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Comparative assessment of novel herbicide molecules and their effects on weed dynamics in sugarcane

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Abstract
A field experiment was conducted at the Vasantdada Sugar Institute, R&D Farm, Manjari, Pune, during the 2023-24 and 2024-25 cropping seasons to evaluate the efficacy of novel herbicide molecules for weed management in sugarcane. The study employed a Randomized Block Design (RBD) comprising nine treatments with three replications. Treatments included pre-emergence (PE) and post-emergence (PoE) applications of advanced herbicide combinations: Clomazone + Metribuzine, Clomazone + Sulfentrazone, 2,4-D sodium salt + Metribuzine + Pyrazosulfuron ethyl, Halosulfuron methyl + Metribuzine, and Topramezone + Atrazine. These were compared against standard checks (Atrazine and 2,4-D sodium salt), a weed-free control, and a weedy control. The results demonstrated that the PoE application of Halosulfuron methyl + Metribuzine (readymix) at 1 L ha^{-1}, applied at the 2-4 leaf stage of weeds followed by earthing up at 120 days after planting (DAP), achieved the highest cane yield (121.37 t ha^{-1}), the lowest weed index (10.40), and the best benefit-cost ratio (1:2.38). Conversely, the maximum commercial cane sugar (CCS) yield of 17.58 t ha^{-1} and superior weed control efficiency (93.91%) were recorded with the PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) at 2.5 kg ha^{-1}, followed by a single intercultivation at 60 DAP (partial earthing up). Overall, both Halosulfuron methyl + Metribuzine and Clomazone + Sulfentrazone herbicide combinations proved highly effective in suppressing weed infestation, enhancing cane productivity, and improving economic returns under the peninsular agro-climatic conditions of Maharashtra. These findings offer promising options for integrated weed management in sugarcane cultivation.

Keywords: Sugarcane, cane yield, weed dynamics, herbicide treatments, weed control efficiency

Introduction
Sugarcane (*Saccharum spp.* hybrid complex) is an important commercial crop grown across a wide latitudinal range from 8°N to 30°N in India, encompassing diverse climatic and soil conditions. India holds the position of the world's second-largest sugar producer (Patel *et al*., 2018) [10]. Due to its relatively long germination period, wide row spacing, slow initial growth, lateral spreading habit, heavy fertilizer requirements, and frequent irrigation, sugarcane fields create an ideal environment for weed growth. Weeds often emerge before the sugarcane crop, negatively impacting germination, overall yield, and crop quality. Previous studies have reported that yield losses caused by weed infestation can vary widely, ranging from 10% to complete crop failure (Srivastava and Chauhan, 2002) [14]. The period of intense crop-weed competition, particularly within the first 120 days after planting, is considered the most critical for controlling weeds, as weed pressure during this stage causes the greatest harm. Therefore, effective weed management during this critical period is essential to maximize sugarcane yield.
It is evident from various experimental results that, integration of different weed control methods is an effective tool for better weed control in sustainable manner. But in recent years, non-availability of labour forced to farmers to relay on chemical weed management and this is easier, time saving and economical intervention.
In this context, there is need to evaluate new pre and post-emergence herbicides and the sequential application of two herbicides with different mode of action for the effective management of complex weed flora in sugarcane. Keeping this in mind the field experiment was conducted to evaluate the efficacy of new herbicide molecules for weed management in sugarcane.

Materials and Methods

The study was carried out over two consecutive years, 2023-24 and 2024-25 under the AICRP's program, at the Vasantdada Sugar Institute's research farm located in Manjari, Pune, on vertisol soil. The experimental site is situated at a latitude of 18.5262° N and longitude of 73.9746° E, with an elevation of 551 meters above sea level.

A randomized block design (RBD) was employed for the experiment, consisting of nine different weed management treatments with three replications each. Among these treatments, two served as controls: a weedy check and a weed-free check. The remaining seven treatments involved combinations of herbicides and cultural practices. Details of these treatments are presented in Table 1.

Each gross plot measured 7.00 meters in length and 6.85 meters in width (covering five rows), while the net plot size was 6.00 meters by 4.11 meters (three rows). The fertilizer regime for the early sugarcane crop followed the recommended dose of 250 kg nitrogen, 115 kg phosphorus (P_2O_5), and 115 kg potassium (K_2O) per hectare. Nitrogen was applied in four split doses, while phosphorus and potassium were applied half at planting and the remaining half during the final earthing up.

