISCUSSION

Effect on weeds

The experimental field was infested with eleven weed species. The most common weeds in mustard field were: *Digitaria sanguinalis*, *Echinochloa colona*, *Cynodon dactylon* among the monocots and *Cleome viscosa, Physalis minima, Spilanthes calva, Oldenlandia corymbosa, Solanum nigrum, Indigofera hirsute*, *Gnaphalium purpureum* and *Ageratum conyzoides* among dicots. The highest density and biomass of broad-leaved, grasses, and total weed density was recorded in weedy plots, whereas lowest weed density and biomass was recorded with hand weeding twice at 20 and 40 DAS which was at par with closer spacing + pendimethalin 0.75 kg/ha PE + mulching with rice straw 4 t/ha **(Table 1** and **2)** as reported by Sar *et al.* (2025). Pendimethalin PE applied alone was not adequate to manage the weeds in mustard. Pendimethalin PE *fb* manual weeding performed better against diverse weed flora as compared to pendimethalin PE used only. Although the HW twice treatment proved to be superior to all others tested treatments, it was comparable with closer spacing *fb* pendimethalin, rice straw or *C. odorata* mulching in lowering total weed density and biomass in mustard. Closer spacing along with pendimethalin at 0.75 kg/ha PE + mulching with rice straw 4 t/ha recorded 86.7 and 89.26 % lower density of total weeds at 45 DAS over weedy check. Integrated use of pendimethalin at 0.75 kg/ha PE *fb* mulching rice straw or *C. odorata* reduced the density of grasses by 71.00-87.00 and 76.03-89.72%, of broad-leaved by 75.00-86.00 and 77.23-88.90% and of total weeds by 73.00-86.00 and 76.68-89.26% in 2023-24 and 2024-25 respectively

Table 1. Weed density at 45 days after seeding (DAS) in mustard as affected by weed management treatments

Treatment	Weed density (no./m^2) at 45 DAS					
	2023-24			2024-25		
	Grasses	Broad-leaved	Total	Grasses	Broad-leaved	Total
Pendimethalin 0.75 kg/ha PE	6.31(39.3)	6.70(44.3)	9.17(83.7)	5.96(35.0)	6.57(42.7)	8.84(77.7)
Mulching with rice straw 4 t/ha	6.12(37.0)	6.62(43.3)	8.99(80.3)	5.79(33.0)	6.47(40.7)	8.61(73.7)
Mulching with *Chromolaena odorata* 20 t/ha	6.15(37.3)	6.57(42.7)	8.97(80.0)	5.90(34.3)	6.52(41.3)	8.73(75.7)
Pendimethalin at 0.75 kg/ha PE *fb* mulching with paddy straw 4 t/ha	4.53(20.0)	4.67(21.3)	6.47(41.3)	4.18(17.0)	4.49(19.7)	6.09(36.7)
Pendimethalin t 0.75 kg/ha PE *fb* mulching with *Chromolaena odorata* 20 t/ha	5.08(25.3)	5.31(27.7)	7.31(53.0)	4.78(22.3)	4.98(24.3)	6.87(46.7)
Closer spacing + pendimethalin 0.75 kg/ha PE	5.68(32.0)	6.01(35.7)	8.25(67.7)	5.43(29.0)	5.78(33.0)	7.90(62.0)
Closer spacing + mulching with rice straw 4 t/ha	5.61(31.0)	5.96(35.0)	8.15(66.0)	5.30(27.7)	5.61(31.0)	7.69(58.7)
Closer spacing + mulching with *Chromolaena odorata* 20 t/ha	5.64(31.3)	5.99(35.3)	8.20(66.7)	5.34(28.0)	5.67(31.7)	7.75(59.7)
Closer spacing + pendimethalin at 0.75 kg/ha PE+ mulching with rice straw 4 t/ha	2.73(7.0)	3.08(9.0)	4.06(16.0)	2.34(5.0)	2.68(6.7)	3.48(11.7)
Closer spacing (30 cm x 10 cm) + pendimethalin at 0.75 kg/ha PE+ mulching with *Chromolaena odorata* 20 t/ha	3.98(15.3)	4.10(16.3)	5.67(31.7)	3.49(11.7)	3.76(13.7)	5.08(25.3)
Hand weeding twice at 20 and 40 DAS	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	7.37(54.0)	8.1(66.7)	11.0(120.7)	7.00(48.7)	7.74(60.0)	10.4(108.7)
LSD (p=0.05)	0.43	0.54	0.64	0.37	0.50	0.59

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

(Table 1). Sole application of pendimethalin or weed mulch was not effective to manage broad spectrum of weeds. Integration of both herbicide and weed mulch provided a broader spectrum of weed management as also observed by Duary *et al*. (2014), Fatima and Duary (2020). Amongst different weed management treatments, hand weeding twice at 20 and 40 DAS registered the highest WCE, followed by closer spacing + pendimethalin 0.75 kg/ha PE+ mulching with rice straw 4 t/ha at 45 DAS (**Figure 1**). Among other treatments, closer spacing (30 cm x 10 cm) + pendimethalin at 0.75 kg/ha PE+ mulching with *Chromolaena odorata* 20 t/ha effectively controlled the complex weed flora, registering the highest WCE against total weeds.

Effect on mustard

Hand weeding twice recorded significant increase in the mustard yield attributing characters such as the number of siliqua per plant, test weight and mustard seed yield over other weed management practices and it was at par with closer spacing along with pendimethalin 0.75 kg/ha PE + mulching with rice straw 4 t/ha, during both the years **(Table 3)**. All the weed management treatments significantly increased mustard seed yield over unweeded control. because these treatments-controlled weeds (Sar *et al.* 2025). Sar *et al*. (2025) also observed that weed free treatment recorded the highest seed yield over other treatments. Integrated use of closer spacing (30 cm x 10 cm) + pendimethalin at 0.75 kg/ha + mulching with

Table 2. Weed biomass at 45 days after seeding (DAS) in mustard as affected by weed management treatments

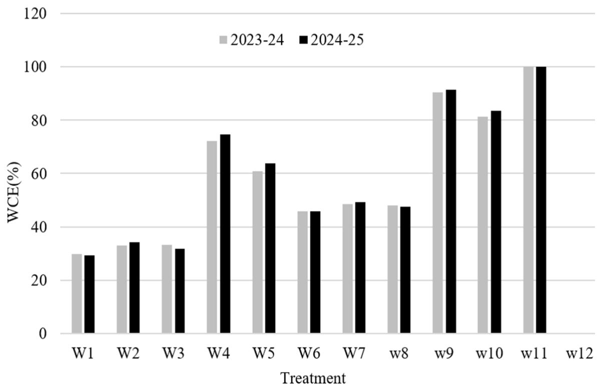
Treatment	Weed biomass (g/m^2) at 45 DAS					
	2023-24			2024-25		
	Grasses	Broad-leaved	Total	Grasses	Broad-leaved	Total
Pendimethalin 0.75 kg/ha PE	5.82(33.3)	6.39(40.3)	8.61(73.7)	5.61(31.0)	6.20(38.0)	8.33(69.0)
Mulching with rice straw 4 t/ha	5.61(31.0)	6.31(39.3)	8.42(70.3)	5.39(28.7)	6.01(35.7)	8.05(64.3)
Mulching with *Chromolaena odorata* 20 t/ha	5.64(31.3)	6.26(38.7)	8.40(70.0)	5.49(29.7)	6.12(37.0)	8.19(66.7)
Pendimethalin at 0.75 kg/ha PE *fb* mulching with paddy straw 4 t/ha	3.81(14.0)	3.98(15.3)	5.46(29.3)	3.49(11.7)	3.67(13.0)	5.02(24.7)
Pendimethalin t 0.75 kg/ha PE *fb* mulching with *Chromolaena odorata* 20 t/ha	4.45(19.3)	4.71(21.7)	6.44(41.0)	4.10(16.3)	4.41(19.0)	5.98(35.3)
Closer spacing + pendimethalin 0.75 kg/ha PE	5.12(26.0)	5.60(31.0)	7.58(57.0)	4.97(24.3)	5.40(28.7)	7.31(53.0)
Closer spacing + mulching with rice straw 4 t/ha	5.05(25.0)	5.43(29.0)	7.38(54.0)	4.85(23.0)	5.21(26.7)	7.08(49.7)
Closer spacing + mulching with *Chromolaena odorata* 20 t/ha	5.08(25.3)	5.46(29.3)	7.43(54.7)	4.91(23.7)	5.30(27.7)	7.20(51.3)
Closer spacing + pendimethalin at 0.75 kg/ha PE+ mulching with rice straw 4 t/ha	2.34(5.0)	2.34(5.0)	3.23(10.0)	2.20(4.3)	2.10(4.0)	2.96(8.3)
Closer spacing (30 cm x 10 cm) + pendimethalin at 0.75 kg/ha PE + mulching with *Chromolaena odorata* 20 t/ha	3.13(9.3)	3.29(10.3)	4.49(19.7)	2.79(7.3)	3.02(8.7)	4.05(16.0)
Hand weeding twice at 20 and 40 DAS	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	6.88(47.0)	7.60(58.0)	10.2(105.0)	6.61(43.3)	7.35(54.3)	9.86(97.7)
LSD (p=0.05)	0.48	0.60	0.66	0.42	0.68	0.72

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

Table 3. Yield attributes and yield of mustard as affected by weed management treatments

Treatment	No. of siliqua / plant		No. of seeds / siliqua		Test weight (g)		Seed yield (kg/ha)		Net returns (Rs./ha) (pooled mean)	Returns / rupee Invested (pooled mean)
	2023 -24	2024 -25	2023 -24	2024 -25	2023 -24	2024 -25	2023 -24	2024 -25		
Pendimethalin 0.75 kg/ha PE	66	70	13	16	3.38	3.99	724	849	7639	1.22
Mulching with rice straw 4 t/ha	67	72	14	17	3.43	4.08	754	867	3654	1.09
Mulching with *Chromolaena odorata* 20 t/ha	67	71	14	16	3.40	4.04	740	859	7231	1.20
Pendimethalin at 0.75 kg/ha PE *fb* mulching with paddy straw 4 t/ha	93	99	21	23	4.27	4.58	1134	1246	24664	1.58
Pendimethalin t 0.75 kg/ha PE *fb* mulching with *Chromolaena odorata* 20 t/ha	85	97	19	22	4.20	4.46	1019	1158	22212	1.58
Closer spacing + pendimethalin 0.75 kg/ha PE	75	88	16	19	3.78	4.20	879	1059	16882	1.48
Closer spacing + mulching with rice straw 4 t/ha	77	90	17	20	3.83	4.29	906	1074	12668	1.31
Closer spacing + mulching with *Chromolaena odorata* 20 t/ha	76	89	17	19	3.80	4.23	900	1067	16751	1.46
Closer spacing + pendimethalin at 0.75 kg/ha PE+ mulching with rice straw 4 t/ha	108	110	26	29	4.67	4.97	1401	1523	40531	1.95
Closer spacing (30 cm x 10 cm) + pendimethalin at 0.75 kg/ha PE+ mulching with *Chromolaena odorata* 20 t/ha	100	104	23	27	4.34	4.71	1248	1359	35867	1.93
Hand weeding twice at 20 and 40 DAS	109	114	26	31	4.79	5.23	1434	1561	40714	1.91
Weedy check	58	61	9	12	3.00	3.40	492	633	-4545	0.87
LSD (p=0.05)	7	8	1.5	3.5	0.35	0.58	111	130	-	-

PE: pre-emergence application; *fb:* followed by



W_1- pendimethalin at 0.75 kg/ha PE, W_2- mulching with rice straw 4 t/ha, W_3- mulching with *Chromolaena odorata* 20 t/ha, W_4- pendimethalin at 0.75kg/ha followed by (*fb*) mulching with rice straw 4 t/ha, W_5- pendimethalin at 0.75kg/ha *fb* mulching with *Chromolaena odorata* 20 t/ha, W_6-closer spacing (30 × 10 cm) + pendimethalin at 0.75 kg/ha PE, W_7- closer *fb* spacing + mulching with rice straw 4 t/ha, W_8-closer spacing + mulching with *Chromolaena odorata* 20 t/ha, W_9-closer spacing + pendimethalin at 0.75 kg/ha PE + mulching with rice straw 4 t/ha, W_{10}- closer spacing + pendimethalin at 0.75 kg/ ha PE + mulching with *Chromolaena odorata* 20 t/ha, W_{11}-hand weeding twice at 20 and 40 days after seeding and W_{12}- weedy check.

Figure 1. Weed control efficiency (%) as affected by weed management treatments

rice straw increased mustard seed yield by 86%,75.66% and 93.50%,79.38% over sole application of paddy straw mulch and pendimethalin in 2023-24 and 2024-25 respectively **(Table 3)**. Paddy straw or *Chromolaena odorata* mulching with closer spacing recorded at par value of seed yield of mustard. Hand weeding twice at 20 and 40 DAS recorded highest harvest index. Mulching conserved soil moisture and increased in yield of mustard (Regar *et al.* 2007 and Saikia *et al.* 2014). Mustard seed yield reduction due to weeds was 65.69 and 59.44 % in 2023-24 and 2024-25, respectively. Pendimethalin PE alone registered 47.15 and 34.12% yield increase over unweeded control in 2023-24 and 2024-25, respectively. Similarly, *Chromolaena odorata* mulching alone was able to improve yield by 50.40-53.25 % and 35.70-36.96% over unweeded control in 2023-24 and 2024-25, respectively. This could be because the weed mulch helps keep the soil moist, adds nutrients, and provides other things that helped improved mustard growth. However, integrated use of herbicide and weed mulch along with closer spacing resulted in 153-185 and 114.69-140.60% higher yield over unweeded control in 2023-24 and 2024-25, respectively due to reduced competition between the crops and weeds from the early stages of the crop's growth until it was fully mature. Due to minimised weed competition, the crops had better access to nutrients and water, faster photosynthesis, more space to grow properly, and this led to more dry matter being stored and higher overall yields. The maximum net return and returns/rupee invested was recorded with closer spacing along with pendimethalin at 0.75 kg/ha PE + mulching with rice straw **(Table 3)**.

Conclusion

The closer spacing of mustard (30 cm x 10 cm) along with pendimethalin at 0.75 kg/ha PE + mulching with rice straw 4 t/ha was found to be promising for effective weed management and higher mustard productivity and monetary returns.

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RESEARCH ARTICLE

Organic weed management approaches and their impact on weeds, *Rabi* fennel productivity, economic returns and soil fertility

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ABSTRACT

Eco-friendly weed management is crucial for enhancing crop productivity while preserving ecological balance. A field experiment was conducted at the Centre for Organic and Natural Farming Research, Sardarkrushinagar in loamy sand soil, during the *Rabi* seasons from 2019–20 to 2021–22 to evaluate different weed management strategies in organic *Rabi* fennel. A Randomized Block Design (RBD) with three replications was used. Eight weed management treatments were tested, *viz.* stale seed bed followed by (*fb*) hand weeding (HW) at 30 days after sowing (DAS); castor shell mulch 5 t/ha *fb* HW at 30 DAS, mustard straw mulch 5 t/ha *fb* HW at 30 DAS; sunn hemp mulch 5 t/ha *fb* HW at 30 DAS; wheat straw mulch 5 t/ha *fb* HW at 30 DAS; interculturing (IC) *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS; IC at 30 and 60 DAS *fb* earthing up at 70 DAS and weedy check. Among the eight treatments, IC *fb* HW at 30 and 60 DAS and earthing up at 70 DAS significantly improved fennel plant height, branch number, seed, and stalk yield followed by treatment with stale seed bed *fb* HW at 30 DAS, which also recorded the highest umbels per plant. IC *fb* HW at 30 and 60 DAS and earthing up at 70 DAS resulted in the lowest weed density and biomass at 50 DAS, with the highest weed control efficiency (66%). The lowest weed density at 25 DAS and weed index were observed in the stale seed bed *fb* HW at 30 DAS. Furthermore, organic carbon and available N, P, and K were highest under IC *fb* HW at 30 and 60 DAS and earthing up at 70 DAS, it was found at par with wheat straw mulch 5 t/ha *fb* HW. Economically, IC *fb* HW at 30 and 60 DAS and earthing up at 70 DAS also yielded the highest net return, while stale seed bed *fb* HW at 30 DAS had the highest benefit-cost ratio (2.49).

Keywords: Mulch, Earthing up, Fennel, Inter cultivation, Mulching Stale seedbed, Soil fertility, Organic weed management

INTRODUCTION

Fennel (*Foeniculum vulgare* Mill.) is a flowering plant species belonging to Apiaceae family. It is a hardy, perennial herb with yellow flowers and feathery leaves. Fennel is known for its licorice-like flavor, but it also has many health benefits, and it has long been used in natural remedies and it is cultivated extensively in the U.S.A., France, India and Russia. Medicinal and aromatic plants are major crops of domestic and industrial interest. Medicinal and aromatic plants are increasingly organically grown to enhance profitability. However, the presence of weeds may lead to a decrease in both yield and quality. Therefore, nonchemical methods of weed control are needed. Weed management in organic production systems must involve the use of many techniques and strategies, all with the goal of achieving economically acceptable weed control and crop yields. The cultural practices used in crop production (for instance, using transplanting, pre-emergent flaming of weeds, pre-germination of weeds) often provide crops with a competitive advantage in terms of nutrient and sunlight availability over weeds (Kolb and Gallandt 2012). Providing the crop a competitive advantage through organically acceptable techniques and subsequent hand weeding operations, the cost can be minimized. Stale seed bed technique (SSB) is one of the most important cultural management strategies that can be used before any crop to reduce the weed seed bank. This technique helps to provide an opportunity for crop emergence and growth before the next flush of weeds. Physical methods for weed suppression are the methods of integrated non-chemical weed management strategy and are very useful in organic farming. Mulches are commonly used in cultivation of vegetables and other spices and medicinal crops (Deka and Talukdar 2017) and are acceptable in organic farming as well as in any other crop production. Soil mulching with plant wastes or synthetic mulches is one of the management practices for reducing soil evaporation; it increases water retention, increasing water use

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efficiency (WUE) and weed control in crop fields (Awodoyin *et al*. 2007). With the decomposition of mulch, humus is added in to the soil which increases water holding capacity of soil. Thus, the application of mulch in the field offers dual benefits, *viz*. weed management through ecofriendly way and improvement of soil fertility. In light of this, the current study was carried out to assess the effect of organic weed management treatments on weed growth, fennel yield, yield, weeds and soil fertility status in organic *rabi* fennel.

MATERIAL AND METHODS

The experiment was conducted during the *Rabi* seasons of 2019-20, 2020-21, and 2021-22 at the Centre for Organic and Natural Farming Research, C.N.R.M., Sardarkrushinagar, Gujarat, India. The research field is located at 24°18' N latitude and 17°16' E longitude. The soil of the experimental field was classified as loamy sand, with a pH of 7.8. During the initial period of 2019-20, the organic carbon, available N, P, and K content in the soil were found to be 0.21% (low), 138.0 kg/ha (low), 31.52 kg/ha (medium), and 252.0 kg/ha (high), respectively. The experiment was laid out in a randomized block design (RBD) with three replications. The experiment consisted of eight treatments, *viz*. stale seed bed followed by (*fb*) hand weeding (HW) at 30 DAS; castor shell mulch 5 t/ha *fb* HW at 30 DAS; mustard straw mulch 5 t/ha *fb* HW at 30 DAS; sunn hemp mulch 5 t/ha *fb* HW at 30 DAS; wheat straw mulch 5 t/ha *fb* HW at 30 DAS; interculturing (IC) *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS; IC at 30 and 60 DAS *fb* earthing up at 70 DAS and weedy check. All standard packages of practices were followed throughout the growing season. Different straw mulches used in different treatments were spread after sowing as per the treatment. The organic manures [recommended dose of nutrients (RDN) [N, P and K kg /ha: 90-30-00] were applied using organic sources. Equivalent N of RDN was applied by 50% FYM + 25% vermi-compost + 25% castor cake) as per treatment directly in the furrow. The fennel variety Gujrat Fennel (GF) 12 was sown in the experimental field on November 11, 2019, November 03, 2020, and October 29, 2021, with a row-to-row spacing of 45 cm and a seed rate of 5-6 kg/ha. Manual weeding operations like IC and HW were carried out as per the treatments. The weed density was recorded at 25 and 50 DAS. Dry weight of weeds (weed biomass) was recorded at harvest. Weed index and weed control efficiency (WCE) were calculated. For economic analysis, the economic value of the entire output was expressed as gross returns, while net return and the benefit: cost (B:C) ratio were calculated using standard procedures. The experimental data were analyzed statistically by applying the technique of analysis of variance (ANOVA) prescribed for the design to test the significance of overall difference among treatments by the F test and conclusions were drawn at 5% probability level.

RESULTS AND DISCUSSION

Effect on crop

The fennel plant height and the number of umbels per plant were significantly influenced by different weed management treatments (**Table 1**). Among the treatments, IC *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS recorded maximum plant height which can be attributed to effective weed suppression during critical growth stages, resulting in minimized competition for vital resources such as nutrients, light, and water, allowing plants to grow taller. Conversely, the number of umbels per plant was highest with stale seedbed preparation *fb* HW at 30 DAS which is likely due to the stale seedbed technique that reduced the germination of weed seeds early in the growing season, thereby improving early weed control. Additionally, the HW at 30 DAS reduced competition during the critical reproductive phase, supporting the development of reproductive structures like umbels. However, plant height and the number of umbels per plant did not show significant differences among weed management treatments in individual years. Furthermore, weed management practices had no significant impact on fennel plant population at harvest, the number of branches per plant, or test weight during individual years or in the pooled analysis (**Table 1**).

Fennel seed and stalk yield

Among the treatments, significantly higher fennel seed yields and stalk yield were recorded with IC *fb* HW at 30 and 60 DAS *fb* earthing up at 70 DAS during study years (**Table 2**). During 2019–20, the seed yield with IC *fb* HW at 30 and 60 DAS *fb* earthing up at 70 DAS was statistically comparable to stale seedbed *fb* one HW at 30 DAS. Similar results were observed in the pooled analysis. The variation in climatic conditions, particularly rainfall and temperature likely contributed to the differential yield response of fennel under the same weed management practices across years. The superior seed and stalk yield under IC *fb* HW at 30 and 60 DAS + earthing up at 70 DAS can be attributed to the combined effects of inter-culturing, which disrupted the weed root zone, and HW, which effectively removed weeds, thereby reducing competition for resources such as nutrients, water, and light. Additionally, earthing up at 70 DAS minimized weed regrowth and enhanced root development, contributing to improved plant Vigor and higher reproductive output as reported earlier by Rajender Kumar *et al.* (2019). The improved yields with stale seedbed *fb* HW at 30 DAS can be attributed to the depletion of the weed seed bank through stale seedbed preparation, which gave the crop a competitive advantage during early growth stages. Mulching treatments also contributed to increased yields by providing effective weed control, conserving soil moisture, and enhancing nutrient availability. The created favorable micro-environment likely enhanced photosynthesis and facilitated the translocation of photosynthates to various metabolic sinks, boosting growth and yield. Thakral *et al.* (2007) highlighted the role of integrated weed management practices in enhancing crop productivity by reducing weed competition and improving resource utilization.

