The Indian Journal of Agricultural Sciences 96 (6): 727–733, June 2026/Article
https://doi.org/10.56093/ijas.v96i6.171805

Efficacy of post-emergence herbicides on weed dynamics, productivity and economics in spring planted sugarcane (*Saccharum officinarum*)

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Received: 16 September 2025; Accepted: 18 May 2026

ABSTRACT

Sugarcane (*Saccharum officinarum* L.) is a major cash crop in India, playing a vital role in the country's agricultural economy. However, its productivity is often hampered by intense weed competition. Effective weed management is thus crucial to ensure optimal cane yield and profitability. The present experiment was aimed to see the performance of the various post-emergence herbicide treatments in spring-planted sugarcane conducted during 2023–24 and 2024–25 at Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh. The experiment was laid out in a randomised complete block design (RCBD) with nine treatments, including solo and tank-mix applications of 2,4-D sodium salt, ametryn, halosulfuron-methyl, mesotrione + atrazine, a premix of 2,4-D + ametryn + halosulfuron-methyl at three dose levels (3.5, 4.5 and 5.625 kg/ha), along with a hand-weeding treatment and an untreated control. The dominant weed flora observed in the field were *Cyperus rotundus*, *Cynodon dactylon*, *Digitaria sanguinalis*, *Ipomoea aquatica*, *Sida acuta* and *Solanum nigrum*. Among all the treatments, the premix of 2,4-D + ametryn + halosulfuron-methyl at 5.625 kg/ha recorded the highest weed suppression (96.27% weed control efficiency), cane yield (148 t/ha), net return (₹4,05,260/ha), juice quality (24.63% brix), lowest weed density (3.01/m²) and minimum weed biomass (3.14 g/m²). The positive outcomes were also credited to reduced competition between crops and weeds, with no phytotoxicity. These findings highlight the weed control efficacy of post-emergence application (30 DAP) of ready-mix herbicide molecules (2,4-D + ametryn + halosulfuron-methyl at 5.625 kg/ha) which may be adopted by sugarcane growers, particularly under agro-climatic conditions of the eastern Uttar Pradesh.

Keywords: Brix value, Net return, Sugarcane yield, Weed control efficiency

India is the second-largest sugarcane (*Saccharum officinarum* L.) producer globally, with Uttar Pradesh being a leading contributor to national output (Mishra *et al.* 2025). In particular, spring-planted sugarcane in the eastern Gangetic plains benefits from extended crop duration and favourable early-season climatic conditions, contributing to its agronomic potential (Verma *et al.* 2019, Kumar *et al.* 2024). However, one of the most formidable biotic constraints limiting sugarcane productivity is weed infestation, especially during the crop's early phenological stages. Weed interference in sugarcane is exacerbated by the crop's inherently slow initial growth, delayed canopy closure and wide row spacing, which collectively provide an ecological niche for aggressive weed colonisation. This interference adversely affects tiller development and biomass accumulation, often resulting in substantial yield losses (Sanghera 2021, Giraldeli *et al.* 2024).

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Traditionally, weed control in sugarcane has relied on manual weeding and mechanical intercultural operations. While effective, these methods are increasingly problematic due to labour shortages and escalating costs. In contrast, post-emergence broad spectrum herbicides offer a more efficient and cost-effective alternative with improved operational ease. Their success, however, is contingent upon multiple factors, including crop selectivity, weed species composition, environmental safety and economic return. Supporting this, Madhu *et al.* (2021) demonstrated that early post-emergence application of topramezone + atrazine effectively suppressed weed growth without compromising sugarcane health. Spring sugarcane fields in eastern Uttar Pradesh are typically infested with a complex weed flora comprising grasses such as *Cynodon dactylon* and *Digitaria sanguinalis*, sedges like *Cyperus rotundus* and broad-leaved weeds including *Ipomoea aquatica*, *Sida acuta* and *Solanum nigrum*. Managing such a mixed weed flora requires herbicide strategies that combine efficacy with crop safety. Tank-mix and premix formulations of post-emergence herbicides have shown promise in delivering enhanced weed control under diverse cropping systems.

Studies by Sivamurugan *et al.* (2024) reported that tank-mix and sequential herbicide applications significantly improved weed suppression and profitability across multiple agricultural systems. Similarly, Ramesha *et al.* (2018) observed that integrated weed management strategies incorporating sulfonylurea-based herbicides substantially reduced weed pressure and enhanced cane yields. Earlier findings from subtropical regions also supported the efficacy of herbicide-based interventions. For example, Choudhary and Singh (2015) demonstrated that sequential applications of ametryn followed by 2,4-D achieved weed control efficiency above 90%, cane yields exceeding 132 t/ha and favourable benefit-cost ratio.

Considering the recurring challenges posed by diverse and persistent weed flora in sugarcane cultivation, the present experimentation was undertaken to assess bio-efficacy of selected post-emergence herbicides, evaluated both as tank-mix and premix formulations, for their effectiveness in weed suppression, influence on crop growth, enhancement of productivity and improvement in economic return in spring-planted sugarcane under the agro-climatic conditions of eastern Uttar Pradesh. The study is intended to identify efficient, sustainable and location-specific weed management strategies that not only optimise resource utilisation and improve crop profitability but also contribute to long-term agro-ecological stability and resilience.