Throughout the experimental period, the predominant weed species observed included *Cynodon dactylon*, *Cyperus species*, *Convolvulus arvensis*, *Parthenium hysterophorus*, *Ipomoea species*, *Chenopodium album*, *and Euphorbia hirta* among others.

Weeds from one-meter square were taken from the quadrate from each plot. Weeds were air-dried followed by oven dried at 65^0C ±2 for 48 hrs. and weighed. The effect of tested herbicide on density (no./m^2) and dry weight of weeds (g/m^2) was recorded at 30, 60, 90 and 120 DAP and the data were transformed on squre root transformation by adding 1 to original value prior to statistical analysis. calculate the weed control efficacy (WCE) by using formula given by Mani *et al.* (1973) [5] as followed.

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

Where,
WDc= Dry weight of weed in control
WDt= Dry Weight of weed in treatment

Further to know the losses caused by weeds in sugarcane, weed index was computed as procedure given by Gill and Kumar (1969) [2] using the following formula:

$$WI\ (\%) = \frac{x - y}{x} \times 100$$

Where,
X= Yield from weed free plot
Y= Yield of plot for which WI is calculated

Data on yield, quality, and contributing factors were collected throughout the entire growing season. The number of tillers was recorded at 120 days after planting, whereas all other parameters were assessed at harvest. The count of millable canes (NMC) was taken during harvest as well. Cane juice was extracted using a power crusher to evaluate quality, with brix and sucrose content measured following the procedure described by Meade and Chen (1977) [7]. Sucrose percentage was calculated using Schmitz's Tables. Commercial cane sugar (CCS) percentage was computed using the formula: CCS% = {Sucrose% - (Brix% - Sucrose%) × 0.4} × 0.74. The collected data on cane yield and related parameters were subjected to statistical analysis and interpretation according to the methods outlined by Panse and Sukhatme (1978) [9]. Economic analysis was also performed.

Table 1: Weed management treatment details:

Symbol	Treatment	Dose (kg/ha)	Application time
T_1	Clomazone 22.5% +Metribuzine 21% WP (ready mix) *fb* one inter- cultivation at 60 DAP	2.5	Pre-emergence
T_2	Clomazone 30% + Sulfentrazone 28% WP (ready mix) *fb* one inter- cultivation at 60 DAP	2.5	Pre-emergence
T_3	2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) *fb* earthing up at 120 DAP	3.0	Post emergence
T_4	Halosulfuron methyl + Metribuzine (ready mix) at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.0	Post emergence
T_5	Topramezone + Atrazine (ready mix) at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	3.0	Post emergence
T_6	Atrazine 80% WP *fb* one inter-cultivation at 60 DAP	2.5	Pre-emergence
T_7	2,4 D Na salt at 2-4 leaf of weeds *fb* earthing up at 120 DAP	2.5	Post emergence
T_8	T_8 Weed free check	-	-
T_9	T_9 Weedy check	-	-

*PE-Pre emergence, PoE- Post emergence, *fb*- followed by, DAP- days after planting

Results

Growth attributes

The data clearly indicated that the growth attributes of sugarcane were significantly influenced by different weed management practices. The highest crop emergence (63.22%) was recorded under the treatment with pre-emergence (PE) application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) at 2.5 kg/ha, followed by one intercultivation at 60 DAP (partial earthing up). In contrast, the treatment involving PE application of Clomazone 22.5% + Metribuzine 21% WP (ready mix) at 2.5 kg/ha followed by one intercultivation at 60 DAP (partial earthing up) resulted in a significantly higher tiller population (103.00 thousand/ha) at 120 DAP and millable cane population (92.25 thousand/ha) at harvest. These findings align closely with those reported by Worku Tadele *et al.* (2022) [15], Singh *et al.* (2016) [12], and Ombase *et al.* (2019) [8], who also noted that effective weed control positively influences sugarcane growth and plant stand.

Yield and yield attributes

The yield attributes of sugarcane were markedly influenced by different weed management strategies (Table 2). The highest single cane weight (1.36 kg) was recorded under the treatment involving PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) at 2.5 kg/ha, followed by one intercultivation at 60 DAP and PoE application of Halosulfuron methyl + Metribuzine (ready mix) @ 1 L/ha at the 2-4 leaf stage of weeds with earthing up at 120 DAP.