Effect on weeds

Among the weed management treatments, IC *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS, recorded the lowest weed biomass during 2020-21, 2021-22, and in the pooled results (**Table 3**). The weedy check consistently recorded the highest weed biomass due to the absence of control measures, which allowed for the unrestricted growth of weeds (**Table 3**) as observed by Meena and Mehta (2009). The weed density recorded at 25 DAS was found to be non-significant in individual years, although it was significant in the pooled analysis (**Table 3**). The lowest weed density at 25 DAS was recorded with stale seedbed *fb* HW at 30 DAS. Nalayini *et al.* (2023) reported efficacy of stale seedbed in other crops. The lowest weed density at 50 DAS was recorded with IC *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS, whereas the highest weed density was observed under the weedy check (**Table 3**). Furthermore, weed control efficiency (WCE), calculated based on the weed biomass at harvest in the pooled analysis, further highlight the effectiveness of different treatments (**Table 3**). The maximum WCE (66%) was observed with IC *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS. In contrast, the minimum WCE was recorded with sunhemp mulch 5 t/ha *fb* HW at 30 DAS, which may be attributed to the gradual decomposition of the mulch and insufficient suppression of weeds over time. Additionally, weed index (%), calculated based on grain yield, varied significantly across treatments

Table 1. Effect of weed management treatments on fennel growth and yield attributes (pooled)

Treatment	Plant population (per meter row length)	Plant height (cm)	No. of branches/ plant	Test weight (g)	No. of umbels/ plant
Stale seed bed *fb* HW at 30 DAS	6.67	107.2	4.20	5.32	27.67
Castor shell mulch 5 t/ha *fb* HW at 30 DAS	7.00	99.25	4.09	5.03	25.56
Mustard straw mulch 5 t/ha *fb* HW at 30 DAS	6.33	97.69	3.73	4.94	24.44
Sunhemp mulch 5 t/ha *fb* HW at 30 DAS	7.00	100.1	3.98	4.98	22.33
Wheat straw mulch 5 t/ha *fb* HW at 30 DAS	6.67	102.4	3.89	5.02	23.89
IC *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS	7.00	111.2	4.22	5.37	27.00
IC twice at 30 and 60 DAS *fb* earthing up at 70 DAS	6.67	95.25	3.76	4.92	22.78
Weedy check	5.67	88.85	3.51	4.52	18.56
LSD (p=0.05)	NS	9.05	NS	NS	3.12

HW: hand weeding; DAS: days after seeding; IC: inter-cultivation; *fb:* followed by

Table 2. Effect of weed management treatments on fennel seed and stalk yield

Treatment	Fennel seed yield	Fennel stalk yield
	Pooled	Pooled
Stale seed bed *fb* 1 HW at 30 DAS	1344	3109
Castor shell mulch 5t/ha *fb* HW at 30 DAS	1201	2850
Mustard straw mulch 5t/ha *fb* HW at 30 DAS	1127	2805
Sunhemp mulch 5 t/ha *fb* HW at 30 DAS	1055	2683
Wheat straw mulch 5 t/ha fb HW at 30 DAS	1181	2753
Interculturing fb HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS	1423	3191
IC twice at 30 and 60 DAS *fb* earthing up at 70 DAS	1094	2712
Weedy check	554.9	2092
LSD (p=0.05)	152	336

***** *fb*: followed by; HW: hand weeding; DAS: days after seeding; IC: inter-cultivation; *fb:* followed by

(**Table 3**). The lowest weed index was observed with stale seedbed *fb* HW at 30 DAS. Conversely, the highest weed index was recorded under the weedy check, followed by sunhemp mulch 5 t/ha *fb* HW at 30 DAS.

Effect on soil

Soil amendment with straw alters the physical, chemical, and biological properties of soil, thereby influencing plant growth, soil microbial community structure, and abundance. However, in this study, there were no significant differences in EC, pH, organic carbon, or available nutrients such as N, P, and K across various weed management treatments (**Table 4**). Nonetheless, numerically higher levels of organic carbon and available N, P, and K were observed under the treatment involving inter-culturing *fb* HW at 30 DAS *fb* 60 DAS, combined with earthing up at 70 DAS. This treatment was statistically at par with the treatment involving wheat straw mulch applied at 5 t/ha *fb* HW at 30 DAS. Furthermore, microbial populations were found to be higher in mulched soils compared to un mulched soils as reported by (Tiquia *et al*. 2002). Zhang *et al*. (2018) noted that in soils amended with maize straw, there was an increase in microbial populations and enzymatic activities. These increases facilitated straw degradation, thereby enhancing soil organic carbon content and overall soil quality, which contributed to improved crop yield. Liu *et al*. (2017) further highlighted that the formation of macro-aggregates and crop yield were positively correlated with increasing soil organic carbon concentrations.

Correlation

The correlation analysis revealed significant relationships between plant height, yield, and weed parameters (**Table 6**). Plant height and yield exhibit a strong positive correlation (r = 0.91), indicating that taller plants are associated with higher yields supporting observations of Al-Kordy (2000), Bahmani *et al*. (2012) and Thakur and Sirohi (2009). Conversely, weed parameters, including weed density at 25 DAS, 50 DAS, and weed biomass at harvest, showed negative correlations with both plant height and yield (Table 6). For instance, the weed density at 50 DAS has a strong negative correlation with plant height (r = -0.95) and yield (r = -0.92), which suggest that higher weed infestation reduces both growth and productivity. Weed biomass at harvest also negatively correlates with yield (r = -0.89), emphasizing the detrimental impact of weed biomass on crop performance. Weed density, weed biomass and weed index was significantly highly negative correlated

Table 3. Effect of weed management treatments on weed parameters at harvest (pooled)

Treatment	Weed biomass at harvest (g/m^2)	Weed density ($no./m^2$)		Weed index (%)	Weed control efficiency (%)
		at 25 DAS	at 50 DAS		
Stale seed bed *fb* HW at 30 DAS	7.69(60.8)	4.73(23.1)	5.45(32.3)	5.55	66.19
Castor shell mulch 5 t/ha *fb* HW at 30 DAS	8.73(84.2)	6.00(37.0)	8.77(81.3)	15.60	50.33
Mustard straw mulch 5 t/ha *fb* HW at 30 DAS	10.41(112)	6.52(43.8)	7.88(64.1)	20.80	34.21
Sunhemp mulch 5 t/ha *fb* HW at 30 DAS	11.51(141)	6.15(41.0)	7.81(65.9)	25.86	17.01
Wheat straw mulch 5 t/ha *fb* HW at 30 DAS	9.26(90.0)	7.04(51.1)	7.66(60.3)	17.01	46.93
IC *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS	7.30(58.2)	5.97(37.7)	4.87(27.3)	0.00	63.63
IC twice at 30 and 60 DAS *fb* earthing up at 70 DAS	8.37(72.3)	6.90(49.8)	8.29(71.7)	23.12	57.39
Weedy check	12.63(170)	7.63(60.3)	10.67(117)	61.00	0.00
LSD (p=0.05)	2.05	1.37	1.85	-	-

Data subjected to ($\sqrt{x+1}$) transformation. Figures in parentheses are original values; * *fb* = followed by; HW = hand weeding; DAS = days after seeding; IC = inter-cultivation

Table 4. Effect of weed management treatments on EC, pH, OC, available N, P and K (kg/ha) after harvest of fennel (after three year)

Treatment	EC (1: 2.5) dS/m	pH (1:2.5)	OC%	Available (kg/ha)		
				N	P	K
Stale seed bed *fb* HW at 30 DAS	0.158	7.82	0.25	149.5	35.55	280
Castor shell mulch 5 t/ha *fb* HW at 30 DAS	0.176	7.77	0.25	143.5	34.50	272
Mustard straw mulch 5 t/ha *fb* HW at 30 DAS	0.183	7.89	0.25	147.5	34.83	278
Sunhemp mulch 5 t/ha *fb* HW at 30 DAS	0.164	7.83	0.25	145.8	34.83	276
Wheat straw mulch 5 t/ha *fb* HW at 30 DAS	0.167	7.85	0.26	156.4	38.17	293
IC *fb* HW at 30 DAS and 60 DAS + Earthing up at 70 DAS	0.176	7.71	0.26	157.2	38.83	314
Two IC at 30 and 60 DAS + earthing up at 70 DAS	0.169	7.77	0.24	141.5	33.75	269
Weedy check	0.172	7.87	0.24	139.7	33.05	265
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Initial Soil Analysis	-	-	0.212	138	31.52	252

* *fb* = followed by; HW = hand weeding; DAS = days after seeding; IC = inter-cultivation

Table 5. Effect of weed management treatments on economics of fennel cultivation (pooled basis)

Treatment	Seed yield (kg/ha)	Total Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net returns (₹/ha)	B: C Ratio
Stale seed bed *fb* HW at 30 DAS	1344	26417	65856	39439	2.49
Castor shell mulch 5 t/ha *fb* HW at 30 DAS	1201	31859	58849	26990	1.85
Mustard straw mulch 5 t/ha *fb* HW at 30 DAS	1127	41859	55223	13364	1.32
Sunhemp mulch 5 t/ha *fb* HW at 30 DAS	1055	29359	51695	22336	1.76
Wheat straw mulch 5 t/ha *fb* HW at 30 DAS	1181	41859	57869	16010	1.38
IC *fb* HW at 30 DAS and 60 DAS + earthing up at 70 DAS	1423	28229	69727	41498	2.47
Two IC at 30 and 60 DAS + earthing up at 70 DAS	1094	29633	53606	23973	1.81
Weedy check	554.9	21885	27190	5305	1.24

Fennel seed selling price: 49 Rs/kg; *** *fb* = followed by; HW = hand weeding; DAS = days after seeding; IC = inter-cultivation

Table 6. The correlation matrix between fennel plant height, yield and weed parameters of in fennel (pooled basis)

	Plant height	Yield	Weed count at 25 DAS	Weed count at 25 DAS* converted	Weed density at 50 DAS	Weed density at 50 DAS converted	Weed biomass at Harvest	Weed biomass converted
Plant height	1							
Yield	0.908985077	1						
Weed count density at 25 DAS	-0.729528275	-0.770219067	1					
Weed density at 25 DAS converted	-0.739403763	-0.741850055	0.986179969	1				
Weed count density at 50 DAS	-0.947876501	-0.922017223	0.736244376	0.743927576	1			
Weed density at 50 DAS converted	-0.959881204	-0.89088863	0.72639531	0.753630978	0.989891444	1		
Weed biomass at Harvest	-0.741185885	-0.889714917	0.623579817	0.599459349	0.782121786	0.760865618	1	
Weed biomass converted	-0.758092264	-0.877896696	0.619902867	0.60843701	0.775999556	0.768797488	0.994448358	1

*DAS= days after seeding

with grain yield indicating serious reduction in grain yield supporting observations of Daniya *et al.* (2013) in sesame crop. These findings underscore the importance of effective weed management to enhance fennel growth and yield. The strong correlations highlight the critical interplay between plant traits and weed dynamics in agricultural systems.

Economics

The various weed management treatments had a significant impact on gross returns, net returns, and the benefit-cost (B:C) ratio across all years of experimentation (**Table 5**). Among the treatments, IC *fb* HW at 30 and 60 DAS + earthing up at 70 DAS, achieved the highest net returns with a B:C ratio of 2.47. This was closely followed by the stale seedbed preparation *fb* HW at 30 DAS. Notably, the highest B:C ratio (2.49) was observed under the stale seedbed *fb* HW at 30 DAS confirming the findings of Patel *et al.* (2019).

Conclusion

It is concluded that adopting stale seedbed preparation followed by hand weeding at 30 days after sowing, or inter-culturing followed by hand weeding at 30 and 60 days after sowing, along with earthing up at 70 days after sowing, is effective in managing weeds and ensures profitable fennel seed yield, along with better soil health, in *Rabi* fennel cultivation under organic farming.

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RESEARCH ARTICLE

Management of *Ipomoea* spp. infestation in sunn hemp (*Crotalaria juncea* L.) seed crop

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ABSTRACT

Morning glories (*Ipomoea* spp.), whether annual or perennial, are aggressive broad-leaved weeds that frequently infest many *Kharif* season crops including sunn hemp (*Crotalaria juncea* L.). *Ipomoea* spp. competes with the sunn hemp for light, nutrients, and moisture but also complicate harvesting operations, ultimately lowering seed yields, if they are not controlled. A field experiment was conducted during the *Kharif* seasons of 2023 and 2024 at Regional Research Station, Kapurthala of Punjab Agricultural University with an objective to evaluate the efficacy of different herbicides to manage *Ipomoea* spp. in sunn hemp. A randomized complete block design with three replications was used. The pre-emergence application (PE) of pendimethalin 750-900 g/ha + imazethapyr 75 g/ha (tank-mix) or imazethapyr + pendimethalin 800 g/ha (pre-mix) recorded higher control efficiency (70-81%) of *Ipomoea* spp. with 83.2-93.5% higher seed yield over the weedy check in sunn hemp seed crop. These two treatments effectively controlled the *Ipomoea* spp. and other weeds at the establishment stage, gave satisfactory weed control and improved sunn hemp seed productivity.

Keywords: Imazethapyr, *Ipomoea*, Pendimethalin, Pyroxasulfone, Sunn hemp, Weed management

INTRODUCTION

Crotalaria juncea L. (sunn hemp) is an annual herbaceous plant, typically reaching 1.0-3.0 m in height, believed to have originated in the Indo-Pakistan subcontinent. It is widely cultivated in tropical regions as a green manure or cover crop and for seed production (Mosjidis and Wehtje 2011). It is utilized in various ways in Indian households and industries as India is the major producer of sunn hemp (Bhandari *et al.* 2022). As a member of the Leguminosae family and only cultivated species in the *Crotalarieae* tribe, it offers several economic and ecological benefits to farmers and the environment, respectively and its roots characteristically harbour nitrogen-fixing bacteria (*Rhizobium*), enhancing nitrogen in the soil. The rapid growth, abundant foliage, high biomass accumulation, and favourable C:N of *C. juncea* make it highly suitable as both a cover crop and a green manure crop. It thrives best in tropical and sub-tropical regions, performing well during summer and rainy seasons, but is sensitive to low temperatures and frost. When harvested at the vegetative stage, before seed formation, sun hemp can also serve as a valuable feedstock for cattle (Garzon *et al.* 2021). The strong weed-suppressing capacity of sunn hemp is largely a result of its rapid growth and dense canopy (Morris et al. 2015), although weeds such as *Ipomoea* spp. that emerge at the crop establishment stage, compete for space, light, water and nutrients, and intertwine with the crop. Furthermore, some *Ipomoea* species act as alternate hosts for pests and diseases and, may also release allelopathic substances, indirectly impacting sunn hemp health (Barroso *et al.* 2019). Controlling *Ipomoea* in sunn hemp continues to be a challenge to farmers as there is no label claim of herbicide for sun hemp.

In recent years, two invasive broad-leaved weeds, Japanese morning glory (*Ipomoea nil* (L.) Roth) and obscure morning glory (*Ipomoea obscura* (L.) Ker Gawl.) have been reported in northern part of India (Marimuthu *et al.* 2002). These species are now widespread and problematic in Punjab, where they also infest crops such as cotton, maize, soybean and various vegetables (Bhullar *et al.* 2012). Considering the limitations of current weed management practices in sunn hemp, where growers depend predominantly only on post-emergence

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application (PoE) of herbicides, the integration of pre-emergence (PE) herbicides into the control strategy can offer an early advantage by lowering initial weed pressure, improving crop competitiveness, and ultimately increasing crop productivity. There are no reported herbicide options available for weed management in sun hemp in India. This study was undertaken to evaluate the efficacy of pre-emergence (standalone or tank-mix or pre-mix), post-emergence herbicides and their sequential applications in managing weeds and improve sunn hemp crop productivity.

MATERIALS AND METHODS

A field experiment under natural weed infestations in sunn hemp was carried out during *Kharif* 2023 and 2024 at Punjab Agricultural University (PAU), Regional Research Station, Kapurthala. The Kapurthala district of Punjab, India, is situated at 31°23'N and 75°25'E. During winter season, minimum temperature falls below 3°C while during summer season, sometimes temperature reaches 40°C and many a time touches 46°C. The soil of the experiment site was classified as a Typic Ustochrept, sandy loam in texture, with a pH of 7.2 and EC 0.18 dS/m. The fertility status of soil was medium in OC (0.44%), low in $KMnO_4$-N (241.3 kg/ha), high in Olsen P (31.9 kg/ha) and medium in NH_4OAc-K (195.4 kg/ha). The treatments in field experiment consisted of standalone, tank-mix, pre-mix and sequential application of PE and PoE herbicidal applications. Thirteen treatments were evaluated including: imazethapyr 75 g/ha PE, imazethapyr 75 g/ha PoE, sequential application of imazethapyr 75 g/ha PE followed by (*fb*) PoE, pyroxasulfone 127 g/ha PE, pyroxasulfone 127 g/ha PE *fb* imazethapyr 75 g/ha PoE, pendimethalin 750 g/ha PE, pendimethalin 750 g/ha PE *fb* imazethapyr 75 g/ha PoE, pendimethalin 750 g/ha PE *fb* pyroxasulfone 127 g/ha PoE, pendimethalin 900 g/ha + imazethapyr 75 g/ha (tank-mix) PE, pendimethalin 750 g/ha + imazethapyr 75 g/ha (tank-mix) PE, imazethapyr + pendimethalin 800 g/ha (pre-mix) PE, weedy control and hand weeding (at 3 weeks after sowing). A randomized complete block design (RCBD) with three replications was used. Sunn hemp cv. PAU 1691 was sown on June 14, 2023, and June 10, 2024, maintaining a row spacing of 45 cm and a seed rate of 25 kg/ha. Each plot measured 5.0 m × 3.6 m, covering an area of 18 m^2. A pre-sowing irrigation was applied across the experimental site. Standard agronomic practices were adopted for crop cultivation, excluding weed management interventions. The full dose of phosphorus at a rate of 40 kg/ha was applied as basal. Pre-emergence herbicide was applied within 2 days of sowing while PoE herbicides were applied 2-4 leaf stage of weeds, at 15-20 days after sowing (DAS) during both the years. Herbicide applications, both PE and PoE, were carried out on moist soil using a battery-operated knapsack sprayer equipped with a flood jet nozzle for PE spray (500 L/ha water volume) and a flat fan nozzle for PoE spray (375 L/ha water volume).

Weed data were recorded using a 50 cm × 50 cm quadrat placed at two randomly selected spots in each plot at 45 DAS and at crop harvest. Weeds were identified species-wise, counted and cut at the collar region. The collected samples were placed in separate brown paper bags and sun-dried for 3-5 days to remove excess moisture. Subsequently, the samples were oven-dried at 70 ± 2 °C for 72 hours until a constant weight was obtained, which was taken as the biomass of each weed species. For data analysis, the average values from the two quadrats were expressed as weed density (no./m^2) and weed biomass (g/m^2), respectively. Plant height at harvest and seed yield were recorded. Cost of herbicide application and hand weeding was computed to calculate returns over weedy check and hand weeding treatment.

The analysis of variance (ANOVA) was performed to evaluate different weed management practices against complex weed flora in *C. juncea*. Statistical analysis of the recorded data was performed using IBM SPSS Statistics 19 with weed control treatments as fixed effect. Results were interpreted at 5% level of significance (p=0.05) with the help of Fisher's least significant difference test (Cochran and Cox 1957). To normalize the variance, weed data was square transformed before analysis, wherever required.

RESULTS AND DISCUSSION

Weed density

The density of grasses and broad-leaved weeds at 45 DAS was significantly influenced by all the weed control treatments over the untreated control. At 45 DAS, imazethapyr 75 g/ha PE, sequential application of imazethapyr 75 g/ha PE and PoE, pendimethalin 750 g/ha *fb* imazethapyr 75 g/ha, pendimethalin 900 g/ha + imazethapyr 75 g/ha (tank-mix) PE, pendimethalin 750 g/ha + imazethapyr 75 g/ha (tank-mix) PE and of imazethapyr + pendimethalin (pre-mix) 800 g/ha PE recorded statistically at par density of *Ipomoea* and other broad-leaved weeds and were significantly lower over all other weed control treatments. Further, pendimethalin 750 g/ha *fb* pyroxasulfone 127 g/ha also recorded statistically at par density of *Ipomoea* at 45 DAS with all the above treatments. In case of grasses at 45 DAS, pendimethalin 750 g/ha PE, pendimethalin 750 g or 900 g/ha + imazethapyr 75 g/ha (tank-mix) PE and imazethapyr + pendimethalin 800 g/ha (pre-mix) PE resulted in significantly lower grass weed density as compared to all other weed control treatments (**Table 1**). This indicated that the growth of newly germinated weed seeds or seedlings may be inhibited with the application of tank-mix and pre-mix PE herbicides due to their synergistic effect of the two mechanisms of actions. Therefore, during the initial periods of crop growth, total weed density was significantly less. Mixing of pendimethalin with other herbicides also resulted in better residual weed control throughout the growing season over application of single herbicide. Pendimethalin is a member of the dinitroaniline family that disrupts microtubule synthesis, which is crucial for the formation of cell wall microfibrils. This disruption halts cell elongation and interferes with chromosome movement during mitosis in germinating seeds and young weed seedlings, thereby providing effective weed control and contributing to higher crop productivity. Imazethapyr acts by inhibiting the plastid enzyme acetolactate synthase (ALS), which catalyses the initial step in the biosynthesis of the essential branched-chain amino acids (valine, leucine, and isoleucine). In this study, weeds were effectively controlled by sequential application of herbicides.

Weed biomass

Imazethapyr 75 g/ha PE, pendimethalin 750 g or 900 g/ha + imazethapyr 75 g/ha (tank-mix) PE and imazethapyr + pendimethalin 800 g/ha (pre-mix) PE recorded 60.1%, 67.6%, 69.8% and 63.2% reduction of total weed biomass at 45 DAS over weedy control, respectively and was significantly lower as compared to all other weed control treatments. Significant reduction of grasses and broad-leaved weed biomass at crop harvest was observed when sequential application of pendimethalin 750 g/ha *fb* imazethapyr 75 g/ha, pendimethalin 750 g or 900 g/ha + imazethapyr 75 g/ha (tank-mix) PE and imazethapyr + pendimethalin as PE 800 g/ha (pre-mix) was applied (**Table 1**). Better control of weed density with tank-mix, pre-mix and sequential application of herbicides leads to a reduction in biomass of grasses and broad-leaved weeds. The soil colloids bind the PE herbicide applied to the soil surface, forming a thin protective layer that inhibits weed establishment. As weed seedlings emerge, absorb it, and subsequently exhibit phytotoxic symptoms, leading to suppressed growth and reduced biomass. This was mainly due to better control of weeds in critical period of crop-weed competition, resulting in lower weed biomass.