MATERIALS AND METHODS

Study area and data collection: The present experiment was conducted during 2023–24 and 2024–25 at Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (25°18′N, 83°03′E; at an elevation of 80.71 m amsl), Uttar Pradesh. The experimental site was characterised by sandy clay loam soil with a neutral reaction (*p*H 7.40), low available nitrogen (189 kg/ha), medium available phosphorus (23.43 kg/ha) and potassium (207 kg/ha) with an electrical conductivity of 0.31 dS/m. The weekly meteorological data were also collected during cropping period during both the both years (Fig. 1). The region received 659.1 mm rainfall in 2023–24 and 1000.4 mm in 2024–25, with the bulk of precipitation occurring during July–August. The ambient temperature ranged from 15.2–44.8°C (Fig. 1), while relative humidity fluctuated between 40–96%. The field experiment was conducted following a randomised complete block design (RCBD) comprising nine treatments, each replicated thrice. The treatments comprised a premix applications of 2,4-D sodium salt 30% + ametryn 40% + halosulfuron-methyl 1.33% WP @3.5, 4.5 and 5.625 kg/ha and individual application of 2,4-D sodium salt 80% w/w @3.2 kg/ha, ametryn 80% WDG @2.5 kg/ha, halosulfuron-methyl 75% WG @0.09 kg/ha and premix of mesotrione 2.27% + atrazine 22.7% w/w SC @3.5 L/ha, along with hand weeding and a weedy control. Sugarcane cultivar 'CoLK-14204' was planted at 90 cm row spacing using three-budded setts treated with carbendazim (2 g/L for 15 min) prior to planting. A fertiliser rate of 150, 80, 80 kg NPK/ha was applied, with nitrogen supplied in three equal splits at planting, 60 and 90 days after planting (DAP). Herbicide treatments were imposed at 30 DAP using a knapsack sprayer fitted with a flat-fan nozzle, delivering 500 L spray solution/ha. Weed density and biomass were recorded at 30, 60 and 90 days after herbicide application (DAA) using 0.25 m² quadrat placed randomly in each plot. Weed dry matter was measured by oven-drying weeds at

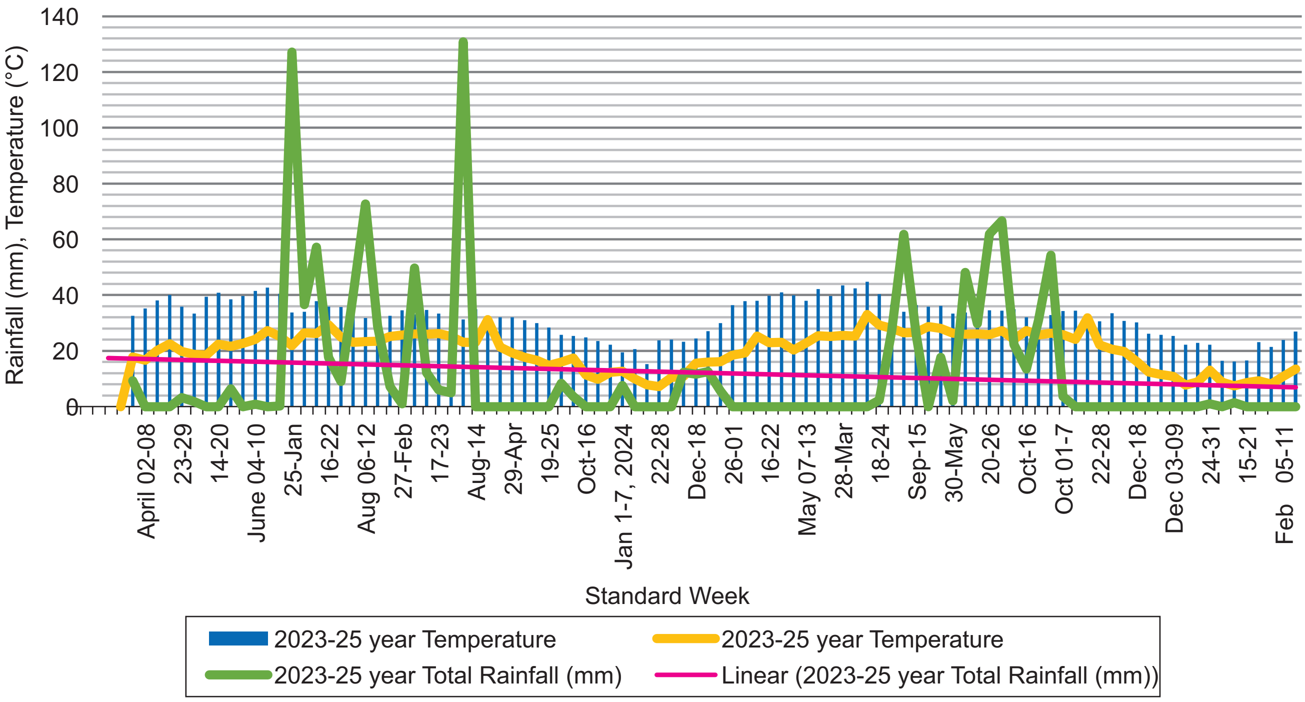

Fig. 1 Weekly meteorological data during experimental duration (2023–25).