Notably, the PoE Halosulfuron methyl + Metribuzine treatment produced the highest cane yield (121.37 t/ha), which was

statistically comparable with PE Clomazone 22.5% + Metribuzine 21% WP (117.08 t/ha) and PE Clomazone 30% + Sulfentrazone 28% WP (119.95 t/ha) treatments. Similarly, the maximum CCS yield (17.58 t/ha) was achieved with PE Clomazone 30% + Sulfentrazone 28% WP, followed closely by PE Clomazone 22.5% + Metribuzine 21% WP (17.15 t/ha) and PoE Halosulfuron methyl + Metribuzine (16.87 t/ha).

The superior yield performance under these treatments can be attributed to effective early weed suppression, which minimized crop-weed competition and facilitated better nutrient uptake and growth. These findings are in line with the reports of, Maurya *et al*. (2020) [6], who also highlighted the effectiveness of halosulfuron + metribuzin and related herbicidal combinations in enhancing cane productivity.

Weed Studies

The impact of various weed management practices on weed density, weed dry matter, and weed control efficiency was assessed at 30, 60, 90, and 120 DAP (Tables 4-12). All parameters were significantly influenced by the treatments. The weedy check recorded the highest population of monocots, dicots, and sedges, whereas all weed management treatments significantly reduced weed growth and maintained better control throughout the crop period.

Weed density

At 30, 60, and 90 DAP, the lowest monocot weed counts were observed with pre-emergence application of Clomazone 22.5% + Metribuzine 21% WP (2.5 kg/ha) followed by intercultivation at 60 DAP, closely followed by Clomazone 30% + Sulfentrazone 28% WP. By 120 DAP, Clomazone + Sulfentrazone showed the best monocot control.

For dicot weeds, Topramezone + Atrazine (PoE at 3 L/ha) reduced counts significantly at 30 DAP, while Halosulfuron methyl + Metribuzine (PoE at 1 L/ha) effectively minimized dicot density at 60 and 90 DAP, comparable to other herbicide combinations. At 120 DAP, Clomazone + Sulfentrazone provided the most sustained broadleaf weed control.

Halosulfuron methyl + Metribuzine (PoE) also recorded the lowest sedge population. Total weed density was lowest with Topramezone + Atrazine at 30 DAP, but Clomazone + Sulfentrazone (PE) plus intercultivation effectively reduced total weed numbers at later stages (60-120 DAP).

Weed dry matter (g/m^2)

At 30, 60, and 90 DAP, pre-emergence (PE) application of Clomazone 22.5% + Metribuzine 21% WP (2.5 kg/ha) followed by intercultivation at 60 DAP effectively reduced grass dry matter early on. By 120 DAP, Clomazone 30% + Sulfentrazone 28% WP (PE at 2.5 kg/ha) maintained the lowest grass biomass, indicating strong residual control.

For broadleaf weeds, post-emergence (PoE) application of Topramezone + Atrazine (3 L/ha) at 30 DAP showed the greatest early reduction in dry matter. Halosulfuron methyl + Metribuzine (PoE at 1 L/ha) sustained broadleaf suppression at 60 and 90 DAP, while Clomazone + Sulfentrazone (PE) provided the most consistent control through 120 DAP.

Sedge dry matter was lowest under PoE Halosulfuron methyl + Metribuzine at all stages. Total weed dry weight was minimized by Clomazone + Sulfentrazone at 30 and 120 DAP, highlighting its long-term efficacy. Meanwhile, Halosulfuron methyl + Metribuzine excelled in reducing total weed biomass during mid-season (60 and 90 DAP). Together, these treatments offered effective, complementary weed control throughout the growing season.

Weed control efficiency

At 30 and 120 DAP, pre-emergence application of Clomazone 30% + Sulfentrazone 28% WP (2.5 kg/ha) followed by intercultivation at 60 DAP showed the highest weed control efficiency due to its strong residual and broad-spectrum activity. In contrast, post-emergence application of Halosulfuron methyl + Metribuzine (1 L/ha) at the 2-4 leaf stage, followed by earthing up at 120 DAP, was most effective at 60 and 90 DAP, providing superior mid-season weed suppression.

These results are consistent with Tropaldi *et al*. (2021) [16], who highlighted the prolonged residual control of the Clomazone + Sulfentrazone mixture under tropical conditions. Additionally, the FMC Authority NXT Technical Bulletin (2020) [1] endorses this premix at 2.5 kg/ha for effective early-season weed management in sugarcane, supporting the findings of this study.