Weed control efficiency

Due to a significant reduction of weeds, higher weed control efficiency was observed with sequential application of pendimethalin 750 g/ha *fb* imazethapyr 75 g/ha, pendimethalin 750 g or 900 g/ha + imazethapyr 75 g/ha (tank-mix) PE and imazethapyr + pendimethalin 800 g/ha (pre-mix) PE over control

Table 1. Density and biomass of *Ipomoea* spp. and other weeds in sunn hemp as affected by weed management treatments (pooled data of two years)

Treatment	Weed density (no./m^2) at 45 DAS			Total weed biomass at 45 DAS (g/m^2)	Weed biomass (g/m^2) at harvest	
	Ipomoea spp.	Other broad-leaved weeds	Grasses		*Ipomoea* spp.	Other weeds
Imazethapyr 75 g/ha PE	1.6 (2)	1.4 (1)	1.6 (2)	144	600	589
Imazethapyr 75 g/ha PoE	1.9 (3)	2.3 (4)	1.8 (2)	243	608	578
Imazethapyr 75 g/ha PE and PoE	1.4 (1)	1.0 (0)	2.1 (4)	165	309	861
Pyroxasulfone 127 g/ha PE	2.0 (3)	1.7 (2)	2.1 (3)	231	592	533
Pyroxasulfone 127 g/ha PE *fb* imazethapyr 75 g/ha PoE	1.9 (3)	1.7 (2)	1.6 (2)	165	446	609
Pendimethalin 750 g/ha PE	2.0 (3)	2.2 (4)	1.3 (1)	242	472	567
Pendimethalin 750 g/ha PE *fb* imazethapyr 75 g/ha PoE	1.1 (0)	1.3 (1)	1.7 (2)	159	152	367
Pendimethalin 750 g/ha PE *fb* pyroxasulfone 127 g/ha PoE	1.5 (1)	1.8 (2)	1.4 (1)	224	517	552
Pendimethalin 900 g/ha + imazethapyr 75 g/ha (tank-mix) PE	1.0 (0)	1.0 (0)	1.0 (0)	109	87	405
Pendimethalin 750 g/ha + imazethapyr 75 g/ha (tank-mix) PE	1.1 (0)	1.4 (1)	1.0 (0)	117	98	418
Imazethapyr + pendimethalin 800 g/ha (pre-mix) PE	1.0 (0)	1.0 (0)	1.0 (0)	133	104	433
Weedy control	2.4 (5)	3.2 (10)	2.3 (4)	361	993	735
Hand weeding	2.2 (4)	2.8 (7)	2.0 (3)	280	463	546
LSD (p=0.05)	0.8	0.5	0.3	45	207	141

*Data is subjected to square root transformation ($\sqrt{x+1}$). Figures in parentheses are means of original values in round figures; DAS = days after seeding; PE = pre-emergence application PoE= post-emergence application; *fb* = followed by

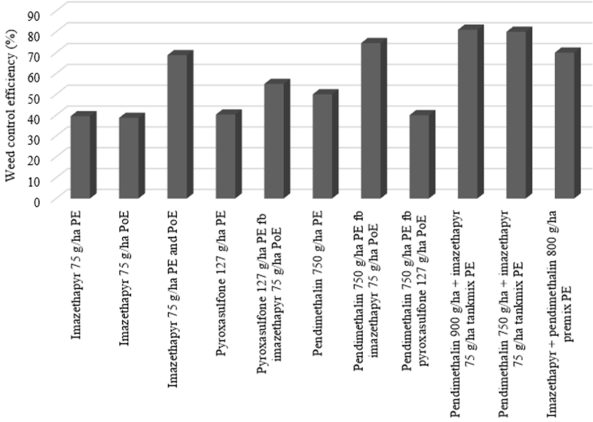

Figure 1. Weed control efficiency (%) of *Ipomoea* spp. in sunn hemp as affected by weed management treatments (pooled data of two years)

plot (**Figure 1**). The differences in weed control efficiency are closely linked to the corresponding weed biomass recorded under each treatment. The lower weed biomass accumulation in turn led to higher control efficiency (Yadav *et al.* 2021). The herbicide mixture strategy would not only offer broad-spectrum weed control but also help delay the evolution of herbicide resistance in weeds, manage existing herbicide resistance issues and contribute to the sustainability of *C. juncea* productivity.

Sunn hemp growth and seed yield

All weed control treatments registered a significant impact on the sunn hemp seed yield. However, the plant height of sunn hemp at harvest did not differ significantly among all weed control treatments. Sunn hemp seed yield in various herbicidal treatments ranged from 1.07 t/ha to 2.07 t/ha. Pendimethalin 900 g/ha + imazethapyr 75 g/ha (tank-mix) PE, pendimethalin 750 g/ha + imazethapyr 75 g/ha PE and of imazethapyr + pendimethalin 800 g/ha (pre-mix) PE recorded at par seed yield of sunn hemp with significantly 93.5%, 86.0% and 83.2%, respectively higher sunn hemp seed yield than weedy control (**Table 2**). There was slight phytotoxicity because of sequential application of pendimethalin and pyroxasulfone with imazethapyr in the crop as there was reduction in final plant height but the differences between different treatments were non-significant. The reduced crop-weed competition and marked increase in weed control efficiency with herbicide treatments resulted in better development of reproductive structures and translocation of photosynthates into the sink. By effectively suppressing weed growth at early stages, pre-emergence herbicides reduced competition for essential resources such as moisture, nutrients, space, and light, thereby promoting higher crop productivity. Mosjidis and Wehtje (2011) reported that pendimethalin 1120 g/ha PE alone provided consistent effective weed control and maximum sunn hemp biomass in U.S.A., but when yellow nutsedge was present, imazethapyr 70 g/ha was required for effective control and greater sunn hemp biomass. Contrary to our observations, Mosjidis and Wehtje (2011) reported that the combination of pendimethalin and imazethapyr at the same rate was detrimental to sunn hemp biomass yield.

Pendimethalin 900 g/ha + imazethapyr 75 g/ha (tank-mix) PE, pendimethalin 750 g/ha + imazethapyr 75 g/ha PE and of imazethapyr + pendimethalin 800 g/ha (pre-mix) PE resulted in more returns per hectare by Rs. 59550-67160 and 46370-53980 as compared to weedy check and hand weeding,

Table 2. Plant height, yield and economics of sunn hemp under different weed management treatments

Treatment	Final plant height (cm)	Seed yield (t/ha)			Cost of treatment (Rs./ha)	Returns (Rs./ha) over	
		2023	2024	Pooled		Weedy control	Hand weeding
Imazethapyr 75 g/ha PE	240.3	1.24	1.52	1.38	770	20930	7750
Imazethapyr 75 g/ha PoE	234.1	1.18	1.45	1.32	770	16730	3550
Imazethapyr 75 g/ha PE and PoE	240.4	1.29	1.53	1.41	1540	22260	9080
Pyroxasulfone 127 g/ha PE	248.0	1.16	1.38	1.27	3425	10575	-2605
Pyroxasulfone 127 g/ha PE *fb* imazethapyr 75 g/ha PoE	229.7	1.13	1.35	1.24	4195	7705	-5475
Pendimethalin 750 g/ha PE	239.5	1.32	1.54	1.43	2225	22975	9795
Pendimethalin 750 g/ha PE *fb* imazethapyr 75 g/ha PoE	231.9	1.34	1.56	1.45	2995	23605	10425
Pendimethalin 750 g/ha PE *fb* pyroxasulfone 127 g/ha PoE	238.4	1.35	1.56	1.46	5650	21650	8470
Pendimethalin 900 g/ha + imazethapyr 75 g/ha (tank-mix) PE	236.6	1.94	2.20	2.07	2840	67160	53980
Pendimethalin 750 g/ha + imazethapyr 75 g/ha (tank-mix) PE	232.4	1.88	2.10	1.99	2495	61905	48725
Imazethapyr + pendimethalin 800 g/ha (pre-mix) PE	231.0	1.84	2.07	1.96	2750	59550	46370
Weedy control	237.8	0.99	1.15	1.07	-	-	-
Hand weeding	235.1	1.27	1.54	1.40	9920	13180	-
LSD (p=0.05)	NS	0.33	0.41	0.38	-	-	-

*DAS = days after seeding; PE = pre-emergence application PoE= post-emergence application; *fb* = followed by

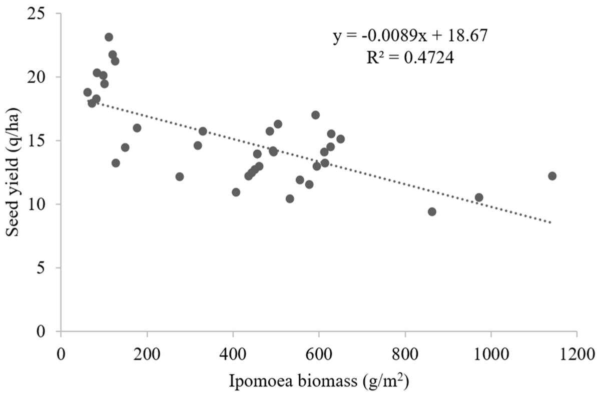

Figure 2. The relationship of seed yield of *sunn hemp* with *Ipomoea* spp. biomass (pooled data of two years) at harvest

respectively (**Table 2**). Pyroxasulfone 127 g/ha herbicide treatments resulted in the negative returns over hand weeding. Further, the linear regression analysis illustrates the strong negative linear correlation between *Ipomoea* biomass at harvest and sunn hemp seed yield (**Figure 2**). The coefficient of determination of 0.4724 indicates that *Ipomoea* biomass accounted for 47% of the sunn hemp yield variation. The findings highlight a significant influence of weed control treatments on both *Ipomoea* biomass and sunn hemp seed yield. As total *Ipomoea* biomass increased, sunn hemp seed yield decreased correspondingly.

It can be concluded that pre-emergence application of pendimethalin 750-900 g/ha + imazethapyr 75 g/ha (tank-mix) or imazethapyr + pendimethalin 800 g/ha (pre-mix) provided good control of the *Ipomoea* spp. and other associated weeds in sunn hemp with increased the sunn hemp productivity.

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RESEARCH NOTE

Weed management and nitrogen regimes impact on weeds growth and aerobic direct-seeded rice productivity in middle Gangetic Plains of Uttar Pradesh

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ABSTRACT

Aerobic direct-seeded rice (DSR) is a resource-efficient alternative to puddled transplanted rice but its adoption is influenced by weed infestation and nitrogen (N) management factors. A field experiment was conducted in *Kharif* 2020 at Kumarganj, Ayodhya, Uttar Pradesh (U.P.), India using a split-plot design with three replications. The objective of this study was to assess the impact of weed management and nitrogen (N) levels on weeds growth and aerobic DSR productivity. The main plots comprised of three N levels, *viz.* 100%, 125%, and 150% of the recommended dose (RDN), while sub-plots included five weed management options: pre-emergence application (PE) of pyrazosulfuron 25 g/ha; sequential application of pyrazosulfuron 25 g/ha PE followed by (*fb*) post-emergence application (PoE) of bispyribac-Na 25 g/ha; hand weeding twice at 20 and 40 days after seeding (DAS); weed-free, and unweeded check. 150% RDN significantly reduced weed density and dry biomass (by 27.76%) and improved rice plant height, dry matter, yield attributes, and DSR grain yield (by 14.18%) over 100% RDN. Maximum grain and straw yield were recorded with 150% RDN with hand weeding twice. However, the highest net return and benefit cost ratio (B:C) were recorded with 150% RDN and sequential application of pyrazosulfuron 25 g/ha PE *fb* bispyribac-Na 25 g/ha PoE.

Keywords: Aerobic direct-seeded rice, Bispyribac-Na, Nitrogen levels, Pyrazosulfuron, Rice, Sequential herbicides application, Weed management

Half of the world's population relies on rice as their main staple diet, forming a cornerstone of food security across Asia, including India. India ranks as the world's second-largest producer and consumer of rice after China, cultivates across approximately 47.83 million hectares, resulting in a production of around 137.83 million tonnes. However, the rice productivity is relatively low at approximately 4.32 t/ha (USDA 2025). The Indo-Gangetic Plains (IGP) adopts rice-wheat crop rotation (Ladha *et al.* 2003). Conventional rice cultivation in the Indo-Gangetic Plains and Eastern India relies predominantly on puddled transplanted rice (PTR), a system characterized by labour- and water-intensive practices such as nursery preparation, seedling uprooting, puddling and manual transplanting. Although effective in controlling early weed growth through standing water, PTR imposes significant environmental and economic burdens, particularly in regions experiencing labour shortages and declining irrigation resources (Ladha *et al.* 2009).

To address these constraints, direct-seeded rice (DSR) has emerged as a promising and resource-efficient alternative, offering advantages such as reduced water and labour input, early crop establishment and lower production costs (Kumar and Ladha 2011). The aerobic rice systems cultivated under non-puddled, well-drained conditions have demonstrated water savings of up to 73% during land preparation and 56% during the crop growth phase compared to traditional lowland rice (Yaduraju *et al.* 2021). The prominent impediment to encouraging extensive adoption of DSR is increased weed pressure, arising from the absence of standing water during early growth stages. DSR allows for the simultaneous germination of rice and weeds, resulting elevated weed pressure on crop and potential yield losses ranging 35% to 90% due to lack of efficient weed control measures (Singh *et al.* 2016). Weed management in DSR is primarily achieved with herbicides, as manual weeding is constrained by labour shortages and high costs. Employing a single herbicide usually insufficient owing to the diverse and intricate DSR weed flora. Therefore, integrating

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sequential application of both pre-emergence (PE) and post-emergence (PoE) herbicides was found to be essential for effective management (Barla *et al.* 2021)

Simultaneously, nitrogen (N) management in DSR presents unique challenges due to the aerobic soil environment, which intensifies N losses through volatilization and denitrification (Thind *et al.* 2018). Consequently, higher N application rates (150–180 kg/ha) are often required to achieve yields comparable to PTR. The N availability and utilization, weed pressure further modulates DSR system as weeds compete with rice for nutrients. Studies have revealed that poor weed control can reduce N-use efficiency by 30–50%, thereby exacerbating yield losses (Patel *et al.* 2018, Mahajan and Timsina 2011). Conversely, appropriate N fertilization enhances crop vigour, expedites canopy closure and suppresses weed emergence, suggesting a dynamic interaction between weed control and nutrient management (Kumawat *et al.* 2017).

This study was conducted with an objective to evaluate aerobic DSR performance under varying weed management and nitrogen regimes and identify effective weed management option and optimal nitrogen dosage rate to optimise DSR productivity.

This field study was laid out in the *Kharif* season of 2020 at the Agronomy Research Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, situated at $26^0 47'$N latitudes, $82^0 12'$E longitudes with an altitude of 126 meters above mean sea-level. The location is representative of the region's medium-land-growing zone. The experimental soil was alkaline in nature had a pH 9.1, organic carbon 0.23%, low available nitrogen (115.4 kg/ha), medium available phosphorus (15.6 kg/ha) and potassium (240 kg/ha). Split-plot design with three replications was used for the experimentation. Three-nitrogen (N) levels, *viz.* 100% recommended dose (RDN) (120 kg N, 60 kg P and 40 kg K/ha), 120% RDN and 150% RDN were in main plots. Five options of managing weeds were tested including: pre-emergence application (PE) of pyrazosulfuron at 25 g/ha, pyrazosulfuron 25 g/ha PE followed by (*fb*) post-emergence application (PoE) of bispyribac-Na (PoE) at 25 g/ha, hand-weeding twice at 20 and 40 days after seeding (DAS), weed-free (up 60 DAS) and unweeded-check in sub-plots. Rice variety 'NDR-2065' (medium duration, 120-125 days with large bold grains) was sown on 24^{th} June 2020 using manual line sowing at a depth of 2-3 cm, following basal fertilizer application. Seeds were sown in rows spaced 20 cm apart, at a rate of 20 kg/ha. Harvesting was done on November 14, 2020. Urea, diammonium phosphate and muriate of potash were used as fertilizers for N, phosphorous (P) and potash (K), respectively. Half of the N dose was applied to all the treatments, while entire dosage of P and K were applied as basal. When the crop reached its maximum tillering and panicle initiation stage the remaining N was top-dressed in two equal splits.

Herbicides were applied according to the treatment using a manually operated knapsack sprayer with a flat-fan nozzle, delivering a 600 L/ha spray volume for uniform coverage. At 20 and 40 DAS, weeds were physically pulled out in accordance with the treatment. At 60 and 90 DAS, the weed density was measured. A weedy-check and weed-free plots were maintained for comparison with herbicidal treatments. Two randomly chosen quadrats (0.50 m × 0.50 m) were randomly placed at two places in each of the plot to measure weed density and dry weight (biomass) at 60 and 90 DAS. Weeds clipped at ground level were sun-dried for 2-3 days, then oven-dried at 70°C until a constant weight was achieved to determine dry biomass. Five tagged plants in each net plot had their rice yield parameters noted and averaged. Effective tillers/m^2 were counted from two randomly selected locations in each net plot and averaged. Grain yield was measured by hand threshing the harvested crop after it had been bundled in respective plots

The data were analysed using analysis of variance (ANOVA) to evaluate statistical differences among treatments through "F" test, with conclusions noted 5% level of probability. Weed density and biomass data were transformed using a square root transformation $\sqrt{x+0.5}$ before analysis. On the basis of weed data, the weed control efficiency (WCE) and weed index (WI) were calculated using the standard formulas given by Mani *et al.* 1973 and Gill and Kumar (1969), respectively, as following:

$$\mathrm{WCE}\ (\%) = \frac{\mathrm{WDc} - \mathrm{WDt}}{\mathrm{WDc}} \times 100$$

Where, WDc: weed dry matter in unweeded control (g/m^2) and WDt: weed dry matter in treated plot (g/m^2).

$$\mathrm{WI}\ (\%) = \frac{\mathrm{X} - \mathrm{Y}}{\mathrm{X}} \times 100$$

Where, X: crop yield from weed-free (up to 60 DAS) plot and Y: crop yield from treated plot for which weed index need to be calculated.

Effect on weeds

The experimental field was dominated by *Eclipta alba* (25.06%), *Cyperus species* (23.90%), *Echinochloa* spp. (18.88%), *Paspalum maximum* (16.45%) and *Commelina benghalensis* (15.70%). Singh *et al.* (2016a), Singh *et al.* (2016) and Jaiswal and Duary (2023) also observed these weed species throughout the growth cycle of DSR.

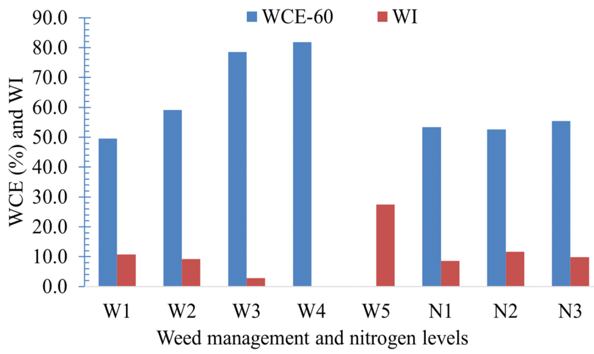
Application of higher nitrogen level *i.e.* 150% recommended N significantly lowered weed density and biomass up to 26.21 at 60 DAS when compared to the lowest amount of N *i.e.* 100% recommended N (**Table 1**). This may be attributed to enhanced crop vigour, faster canopy closure and greater competitive ability of rice plants due to efficient N uptake by crop while reducing nitrogen availability to weeds, which limit the availability of light and space for weed growth. In comparison to weedy-check, the pyrazosulfuron 25 g/ha PE *fb* bispyribac-Na 25 g/ha PoE has reduced weed density by 59.88% at 60 DAS, which is comparable to manual weeding twice at 20 and 40 DAS. while Pre-emergence herbicides reduce the density of the first flush of weeds while the post-emergence herbicides control weeds that emerge later during the crucial stage of crop-weed competition (Singh *et al.* 2016a, Singh *et al.* 2023 and Patel *et al.* 2018).

The interaction between N levels and weed management practices indicated that the applying 150% recommended N combined with hand weeding twice at 20 and 40 DAS resulted in significantly reduced weed density at 60 DAS, with a reduction of 68.37%, compared to the unweeded control with 100% recommended N (**Table 1**). Among herbicidal treatments, pyrazosulfuron 25 g/ha PE *fb* bispyribac-Na PoE with 150% recommended N, significantly reduced weed density by 46.94% at 60 DAS, relative to unweeded control. Hand weeding twice at 20 and 40 DAS and pyrazosulfuron PE *fb* bispyribac-Na PoE with 150% recommended N caused a statistically significant lowest weed biomass of 70.54%, at 60 DAS, compared to the unweeded control with 100% recommended N.

The N levels did not significantly influence weed control efficiency. However, weed index was significantly lower with 100% recommended nitrogen (8.51), followed by 150% recommended nitrogen (9.84). Among the weed management options, hand weeding twice at 20 and 40 DAS recorded the highest weed control efficiency (81.85%) and the lowest weed index (2.77) while pyrazosulfuron PE *fb* bispyribac-Na PoE, recorded weed control efficiency of 78.50% and weed index of 9.44. (**Figure 1**).