Weed Index and economics

Treatment PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP noted lowest weed index (10.40) and highest B:C ratio (1:2.38). Chaturvedi *et al*. (2020) observed that halosulfuron methyl in combination with metribuzin provided superior weed suppression and higher net returns compared with single-herbicide molecule.

Table 2: Germination percentage, tiller and millable cane population of sugarcane as influenced by different herbicide treatments

Treatment	Germination percentage	Tillers count at 120 DAP ('000'/ha)	NMC at harvest ('000'/ha)
T_1 PE application of Clomazone 22.5% +Metribuzine 21% WP (ready mix) 2.5 kg/ha *fb* one inter- cultivation at 60 DAP (partial earthing up)	57.87	103.00	92.25
T_2 PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) 2.5 kg/ha *fb* one inter- cultivation at 60 DAP (partial earthing up)	63.22	102.17	89.08
T_3 PoE application of 2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) 3 kg/ha at 2- 4 leaf stage of weeds *fb* earthing up at 120 DAP	60.43	98.33	84.25
T_4 PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	58.99	101.67	91.08
T_5 PoE application of Topramezone + Atrazine (ready mix) @ 3 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	53.88	92.00	80.25
T_6 PE application of Atrazine 80% WP @ 2.5 kg/ha at *fb* one inter-cultivation at 60 DAP (partial earthing up)	55.77	84.67	72.58
T_7 PoE application of 2,4 D Na salt @ 2.5 kg/ha at 2-4 leaf of weeds *fb* earthing up at 120 DAP	49.70	78.33	70.42
T_8 Weed free check	64.63	109.17	92.75
T_9 Weedy check	45.59	70.33	53.75
Sem±	1.58	1.21	1.21
C.D. @ 5%	4.54	3.49	3.50

Table 3: Yield attributing characters of sugarcane as influenced by different herbicide treatments

Treatment	Single cane wt. (kg)	Cane Yield (t/ha)	CCS Yield (t/ha)
T_1 PE application of Clomazone 22.5% +Metribuzine 21% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.27	117.08	17.15
T_2 PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.36	119.09	17.58
T_3 PoE application of 2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) 3 kg/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.28	108.07	15.48
T_4 PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.36	121.37	16.87
T_5 PoE application of Topramezone + Atrazine (ready mix) @ 3 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.29	103.55	14.74
T_6 PE application of Atrazine 80% WP @ 2.5 kg/ha at *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.27	91.87	13.07
T_7 PoE application of 2,4 D Na salt @ 2.5 kg/ha at 2-4 leaf of weeds *fb* earthing up at 120 DAP	1.16	82.92	11.50
T_8 Weed free check	1.41	135.48	19.88
T_9 Weedy check	1.03	51.08	7.12
Sem±	0.02	2.80	0.41
C.D. @ 5%	0.06	8.06	1.19

Table 4: Juice Quality parameters of sugarcane as influenced by different herbicide treatments

Treatment	Brix (0^0)	Sucrose (%)	CCS (%)
T_1 PE application of Clomazone 22.5% +Metribuzine 21% WP (ready mix) 2.5 kg/ha *fb* one inter- cultivation at 60 DAP (partial earthing up)	21.76	20.36	14.65
T_2 PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) 2.5 kg/ha *fb* one inter- cultivation at 60 DAP (partial earthing up)	21.93	20.53	14.78
T_3 PoE application of 2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) 3 kg/ha at 2- 4 leaf stage of weeds *fb* earthing up at 120 DAP	21.49	19.96	14.32
T_4 PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	21.39	19.53	13.90
T_5 PoE application of Topramezone + Atrazine (ready mix) @ 3 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	21.23	19.84	14.27
T_6 PE application of Atrazine 80% WP @ 2.5 kg/ha at *fb* one inter-cultivation at 60 DAP (partial earthing up)	21.32	19.84	14.24
T_7 PoE application of 2,4 D Na salt @ 2.5 kg/ha at 2-4 leaf of weeds *fb* earthing up at 120 DAP	20.55	19.30	13.91
T_8 Weed free check	21.49	20.32	14.68
T_9 Weedy check	20.91	19.45	13.95
Sem±	0.37	0.39	0.32
C.D. @ 5%	NS	NS	NS

Table 5: Effect of different herbicide treatments on density of monocot weeds in sugarcane

Treatment	Monocots (no./m2) at			
	30 DAP	60 DAP	90 DAP	120 DAP
T_1 PE application of Clomazone 22.5% +Metribuzine 21% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.00 (0.00)	1.91 (2.67)	2.00 (3.50)	3.05 (12.67)
T_2 PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.00 (0.00)	2.16 (3.83)	2.33 (4.83)	2.64 (6.17)
T_3 PoE application of 2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) 3 kg/ha at 2- 4 leaf stage of weeds *fb* earthing up at 120 DAP	2.64 (6.00)	2.94 (7.67)	2.93 (7.67)	4.92 (25.50)
T_4 PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	2.65 (6.17)	3.03 (8.33)	3.43 (11.67)	3.84 (14.33)
T_5 PoE application of Topramezone + Atrazine (ready mix) @ 3 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.87 (2.67)	4.08 (16.00)	4.50 (19.33)	5.12 (26.33)
T_6 PE application of Atrazine 80% WP @ 2.5 kg/ha at *fb* one inter-cultivation at 60 DAP (partial earthing up)	2.91 (9.50)	3.79 (13.33)	3.70 (13.17)	4.34 (17.83)
T_7 PoE application of 2,4 D Na salt @ 2.5 kg/ha at 2-4 leaf of weeds *fb* earthing up at 120 DAP	4.58 (20.00)	4.18 (16.50)	4.89 (23.50)	5.80 (32.67)
T_8 Weed free check	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
T_9 Weedy check	6.31 (38.83)	7.30 (52.33)	7.58 (56.50)	7.75 (59.17)
Sem±	0.39	0.18	0.41	0.60
C.D. @ 5%	1.17	0.54	1.23	1.80

Figures in the parentheses are square root transformed values $\sqrt{(x+1)}$

Table 6: Effect of different herbicide treatments on density of dicot weeds in sugarcane

Treatment	Dicot (no./m^2) at			
	30 DAP	60 DAP	90 DAP	120 DAP
T_1 PE application of Clomazone 22.5% +Metribuzine 21% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	2.37 (4.67)	2.68 (6.33)	2.97 (8.00)	4.37 (18.33)
T_2 PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	2.41 (5.33)	1.58 (1.67)	1.59 (1.83)	3.71 (13.17)
T_3 PoE application of 2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) 3 kg/ha at 2- 4 leaf stage of weeds *fb* earthing up at 120 DAP	1.98 (3.00)	1.00 (0.00)	1.97 (3.50)	4.15 (16.33)
T_4 PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.48 (1.33)	1.00 (0.00)	1.33 (0.83)	6.67 (44.50)
T_5 PoE application of Topramezone + Atrazine (ready mix) @ 3 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.07 (0.17)	1.32 (0.83)	1.56 (1.50)	6.75 (44.83)
T_6 PE application of Atrazine 80% WP @ 2.5 kg/ha at *fb* one inter-cultivation at 60 DAP (partial earthing up)	3.86 (14.50)	3.56 (12.67)	4.09 (15.83)	7.36 (53.33)
T_7 PoE application of 2,4 D Na salt @ 2.5 kg/ha at 2-4 leaf of weeds *fb* earthing up at 120 DAP	5.53 (29.67)	5.26 (26.67)	2.86 (7.83)	7.25 (51.83)
T_8 Weed free check	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
T_9 Weedy check	7.75 (59.17)	8.92 (78.83)	9.62 (93.00)	11.48 (130.83)
Sem±	0.32	0.31	0.40	0.36
C.D. @ 5%	0.95	0.94	1.21	1.08

Figures in the parentheses are square root transformed values √(x+1)

Table 7: Effect of different herbicide treatments on density of sedges in sugarcane

Treatment	Sedges (no./m^2) at			
	30 DAP	60 DAP	90 DAP	120 DAP
T_1 PE application of Clomazone 22.5% +Metribuzine 21% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.76 (2.17)	1.86 (2.50)	1.88 (2.67)	2.04 (3.17)
T_2 PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.52 (1.33)	1.41 (1.00)	1.81 (2.33)	1.95 (2.83)
T_3 PoE application of 2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) 3 kg/ha at 2- 4 leaf stage of weeds *fb* earthing up at 120 DAP	1.61 (1.67)	1.77 (2.17)	2.08 (3.33)	1.90 (2.67)
T_4 PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.21 (0.50)	1.32 (0.83)	1.58 (1.50)	1.52 (1.33)
T_5 PoE application of Topramezone + Atrazine (ready mix) @ 3 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.67 (1.83)	1.51 (1.33)	1.85 (2.50)	1.99 (3.00)
T_6 PE application of Atrazine 80% WP @ 2.5 kg/ha at *fb* one inter-cultivation at 60 DAP (partial earthing up)	2.12 (3.50)	1.95 (2.83)	2.27 (4.33)	2.45 (5.00)
T_7 PoE application of 2,4 D Na salt @ 2.5 kg/ha at 2-4 leaf of weeds *fb* earthing up at 120 DAP	1.92 (2.83)	2.11 (3.50)	2.40 (4.83)	2.36 (4.67)
T_8 Weed free check	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
T_9 Weedy check	2.86 (7.50)	3.31 (10.00)	3.71 (12.83)	4.22 (16.83)
Sem±	0.20	0.14	0.17	0.12
C.D. @ 5%	0.59	0.42	0.52	0.37