Effect on rice

Application of N level 150% of recommended N resulted in significant increase in rice plant height and dry matter accumulation (DMA) to the extent of 7.85% and 11.78% compared to 100% recommended N, respectively supporting findings of Tiwari *et al.* (2017). Among herbicide treatments, pyrazosulfuron PE *fb* bispyribac-Na PoE recorded significant increase in plant height (19.24%) and DMA (23.23%) compared to unweeded check. The combined effect of N level and weed management revealed that the significantly maximum DMA of rice found in



W1: Pyrazosulfuron 25 g/ha PE; W2: Pyrazosulfuron 25 g/ha PE *fb* bispyribac-Na 25 g/ha PoE; W3: Hand weeding twice (20 and 40 DAS); W4: Weed free; W5: Weedy check; N1: 100% RDN; N2: 125% RDN; N3 = 150% RDN

Figure 1. Weed control efficiency and weed index

Table 1. Interaction effect of nitrogen levels and weed management treatments on weed density and biomass at 60 days after sowing

Treatment	Weed density (no./m^2)			Weed dry biomass (g/m^2)		
	100% RDN	125% RDN	150% RDN	100% RDN	125% RDN	150% RDN
Pyrazosulfuron 25 g/ha PE	7.27(52.40)	7.06(49.40)	6.25(40.20)	6.09(36.68)	5.92(34.58)	5.35(28.14)
Pyrazosulfuron 25 g/ha PE *fb* bispyribac-Na 25 g/ha PoE	6.48(41.60)	6.19(38.00)	5.81(33.30)	5.44(29.12)	5.20(26.60)	4.87(23.31)
Hand weeding twice (20 and 40 DAS)	5.03(24.80)	4.74(22.00)	4.34(18.40)	4.22(17.36)	3.99(15.40)	3.66(12.88)
Weed free	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)
Weedy check	10.60(112.00)	9.54(91.00)	8.88(78.40)	8.87(78.40)	8.00(63.70)	7.43(54.88)
LSD (p=0.05)		0.586			0.435	

*Data in parentheses are original value which were transformed to $\sqrt{x+0.5}$ for analysis

PE = pre-emergence application; PoE = post-emergence application; *fb* = followed by; RDN = recommended dose of nitrogen

Table 2. Effect of nitrogen levels and weed management treatments on rice plant height, yield attributes, yields and economics of direct-seeded rice

Treatment	Plant height (cm)	Effective tillers (no./m^2)	Panicle length (cm)	Grains/ panicle (no./ panicle)	1000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Gross returns (₹)	Net returns (₹)	B:C ratio
Weed management										
Pyrazosulfuron 25 g/ha PE	108.67	325.20	21.53	74.52	22.18	5.38	8.25	259751	190263	2.74
Pyrazosulfuron 25 g/ha PE *fb* bispyribac-Na 25 g/ha PoE	112.93	341.73	22.90	75.24	22.23	5.46	8.74	263028	193440	2.78
Hand weeding twice (20 and 40 DAS)	115.96	343.57	23.47	76.53	22.25	5.86	8.88	270869	184106	2.12
Weed free	116.33	342.50	23.97	78.84	22.29	6.02	9.12	274830	181943	1.96
Weedy check	91.20	181.80	18.43	71.28	22.13	4.36	6.74	235358	166870	2.44
LSD (p=0.05)	2.18	15.88	1.20	4.24	1.66	0.15	0.25	16014	15449	0.43
Nitrogen Levels										
100% RDN	103.44	277.88	20.34	73.24	22.19	5.036	7.69	251175	174159	2.30
125% RDN	111.36	308.70	22.82	76.06	22.23	5.50	8.61	262950	185506	2.44
150% RDN	112.25	334.30	23.02	76.55	22.24	5.74	8.74	268177	190308	2.48
LSD (p=0.05)	2.35	21.36	1.43	3.01	1.25	0.10	0.18	21180	14936	0.26
Interaction (W × N)										
LSD (p=0.05)	NS	37.00	NS	NS	NS	0.61	0.31	NS	NS	NS

PE = pre-emergence application; PoE = post-emergence application; *fb* = followed by; RDN = recommended dose of nitrogen

Table 3. Interaction effect of nitrogen levels and weed management options on rice dry matter accumulation, grain yield and straw yield of direct-seeded rice (DSR)

Treatment	100% RDN	125% RDN	150% RDN	LSD (p=0.5)
Rice dry matter accumulation (g/m^2)				
Pyrazosulfuron 25 g/ha PE	1243.0	1421.0	1424.5	
Pyrazosulfuron 25 g/ha PE *fb* bispyribac-Na 25g/ha PoE	1321.5	1503.0	1513.0	
Hand weeding twice (20 and 40 DAS)	1342.0	1534.0	1546.0	157.45
Weed free	1383.0	1574.0	1586.0	
Weedy-check	1068.0	1125.0	1137.0	
Rice grain yield (t/ha)				
Pyrazosulfuron 25 g/ha PE	4.90	5.58	5.67	
Pyrazosulfuron 25 g/ha PE *fb* bispyribac-Na 25g/ha PoE	5.22	5.22	5.95	
Hand weeding twice (20 and 40 DAS)	5.33	6.03	6.21	0.18
Weed free	5.50	6.21	6.37	
Weedy-check	4.19	4.38	4.50	
Rice straw yield (t/ha)				
Pyrazosulfuron 25 g/ha PE	7.53	8.60	8.61	
Pyrazosulfuron 25 g/ha PE *fb* bispyribac-Na 25g/ha PoE	8.00	9.08	9.14	
Hand weeding twice (20 and 40 DAS)	8.09	9.21	9.35	0.30
Weed free	8.33	9.48	9.55	
Weedy-check	6.49	6.67	7.07	

PE = pre-emergence application; PoE = post-emergence application; *fb* = followed by; RDN = recommended dose of nitrogen

application of 150% recommended N along with pyrazosulfuron *fb* bispyribac-Na up to 29.41% as compared to 100% recommended N under weedy-check plot (**Table 2** and **3**).

Significantly higher effective tillers, panicle length, grains per panicle, grain yield and straw yield were recorded by 150% of recommended N amongst N levels tested and by hand weeding twice and pyrazosulfuron *fb* bispyribac-Na among weed management treatments (**Table 2**). The findings are consistent with the results reported by Joshi *et al.* (2015), Ahmad *et al.* (2016) and Patel *et al.* (2018).

Interaction between N levels and weed management options indicated that application of 150% recommended N along with hand weeding twice at 20 and 40 DAS resulted in significantly higher grain and straw yield followed by application of pyrazosulfuron *fb* bispyribac-Na (**Table 3**).

Economics

The maximum gross return (₹ 268177/ha), net return (₹ 190308/ha) and B-C ratio (2.48) was recorded in 150% recommended N among nutrient management. Among weed management options, hand weeding (at 20 and 40 DAS) resulted highest grass return (₹ 270869) but net return (₹ 193440) and B-C ratio (2.78) was observed in sequential application of pyrazosulfuron PE *fb* bispyribac-Na PoE (**Table 2**).

Conclusion

Based on one year experiment, it can be concluded that, the highest grain yield and net returns can be obtained with the combination of 150% recommended nitrogen with sequential application of pyrazosulfuron 25 g/ha PE *fb* bispyribac-Na 25 g/ha PoE in aerobic direct-seeded rice.

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RESEARCH NOTE

Integrated strategies for effective weed management and improved yield of maize

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ABSTRACT

The impact of integrated weed management practices (herbicides and mulching) on weeds and morpho-physiological traits and the yield of maize was evaluated in a field experiment using a split plot design with three replications during rainy (*Kharif*) season 2022. The treatments comprised of three levels of rice straw mulch in main plots and five weed management treatments in subplots. The higher the level of residue (8 t/ha), the greater was the reduction in weed incidence, weed biomass, and weeds nutrient uptake, which ultimately resulted in better maize growth and yield when compared to residue level of 5 t/ha and no residue mulch. Among weed management options, sequential use of atrazine 1.0 kg/ha followed by tembotrione 0.120 kg/ha resulted in grater reduction in weed density, biomass and nutrient uptake per unit area which led to improved maize morphological and physiological parameters, higher yield, harvest index and nutrient uptake.

Keywords: Atrazine, Maize, Mulching, Rice straw, Tembotrione, Topramezone

Maize (*Zea mays* L.), also known as the "Queen of cereals" owing to its higher yield potential, possesses greater adaptability to diverse agroclimatic conditions and has a versatile usage. But wider spacing and slow initial growth results in greater infestation by various types of weeds leading to severe competition from weeds for inputs such as sunlight, moisture, and nutrients resulting in maize yield loss of 28% to 100% (Das 2008, Patel *et al.* 2006). Thus, effective weed management plays crucial role in maize yield enhancement (Ramesh *et al.* 2017). Manual controlling of weeds although provides satisfactory results, is time consuming and expensive due to its higher labour requirement and most often is not practiced by farmers during the most crucial period of competition for resources between crop and weeds as hand weeding is impractical and uneconomical (Das 2001, Rao *et al.* 2020, Kaul *et al.* 2023).

Weed management using herbicides can be done with comparatively lower cost but sole and continuous herbicide use is not environmentally advisable due to the possibility of resistance development and adverse impact of the herbicides. Sequential use of herbicides with different mode of action instead of single pre- or post- emergence herbicide will be able to address this issue. Post-emergence herbicide application also takes care of the competition for resources caused by weeds even at the later stages. Use of rice straw mulch to suppress weeds as a cultural practice is a viable option as well (Singh *et al.* 2022). Therefore, combining the rice straw mulch and herbicides can offer effective weed management to enhance the maize growth and productivity. Thus, a study was conducted to assess the integrated effect of herbicides and mulch as components of integrated weed management options on the weeds as well as the growth and yield of maize.

The field experiment was conducted at Baronda farm of *ICAR- National Institute of Biotic Stress Management, Raipur, Chhattisgarh* during rainy (*Kharif*) season of 2022. The experimental site had a clayey textured soil with 7.4 pH value, 0.62% organic carbon, 188 kg/ha available N (low), 13.4 kg/ha available P (medium) and 210 kg/ha K (medium). Split plot design having 15 treatment combinations with three replications for each treatment was adopted for laying out the experiment. Three levels of rice straw mulch (RSM) *viz*. 8 t/ha, 5 t/ha, no mulch were assigned in main plots and five herbicidal weed

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management options were in the subplot which include: pre-emergence application (PE) of atrazine 1.0 kg/ha (atrazine PE), atrazine 1.0 kg/ha followed by (*fb*) post-emergence application (PoE) of tembotrione 0.120 kg/ha (atrazine PE *fb* tembotrione PoE), atrazine 1.0 kg/ha followed by topramezone 0.030 kg/ha (atrazine PE *fb* topramezone PoE), weed free check and weedy check. Maize hybrid variety *Super 459 Gold* was sown at 0.60 m × 0.25 m spacing on 25th of July, 2022. The pre-emergence application was carried out 2 days after sowing (DAS) while tembotrione and topramezone were applied at 25 DAS, as per the treatments. Recommended N, P and K doses (120 kg, 26.2 kg and 33.2 kg/ha, respectively) were applied using urea, DAP and MOP. Three split applications of N including one basal and full dose of P and K as basal were done. Square-root transformation ($\sqrt{x+0.5}$) of weed density and dry matter (biomass) data was done before statistical analysis (Das 1999). Data analysis was carried out using the analysis of variance (ANOVA) recommended for split plot design in OPStat software and the treatment means were compared by Fisher's least significant difference test at 5% level of significance (Gomez and Gomez 1984).

The experimental plot was dominated by the weed species such as *Echinochloa colona*, *Cynodon dactylon* (grasses), *Physalis minima*, *Alternanthera sessilis*, *Commelina benghalensis*, *Ludwigia parviflora* (broad-leaved) and *Cyperus rotundus* (sedge) at 60 DAS. The highest weed density and biomass were recorded when straw mulch was not applied and were reduced with mulching. RSM 8 t/ha and RSM 5 t/ha lowered the weed density by 45.3% and 34.4%, respectively while weed biomass was reduced by 37.0% and 19.9% (**Table 1**). The highest weed density and biomass were found in weedy check plot. Sequential application of atrazine PE *fb* tembotrione PoE significantly reduced weed density and weed biomass which was statistically at par with atrazine PE *fb* topramezone PoE . Higher weed

Table 1. Effect of rice straw mulch and weed management treatments on weed density, weed biomass and their percent reduction in maize

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	Weed density reduction (%)	Weed biomass reduction (%)
Rice straw mulch (RSM)				
RSM 8 t/ha	5.0 (31.1)^{*c}	6.1 (47.6)^{c}	45.4	37.1
RSM 5 t/ha	5.5 (37.3)^{b}	6.8 (60.5)^{b}	34.4	20.0
No mulch	6.6 (56.9)^{a}	7.6 (75.6)^{a}	0.0	0.0
Weed management				
Atrazine PE	6.6 (44.2)^{b}	7.9 (62.6)^{b}	57.7	60.8
Atrazine PE *fb* tembotrione PoE	5.4 (28.4)^{c}	6.2 (38.4)^{d}	72.8	75.9
Atrazine PE *fb* topramezone PoE	5.6 (31.6)^{c}	6.8 (45.7)^{c}	69.9	71.5
Weed free check	0.7 (0.0)^{d}	0.7 (0.0)^{e}	100.0	100.0
Weedy check	10.1 (104.7)^{a}	12.6 (159.5)^{a}	0.0	0.0
Interaction	S	S	-	-

(*Original values are given in the parentheses); *fb* = followed by; PE = pre-emergence application; PoE = post-emergence application

Table 2. Effect of rice straw mulch and weed management treatments on maize morpho-physiological traits at 60 DAS, yield attributes and yield of maize

Treatment	Plant height (cm)	LAI	Dry matter accumulation (g/m^2)	SPAD	CGR (g/m^2/ day)	Cob length (cm)	Grains /row	Grains /cob	Grain yield (t/ha)	Harvest Index (%)
Rice straw mulch (RSM)										
RSM 8 t/ha	179.7^{a}	4.10^{a}	623.2^{a}	48.67^{a}	15.40^{a}	16.5^{a}	35.2^{a}	427.7^{a}	5.68^{a}	44.9^{a}
RSM 5 t/ha	176.0^{b}	3.86^{b}	588.1^{b}	46.78^{b}	14.55^{b}	13.8^{a}	33.7^{a}	392.3^{b}	5.34^{b}	43.5^{b}
No mulch	170.4^{c}	3.28^{c}	575.7^{c}	43.57^{c}	14.08^{c}	12.4^{a}	31.9^{a}	357.6^{c}	4.63^{c}	42.2^{c}
Weed management										
Atrazine PE	173.5^{c}	3.41^{d}	554.0^{d}	37.46^{c}	13.21^{d}	14.0^{c}	31.3^{d}	374.9^{d}	5.04^{d}	42.6^{c}
Atrazine PE *fb* tembotrione PoE	179.6^{b}	4.02^{b}	612.8^{b}	55.96^{b}	15.81^{b}	15.4^{b}	34.0^{b}	397.6^{b}	5.69^{b}	44.2^{b}
Atrazine PE *fb* topramezone PoE	177.3^{b}	3.79^{c}	598.9^{c}	55.02^{b}	14.55^{c}	14.8^{b}	33.3^{c}	385.1^{c}	5.44^{c}	43.7^{b}
Weed free check	182.9^{a}	4.28^{a}	691.7^{a}	58.89^{a}	17.36^{a}	16.3^{a}	38.9^{a}	472.4^{a}	6.18^{a}	45.6^{a}
Weedy check	163.7^{d}	3.23^{e}	520.8^{e}	24.39^{d}	12.45^{e}	11.0^{d}	30.6^{e}	332.7^{e}	3.73^{e}	41.4^{d}
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	S	NS

fb = followed by; PE = pre-emergence application; PoE = post-emergence application control in the two sequential herbicide treatments was achieved possibly due to activity of atrazine which controlled grassy and broad-leaved weeds in the initial stages while tembotrione and topramezone PoE controlled weeds at later stage due to their broad-spectrum action.

The RSM 8 t/ha recorded the maximum maize plant height among the straw mulch treatments while the lowest plant height was recorded from weedy check due to severe competition caused by the weeds (**Table 2**). Herbicide usage reduced weed density and biomass which favoured greater maize plant growth due to adequate resource availability (Ehsas *et al*. 2016). Height of maize was statistically at par in atrazine PE *fb* tembotrione PoE and atrazine PE *fb* topramezone PoE. Leaf area index (LAI) is the indicator of source size and therefore plays important role in photosynthesis. The greater weed suppression and availability of growth factors resulted in higher LAI and maize dry matter accumulation per unit area and crop growth rate (CGR). RSM 8 t/ha recorded statistically higher values of maize LAI and dry matter accumulation per unit area in comparison with RSM 5 t/ha and no mulch. Atrazine PE *fb* tembotrione PoE recorded significantly higher LAI than atrazine PE *fb* topramezone PoE and atrazine PE. Maximum LAI, however was obtained in weed free check. Level of chlorophyll content in leaves implies variation in photosynthetic efficiency of the crop which influences the crop growth and ultimately the yield. The leaf chlorophyll content (in terms of SPAD value) recorded at 60 DAS was higher in the 8 t/ha straw mulch and it was statistically at par with that of 5 t/ha mulch application. No mulch treatment recorded the lowest value. Atrazine PE *fb* tembotrione PoE recorded significantly higher chlorophyll content in leaves, dry matter accumulation per unit area and CGR which were statistically similar to the value observed in atrazine PE *fb* topramezone PoE. Minimum SPAD reading, dry matter accumulation per unit area, and CGR were recorded from weedy check plots.

Yield attributes such as cob length, no. of grains/row and no. of grains/cob were found to be higher in the 8 t/ha straw mulch. Atrazine PE *fb* tembotrione PoE recorded significantly higher values of aforementioned yield attributes as compared to atrazine PE *fb* topramezone PoE and atrazine PE. The highest maize grain yield was recorded with RSM 8 t/ha which was 22.6% higher compared to no mulch (**Table 2**). Shah *et al*. (2014) also made similar observations. Atrazine PE *fb* tembotrione PoE recorded the highest grain yield (5.69 t/ha) and it was significantly higher than all the other treatments tested. Percentage yield increase in atrazine PE *fb* tembotrione PoE and atrazine PE *fb* topramezone PoE was 52.5% and 45.8% respectively over weedy check. Ghasiram *et al*. (2020) also reported similar results. Harvest index followed similar trend as maize grain yield.

The lowest N, P and K uptake by weeds at harvest and highest uptake by maize was observed with 8 t/ha rice straw mulch due to less weed occurrence and subsequent growth (**Table 3**; **Figure 1**). Likewise, use of atrazine PE *fb* tembotrione PoE and atrazine PE *fb* topramezone PoE recorded the lower nutrient uptake by weeds and higher uptake by maize, which were statistically at par. Profuse weed growth without any control measures caused highest nutrient uptake in weedy check.

It can be concluded that application of rice straw mulch 8 t/ha in combination with sequential application of atrazine 1 kg/ha PE *fb* tembotrione 0.120 kg/ha PoE at 25 DAS recorded better weed control with significantly lower weed density and biomass resulting in improved maize growth parameters, higher maize yield and harvest index.

Table 3. Effect of rice straw mulch and weed management treatments on nutrient uptake by maize crop at harvest

Treatment	N uptake (kg/ha)			P uptake (kg/ha)			K uptake (kg/ha)		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
Rice straw mulch (RSM)									
RSM 8 t/ha	79.2[a]	30.2[a]	109.4[a]	33.4[a]	20.3[a]	53.7[a]	19.8[a]	73.1[a]	93.0[a]
RSM 5 t/ha	73.4[b]	28.1[b]	101.5[b]	30.8[b]	19.3[b]	50.1[b]	17.8[b]	69.9[b]	87.7[b]
No mulch	61.3[c]	24.3[c]	85.6[c]	25.7[c]	17.7[c]	43.4[c]	14.8[c]	64.2[c]	79.0[c]
Weed management									
Atrazine PE	68.1[d]	25.5[d]	93.6[d]	28.4[d]	18.0[d]	46.4[d]	15.8[d]	66.8[c]	82.5[d]
Atrazine PE *fb* tembotrione PoE	78.3[b]	29.1[b]	107.4[b]	33.3[b]	20.6[b]	53.8[b]	19.3[b]	72.7[b]	92.0[b]
Atrazine PE *fb* topramezone PoE	74.2[c]	28.1[c]	102.3[c]	31.1[c]	18.9[c]	50.1[c]	18.1[c]	70.1[b]	88.2[c]
Weed free check	86.6[a]	35.1[a]	121.7[a]	36.9[a]	24.5[a]	61.4[a]	23.2[a]	82.1[a]	105.3[a]
Weedy check	49.2[e]	19.9[e]	69.1[e]	20.2[e]	13.5[e]	33.7[e]	11.1[e]	53.6[d]	64.7[e]
Interaction	S	S	S	S	S	S	S	NS	S

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

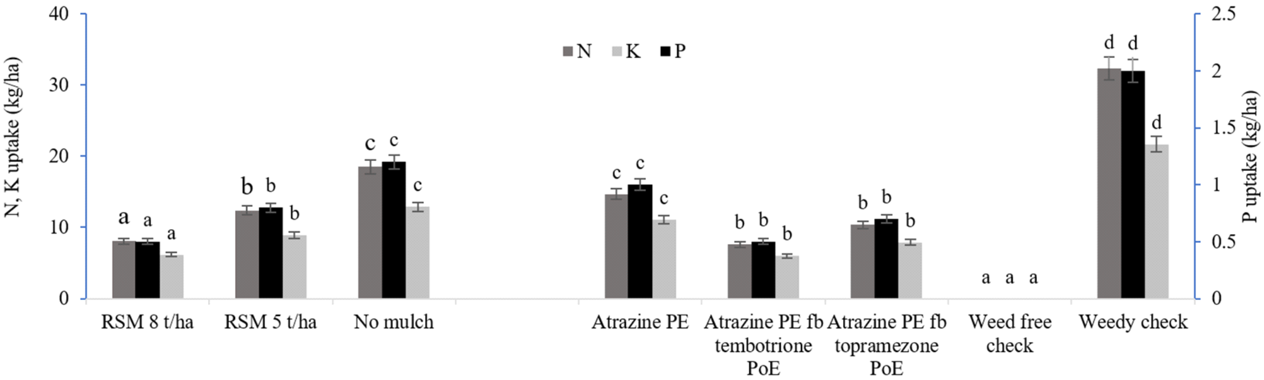

Figure 1. Effect of rice straw mulch and weed management treatments on nutrient uptake by weeds at harvest

RSM = rice straw mulch; *fb* = followed by; PE = pre-emergence application; PoE = post-emergence application

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RESEARCH NOTE

Effect of herbicide application by unmanned aerial vehicle (UAV) on diverse weed flora, summer cotton growth, yield and economics

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ABSTRACT

A field experiment was conducted during February to July 2024 at Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry, to study the effect of herbicide application using Unmanned Aerial Vehicle (UAV) on the diverse weed flora, cotton growth, yield and economics. The experiment consisted of seven treatments, *viz.* pre-emergence application (PE) of pendimethalin 1.0 kg/ha using UAV with spray volume of 25, 37.5, 50 L/ha; pendimethalin 1.0 kg/ha PE using knapsack sprayer with spray volume of 500 L/ha water, inter-cultivation twice at 20 and 45 days after seeding (DAS), inter-cultivation twice followed by (*fb*) manual weeding at 60 DAS and unweeded control. A randomized block design with three replications was used. The grasses were dominant in the experimental plot, with 57.8 % relative density of *Echinochloa colona*. Pendimethalin 1.0 kg/ha on 3 DAS using UAV with a spray volume of 37.5 L/ha resulted in greater reduction in total weed density and biomass with better cotton growth (plant height), yield parameters (number of bolls/plant, boll weight), yield, higher net return and benefit:cost ratio. Uncontrolled weeds caused 87.7 % yield loss in summer cotton of the coastal deltaic ecosystem.

Keywords: Cotton, Economics, Pendimethalin, Spray volume, Unmanned aerial vehicle, Weed management

In India, cotton is a major commercial crop, also known as '*White Gold*' or the '*King of Fibers*' It is an important cash crop that holds a significant position in global agriculture and the industrial economy. It is a long-duration, widely spaced crop that grows slowly in its early stages which is prone to severe weed infestations. Weeds that grow alongside cotton plants cause intense competition and yield reduction to an extent of 50 to 85% (Singh *et al*. 2022). Cotton with minimal weed competition during the early phase, up to 60 days, tends to yield better. To overcome weeds challenge, several weed management practices were developed to achieve effective weed control including the usage of pre-emergence herbicides in the early period of the cotton growth.

Traditionally, manual knapsack sprayers have been used to apply herbicides which consume considerable amounts of energy, time and labour. Additionally, knapsack sprayer usage requires a higher volume of spray liquid and lead to herbicide wastage. Recently, unmanned aerial vehicle (UAV) spray technology has emerged as an ideal alternative for the optimization of resources for herbicide applications as it was found to reduce herbicide wastage, water usage, time, and energy (Supriya *et al.* 2021), while increasing herbicide efficacy, making it a more effective approach for herbicide application. However, the use of UAVs in herbicide application is still novel, and the proper volume of spray liquid for effective weed management in summer cotton are yet to be standardized. Therefore, a field experiment was conducted to evaluate the efficacy of UAV sprayer usage to apply recommended pre-emergence herbicide for managing diverse weed flora in summer cotton of the coastal deltaic ecosystem, Karaikal, Puducherry UT, India.