Figures in the parentheses are square root transformed values √(x+1)

Table 8: Total weed density in sugarcane as affected by different herbicide treatments

Treatment	Total (no./m^2) at			
	30 DAP	60 DAP	90 DAP	120 DAP
T_1 PE application of Clomazone 22.5% +Metribuzine 21% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	2.78 (6.83)	3.53 (11.50)	3.86 (14.17)	5.72 (34.17)
T_2 PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	2.71 (6.67)	2.68 (6.50)	3.15 (9.00)	4.80 (22.17)
T_3 PoE application of 2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) 3 kg/ha at 2- 4 leaf stage of weeds *fb* earthing up at 120 DAP	3.41 (10.67)	3.29 (9.83)	3.91 (14.50)	6.65 (44.70)
T_4 PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	2.95 (8.00)	3.16 (9.17)	3.75 (14.00)	7.73 (60.17)
T_5 PoE application of Topramezone + Atrazine (ready mix) @ 3 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	2.36 (4.67)	4.34 (18.17)	4.92 (23.33)	8.65 (74.17)
T_6 PE application of Atrazine 80% WP @ 2.5 kg/ha at *fb* one inter-cultivation at 60 DAP (partial earthing up)	5.17 (27.50)	5.41 (28.83)	5.85 (33.33)	8.78 (76.17)
T_7 PoE application of 2,4 D Na salt @ 2.5 kg/ha at 2-4 leaf of weeds *fb* earthing up at 120 DAP	7.31 (52.50)	6.90 (46.67)	6.05 (36.17)	9.49 (89.17)

T_8 Weed free check	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
T_9 Weedy check	10.31 (105.50)	11.92 (141.17)	12.75 (162.33)	14.42 (206.83)
Sem±	0.41	0.28	0.35	0.48
C.D. @ 5%	1.23	0.84	1.04	1.44

Figures in the parentheses are square root transformed values √(x+1)

Table 9: Effect of different herbicide treatments on dry matter of monocot weeds in sugarcane

Treatment	Monocots (g/m^2) at			
	30 DAP	**60 DAP**	**90 DAP**	**120 DAP**
T_1 PE application of Clomazone 22.5% +Metribuzine 21% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.00 (0.00)	1.27 (0.64)	1.37 (0.88)	2.08 (4.41)
T_2 PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.00 (0.00)	1.85 (2.75)	1.69 (1.86)	2.06 (3.46)
T_3 PoE application of 2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) 3 kg/ha at 2- 4 leaf stage of weeds *fb* earthing up at 120 DAP	1.59 (1.75)	2.29 (4.40)	1.86 (2.53)	3.14 (10.23)
T_4 PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.77 (2.18)	2.28 (4.26)	1.94 (2.75)	2.58 (6.13)
T_5 PoE application of Topramezone + Atrazine (ready mix) @ 3 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.46 (1.16)	2.62 (5.87)	2.55 (5.65)	3.43 (11.31)
T_6 PE application of Atrazine 80% WP @ 2.5 kg/ha at *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.18 (0.43)	3.65 (12.60)	3.06 (8.45)	3.49 (11.36)
T_7 PoE application of 2,4 D Na salt @ 2.5 kg/ha at 2-4 leaf of weeds *fb* earthing up at 120 DAP	2.47 (5.19)	4.54 (20.31)	4.66 (21.64)	4.86 (22.60)
T_8 Weed free check	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
T_9 Weedy check	3.10 (8.60)	5.57 (30.07)	6.05 (35.66)	6.96 (47.59)
Sem±	0.15	0.31	0.27	0.37
C.D. @ 5%	0.44	0.92	0.80	1.12

Figures in the parentheses are square root transformed values √(x+1)