A field experiment was carried out at Eastern Research Farm of Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry UT, India (10° 55' N latitude and 79° 49' E longitude, 4 meters above mean sea level), during February to July 2024 (Summer). The rainfall distribution pattern of the field site is depicted in **Figure 1**. The soil was neutral in pH (6.72) with the texture of sandy clay loam, low in available N (156.8 kg/ha), high in available P (38.8 kg/ha) and medium in available K (176.0 kg/ha). The experiment was arranged in randomized block design with three replications. Seven treatments were included, *viz.* pre-emergence application (PE) of pendimethalin 1.0 kg/ha using UAV spray with spray volume of 25, 37.5, 50 L/ha; and pendimethalin 1.0 kg/ha PE using knapsack spray with spray volume of 500 L/ha; inter-

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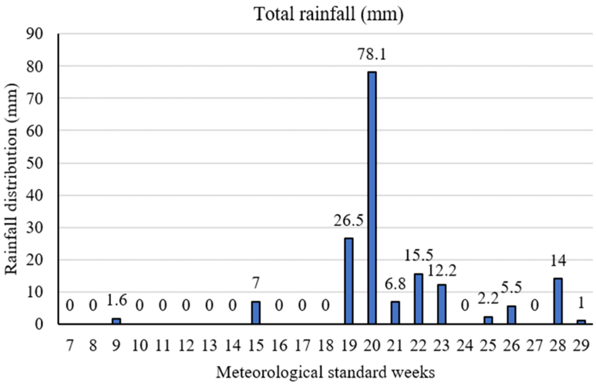

Figure 1. Rainfall prevailed during the cropping period from February to July 2024

cultivation (IC) twice at 20 and 45 days after seeding (DAS); IC twice *fb* manual weeding at 60 DAS and un-weeded control. The pendimethalin 1.0 kg/ha PE (38.7 % CS) was sprayed on 3 DAS. Inter-cultivation twice was carried out using power tiller at 20 and 45 DAS. Further, a common inter-cultivation was carried out in the experimental plots using power tiller at 20 DAS in all pre-emergence pendimethalin sprayed experimental plots. Preceding to cotton, rice crop was cultivated in the experimental fields. After the harvest of rice, experimental area was ploughed twice using tractor- drawn cultivator and then, rotavator was used to break up soil clumps and create a fine, level field for sowing. Cotton Hybrid '*RCH 659 BG II*' (with duration of 160 days) seed was sown during the fourth week of February and harvested during the fourth week of July in 2024. Manual seeding was done using 2.4 kg/ha of seed rate, with 90 cm x 60 cm spacing. The size of the experimental plots was 10.8 m x 8.1 m. The field was surface irrigated immediately after sowing operation to ensure sufficient moisture for the application of pre-emergence herbicide.

The UAV used for herbicide application was hexacopter in nature, equipped with a 10 L tank capacity. It was fitted with four flat fan nozzles, ensuring uniform spray distribution with a spray height of 1 m, with water as a spray fluid using spray volume of 25, 37.5 and 50 L/ha for UAV and the spray speed varies with spray fluid *i.e.,* speed of 7.4, 4.4, 2.7 m/s respectively, and 500 L/ha water was used for spraying pendimethalin 1.0 kg/ha with knapsack sprayer. Entire quantity of phosphorus (60 kg/ha), 50 % of nitrogen and potash were applied basally. The remaining half dose were applied in two equal splits at 45 DAS and 65 DAS. Weed density and dry weight (biomass) data were collected at 80 DAS using a 0.5 m x 0.5 m quadrat (Saravanane 2020). The quadrat was placed at two randomly selected locations within each plot, and the relative density (RD) determined using a standard calculation formula. Weeds were uprooted at ground level during the weed observation at 80 DAS, washed with running water, shade-dried, oven-dried at 70°C for 48 h, and then weighed to determine the weed biomass. Seed cotton yield was measured from the net plot leaving the border rows and expressed in kg/ha. The cost of commercial formulation of pendimethalin used in the study was Rs.650/litre. The drone rental cost during the study period was Rs.400/ac. Based on input, output and drone rental cost, economic indices like gross return, net return, and benefit-cost ratio (BCR) were computed.

The data on weed density and biomass were square root transformed ($\sqrt{x+0.5}$) to normalize their distribution before analysis. The relationship between seed cotton yield and weed biomass at harvest was evaluated using linear regression analysis. The experimental data were analyzed using standard statistical methods (Panse and Sukhatme 1967).

Weed flora

Diverse weed flora was observed in the experimental field including grasses, sedges, broad-leaved weeds and volunteer rice (*Oryza sativa*). Totally nine species of weeds belonging to six families were observed including: three grasses (*Echinochloa colona*, *Dactyloctenium aegyptium* and *Leptochloa chinensis*); one sedge (*Cyperus iria*) and four broad-leaved weeds (*Cleome viscosa*, *Corchorus tridens*, *Phyllanthus niruri* and *Trianthema portulacastrum*). *Echinochloa colona* Link. dominated the weed flora with higher relative density (57.8%) which was followed by *Cleome viscosa* L. (11.4%), *Dactyloctenium aegyptium* (7.0%) and *Trianthema portulacastrum* L. (6.5%). The growth of *Echinochloa colona* in the experimental field was abundant, as it is a troublesome annual C_4 grass with its early flowering ability (Hegazy *et al.* 2005) and further, resilience to high temperatures grant it a competitive advantage over other weeds, especially in dryland conditions common in cotton cultivation. The volunteer rice was also observed in the experimental plot (**Table 1**) due to the use of combined harvesters in preceding rice harvest which lead to shattering of rice seeds and the germination of volunteer rice in the succeeding cotton crop.

Weed density, biomass and weed control efficiency

The density of all the weed species was drastically reduced with pendimethalin application except volunteer rice. Pendimethalin sprayed with both knapsack and UAV sprayers was ineffective in suppressing volunteer rice since pendimethalin herbicide is the recommended selective herbicide in dry direct-seeded rice (Rao 2007, Saravanane 2020). *Echinochloa colona* density and biomass were significantly reduced in UAV spray of 37.5 L/ha with a reduction in the density and dry weight of 84.9 and 95.7%, respectively when compared to the unweeded control (**Table 1**). When pendimethalin was applied to the soil, it was absorbed via root hairs, which inhibited microtubule formation in weeds and effectively controlled the weeds (Saravanane 2020), particularly *Echinochloa colona*. Lower spray fluid volume resulted in more concentrated spray which would potentially increase its effectiveness in suppressing germinating weeds. The spray fluid volume of 37.5 L/ha was lower, leading to a higher herbicide concentration compared to 50 and 500 L/ha, which eventually resulted in effective suppression of weeds and higher weed control efficiency (95.9 %) at 80 DAS. However, higher herbicide concentration under lower spray fluid volume of 25 L/ha resulted in reduced weed control efficiency (89.8 %) which might be due to high operation speed of UAV (7.4 m/s) under low spray volume resulting in poor coverage of experimental field as observed by Karthickraja *et al.* (2024) in direct dry-seeded rice. The results of the current study are in agreement with earlier findings that pre-emergence herbicides serve as the principal tool and foundation of the most effective weed management programs in cotton.

Cotton, yield attributes, yield

Implementing weed management measures led to better growth and yield attributes compared to the un-weeded control. Application of UAV spray using spray volume of 37.5 L/ha resulted in increased plant

Table 1. Effect of weed management treatments on weed density, weed biomass and weed control efficiency (WCE) at 80 DAS in summer cotton

Treatment	Volunteer rice	*E. colona*	Other grasses	*C. iria*	*C. viscosa*	Other BLW	Total weeds	WCE
Weed density (no./m^2)								
Pendimethalin 1.0 kg/ha PE using knapsack sprayer - spray volume of 500 L/ha	1.96(3.3)	7.56(56.7)	0.71(0.0)	2.68(6.7)	3.44(11.3)	1.96(3.3)	9.05(81.3)	92.8
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 25 L/ha	2.55(6.0)	8.40(70.0)	0.71(0.0)	2.92(8.0)	3.63(12.7)	2.27(4.7)	10.1(102.0)	89.8
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 37.5 L/ha	1.58(2.0)	6.52(42.0)	0.71(0.0)	2.27(4.7)	3.03(8.7)	0.71(0.0)	7.65(58.0)	95.9
Pendimethalin 1.0 kg/ha PE using drone- spray volume of 50 L/ha	2.12(4.0)	7.11(50.0)	0.71(0.0)	2.68(6.7)	3.24(10.0)	1.08(0.7)	8.55(72.7)	93.5
Inter-cultivation twice at 20 and 45 DAS	2.27(4.7)	8.63(74.0)	0.71(0.0)	2.42(5.3)	3.14(9.3)	2.68(6.7)	10.2(104.0)	90.3
Inter-cultivation twice + manual weeding at 60 DAS	1.35(1.3)	6.72(44.7)	0.71(0.0)	2.27(4.7)	3.03(8.7)	0.71(0.0)	7.82(60.7)	95.7
Un-weeded control	2.42(5.3)	16.7(279.3)	7.69(58.7)	5.58(30.7)	7.47(55.3)	7.52(56.0)	22.0(483.3)	-
LSD (p=0.05)	0.6	1.7	0.1	0.4	0.4	0.6	1.3	
Weed biomass (g/m^2)								
Pendimethalin 1.0 kg/ha PE using knapsack sprayer - spray volume of 500 L/ha	2.51(5.8)	4.39(18.7)	0.71(0.0)	1.65(2.2)	2.50(5.7)	1.81(2.8)	5.89(34.2)	
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 25 L/ha	3.14(9.4)	4.84(22.9)	0.71(0.0)	1.96(3.3)	2.75(7.1)	2.51(5.8)	7.00(48.5)	
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 37.5 L/ha	1.47(1.6)	3.86(14.4)	0.71(0.0)	1.33(1.3)	1.65(2.2)	0.71(0.0)	4.47(19.5)	
Pendimethalin 1.0 kg/ha PE using drone- spray volume of 50 L/ha	2.30(4.8)	4.24(17.5)	0.71(0.0)	1.57(2.0)	2.26(4.6)	1.09(0.7)	5.58(30.7)	
Inter-cultivation twice at 20 and 45 DAS	2.68(6.7)	5.22(26.8)	0.71(0.0)	1.98(3.4)	1.95(3.3)	2.55(6.0)	6.83(46.2)	
Inter-cultivation twice + manual weeding at 60 DAS	1.29(1.2)	3.95(15.1)	0.71(0.0)	1.40(1.4)	1.72(2.5)	0.72(0.0)	4.55(20.2)	
Un-weeded control	2.07(3.8)	18.4(339.4)	6.73(44.8)	4.33(18.2)	4.28(17.9)	7.11(50.0)	21.8(474.1)	
LSD (p=0.05)	0.1	0.4	0.1	0.1	0.1	0.3	0.4	

* Data in parentheses are original values; Data were subjected to square root transformation ($\sqrt{x+0.5}$); DAS = days after seeding; PE = pre-emergence application; BLW = broad-leaved weeds; *E. colona*: *Echinochloa colona; C. iria: Cyperus iria; C. viscosa: Cleome viscosa*

Table 2. Effect of weed management treatments on growth, yield and weed index in summer cotton

Treatment	Plant height (cm)	No. of bolls/ plant	Boll weight (g)	Seed cotton yield (kg/ha)	Weed index
Pendimethalin 1.0 kg/ha PE using knapsack sprayer - spray volume of 500 L/ha	160.5	56.4	4.4	3735.9	10.9
Pendimethalin 1.0 kg/ha PE using drone -spray volume of 25 L/ha	154.9	51.7	4.1	3516.8	16.1
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 37.5 L/ha	184.3	63.6	4.6	4193.9	-
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 50 L/ha	176.6	62.1	4.5	4076.5	2.8
Inter-cultivation twice at 20 and 45 DAS	140.6	46.7	4.0	3053.4	27.2
Inter-cultivation twice + manual weeding at 60 DAS	158.1	49.5	4.4	3300.7	21.3
Un-weeded control	90.1	11.7	3.2	515.2	87.7
LSD (p=0.05)	4.1	3.4	0.3	362.3	

*DAS = days after seeding; PE = pre-emergence application

Table 3. Effect of various weed management treatments on economics of summer cotton

Treatment	General cost of cultivation including harvesting ($\times10^3$ Rs./ha)	Weed management cost ($\times10^3$ Rs./ha)	Total cost of cultivation ($\times10^3$ Rs./ha)	Gross returns ($\times10^3$ Rs./ha)	Net returns ($\times10^3$ Rs./ha)	B:C ratio
Pendimethalin 1.0 kg/ha PE using knapsack sprayer – spray volume of 500 L/ha	84.74	3.38	88.12	242.83	15.47	2.75
Pendimethalin 1.0 kg/ha PE using drone -spray volume of 25 L/ha	81.14	2.68	83.82	228.59	14.48	2.73
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 37.5 L/ha	90.74	2.68	93.42	272.60	17.92	2.90
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 50 L/ha	89.14	2.68	91.82	264.97	17.31	2.88
Intercultivation twice at 20 and 45 DAS	71.84	7.50	79.34	198.47	11.91	2.50
Intercultivation twice + manual weeding at 60 DAS	75.04	13.50	88.54	214.55	12.60	2.42
Unweeded control	37.84	-	37.84	33.47	-4.4	0.88

Statistically not analysed; DAS = days after seeding; PE = pre-emergence application

height by 51.1% compared to the un-weeded control. The efficient suppression of weed growth in 37.5 L/ha, enhanced nutrient absorption, higher interception of sunlight resulting in greater resource allocation of photosynthates to the yield-attributes and increased 81.6 and 34.7% higher boll numbers and boll weight, respectively compared to the un-weeded control (**Table 2**). Application of UAV spray at 37.5 L/ha recorded higher seed cotton yield due lower weed density, biomass and higher weed control efficiency. However, when weeds were left uncontrolled throughout the growing season induced stress on cotton by competing for resources and hindering overall cotton growth and reducing cotton yield by 87.7%

The scatter plot reveals a strong negative correlation (R^2 = 0.88) between seed cotton yield and weed biomass, indicating that in increase in weed biomass by 1.0 g significant decrease in seed cotton yield by 13.5 kg/ha (**Figure 2)**. Singh *et al*. (2022) reported cotton yield losses of 50 to 85% due to uncontrolled weeds in cotton.

Economics

Application of pendimethalin 1.0 kg/ha PE using drone-spray volume of 37.5 L/ha resulted in the higher gross, net return and B: C ratio of 2.90 **(Table 3)**. The lowest B: C ratio (0.88) and net return were observed in un-weeded control because of poor seed cotton yield. In general, the cost of weed management was lower with pendimethalin 1.0 kg/ha PE using all drone-spray volume plots (₹ 2679/ha) compared to either inter-cultivation twice *fb* manual weeding plot (₹ 13500/ha) or application of pendimethalin 1.0 kg/ha PE using with knapsack sprayer (₹ 3379/ha). Garre and Harish (2018) opined that using drones to apply plant protection chemicals could reduce production costs.

Thus, it was concluded that farmers can opt for pre-emergence application of pendimethalin 1.0 kg/ha 3 DAS using UAV spray with a spray volume of 37.5 L/ha to effectively manage the diverse weed flora and enhance the summer cotton yield.

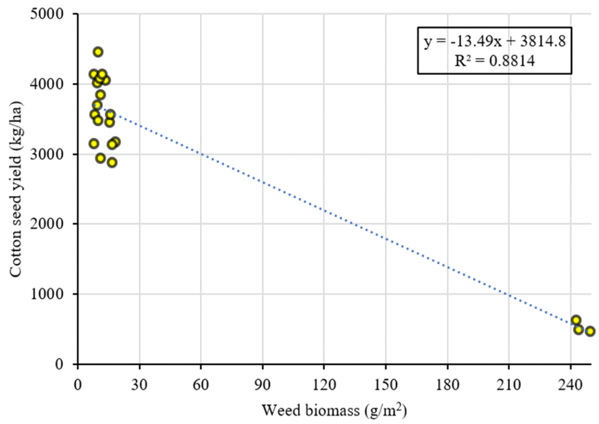

Figure 2. Relationship between weed biomass and seed cotton yield at harvest stage in summer cotton

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RESEARCH NOTE

Weed dynamics and productivity of soybean as influenced by different post-emergent herbicides

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ABSTRACT

A field experiment was conducted at Punjab Agricultural University, Ludhiana and Dr J C Bakhshi Regional Research Station, Abohar, Punjab (India), during *Kharif* (rainy season) 2021to identify effective and economic post-emergent herbicide for managing weeds in soybean and improve productivity of soybean [*Glycine max* (L.) Merrill]. The experiment consisted of 12 treatments, *viz.* post-emergence application (PoE) of imazethapyr 75 g/ha; propaquizafop + imazethapyr at 75, 100, and 125 g/ha; sodium-acifluorfen + clodinafop-propargyl at 147, 196, and 245 g/ha; imazamox + imazethapyr at 42, 56 and 70 g/ha; hand weeding (HW) twice at 20 and 40 days after sowing (DAS) and weedy check. A randomized complete block design with three replications was used. The lowest weed density and highest soybean biological and seed yield were recorded with HW twice, which was statistically at par with imazamox + imazethapyr 70 g/ha PoE at 15-20 DAS. It was concluded that imazamox + imazethapyr 70 g/ha PoE at 15-20 DAS improves the soybean seed yield with highest benefit:cost ratio, due to effective broad spectrum weed control.

Keywords: Imazamox + imazethapyr**,** Post-emergent herbicides, Soybean, Weed management

Soybean [*Glycine max* (L.) Merrill] is an important legume crop worldwide. Its global production reached 353.2 million tonnes (mt) from 139.4 million hectares (mha) area, with an average yield of 2.53 t/ha. India produced 15.2 mt from 13.1 mha area, with a productivity of 1.02 t/ha (FAOSTAT 2025). Soybean seeds are rich in protein (36-43%) and oil (18-24%), containing high levels of polyunsaturated fatty acids, especially Omega 6 and Omega 3 (Kumar *et al.* 2022). Weeds pose a significant challenge to soybean productivity, reducing yields by 50-76% (Virk *et al.* 2018) due to competition for light, moisture, and nutrients, and by harboring pests. Soybean's low competitiveness during early growth and its rainy-season cultivation makes it vulnerable to weed infestations. Economic losses due to weeds in Indian soybean were estimated at USD 1559 million (Gharde *et al.* 2018). Manual weeding is challenging due to labour shortages and frequent heavy rainfall; therefore, using herbicides a more viable option (Rajput and Kasana 2020).

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Although pendimethalin continues to be widely used as a pre-emergence herbicide in soybean, its efficacy diminishes when application is delayed (Virk *et al.* 2018). Post-emergence herbicides, applied within 15-20 days of sowing, offer a more effective solution for weed control during critical crop-weed competition periods. The post-emergence application (PoE) of imazethapyr + imazamox at 80 g/ha proved highly effective in managing both dominant grassy and broad-leaved weeds, resulting in the highest greengram seed yield (Gupta *et al.* 2019). The need for effective control of the diverse weed flora necessitates the use of various herbicide combinations (Patel *et al.* 2021) and to study the efficacy of different post-emergence herbicides on weeds and productivity of soybean under different agro-climatic regions. Hence, this study was conducted with an objective to identify effective and economic post-emergent herbicide for managing weeds in soybean and improve soybean productivity.

A field experiment was conducted during *Kharif* (rainy) 2021 at Research Farm of Pulses Section, Department of Plant Breeding and Genetics, Punjab Agricultural University (PAU), Ludhiana and Dr J C Bakhshi Regional Research Station, Abohar, PAU Ludhiana. The soil of the experimental sites had a pH of 7.3 and 7.1, organic carbon content of 0.22 and 0.38%, available phosphorus of 24.0 and 13.5 kg/ha and available K of 274.3 and 267.2 kg/ha at Ludhiana and Abohar, respectively. A total 770.6 and 127.8 mm rainfall was received at Ludhiana and Abohar, respectively during the crop growing season. Both experiments were arranged in a randomized complete block design with three replications. There were 12 treatments viz., post-emergence application (PoE) of imazethapyr 75 g/ha; propaquizafop + imazethapyr at 75, 100, and 125 g/ha; sodium acifluorfen + clodinafop propargyl at 147, 196, and 245 g/ha; imazamox + imazethapyr at 42, 56, and 70 g/ha; hand weeding (HW) twice at 20 and 40 days after sowing (DAS) and a weedy check. Before sowing, a pre-sowing irrigation was applied and the field was ploughed twice followed by *(fb)* planking for seedbed preparation. Soybean variety '*SL 958*' was sown on 4^{th} June, 2021 at Abohar and 10^{th} June, 2021 at Ludhiana with seed rate of 75 kg/ha, row spacing of 45 cm and plant to plant spacing of 5 cm. Herbicides were sprayed at 15-20 days, *i.e*. on 25th June at Ludhiana and 22nd June at Abohar in 2021, after crop emergence using 375 litres of water/ha using a knapsack sprayer fitted with a flat fan nozzle. Hand weeding was done manually using khurpa in the hand weeding twice treatment, while in the weedy check, weeds were not removed throughout the crop season. A total of 31.25 kg/ha nitrogen and 60 kg/ha phosphorus were applied using urea and SSP during sowing as basal.

The weed density was measured at 30 and 60 DAS using a 50 × 50 cm quadrat by randomly placing quadrat at two places in each of the plot. The number of weeds within the quadrat was counted specie-wise and converted to number per square meter. Weed control efficiency (WCE) was estimated from the total weed population (weed density) at 30 and 60 DAS using the equation:

$$\text{Weed control efficiency (\%)} = \frac{\text{Weed population in weedy check (no./m}^2\text{)- Weed population in treated plot}}{\text{Weed population in weedy check (no./m}^2\text{)}}$$

The weight of sun-dried bundles of crop from each plot was measured prior to threshing and recorded as the biological yield/plot and converted into t/ha. After sun drying, the crop from each plot was threshed and seed yield from each plot was weighed separately and converted into t/ha. The harvest index was calculated as the ratio of seed yield to biological yield:

$$\text{Harvest index (\%)} = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

The benefit-cost (B:C) ratio was calculated by dividing net returns with total variable costs. Data were analysed with RStudio using ANOVA for a randomized complete block design (R 2024). Weed density was transformed using square root and means were compared via Duncan's multiple range test (DMRT) at the 0.05 level. Data on weed density were square root transformed and means were compared via DMRT at the 5% level of significance (p=0.05).

Effect on weeds

At Ludhiana, the predominant weed species were: *Digitaria sanguinalis*, *Dactyloctenium aegyptium*, *Commelina benghalensis*, and *Acrachne racemosa among grassy weeds*, *Trianthema portulacastrum* among broad-leaved weeds and *Cyperus rotundus* among sedges (**Table 1**). At Abohar, the major weeds were *Digitaria sanguinalis* and *Dactyloctenium aegyptium* among grassy weeds, *Trianthema portulacastrum* and *Digera arvensis* among broad-leaved weeds and *Cyperus rotundus* dominant among sedges.

At Ludhiana, at 30 DAS, imazethapyr 75 g/ha recorded the highest relative density of grassy weeds (72.1%), indicating its lower efficacy against this group. The grassy weed dominance (65–70%) was observed in propaquizafop + imazethapyr and sodium-acifluorfen + clodinafop treated plots. Imazamox + imazethapyr caused greater reduction in density of grassy weeds by 66.7–67.7% and sedges by 23–24%. At 60 DAS, sodium-acifluorfen + clodinafop 245 g/ha was most effective on broad-leaved weeds and caused the highest suppression of broad-leaved and sedge weeds. Likewise, imazamox + imazethapyr 70 g/ha and propaquizafop + imazethapyr 125 g/ha effectively managed non-grassy weeds, with over 93% of the total weed density being grassy.

At Abohar, at 30 DAS, grassy weeds were dominant in all treatments (52.4–63.5%), with the highest in imazamox + imazethapyr. Sodium-acifluorfen + clodinafop and propaquizafop + imazethapyr showed better management of grasses. Broad-leaved weeds remained below 18.5% under all herbicides, while their complete control was achieved with hand weeding twice. Sedge weeds proportion was highest with hand weeding twice (41.7%) and lowest with imazamox + imazethapyr 70 g/ha (24.1%). At 60 DAS, grassy weeds remained dominant, especially with imazamox + imazethapyr (up to 86.2%). Sodium-acifluorfen + clodinafop effectively reduced sedges (7.4%) with moderate grassy weed infestation. Propaquizafop + imazethapyr showed balanced weed control, with 68–69% reduction in grassy weeds density and lower density of broad-leaved and sedge weeds.

The lowest density of grassy weeds, broad-leaved weeds and sedges and the highest WCE at 30 and 60 DAS (**Table 2**) was observed with HW twice at both locations. Imazamox + imazethapyr 70 g/ha recorded the lowest density of grassy and broad-leaved weeds and the highest WCE at 30 and 60 DAS followed by sodium-acifluorfen + clodinafop-propargyl 245 g/ha, propaquizafop + imazethapyr 125 g/ha and imazethapyr 75 g/ha at 15-20 DAS. The sedges were effectively controlled by imazamox + imazethapyr 70 g/ha followed by imazethapyr 75 g/ha at 20 DAS at both locations. Weed control efficiency increased at 60 DAS due to reduction in growth of weeds and improvement in growth of crop, which helped in suppressing the weeds. The higher WCE at 60 and 90 DAS in soybean was reported with imazethapyr + imazamox at 100 g/ha at 20 DAS followed by one hoeing at 35 DAS by Rajput et al. (2019). The efficacy of imazethapyr + imazamox 80 g/ha PoE in managing weeds in black gram was reported earlier (Rana *et al.* 2019).

Effect on soybean

Biological and seed yield were significantly influenced by different treatments of weed control (**Table 2**). Hand weeding twice recorded the highest soybean biological yield and seed yield, statistically similar to imazamox + imazethapyr 70 g/ha at 15-20 DAS, at both the locations due to better growth as a consequence of lesser crop-weed competition, which ultimately shifted the nutrients, light, water and space in favour of the crop. The lowest yield was recorded in the weedy check due to more weed density, which resulted in more competition of weeds with crop thereby reducing its growth. Weeds caused 46.7% and 51.2% soybean yield reduction in weedy check when compared to hand weeding twice, at Ludhiana and Abohar, respectively. Herbicides significantly affected the harvest index at Abohar but not at Ludhiana, which could be due to the large difference in rainfall between the locations. Limited rainfall at Abohar (127.8 mm) caused moisture stress that intensified weed competition and reduced seed filling, while Ludhiana's ample rainfall (770.6 mm) minimized stress, resulting in less variation in harvest index across treatments.

The highest harvest index was recorded with HW twice which was statistically similar to imazethapyr 75 g/ha, propaquizafop + imazethapyr,

Table 1. Effect of different weed management treatments on weed density at 30 and 60 days after seeding (DAS) in Ludhiana (LDH) and Abohar (ABH)

Treatment	Grassy weeds				Broad-leaved weeds				Sedges			
	30 DAS		60 DAS		30 DAS		60 DAS		30 DAS		60 DAS	
	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH
Imazethapyr 75 g/ha	10.7^{c} (114.6)	7.8^{b} (60.0)	8.1^{c} (66.6)	5.5^{d} (29.3)	3.6^{c} (12.0)	4.4^{b} (18.6)	1.0^{c} (0.0)	2.5^{c} (5.3)	5.7^{c} (32.0)	5.1^{c} (25.3)	2.7^{d} (6.6)	3.4^{d} (10.6)
Propaquizafop + imazethapyr 75 g/ha	11.2^{b} (124.0)	8.2^{b} (66.7)	8.2^{c} (66.6)	7.0^{b} (48.0)	4.3^{b} (17.3)	4.1^{c} (16.0)	1.0^{c} (0.0)	2.2^{c} (4.0)	6.9^{b} (48.0)	6.4^{ab} (40.0)	4.7^{b} (21.3)	4.3^{b} (17.3)
Propaquizafop + imazethapyr 100 g/ha	10.7^{c} (113.3)	7.9^{b} (61.3)	7.4^{d} (54.6)	6.1^{c} (36.0)	3.9^{b} (14.6)	4.0^{c} (14.6)	1.0^{c} (0.0)	1.9^{d} (2.7)	6.4^{b} (41.3)	5.7^{b} (32.0)	3.4^{c} (10.6)	3.8^{c} (13.3)
Propaquizafop + imazethapyr 125 g/ha	9.9^{d} (97.3)	7.4^{c} (53.3)	6.3^{e} (38.6)	4.6^{f} (20.0)	3.6^{c} (12.0)	3.7^{e} (13.3)	1.0^{c} (0.0)	1.5^{e} (1.3)	6.1^{c} (37.3)	5.6^{b} (30.6)	1.8^{e} (2.6)	3.0^{d} (8.0)
Sodium-acifluorfen + clodinafop-propargyl 147 g/ha	10.6^{c} (110.0)	8.0^{b} (64.0)	9.1^{b} (82.6)	6.6^{b} (42.6)	4.1^{b} (16.0)	4.6^{b} (20.0)	1.5^{b} (1.3)	3.6^{b} (12.0)	5.7^{d} (32.0)	5.7^{b} (32.0)	2.5^{d} (5.3)	2.7^{e} (6.6)
Sodium acifluorfen + clodinafop-propargyl 196 g/ha	9.9^{d} (98.6)	7.6^{c} (57.3)	8.2^{c} (68.0)	5.5^{d} (29.3)	3.6^{c} (12.0)	4.1^{c} (16.0)	1.0^{c} (0.0)	2.2^{c} (4.0)	5.6^{d} (30.6)	5.6^{b} (30.6)	1.8^{e} (2.6)	2.5^{e} (5.3)
Sodium-acifluorfen + clodinafop-propargyl 245 g/ha	9.6^{e} (92.0)	7.2^{cd} (50.7)	7.4^{d} (54.6)	5.1^{e} (25.3)	3.6^{c} (12.0)	3.9^{e} (14.6)	1.0^{c} (0.0)	2.2^{c} (4.0)	5.2^{e} (26.6)	5.6^{b} (30.6)	1.4^{f} (1.3)	1.8^{g} (2.6)
Imazamox + imazethapyr 42 g/ha	9.8^{de} (96.0)	7.2^{cd} (52.0)	7.9^{d} (62.6)	6.6^{b} (42.6)	3.9^{b} (14.6)	3.9^{e} (14.6)	1.0^{c} (0.0)	1.9^{d} (2.7)	5.8^{c} (33.3)	4.9^{c} (22.6)	2.5^{d} (5.3)	2.2^{f} (4.0)
Imazamox + imazethapyr 56 g/ha	9.2^{f} (84.0)	6.9^{d} (46.7)	6.7^{e} (45.3)	5.9^{c} (34.6)	3.6^{c} (12.0)	3.6^{f} (12.0)	1.0^{c} (0.0)	1.9^{d} (2.7)	5.5^{c} (29.3)	4.7^{c} (21.3)	1.8^{e} (2.6)	2.2_{f} (4.0)
Imazamox + imazethapyr 70 g/ha	8.5^{g} (72.0)	6.5^{d} (41.3)	5.2^{f} (26.6)	4.1^{g} (16.0)	3.2^{d} (9.3)	3.2^{g} (9.3)	1.0^{c} (0.0)	1.5^{e} (1.3)	5.1^{e} (25.3)	4.1^{d} (16.0)	1.4^{f} (1.3)	1.8^{g} (2.6)
Hand weeding twice	3.8^{h} (13.3)	2.9^{e} (8.0)	4.1^{g} (16.0)	3.2^{h} (12.0)	1.0^{e} (0.0)	1.0^{h} (0.0)	1.0^{c} (0.0)	1.5^{e} (1.3)	3.6^{f} (12.0)	2.5^{e} (5.3)	2.7^{b} (6.6)	2.5^{e} (5.3)
Weedy check	12.4^{a} (153.3)	8.7^{a} (76.0)	15.0^{a} (228.0)	10.2^{a} (102.7)	4.7^{a} (22.6)	5.3^{a} (26.6)	5.8^{a} (33.3)	6.1^{a} (36.0)	7.6^{a} (57.3)	6.7^{a} (44.0)	8.4^{a} (69.3)	7.9^{a} (61.3)

Original data in parenthesis. Data was transformed by square root transformation before statistical analysis, n=3. Transformed means superscripted with same alphabets within a row are not significantly different from each other based on Duncan's multiple range test at $p=0.05$.

Table 2. Effect of weed management treatments on weed control efficiency, soybean, yield, harvest index and B:C ratio in Ludhiana (LDH) and Abohar (ABH)

Treatment	Weed control efficiency (%)				Seed yield (t/ha)		Stover yield (t/ha)		Biological yield (t/ha)		Harvest index (%)		B:C ratio	
	30 DAS		60 DAS											
	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH
Imazethapyr 75 g/ha	31.9^{e}	28.0^{fg}	77.4^{ef}	77.4^{de}	1.70^{b}	1.32^{bc}	4.83^{ab}	5.28^{abcd}	6.54^{ab}	6.60^{bc}	26.09^{a}	20.13^{abc}	1.58^{ab}	1.06^{bc}
Propaquizafop + imazethapyr 75 g/ha	18.6^{g}	15.9^{i}	73.0^{f}	65.2^{g}	1.39^{de}	1.01^{ef}	4.18^{bc}	5.17^{abcd}	5.57^{cde}	5.99^{de}	25.19^{a}	17.17^{cd}	1.07^{e}	0.59^{fg}
Propaquizafop + imazethapyr 100 g/ha	27.1^{f}	24.8^{gh}	80.1^{de}	73.9^{e}	1.49^{cd}	1.15^{cde}	4.36^{b}	5.18^{abcd}	5.86^{cd}	6.34^{cde}	25.46^{a}	18.20^{bcd}	1.17^{bcde}	0.75^{cde}
Propaquizafop + imazethapyr 125 g/ha	37.1^{d}	31.6^{ef}	87.3^{bc}	85.4^{bc}	1.71^{b}	1.34^{bc}	4.94^{ab}	5.39^{abc}	6.65^{ab}	6.74^{bc}	25.94^{a}	20.00^{abc}	1.45^{bcd}	0.98^{bc}
Clodinafop-propargyl + sodium-acifluorfen 147 g/ha	31.8^{e}	19.6^{hi}	72.4^{f}	69.3^{f}	1.23^{ef}	1.04^{def}	3.86^{c}	4.70^{d}	5.09^{e}	5.75^{e}	24.31^{a}	18.26^{bcd}	0.87^{f}	0.64^{ef}
Clodinafop-propargyl + sodium-acifluorfen 196 g/ha	39.4^{cd}	28.1^{fg}	78.1^{de}	80.6^{cd}	1.42^{de}	1.10^{de}	3.89^{c}	4.82^{cd}	5.32^{de}	5.93^{de}	26.88^{a}	18.58^{bcd}	1.12^{de}	0.70^{def}
Clodinafop-propargyl + Sodium acifluorfen 245 g/ha	43.8^{bc}	34.1^{de}	83.1^{cd}	84.1^{bc}	1.56^{bcd}	1.24^{bcd}	4.09^{bc}	5.07^{bcd}	5.65^{cde}	6.31^{cde}	27.84^{a}	19.65^{abc}	1.29^{bcde}	0.89^{bcd}
Imazamox + imazethapyr 42 g/ha	38.1^{cd}	38.8^{cd}	78.7^{de}	75.4^{de}	1.45^{d}	1.34^{bc}	4.33^{b}	5.06^{bcd}	5.79^{cd}	6.41^{cd}	25.23^{a}	20.97^{abc}	1.18^{cde}	1.04^{bc}
Imazamox + imazethapyr 56 g/ha	46.2^{bc}	44.4^{c}	85.4^{bc}	79.4^{cd}	1.68^{bc}	1.40^{b}	4.40^{ab}	5.23^{abcd}	6.08^{bc}	6.64^{bc}	27.84^{a}	21.22^{abc}	1.47^{bc}	1.11^{ab}
Imazamox + imazethapyr 70 g/ha	54.3^{b}	54.7^{b}	91.4^{b}	89.2^{b}	1.92^{ab}	1.62^{ab}	4.88^{ab}	5.53^{ab}	6.81^{ab}	7.15^{ab}	28.28^{a}	22.66^{ab}	1.77^{a}	1.38^{a}
Hand weeding twice at 20 and 40 DAS	89.2^{a}	90.4^{a}	93.1^{a}	90.8^{a}	2.07^{a}	1.72^{a}	5.09^{a}	5.71^{a}	7.16^{a}	7.44^{a}	29.04^{a}	23.26^{a}	1.67^{ab}	1.27^{ab}
Weedy check	0.0	0.0	0.0	0.0	1.10^{f}	0.84^{f}	4.00^{bc}	4.90^{cd}	5.11^{e}	5.74^{e}	21.67^{a}	14.94^{d}	0.76^{f}	0.41^{g}

Data are represented as mean, n=3. Means superscripted with same alphabets within a row are not significantly different from each other based on Duncan's multiple range test at $\sqrt{x+0.5}$. DAS = days after seeding

and sodium-acifluorfen + clodinafop- propargyl at Abohar. The higher soybean seed yield was observed with imazethapyr + imazamox 100 g/ha PoE at 20 DAS + hoeing at 35 DAS in soybean (Deshkari *et al* 2019) and with imazethapyr + imazamox 40 g/ha in blackgram (Yadav *et al.* 2015).

At Ludhiana, imazamox + imazethapyr 70 g/ha PoE at 15–20 DAS recorded the highest B:C ratio (**Table 2**), which was statistically at par with imazethapyr 75 g/ha and hand weeding twice at 20 and 40 DAS. At Abohar, the highest B:C ratio was recorded with imazamox + imazethapyr 70 g/ha, which was comparable with imazamox + imazethapyr 56 g/ha and hand weeding twice.

In conclusion, imazamox + imazethapyr at 70 g/ha PoE at 15-20 DAS significantly reduced the density of dominant weeds recording higher weed control efficiency which resulted in higher soybean seed yield and B:C ratio.

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RESEARCH NOTE

Efficacy of a few new generation herbicides in managing weeds and improving soybean productivity and profitability

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ABSTRACT

The experiment was conducted at the Agricultural Research Station, Adilabad, Professor Jayashankar Telangana State Agricultural University (PJTSAU), Telangana during *Kharif*, 2022 to assess the efficacy of weed management treatments on weed control, soybean productivity and profitability and identify effective and economical option. A randomized block design with 11 treatments replicated thrice was used. Among herbicidal treatments, pre-emergence application (PE) diclosulam 26 g/ha followed by (*fb*) post-emergence application (PoE) of fluazifop-p-butyl + fomesafen 250 g/ha recorded highest soybean seed yield, gross returns and net returns which was comparable with imazethapyr +pendimethalin 960 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE.

Keywords: Soybean, Diclosulam, Fluazifop-p-butyl + fomesafen and Imazethapyr + pendimethalin, Intercultivation

Soybean (*Glycine max* L.) is a vital oilseed crop that has gained popularity worldwide due to its adaptability to diverse agro-climatic conditions, unique chemical composition and multiple uses. It is utilized in feed production, as a food source and in several non-edible industries. Soybean enriches soil fertility by fixing atmospheric nitrogen symbiotically through root nodules and contributes about 25 per cent of the fixed nitrogen to the succeeding crop

The major soybean-growing states in India are Madhya Pradesh, Maharashtra, Rajasthan, Karnataka, and Telangana. In Telangana, soyabean was cultivated in 2,01,066 hectares with a production of 3,24,556 tons and productivity of 1.63 t/ha during 2022-2023 (DES 2025). In Adilabad district, Telangana, soybean is the second major crop, after cotton, predominantly grown in black cotton soils. The sowing window of soybean in the rainy season is very short and farmers prioritize timely sowing. Among several constraints in soybean production, weed infestation is one of the major constraints limiting the higher productivity of soybean (Deshmukh *et al*. 2025). Being a rainy season crop, soybean faces severe weed competition during its early growth stages, which reduces yield potential depending on weed type, intensity, and environmental factors (Jadhav and Kashid 2019). Weeds compete with crop for light, moisture and nutrients (Rao 2022).

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Due to intermittent rainfall and limited labour availability during rainy season, manual weeding at critical stage is often difficult, tedious and costly. Farmers, therefore, are increasingly adopting herbicide-based weed management. However, a single application of herbicide is not effective against complex weed flora throughout the crop-growing season. Sole herbicide use may not effectively control grasses, sedges, and broad-leaved weeds. Therefore, identifying herbicide mixtures with a broad-spectrum activity and residual effect is essential for achieving higher soybean productivity.

New-generation herbicides, effective even at very low application rates, offer lower mammalian toxicity and minimize the risk of environmental pollution. Their use, either alone or in conjunction with manual or chemical weeding, has been shown to effectively suppress weed growth (Deshmukh *et al*. 2025). However, the effectiveness of new-generation herbicides in soybean has not yet been thoroughly evaluated. Their crop selectivity and economic viability must be assessed to design a cost-effective herbicide-based weed management strategy. In this context, the present study was undertaken to identify a suitable herbicide-based weed management approach for soybean by evaluation efficacy of different weed management treatments.

The field experiment was conducted during *Kharif*, 2022 at Agricultural Research Station, Adilabad, Telangana on black soil, neutral in nature, low in available nitrogen, medium in P and high in potassium. The study was laid out in a randomized block design with 11 treatments replicated thrice. The treatments comprised various pre-emergence herbicides in combination with post-emergence herbicides or intercultivation (using hand hoe). The new low dose herbicides used were diclosulam, imazethapyr + pendimethalin, pyroxasulfone for pre-emergence application (PE) and fluazifop-p-butyl + fomesafen, sodium-acifluorfen + clodinafop propargyl for post-emergence application (PoE). The treatments comprised of imazethapyr + pendimethalin 960 g/ha PE followed by (*fb*) intercultivation at 20-25 days after seeding (DAS), pyroxasulfone 127.5 g/ha PE *fb* intercultivation at 20-25 DAS, diclosulam 26 g/ha PE *fb* intercultivation at 20-25 DAS, diclosulam 26 g/ha PE *fb* post-emergence application (PoE) of sodium- acifluorfen + clodinafop-propargyl 250 g/ha, diclosulam 26 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE, imazethapyr + pendimethalin 960 g/ha PE *fb* sodium-acifluorfen + clodinafop propargyl 250 g/ha PoE, imazethapyr + pendimethalin 960 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE, pyroxasulfone 127.5 g/ha PE *fb* sodium-acifluorfen + clodinafop propargyl 250 g/ha PoE , pyroxasulfone 127.5 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE, intercultivation at 20-25 DAS *fb* hand weeding at 40 DAS and unweeded control. Soybean variety JS-335 was sown at a seed rate of 65 kg/ha, with 45 × 10 cm spacing. The crop was fertilized with 50:60:20 kg/ha Nitrogen, Phosphorous and Potassium, respectively in the form of urea DAP, MOP. Seed were inoculated with Brady Rhizobium culture 200 g/8 kg of seed. Pre-emergent herbicides were applied at 2 days after seeding (DAS) while post-emergent herbicides were sprayed at 20 DAS using 500 L of water/ha with a flat fan nozzle fitted knapsack sprayer. The observations on weed density (no/m^2) and weed dry weight (biomass) (g/m^2) were recorded at 15, 30 and 45 DAS using a 0.25 square meter (0.5 x 0.5 m) quadrat, using standard recommended procedures Weed control efficiency (%) was calculated using standard procedure.

Effect on weeds

Grasses and broad-leaved weeds (BLW) were the major weeds in the experimental site. The grasses were: *Cynodon dactylon, Echinichloa colonum, Dactyloctenium aegyptium* and *Digitaria sanguinalis*. The broad-leaved weeds were: *Commelina benghalensis, Amaranthus viridis, Digera arvensis, Parthenium hysterophorus* and *Euphorbia hirta*.

The intercultivation at 20-25 DAS *fb* hand weeding at 40 DAS resulted in the lowest weed density of all weed categories, and it was followed by diclosulam 26 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE , and it was on comparable with imazethapyr + pendimethalin 960 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE, diclosulam 26 g/ha PE *fb* intercultivation 20-25 DAS, diclosulam 26 g/ha PE *fb* sodium- acifluorfen + clodinafop-propargyl 250 g/ha PoE and imazethapyr + pendimethalin 960 g/ha PE *fb* sodium-acifluorfen + clodinafop- propargyl 250 g/ha PoE , which were found to be promising broad-spectrum herbicides for weed control in soybean (**Table 1**). Diclosulam is a soil-applied acetolactate synthase (ALS) inhibiting herbicide which results in a blockage of the synthesis of branched-chain amino acids (valine, leucine, and isoleucine). The deficiency of these amino acids, leading to a decrease in DNA and protein synthesis, which adversely affects cellular division and photosynthate translocation to growing points of

Table 1. Weed density and biomass and weed control efficiency at 45 DAS as influenced by weed management treatments in soybean

Treatment	Weed density (no./m^2)			Weed biomass (g/ m^2)	Weed control efficiency (%)
	Grasses	Broad leaved weeds	Sedges		
Imazethapyr + pendimethalin 960 g/ha PE *fb* intercultivation 20-25 DAS	3.40 (11.0)	3.67 (13.0)	2.37 (5.1)	5.47 (29.5)	71.23
Pyroxasulfone 127.5 g/ha PE *fb* intercultivation 20-25 DAS	4.20 (17.1)	4.01 (15.6)	2.51 (5.8)	5.39 (28.5)	72.14
Diclosulam 26 g/ha PE *fb* intercultivation 20-25 DAS	3.01 (8.6)	3.24 (10.0)	2.01 (3.5)	4.23 (17.4)	82.95
Diclosulam 26 g/ha PE *fb* sodium- acifluorfen + clodinafop-propargyl 250 g/ha PoE	3.19 (9.7)	3.29 (10.3)	2.10 (3.9)	4.38 (18.7)	81.70
Diclosulam 26 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE	2.75 (7.1)	3.06 (8.9)	2.01 (3.5)	3.92 (14.8)	85.51
Imazethapyr + pendimethalin 960 g/ha PE *fb* sodium-acifluorfen + clodinafop- propargyl 250 g/ha PoE	3.29 (11.0)	3.49 (11.7)	2.34 (5.0)	4.61 (20.8)	79.66
Imazethapyr + pendimethalin 960 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE	2.98 (8.4)	3.13 (9.3)	2.04 (3.7)	4.17 (16.9)	83.50
Pyroxasulfone 127.5 g/ha PE *fb* sodium-acifluorfen + clodinafop propargyl 250 g/ha PoE	3.65 (12.8)	4.85 (23.0)	2.73 (7.0)	5.59 (30.7)	70.00
Pyroxasulfone 127.5 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE	3.40 (11.1)	3.53 (12.0)	2.57 (6.1)	5.39 (28.6)	72.07
Intercultivation (20-25 DAS) *fb* hand weeding (40 DAS)	1.61 (2.1)	3.01 (18.6)	1.13 (0.8)	3.12 (9.2)	90.95
Unweeded control	7.27 (52.3)	8.05 (64.3)	3.85 (14.3)	10.1 (102.5)	-
LSD (p=0.05)	0.56	0.45	0.35	0.71	

Note: Figures in parenthesis are the original values; square root transformation ($\sqrt{x+0.5}$) used for statistical analysis. *fb* = followed by; PE = pre-emergence application; PoE = post-emergence application

Table 2. Seed yield, weed index, gross return, net return & B: C ratio as influenced by weed management treatments in soybean

Treatment	Seed yield (kg/ha)	Weed index (%)	Cost of cultivation	Gross returns	Net returns	B:C ratio
Imazethapyr + pendimethalin 960 g/ha PE *fb* intercultivation 20-25 DAS	1545	40.7	52095	66421	14325	1.28
Pyroxasulfone 127.5 g/ha PE *fb* intercultivation 20-25 DAS	1384	47.7	52483	59498	7015	1.13
Diclosulam 26 g/ha PE *fb* intercultivation 20-25 DAS	1954	26.1	51570	84008	32438	1.63
Diclosulam 26 g/ha PE *fb* sodium- acifluorfen + clodinafop-propargyl 250 g/ha PoE	1886	28.4	49883	81084	31201	1.63
Diclosulam 26 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE	2280	14.2	50095	98040	47945	1.96
Imazethapyr + pendimethalin 960 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl 250 g/ha PoE	1654	37	50408	71136	20728	1.41
Imazethapyr + pendimethalin 960 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE	2089	21.5	50620	89813	39193	1.77
Pyroxasulfone 127.5 g/ha PE *fb* sodium-acifluorfen + clodinafop propargyl 250 g/ha PoE	1443	45.8	50795	62049	11254	1.22
Pyroxasulfone 127.5 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE	1548	41.7	51008	66564	15556	1.31
Intercultivation (20-25 DAS) *fb* hand weeding (40 DAS)	2662	-	55170	114466	59296	2.08
Unweeded control	1152	56.3	44920	49550	4630	1.10
LSD (p=0.05)	318			13709		

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

weeds. Further, Kadam *et al*. (2018) reported that fluazifop-p-butyl + fomesafen 250 g/ha PoE effectively reduced total weed density due to its dual mode of action. Fomesafen inhibits lipid synthesis and also fatty acid elongation. Fluazifop-p-butyl inhibits acetyl CoA carboxylase. This combination provides broad-spectrum and prolonged weed control by preventing weed emergence during the early crop growth period.