Table 10: Effect of different herbicide treatments on dry matter of dicot weeds in sugarcane

Treatment	Dicots (g/m^2) at			
	30 DAP	**60 DAP**	**90 DAP**	**120 DAP**
T_1 PE application of Clomazone 22.5% +Metribuzine 21% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.06 (0.12)	3.22 (10.07)	3.78 (13.36)	4.60 (20.21)
T_2 PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.05 (0.10)	2.46 (6.17)	1.28 (0.79)	2.67 (6.15)
T_3 PoE application of 2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) 3 kg/ha at 2- 4 leaf stage of weeds *fb* earthing up at 120 DAP	1.04 (0.08)	1.00 (0.00)	1.75 (2.74)	3.31 (9.97)
T_4 PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.01 (0.03)	1.00 (0.00)	1.06 (0.14)	6.04 (36.09)
T_5 PoE application of Topramezone + Atrazine (ready mix) @ 3 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.00 (0.01)	1.29 (0.83)	1.45 (1.27)	6.27 (38.41)
T_6 PE application of Atrazine 80% WP @ 2.5 kg/ha at *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.10 (0.20)	3.81 (13.49)	3.47 (11.03)	6.37 (39.55)
T_7 PoE application of 2,4 D Na salt @ 2.5 kg/ha at 2-4 leaf of weeds *fb* earthing up at 120 DAP	1.21 (0.46)	4.30 (18.58)	2.52 (6.24)	6.36 (39.50)
T_8 Weed free check	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
T_9 Weedy check	3.69 (12.65)	10.14 (101.81)	11.40 (129.54)	12.80 (162.94)
Sem±	0.06	0.40	0.37	0.24
C.D. @ 5%	0.17	1.19	1.12	0.73

Figures in the parentheses are square root transformed values √(x+1)

Table 11: Effect of different herbicide treatments on dry matter of sedges in sugarcane

Treatment	Sedges (g/m^2) at			
	30 DAP	60 DAP	90 DAP	120 DAP
T_1 PE application of Clomazone 22.5% +Metribuzine 21% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.50 (1.32)	1.85 (2.45)	2.08 (3.53)	2.45 (5.03)
T_2 PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.34 (0.84)	1.43 (1.05)	2.06 (3.28)	2.34 (4.52)
T_3 PoE application of 2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) 3 kg/ha at 2- 4 leaf stage of weeds *fb* earthing up at 120 DAP	1.40 (1.00)	1.83 (2.38)	2.40 (4.79)	2.31 (4.36)
T_4 PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.16 (0.36)	1.27 (0.70)	1.80 (2.25)	1.72 (1.98)
T_5 PoE application of Topramezone + Atrazine (ready mix) @ 3 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.45 (1.13)	1.56 (1.49)	2.10 (3.54)	2.42 (4.95)
T_6 PE application of Atrazine 80% WP @ 2.5 kg/ha at *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.65 (1.73)	2.06 (3.29)	2.68 (6.47)	2.97 (7.86)
T_7 PoE application of 2,4 D Na salt @ 2.5 kg/ha at 2-4 leaf of weeds *fb* earthing up at 120 DAP	1.45 (1.13)	2.27 (4.18)	2.73 (6.58)	2.80 (6.98)
T_8 Weed free check	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
T_9 Weedy check	2.18 (3.86)	3.59 (11.93)	4.41 (18.42)	5.18 (25.93)
Sem±	0.14	0.14	0.19	0.15
C.D. @ 5%	0.41	0.43	0.56	0.44

Figures in the parentheses are square root transformed values √(x+1)

Table 12: Effect of different herbicide treatments on total dry matter of weeds in sugarcane