The percentage reduction in weed biomass over unweeded control ranged from 70 to 90.95 % at 45 DAS (**Table 1**). Maximum weed control efficiency was recorded with intercultivation (20-25 DAS) *fb* hand weeding (40 DAS) followed by diclosulam 26 g/ ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE and imazethapyr + pendimethalin 960 g/ha PE fb sodium-acifluorfen + clodinafop-propargyl 250 g/ha PoE. The effective pre- and post-emergence application of herbicides effectively managed weed growth, shifted crop–weed competition in favour of soybean.

Effect on soybean seed yield, weed index and economics

Significantly higher seed yield of soybean was obtained with intercultivation at 20-25 DAS *fb* hand weeding at 40 DAS and it was followed by diclosulam 26 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE which was comparable with imazethapyr + pendimethalin 960 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE. The yield advantage in these treatments was due to reduced weed density and biomass, and higher weed control efficiency.

Weed competition throughout the crop season resulted in a yield loss of 56.3% in unweeded control. The percentage reduction in yield due to weed infestation was denoted by weed index. Amongst the treatments, the lowest weed index was recorded with diclosulam 26 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE which was followed by imazethapyr + pendimethalin 960 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE.

It is essential for farmers to adopt economically viable weed management practices that can lower input costs without compromising yields. Among herbicidal treatments diclosulam 26 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE and imazethapyr + pendimethalin 960 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE gave significantly higher gross returns, net returns and benefit-cost ratio. These findings are in agreement with Aher *et al.* (2023).

Conclusion

It can be concluded that diclosulam 26 g/ha PE *fb* fluazifop-p-butyl + fomesafen 250 g/ha PoE is an effective and economically viable option for weed management in soybean

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RESEARCH NOTE

Herbicide mixtures effect on weed control, growth and yield of groundnut

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ABSTRACT

A field study was carried out on sandy loam soils at College Farm, Agricultural College, Mahanandi, Andhra Pradesh during *Kharif*, 2024 to assess the efficacy of herbicide mixtures on weeds, growth and yield of groundnut (*Arachis hypogaea* L.). The experiment comprised of ten weed management treatments and was laid out in randomized block design with three replications. The weed density and biomass were significantly lower with hand weeding twice at 20 and 40 days after sowing (DAS) and it was closely followed by pre-emergence application (PE) of diclosulam + pendimethalin 20 + 680 g/ha followed by (*fb*) hand weeding at 40 DAS. Higher groundnut plant height, dry matter accumulation, pod yield, haulm yield and benefit-cost ratio were recorded with hand weeding twice at 20 and 40 DAS which was at par with diclosulam + pendimethalin 20 + 680 g/ha PE *fb* hand weeding at 40 DAS.

Keywords: Diclosulam + pendimethalin, Groundnut, Hand weeding, Herbicide, Weed management

Groundnut (*Arachis hypogaea* L.), is an important oilseed and leguminous crop grown in tropical and subtropical regions worldwide. It is a valuable source of nutrients including proteins, oil and vitamins. It contains 48-50% of oil, 26-28% of protein and essential vitamins and minerals. Globally, India is one of the top producers of groundnut with an area of 48.80 lakh hectares under groundnut cultivation during 2023-24. Among different states of India, Gujarat leads in groundnut production with 36.74 lakh tonnes followed by Rajasthan with 20.86 lakh tonnes. In Andhra Pradesh, the major groundnut growing districts are Sri Sathyasai, Ananthapuramu, Kurnool, Annamayya and Chittoor which together account for 63% of the area and contribute 74% to the state's total groundnut production (Government of Andhra Pradesh 2024). The productivity of groundnut is highest in Guntur district with 4.28 t/ha while the lowest productivity of 0.47 t/ha is observed in Sri Sathyasai district. The average productivity of the state during 2022-23 was 1.01 t/ha (Government of Andhra Pradesh 2024).

There are several reasons for the low productivity of groundnut in India in general and Andhra Pradesh in particular. The weed infestation is major concern. As weeds compete with crop for resources and in cause 13-85% yield loss due to weeds interference (Nambi and Sundari 2008). The yield loss due to weeds depends on the type of weeds, their density and duration of the weed infestation. At present various formulations of pre-emergence and post-emergence herbicides are available in the market that offer broad spectrum weed control which need to be evaluated for their effectiveness to control weeds, and to identify suitable herbicides to manage weeds and improve the growth and yield of groundnut. Thus, this study was undertaken to assess the weed management efficacy of tank mixed pre-emergence and post-emergence herbicides alone and in integration with inter cultivation to improve productivity of groundnut.

A field experiment was conducted during *Kharif*, 2024 at Agricultural College Farm, Mahanandi, Andhra Pradesh, India. The soil was sandy loam in texture, neutral in soil reaction (7.43), with low organic carbon (0.42%), low in available nitrogen (169 kg/ha), medium in available

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phosphorous (38 kg/ha) and high in available potassium (572 kg/ha). The trial was laid out in randomized block design with three replications. There were ten treatments including: pre-emergence application (PE) of diclosulam + pendimethalin 20 + 680 g/ha; pyroxasulfone + pendimethalin 147 + 680 g/ha PE; diclosulam + pyroxasulfone 20 + 147 g/ha PE; pendimethalin 680 g/ha PE followed by (*fb*) post-emergence application (PoE) of quizalofop-ethyl 4.5 g/ha; pendimethalin 680 g/ha PE alone; diclosulam + pendimethalin 20 + 680 g/ha PE *fb* hand weeding at 40 days after seeding (DAS); pyroxasulfone + pendimethalin 147 + 680 g/ha PE *fb* hand weeding at 40 DAS; diclosulam + pyroxasulfone 20 + 147 g/ha PE *fb* hand weeding at 40 DAS; hand weeding twice at 20 and 40 DAS and un weeded control. Herbicides were tank mixed before spraying as per the treatments.

Pre-emergence herbicides (diclosulam, pendimethalin, pyroxasulfone) were applied uniformly at 3 DAS and post-emergence herbicide (quizalofop-ethyl) was applied uniformly at 20 DAS, by using spray fluid 500 litres/ha with the help of knap sack sprayer as per the treatments. Groundnut variety '*TCGS-1694'* was sown by adopting spacing of 30 x 10 cm. Recommended dose of fertilizers 20:40:60 kg/ha N, P_2O_5 and K_2O was applied through urea, SSP and MOP. Entire quantity of nitrogen and potassium was applied in two splits *i.e.,* at basal and at flowering stage and full amount of phosphorous were applied as basal as per the treatments. Sulphur was applied in the form of gypsum 500 kg/ha at 45 DAS. Density and dry weight (biomass) of weeds were recorded by using quadrat (1.0 m^{-2}) in each plot. Weed data was transformed to square root transformation ($\sqrt{x+0.5}$) to normalize their distribution. Weed control efficiency was calculated as per the formula suggested by Mani *et al.* (1973). For the purpose of comparing various treatment means, the critical difference was correlated at 5% significance level as recommended by Panse and Sukhatme (1985).

Effect on weeds

Major weed flora observed in experimental plots were *Cynodon dactylon*, *Dactyloctenium aegyptium*, *Eragrostis curvula*, *Cyperus iria*, *Cyperus rotundus* in monocot category. *Amaranthus viridis*, *Boerhavia diffusa*, *Commelina bengalensis*, *Digera arvensis*, *Parthenium hysterophorus*, *Phyllanthus niruri* and *Trichodesma indicum*, amongst broad-leaved weeds category, were predominant in groundnut.

Hand weeding twice at 20 and 40 DAS recorded lower weed density, at harvest, which was at par with diclosulam + pendimethalin 20 + 680 g/ha PE *fb* hand weeding at 40 DAS (**Table 1**). The lower density of weeds was recorded with the diclosulam 20 g/ha PE might be due to the enzyme Acetolactate Synthase (ALS), which is essential for amino acid synthesis is inhibited. By ALS inhibition, diclosulam disrupts protein synthesis and cell division in the weeds leading to stunted growth and eventually death. The treatments having pendimethalin as one of the components have shown their potential against grassy and broad-leaved weeds and were successful in lowering the density of weed species confirming the findings of Gulaiya *et al.* (2023) and Mukilan *et al.* (2023). Hand weeding twice at 20 and 40 DAS recorded lower weed biomass at harvest which was at par with diclosulam + pendimethalin 20 + 680 g/ha PE *fb* hand weeding at 40 DAS (**Table 1**). Diclosulam and pendimethalin together suppress weeds by preventing amino acid synthesis, interfering with enzyme function and blocking weed growth (Gulaiya *et al.* 2023). Higher weed density and biomass was recorded in un weeded control. Higher weed control

Table 1. Weed density, weed biomass and weed control efficiency at harvest of groundnut as affected by weed management treatments

Treatment	Weed density (no/m^2)	Weed biomass (g/m^2)	WCE (%)
Diclosulam + pendimethalin 20 + 680 g/ha PE	10.85 (117.83)	15.63 (243.73)	34.38
Pyroxasulfone + pendimethalin 147 + 680 g/ha PE	12.62 (158.67)	17.04 (290.05)	21.92
Diclosulam + pyroxasulfone 20 + 147 g/ha PE	11.91 (141.33)	16.40 (268.65)	27.68
Pendimethalin 680 g/ha PE *fb* quizalofop ethyl 4.5 g/ha PoE	13.70 (187.01)	17.70 (312.91)	15.76
Pendimethalin 680 g/ha PE alone	14.53 (210.66)	18.69 (348.88)	6.08
Diclosulam + pendimethalin 20 + 680 PE g/ha *fb* hand weeding at 40 DAS	8.44 (70.67)	11.60 (134.13)	63.89
Pyroxasulfone + pendimethalin PE 147 + 680 g/ha *fb* hand weeding at 40 DAS	10.35 (106.67)	14.66 (214.33)	42.30
Diclosulam + pyroxasulfone 20 + 147 PE g/ha *fb* hand weeding at 40 DAS	9.50 (89.67)	13.75 (188.63)	49.22
Hand weeding twice at 20 and 40 DAS	7.11 (50.01)	9.47 (89.25)	75.97
Un weeded control	15.47 (239.00)	19.29 (371.48)	0.00
LSD (p=0.05)	12.70	25.60	3.90

*Figures in parentheses indicates squares root transformed values; *fb*: followed by; PE: pre-emergence application; PoE: post-emergence application

Table 2. Growth, yield and economics of groundnut as influenced by different weed management treatments

Treatment	Plant height (cm)	DMP (kg/ha)	No. of pods per plant	Shelling percentage	Pod yield (kg/ha)	Haulm yield (kg/ha)	Net returns (₹/ha)	B:C ratio
Diclosulam +pendimethalin 20 + 680 g/ha PE	33.7	5573	32.1	67.8	1551	3312	36714	1.75
Pyroxasulfone + pendimethalin 147 + 680 g/ha PE	32.2	5222	31.1	66.8	1455	3162	29067	1.57
Diclosulam + pyroxasulfone 20 + 147 g/ha PE	33.1	5385	31.6	67.5	1516	3206	32323	1.63
Pendimethalin 680 g/ha PE *fb* quizalofop-ethyl 4.5 g/ha PoE	31.5	5184	30.3	66.2	1356	3008	26256	1.54
Pendimethalin 680 g/ha PE alone	30.9	4984	29.6	65.7	1305	2974	24690	1.52
Diclosulam + pendimethalin 20 + 680 g/ha PE *fb* hand weeding at 40 DAS	36.3	6019	33.7	69.8	1813	3637	47998	1.93
Pyroxasulfone + pendimethalin 147 + 680 g/ha PE *fb* hand weeding at 40 DAS	34.4	5686	32.8	68.1	1676	3412	38104	1.70
Diclosulam + pyroxasulfone 20 + 147 g/ha PE *fb* hand weeding at 40 DAS	35.2	5842	33.1	68.9	1783	3586	43904	1.81
Hand weeding twice at 20 and 40 DAS	38.8	6298	34.2	70.3	1901	3775	52264	2.00
LSD (p=0.05)	3.6	587	3.3	6.0	178	427	9554	0.20

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

efficiency was observed in hand weeding twice at 20 and 40 DAS confirming the findings of Goud *et al.* (2023).

Effect on crop

Groundnut growth parameters at harvest were significantly influenced by different weed management treatments (**Table 2**). Maximum groundnut plant height and dry matter production, number of pods per plant, shelling percentage, higher pod and haulm yields were recorded with hand weeding twice at 20 and 40 DAS which was at par with diclosulam + pendimethalin 20 + 680 g/ha PE *fb* hand weeding at 40 DAS (**Table 2**). This could be because of removal of weeds during crucial time, increasing the amount of light, moisture and space available to the plant. It could also increase plant height (Deepa *et al.* 2017), produce large leaves, greater dry matter production (Kundu *et al.* 2021; Srinivasan *et al.* 2024) and a greater number of pods leads to increase the production of dry matter. It is also because of less competition from weeds for growth resources during the crop development cycle, which encouraged the groundnut growth. Increased pod and haulm yield was the outcome of the combined action of all these growth and yield factors. Cumulative effect of lower weed density, higher WCE and lesser nutrient removal by weeds occurred as a result of reduced crop weed competition, better crop environment and higher uptake of nutrients by groundnut. Subramanyam *et al.* (2020) also observed significantly higher pod and haulm yield with pre-emergence application of diclosulam 20 g/ha supplemented with HW at 40 DAS. Sridhar *et al.* (2021) reported that highest pod yield with diclosulam 27 g/ha PE *fb* hand weeding at 50 DAS due to low crop weed competition throughout the crop growth. The lowest groundnut plant height, dry matter production observed in weedy check confirmed findings of Ravi *et al.* (2023) Suseendran *et al.* (2019).

Higher net returns and benefit-cost ratio (**Table 2**) were observed with hand weeding twice at 20 and 40 DAS which was comparable with diclosulam + pendimethalin 20 + 680 g/ha PE *fb* hand weeding at 40 DAS supporting the findings of Subramanyam *et al.* (2020).

Conclusion

It can be concluded that hand weeding twice at 20 and 40 DAS or diclosulam + pendimethalin 20 + 680 g/ha PE *fb* hand weeding at 40 DAS were observed to be the most effective and economically viable integrated weed management options for enhancing the productivity and maximizing the profitability of groundnut in sandy loam soils of Scarce Rainfall Zone of Andhra Pradesh.

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RESEARCH NOTE

Effect of imazethapyr on weeds and productivity of garden pea (*Pisum sativum* var. *hortense* L.)

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ABSTRACT

A field experiment was conducted during *Rabi* season of 2023-24 at the Vegetable Research Farm Maharajpur, Department of Horticulture, Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur, Madhya Pradesh, to evaluate the effect of imazethapyr on weeds and productivity of garden pea (*Pisum sativum* var. *hortense* L.). The predominant weed species were *Medicago polymorpha, Avena fatua, Cynodon dactylon, Parthenium hysterophorus, Cyperus rotundus, Alternanthera sessilis, Spergula arvensis* and *Cichorium intybus*. Among the tested herbicidal treatments, the post-emergence application (PoE) of imazethapyr 75 g/ha at 20 days after seeding (DAS), was observed to be the most effective in reducing both weed density and biomass with highest weed control efficiency (79.33% and 88.42% at 25 and 50 DAS, respectively), lower weed index of (-13.19%) and higher green pod yield without causing any phytotoxic effects on the crop.

Keywords: Garden pea, Imazethapyr, Phyto-toxicity, Productivity, Weed management

Garden pea (*Pisum sativum* var. *hortense* L.), also called the kitchen pea or green pea, is an essential vegetable crop of India which belongs to the family of Leguminosae. It is grown as a winter vegetable in the plains of northern India and used during summers as well in hill regions (Rana *et al*. 2015). A major source of protein worldwide, this plant is mainly grown for its sweet green pods used in fresh vegetables and it serves as a rich source of protein. Each 100 grams of edible green peas contain 17-22 g of carbohydrates, 6.2-6.5 g of protein, 79 g of moisture, 4.0-5.1 g of fiber, 0.5-1.8 g of fat and offer 81-93 kcal of energy (Kumari and Deka 2021). In India, garden peas are the third most popular *Rabi* (winter) leguminous crop, following chickpeas and lentils. In Madhya Pradesh, peas are cultivated in over 56.1 thousand hectares, with an annual production of 474.2 metric tonnes and productivity of 8.5 tons/ha (Anonymous 2020). The garden pea thrives in well-drained, loose and friable soil with a pH of 6.0-7.5 and rich organic matter content. However, vegetable peas are highly susceptible to weed infestation, leading to potential yield losses of 45-81% (Kumar *et al*. 2015). Hand weeding is effective but uneconomical (Singh and Angiras 2004). Relying solely on pre-emergence herbicides is insufficient for controlling diverse weed species (Mawalia *et al.* 2016), as their effectiveness is compromised by soil surface dryness during winter. Therefore, integrating other methods with herbicides is necessary for effective weed management (Kaur *et al*. 2023). Keeping this in view, the present experiment was conducted to assess the impact of pre- and post-emergence herbicides and mechanical weeding on weeds and productivity of garden pea.

The field experiment was carried out in the *Rabi* season of 2023-24 at the Vegetable Research Farm Maharajpur, affiliated with the Department of Horticulture, Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur (23°10'N, 79°56'E, altitude 412 m), Madhya Pradesh. The soil in the experimental area was sandy clay loam, composed of 49.3% sand, 30.5% silt and 26.8% clay with a pH of 7.51, organic carbon content of 0.76% and available nutrients of 295.5 kg/ha nitrogen, 20.77 kg/ha phosphorus and 130.4 kg/ha potassium. During the 2023-24 growing season, the region received a total rainfall of 152.8 cm over 65 rainy days. Fertilizers used for the crops were 20 kg N, 50 kg P and 40 kg K/ha. Full doses of phosphorus and potassium and half the nitrogen were applied as a basal dose with the remaining nitrogen top-dressed 20 days after sowing (DAS). The twelve treatments tested were: weedy check; hand weeding twice at 20 and 40 DAS; pre-emergence application (PE) of pendimethalin 1 kg/ha; post-emergence application (PoE) of imazethapyr 75 g/ha at 20 DAS; imazethapyr 75 g/ha at 30 DAS; imazethapyr 75 g/ha at 40 DAS; imazethapyr 100 g/ha

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at 20 DAS; imazethapyr 100 g/ha at 30 DAS; imazethapyr 100 g/ha at 40 DAS; imazethapyr 125 g/ha at 20 DAS; imazethapyr 125 g/ha at 30 DAS; imazethapyr 125 g/ha at 40 DAS. A randomized block design with three replications was used. Imazethapyr was applied using 500 L/ha of water with a backpack sprayer equipped with a flat-fan nozzle. The garden pea crop cultivar *'Kashi Nandini'* was sown on 24th September 2023 with a spacing of 30×10 cm and a seed rate of 120 kg/ha. Each plot size was 3×2 m. Seeds were planted at a depth of 3 to 4 cm after being treated with carbendazim at 2 g per kg of seeds. The garden pea growth and yield characteristics were assessed by selecting and labeling five random plants from each plot. The first harvest was done on 29th January 2024 and the second harvest was on 5th February 2024.

A 1m² quadrat was randomly placed at three different locations in each plot and the weeds density within the quadrat was counted at 25 and 50 DAS. The weed biomass (fresh and dry weight) of 1 m² from different plots across all treatments was recorded. Associated weeds were counted and separated manually according to their species. The data on total weed density and dry matter (biomass) were normalized using square root transformation ($\sqrt{X + 0.5}$) to adjust their distribution (Gomez and Gomez, 1984). The collected weeds samples were initially sun-dried, then placed in paper bags and oven-dried at 60 °C for 48 hours until a constant weight was achieved.

Weed control efficiency also calculated based on dry weed biomass. Observations on the phytotoxicity effect of herbicides were made visually with the help of the recommended phytotoxicity scale.

Effect on weeds

The predominant weed species at the experimental site were *Medicago polymorpha*, *Avena fatua*, *Cynodon dactylon*, *Parthenium hysterophorus*, *Cyperus rotundus*, *Alternanthera sessilis*, *Spergula arvensis* and *Cichorium intybus*.