Treatment	Total (g/m^2) at			
	30 DAP	60 DAP	90 DAP	120 DAP
T_1 PE application of Clomazone 22.5% +Metribuzine 21% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.54 (1.44)	3.70 (13.15)	4.33 (17.76)	5.51 (29.65)
T_2 PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.38 (0.94)	3.11 (9.97)	2.63 (5.93)	3.87 (14.13)
T_3 PoE application of 2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) 3 kg/ha at 2- 4 leaf stage of weeds *fb* earthing up at 120 DAP	1.93 (2.83)	2.78 (6.78)	3.28 (10.05)	4.97 (24.56)
T_4 PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.88 (2.56)	2.43 (4.96)	2.47 (5.14)	6.65 (44.20)
T_5 PoE application of Topramezone + Atrazine (ready mix) @ 3 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	1.80 (2.29)	3.03 (8.18)	3.37 (10.45)	7.46 (54.67)
T_6 PE application of Atrazine 80% WP @ 2.5 kg/ha at *fb* one inter-cultivation at 60 DAP (partial earthing up)	1.82 (2.36)	5.51 (29.38)	5.19 (25.95)	7.73 (58.78)
T_7 PoE application of 2,4 D Na salt @ 2.5 kg/ha at 2-4 leaf of weeds *fb* earthing up at 120 DAP	2.77 (6.78)	6.57 (43.07)	5.83 (34.46)	8.37 (69.07)
T_8 Weed free check	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
T_9 Weedy check	5.10 (25.10)	12.03 (143.80)	13.57 (183.63)	15.40 (236.46)
Sem±	0.15	0.38	0.33	0.36
C.D. @ 5%	0.46	1.13	0.99	1.07

Figures in the parentheses are square root transformed values √(x+1)

Table 13: Effect of different herbicide treatments on weed control efficiency

Treatment	Weed control efficiency (%)			
	30 DAP	60 DAP	90 DAP	120 DAP
T_1 PE application of Clomazone 22.5% +Metribuzine 21% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	94.04	90.89	90.21	87.25
T_2 PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) 2.5 kg/ha *fb* one inter-cultivation at 60 DAP (partial earthing up)	96.44	93.12	96.70	93.91
T_3 PoE application of 2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) 3 kg/ha at 2- 4 leaf stage of weeds *fb* earthing up at 120 DAP	89.10	95.28	94.56	89.29
T_4 PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	89.68	96.56	97.22	80.89
T_5 PoE application of Topramezone + Atrazine (ready mix) @ 3 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	90.93	94.31	94.35	76.70
T_6 PE application of Atrazine 80% WP @ 2.5 kg/ha at *fb* one inter-cultivation at 60 DAP (partial earthing up)	90.26	79.59	85.78	75.02
T_7 PoE application of 2,4 D Na salt @ 2.5 kg/ha at 2-4 leaf of weeds *fb* earthing up at 120 DAP	73.52	70.12	81.77	70.65
T_8 Weed free check	-	-	-	-
T_9 Weedy check	-	-	-	-

Table 14: weed index and economics as affected by different herbicide treatments

Treatment	Weed index (%)	B: C ratio
T_1 PE application of Clomazone 22.5% +Metribuzine 21% WP (ready mix) 2.5 kg/ha *fb* one inter- cultivation at 60 DAP (partial earthing up)	13.58	2.31
T_2 PE application of Clomazone 30% + Sulfentrazone 28% WP (ready mix) 2.5 kg/ha *fb* one inter- cultivation at 60 DAP (partial earthing up)	12.08	2.29
T_3 PoE application of 2,4 D sodium salt + Metribuzine +Pyrazosulfuron ethyl (ready mix) 3 kg/ha at 2- 4 leaf stage of weeds *fb* earthing up at 120 DAP	20.21	2.11
T_4 PoE application of Halosulfuron methyl + Metribuzine (ready mix) @1 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	10.40	2.38
T_5 PoE application of Topramezone + Atrazine (ready mix) @ 3 L/ha at 2-4 leaf stage of weeds *fb* earthing up at 120 DAP	23.54	2.01
T_6 PE application of Atrazine 80% WP @ 2.5 kg/ha at *fb* one inter-cultivation at 60 DAP (partial earthing up)	32.15	1.84
T_7 PoE application of 2,4 D Na salt @ 2.5 kg/ha at 2-4 leaf of weeds *fb* earthing up at 120 DAP	38.75	1.66
T_8 Weed free check	-	2.26
T_9 Weedy check	62.24	1.03
Sem±	-	-

Conclusion

Post-emergence application of Halosulfuron methyl + Metribuzine (ready mix) at 1 L/ha during the 2-4 leaf stage of weeds, followed by earthing up at 120 DAP, achieved the highest cane yield of 121.37 t/ha, with a weed index of 10.40 and a benefit-cost ratio of 1:2.38.

In contrast, pre-emergence treatment with Clomazone 30% + Sulfentrazone 28% WP (ready mix) at 2.5 kg/ha, combined with one intercultivation at 60 DAP (partial earthing up), produced the highest commercial cane sugar (CCS) yield of 17.58 t/ha and demonstrated the greatest weed control efficiency of 93.91%, highlighting its strong and lasting impact on weed management and crop performance.

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