The maximum weed density, highest total fresh and dry weed biomass was recorded in weedy check at 25 and 50 DAS (**Table 1, 2** and **3**). The minimum weeds density, lowest total fresh and dry weed biomass and highest weed control efficiency was recorded in hand weeding twice at 20 and 40 DAS and was at par with imazethapyr 75 g/ha PoE at 20 DAS. The pendimethalin 1 kg/ha PE also significantly reduced the density of all the weeds supporting findings of Rakesh *et al.* (2016); Meleta *et al.* (2024) in garden pea. Hand weeding eliminated all types of weeds during active crop growth and development,

Table 1. Effect of weed control treatments tested on weed density in garden pea at 25 DAS

Treatment	*Medicago polymorpha*	*Avena fatua*	*Cynodon dactylon*	*Parthenium hysterophorus*	*Cyperus rotundus*	*Alternanthera sessilis*	*Spergula arvensis*	*Cichorium intybus*
Weedy check (Control)	(56.43) 7.55	(27.33) 5.29	(21.29) 4.70	(17.63) 4.28	(14.64) 3.91	(8.72) 3.06	(5.69) 2.50	(4.67) 2.29
Hand weeding twice at 20 DAS	(2.62) 1.75	(0.00) 0.71	(0.75) 1.11	(0.00) 0.71	(0.36) 0.92	(0.00) 0.71	(0.00) 0.71	(0.00) 0.71
Pendimethalin 1 kg/ha PE	(11.74) 3.46	(4.16) 2.13	(6.79) 2.68	(7.55) 2.82	(5.77) 2.49	(4.33) 2.18	(2.55) 1.74	(2.74) 1.79
Imazethapyr 75 g/ha PoE at 20 DAS	(5.34) 2.39	(3.75) 2.04	(1.43) 1.38	(1.33) 1.34	(2.69) 1.77	(0.58) 1.03	(1.38) 1.36	(0.39) 0.94
Imazethapyr 75 g/ha PoE at 30 DAS	(48.52) 7.02	(23.43) 4.90	(17.92) 4.30	(15.34) 3.98	(13.41) 3.74	(7.69) 2.87	(4.94) 2.34	(4.33) 2.21
Imazethapyr 75 g/ha PoE at 40 DAS	(50.76) 7.17	(24.56) 5.02	(20.36) 4.60	(15.67) 4.03	(13.67) 3.78	(8.17) 2.69	(5.13) 2.38	(4.47) 2.24
Imazethapyr 100 g/ha PoE at 20 DAS	(17.63) 4.22	(6.47) 2.61	(6.89) 2.69	(6.43) 2.61	(5.84) 2.50	(5.43) 2.42	(2.67) 1.77	(2.67) 1.77
Imazethapyr 100 g/ha PoE at 30 DAS	(52.48) 7.29	(25.67) 5.13	(18.66) 4.39	(16.73) 4.16	(12.69) 3.64	(6.94) 2.73	(5.43) 2.44	(3.98) 2.12
Imazethapyr 100 g/ha PoE at 40 DAS	(54.38) 7.42	(26.34) 5.19	(18.73) 4.40	(15.46) 4.00	(13.94) 3.81	(7.71) 2.88	(5.51) 2.46	(4.31) 2.20
Imazethapyr 125 g/ha PoE at 20 DAS	(22.79) 4.79	(9.84) 3.19	(7.87) 2.87	(8.08) 2.91	(6.97) 2.72	(5.78) 2.50	(2.82) 1.81	(2.98) 1.86
Imazethapyr 125 g/ha PoE at 30 DAS	(49.84) 7.11	(24.73) 5.03	(18.36) 4.36	(14.97) 3.94	(13.51) 3.75	(8.16) 2.96	(4.48) 2.23	(4.03) 2.13
Imazethapyr 125 g/ha PoE at 40 DAS	(54.37) 7.42	(25.73) 5.13	(19.74) 4.52	(16.84) 4.18	(13.73) 3.78	(8.38) 3.00	(5.48) 2.45	(4.23) 2.18
LSD (p=0.05)	0.89	0.67	0.61	0.44	0.42	0.43	0.27	0.27

*LSD= Least Significant Difference, DAS= days after sowing, PE= pre-emergence application, PoE= post-emergence application
Note: Figure in the outside of parenthesis denotes square root $\sqrt{x + 0.5}$ transformed value.

Table 2. Effect of weed control treatments on weed density in garden pea at 50 DAS

Treatment	*Medicago polymorpha*	*Avena fatua*	*Cynodon dactylon*	*Parthenium hysterophoru*	*Cyperus rotundus*	*Alternanther sessilis*	*Spergula arvensis*	*Cichorium intybus*
Weedy check (control)	(64.82) 8.20	(48.72) 7.06	(36.31) 6.20	(21.83) 4.85	(26.43) 5.27	(14.62) 3.98	(9.02) 3.14	(7.76) 2.92
Hand weeding twice at 20 and 40 DAS	(4.75) 2.26	(3.94) 2.08	(2.45) 1.70	(0.64) 1.06	(2.73) 1.78	(0.51) 1.00	(0.00) 0.71	(0.00) 0.71
Pendimethalin 1 kg/ha PE	(19.64) 4.44	(12.41) 3.57	(13.97) 3.79	(8.89) 3.05	(9.63) 3.17	(5.07) 2.34	(3.46) 1.98	(3.67) 2.04
Imazethapyr 75 g/ha PoE at 20 DAS	(13.83) 3.74	(8.64) 2.99	(7.18) 2.75	(3.17) 1.90	(6.65) 2.66	(3.04) 1.86	(3.16) 1.90	(0.89) 1.17
Imazethapyr 75 g/ha PoE at 30 DAS	(36.72) 6.09	(18.62) 3.57	(14.14) 3.81	(11.96) 3.52	(10.63) 3.32	(6.37) 2.61	(3.92) 2.09	(2.88) 1.83
Imazethapyr 75 g/ha PoE at 40 DAS	(53.39) 6.64	(20.47) 4.57	(15.52) 3.99	(12.71) 3.63	(12.32) 3.57	(6.81) 2.70	(6.10) 2.58	(3.77) 2.07
Imazethapyr 100 g/ha PoE at 20 DAS	(22.47) 4.75	(13.75) 3.75	(15.16) 3.94	(9.46) 3.14	(9.89) 3.21	(7.78) 2.88	(3.66) 2.03	(2.73) 1.79
Imazethapyr 100 g/ha PoE at 30 DAS	(37.81) 6.18	(21.28) 4.66	(15.96) 4.05	(13.43) 3.73	(11.86) 3.51	(6.44) 2.63	(3.79) 2.06	(2.87) 1.83
Imazethapyr 100 g/ha PoE at 40 DAS	(45.37) 6.79	(22.58) 4.80	(16.84) 4.16	(12.92) 3.66	(11.93) 3.52	(6.96) 2.73	(4.82) 2.30	(2.98) 1.86
Imazethapyr 125 g/ha PoE at 20 DAS	(26.18) 5.13	(14.31) 3.82	(17.37) 4.22	(11.72) 3.49	(9.79) 3.19	(7.99) 2.92	(4.03) 2.12	(3.36) 1.96
Imazethapyr 125 g/ha PoE at 30 DAS	(35.43) 5.98	(21.81) 4.72	(16.74) 4.14	(10.93) 3.37	(11.76) 3.49	(6.78) 2.69	(4.19) 2.16	(3.55) 2.01
Imazethapyr 125 g/ha PoE at 40 DAS	(44.39) 6.72	(22.94) 4.84	(16.84) 4.16	(12.85) 3.65	(11.88) 3.51	(6.97) 2.73	(7.05) 2.77	(3.69) 2.05
LSD (p=0.05)	0.93	0.76	0.75	0.55	0.52	0.55	0.42	0.34

*LSD= Least Significant Difference, DAS= days after sowing, PE= pre-emergence application, PoE= post-emergence application
Note: Figure in the outside of parenthesis denotes square root $\sqrt{x+0.5}$ transformed value.

Table 3. Effect of weed control treatments on weed biomass, green pod yield and phytotoxicity in garden pea

Treatment	Total fresh weed biomass (g/m^2)		Total dry weed biomass (g/m^2)		Weed control efficiency (%)		Weed index (%)	Green pod yield (t/ha)	Phytotoxicity (leaf injury)
	25 DAS	50 DAS	25 DAS	50 DAS	25 DAS	50 DAS			
Weedy check (control)	(340.64) 18.86	(486.51) 22.57	(85.18) 9.40	(121.65) 11.30	0.00	0.00	45.02	5.78	0
Hand weeding twice at 20 and 40 DAS	(9.62) 3.15	(32.00) 5.62	(2.42) 1.69	(8.02) 2.88	93.41	97.16	0.00	10.05	0
Pendimethalin 1 kg/ha PE	(101.15) 9.96	(168.18) 12.86	(25.30) 5.03	(42.06) 6.46	65.42	70.30	3.28	9.75	0
Imazethapyr 75 g/ha PoE at 20 DAS	(39.40) 6.22	(100.53) 9.91	(9.86) 3.18	(25.14) 4.99	79.33	88.42	-13.19	11.49	0
Imazethapyr 75 g/ha PoE at 30 DAS	(217.28) 14.78	(297.85) 17.30	(54.34) 7.41	(74.48) 8.67	12.56	55.33	12.21	9.10	0
Imazethapyr 75 g/ha PoE at 40 DAS	(254.15) 16.07	(305.02) 17.52	(63.55) 8.04	(77.11) 8.83	9.47	47.76	14.01	9.50	0
Imazethapyr 100 g/ha PoE at 20 DAS	(123.95) 11.04	(196.34) 13.92	(33.16) 5.76	(49.10) 6.99	59.64	61.07	-6.73	10.78	0
Imazethapyr 100 g/ha PoE at 30 DAS	(224.85) 15.05	(300.68) 17.38	(56.22) 7.54	(75.19) 8.71	11.73	53.78	12.99	8.78	0
Imazethapyr 100 g/ha PoE at 40 DAS	(254.71) 16.09	(308.26) 17.61	(63.69) 8.05	(77.59) 8.86	8.91	47.64	13.83	8.47	0
Imazethapyr 125 g/ha PoE at 20 DAS	(132.64) 11.44	(204.20) 14.20	(33.51) 5.79	(49.29) 7.00	59.48	60.66	6.61	8.78	10
Imazethapyr 125 g/ha PoE at 30 DAS	(233.34) 15.35	(304.88) 17.51	(58.37) 7.69	(76.18) 8.77	10.56	52.02	26.47	7.28	10
Imazethapyr 125 g/ha PoE at 40 DAS	(260.00) 16.27	(314.53) 17.80	(65.04) 8.14	(80.52) 9.04	5.47	46.53	38.66	6.44	10
LSD (p=0.05)	2.89	3.06	1.19	1.54				16.82	

*LSD= Least Significant Difference, DAS= days after sowing, PE= pre-emergence application, PoE= post-emergence application
Note: Figure in the outside of parenthesis denotes square root $\sqrt{x+0.5}$ transformed value.

Table 4. Effect of weed control treatments on economics of garden pea

Treatment	Gross returns (x10^3 Rs./ha)	Net returns (x10^3 Rs./ha)	B:C ratio
Weedy check (control)	95.666	59096.44	1.62
Hand weeding twice at 20 and 40 DAS	180.93	139.36	3.35
Pendimethalin 1 kg/ha PE	174.87	137.22	3.65
Imazethapyr 75 g/ha PoE at 20 DAS	209.73	171.30	4.46
Imazethapyr 75 g/ha PoE at 30 DAS	169.80	131.36	3.42
Imazethapyr 75 g/ha PoE at 40 DAS	161.87	122.98	3.16
Imazethapyr 100 g/ha PoE at 20 DAS	195.40	156.96	4.08
Imazethapyr 100 g/ha PoE at 30 DAS	155.47	116.58	3.00
Imazethapyr 100 g/ha PoE at 40 DAS	149.33	110.44	2.84
Imazethapyr 125 g/ha PoE at 20 DAS	155.40	116.05	2.95
Imazethapyr 125 g/ha PoE at 30 DAS	125.40	86.05	2.19
Imazethapyr 125 g/ha PoE at 40 DAS	108.73	69.39	1.76
LSD (p=0.05)	-	-	-

*LSD= Least Significant Difference, DAS= days after sowing, PE= pre-emergence application, PoE= post-emergence application,

resulting in a substantial reduction of weed density over control and herbicidal treatments as reported earlier in garden pea by Kumar *et al.* (2015).

The uncontrolled weeds caused 44.02% reduction in yield of garden pea. The weed index was lowest (-13.19%) and negative with imazethapyr 75 g/ha PoE at 20 DAS (**Table 3)** as reported by Rana *et al.* (2019) in blackgram.

Effect on crop

The highest garden pea yield was recorded in with imazethapyr 75 g/ha PoE at 20 DAS (**Table 3**) and it was followed by imazethapyr 100 g/ha PoE at 20 DAS. The lowest yield was in the untreated weedy check. The highest yield was recorded with the use of post-emergence herbicides, highlighting their effectiveness in managing weeds in garden pea. This method proves superior to manual weeding, which, although generally effective, poses significant risks to pea plants due to their delicate nature. The hollow stems and fragile branches of pea plants are easily and frequently/often damaged during manual weeding, particularly during the critical flowering and pod formation stages. Therefore, to minimize plant damage and optimize yield, the use of post-emergence herbicides is recommended as a more suitable and efficient approach to manage weeds..

The maximum gross returns (Rs. 209734/ha), net returns (Rs. 171299/ha) and B:C ratio (4.46) was achieved with imazethapyr 75 g/ha PoE at 20 DAS (**Table 4**) and it was followed by imazethapyr 100 g/ha PoE at 20 DAS.

Crop phytotoxicity

Application of imazethapyr at 125 g/ha at 20, 30 and 40 DAS caused some mild yellowing of the newly leaves of garden pea about 3 days after spray. However, as the garden pea plants continued to grow, they gradually recovered with the yellowing almost completely disappearing within 15 days of the application.

In conclusion, imazethapyr 75 g/ha PoE at 20 days after sowing was proved as the most effective weed management strategy, resulting in effective weed management, higher yield and economics of garden pea.

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RESEARCH NOTE

Herbicides for knocking down *Sesbania aculeata* for brown manuring

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ABSTRACT

Sesbania aculeata (Willd.) Poir. is an important cover crop often used for improving soil health. The strategy of terminating *Sesbania* as a cover crop is different under conventional tillage and no-till conditions. In no-tillage systems, where mechanical incorporation is not feasible, brown manuring through herbicide application becomes necessary. Field studies were conducted during the 2023 and 2024 *Kharif* seasons to evaluate the effectiveness of various herbicides (glyphosate, glufosinate, paraquat, and 2,4-D ethyl ester) applied alone and in combinations to terminate *S. aculeata*. Studies revealed that 2,4-D ethyl ester (2,4-D-E) 500 g/ha and glufosinate 400 g/ha were highly effective in knocking down *Sesbania* as a brown manure crop and these herbicides provided a 100% reduction in biomass of *Sesbania*. Whereas, glyphosate 1500 g/ha and paraquat 500 g/ha were poor for killing *Sesbania* and these herbicides reduced its biomass only by 67.0 and 46.9%, respectively, compared to untreated control. Economically, 2,4-D-E proved more viable than glufosinate. Additionally, 2,4-D-E can be selectively used to kill *Sesbania* if it is grown as co-culture with Gramineae crops such as rice, maize and sugarcane. This research highlights the suitability of 2,4-D-E and glufosinate for brown manuring of *S. aculeata* in conservation agriculture.

Keywords*:* 2,4-D, Cover crop, Glufosinate, Glyphosate, Paraquat

Sesbania aculeata (Willd.) Poir., a fast-growing leguminous cover crop, plays a crucial role in improving soil fertility and structure through nitrogen fixation and biomass addition. Conventionally, *S. aculeata* is incorporated into soil via tillage to improve the soil physico-chemical properties of the soil. However, under conservation agriculture and no-tillage systems, where physical incorporation is not practiced, chemical termination using herbicides is essential and, in this process, browning of the crop is referred to as brown manuring (Singh *et al.* 2007). *S. aculeata* contains approximately 2.11-3.50% N, 0.25-0.6% P, and 1.20-2.14% K and add to the soil approximately 100-109 kg N/ha when turned down as a cover crop (Kharub *et al.* 2003, Kumar *et al.* 2014, Kurdali *et al.* 2019, Chander *et al.* 2023).

Brown manuring provides several agronomic benefits, including weed suppression, soil conservation, moisture conservation, enhanced microbial activity, sequestration of carbon, biological nitrogen fixation, addition of macro and micro-nutrients to soil, and improved physical, chemical, and biological properties of soil (Biswas and Das 2024, Iliger *et al.* 2017, Singh *et al.* 2007). Studies also reported that brown manuring can reduce the need for nitrogenous fertilizers by up to 25% in crops like rice (Sarangi *et al.* 2016) and increases actinomycetes populations in the rhizosphere (Sharma *et al.* 2017). As a consequence of multifarious benefits of brown manuring, various researchers reported improvement in crop growth, yield and economic return of maize, rice, and sugarcane (Singh *et al.* 2009, Anitha and Mathew 2010, Maity and Mukherjee 2011, Ramachandran *et al.* 2012, Gill and Walia 2013, Gangaiah and Babu 2016, Sarangi *et al.* 2016, Singh *et al.* 2007, Chaudhary *et al.* 2018, Fanish and Ragavan 2020).

Earlier literature indicates high susceptibility of *S. aculeata* to 2,4-D herbicide (Dhyani *et al.* 2009, Singh *et al.* 2009, Singh *et al.* 2007) and this herbicide can be effectively used for knocking down *S. aculeata* coexisting with rice or maize crops (Singh *et al.* 2007, Kumari *et al.* 2020, Behera *et al.* 2019). However, the comparative assessments of 2,4-D with other non-selective herbicides such as paraquat, glyphosate, and glufosinate remain limited, especially under no-tillage. Thus, the present study was conducted with aims to evaluate and compare the efficacy and economics of different herbicides for terminating *S. aculeata* as a brown manure crop.

Field experiments were conducted in the *Kharif* seasons of 2023 and 2024 at ICAR-Indian Institute of Wheat and Barley Research, Karnal, Haryana, India

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(Latitude 29°43’N, Longitude 76°58’E at an elevation of 245m above mean sea level). The *S. aculeata* was sown after wheat harvest using a seed rate of 25 kg/ha at a row spacing of 20 cm with a seed cum fertilizer drill on May 20, 2023, and June 2, 2024, respectively. The plot size was 20 m^2, that is, 10 rows spaced at 20 cm with a length of 10 m. A basal dose of 15.7 kg N and 40 Kg P was applied using diammonium phosphate.

The experiments were conducted in a randomized complete block design (RCBD) with three replicates. The herbicide treatments comprised of: glyphosate 1500 g/ha, paraquat 500 g/ha, glufosinate 400 g/ha, 2,4-D-E 500 g/ha, and their tank-mix combinations along with the untreated control (**Figure 1**). The herbicides were applied at 43-44 days after sowing using flat fan nozzles calibrated to deliver 500 litre/ha of the spray solution. Fresh biomass was sampled from 8 m^2 (1.6 x 5 m) per plot, weighed, and converted to kg/ha. The trend of both the years was similar therefore data were pooled over years and the percentage biomass reduction with various herbicide treatments was computed against the untreated control to identify the most suitable herbicide option. The economics analysis of herbicide treatments was performed based on the prevailing market prices of herbicides to identify the most economical knock down herbicide option.

Effect of herbicides on *Sesbania*

All herbicide treatments caused a significant reduction in the fresh weight of *S. aculeata* compared to the untreated control (**Figure 1**). Compared to the fresh weight of *S. aculeata* in the control, the reductions in fresh weight with the application of glyphosate 1500 g/ha, paraquat 500 g/ha, glufosinate 400 g/ha, and 2,4-D-E 500 g/ha were 67.0, 46.9, 100.0 and 100.0%, respectively. The tank-mix combination of glyphosate and paraquat caused a 69.9% *S. aculeata* fresh biomass reduction. This indicated that paraquat and glyphosate had lesser efficacy against *S. aculeata*. However, 2,4-D-E and glufosinate applied alone or in combination effectively reduced the fresh biomass of *S. aculeata* (**Figure 1**). Previous studies (Dhyani *et al*. 2009, Kumari *et al*. 2020, Behera *et al*. 2019) have also reported the effectiveness of 2,4-D in knocking down *S. aculeata*.

Our study showed the effectiveness of 2,4-D-E and glufosinate in killing *Sesbania*. These herbicides can be used to kill a pure stand of *Sesbania* cover crop (without co-culture with crops) as a brown manure crop. However, when *Sesbania* is grown as a co-culture with monocot crops, such as rice, sugarcane, and maize, 2,4-D is a suitable selective option. However, the advantage of glufosinate over 2,4-D-E is in situation having the infestation of grass weeds along with *Sesbania*, which can also be controlled by glufosinate. The application of 2,4-D-E had the fastest action, and symptoms appeared on the day of spraying. The symptoms of paraquat and glufosinate also appeared quickly compared to glyphosate. The combination of 2,4-D with glyphosate, paraquat, or glufosinate can be used to kill *Sesbania* cover crop, along with grass weeds. Both 2,4-D-E and glufosinate are effective in knocking down *S. aculeata*; however, 2,4-D-E is cost-effective (**Figure 2**). The herbicidal cost for 2,4-D-E and glufosinate was Rs 500/ha and Rs 2533/ha, respectively.

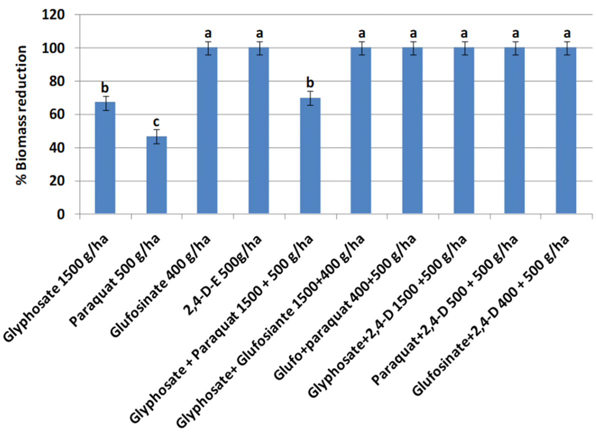

Figure 1. ***Sesbania aculeata*** **fresh weight reduction with various herbicides applied alone and in combinations. Vertical bars represent ± LSD (p=0.05)**

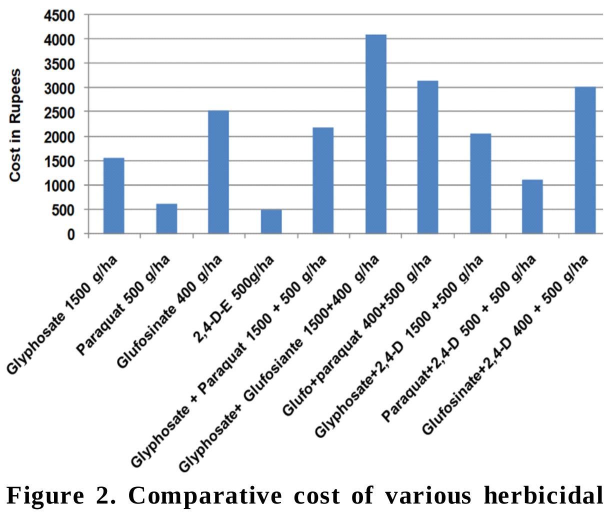

Figure 2. Comparative cost of various herbicidal treatments against *Sesbania aculeata*

Based on the present study, it can be concluded that both 2,4-D and glufosinate are highly effective for knocking down *Sesbania* as a brown manure crop. However, 2,4-D-E application is economical compared to glufosinate and can be selectively applied in co-culture cropping systems with monocot crops. Integration of brown manuring offers a promising, cost-effective strategy for sustainable agriculture under conservation tillage.

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