70°C for 48 h. Weed control efficiency (WCE) was calculated as (Amare *et al.* 2014):

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

Where WDC, Weed dry matter from the control plot (untreated); WDT, Weed dry matter from treated plot.

The data on yield parameters such as cane length, diameter, internode number and length and cane and green top yield were recorded at harvest. At harvest, the diameter of randomly selected cane samples was measured at the bottom, middle and top portions using a vernier caliper. Economic analysis was based on the prevailing market prices for inputs and the produce. Weed biomass and density data were square root-transformed [$\sqrt{(x + 0.5)}$] before ANOVA and treatment means were compared using the critical difference (CD) at 5% significance ($p \leq 0.05$).

RESULTS AND DISCUSSIONS

Weed flora: The early growth stages of spring-planted sugarcane were infested with a heterogeneous weed flora, representing a combination of grasses such as *Cynodon dactylon* and *Digitaria sanguinalis*, sedge like *Cyperus rotundus* and broad-leaved weeds including *Solanum nigrum*, *Sida acuta* and *Ipomoea aquatica*. The co-existence of these diverse functional groups poses serious competition for resources, particularly during the crop's formative stages, thereby emphasising the requirement for post-emergence herbicides with broad-spectrum efficacy. Such herbicides are essential not only to manage the wide range of weed species effectively but also to prevent shifts in weed flora dominance that may occur under selective control. Comparable weed complexes have been observed in sugarcane belts of eastern Uttar Pradesh, where soil texture, fertility status and climatic conditions create a favourable environment for mixed weed populations. Islam *et al.* (2016), similarly documented weed assemblages in the sugarcane ecosystems of Bangladesh, where *Cyperus* spp. and aggressive broad-leaved weeds were reported as dominant, reinforcing the need for integrated and region-specific weed management strategies. Unchecked weed growth during the early stages of sugarcane development has been consistently shown to impose severe yield penalties. Weeds emerging alongside the crop compete directly for light, nutrients and moisture, thereby suppressing cane tillering, reducing nutrient uptake efficiency and lowering cane yield (Suganthi *et al.* 2019). Studies across India and abroad confirmed that uncontrolled weed infestation during the first 60–120 DAP can result in yield losses ranging from 40–67% (Kadam *et al.* 2011). Long-term experiments under different tillage and cropping systems reported that weedy check plots produced significantly lower yields (33.9–49.9 t/ha) compared with managed plots, translating to 22–60% yield reduction (Srivastava *et al.* 2005). Fertility-weed management trials further demonstrated that nutrient uptake was markedly reduced in weedy plots, whereas weed-free treatments facilitated superior uptake and improved crop performance (Kumar *et al.* 2014). These findings highlight the critical importance of timely and effective weed management during the early growth stages of sugarcane to safeguard tillering, nutrient uptake and overall productivity.

Weed density: Weed density was significantly reduced by all herbicidal treatments compared to the untreated control (13.92/m²). The lowest density (3.1, 2.92) during the respective years with mean of 3.01/m² was recorded by the application of 2,4-D sodium salt 30% + ametryn 40% + halosulfuron methyl 1.33% WP at 5.625 kg/ha, which was statistically superior to hand weeding (3.98, 4.68 during the two consecutive years and pooled of 4.33/m²) in comparison to remaining herbicidal treatments (Table 1). The effectiveness of this formulation is attributable to its differential mode of action i.e. 2,4-D disrupts auxin metabolism in broad-leaved weeds, ametryn inhibits photosynthesis by targeting PS II and halosulfuron methyl suppresses cell division through ALS inhibition. These results are consistent with the findings of Choudhary and Singh (2015) who reported superior weed suppression and profitability in sugarcane with new-generation herbicide premixes compared to single-molecule applications. Furthermore, research demonstrates that herbicide premixes reduce the risk of residual weed control failure in crops like maize (Mahoney *et al.* 2015), while integrated weed management strategies including tank mixes and rotation of herbicides play a critical role in delaying herbicide resistance evolution (Heap 2014).

Weed biomass and weed control efficiency: Weed dry matter accumulation and weed control efficiency (WCE) further confirmed the superiority of one shot mixed herbicidal treatments. Post-emergence application of 2,4-D sodium salt 30% + ametryn 40% + halosulfuron methyl 1.33% WP @5.625 kg/ha recorded the lowest weed biomass during both the years with pool value of 3.14 g/m² and the highest WCE of 96.27% of pool of the two years, followed closely by its lower dose of 4.5 kg/ha. These values were significantly higher than those observed under manual weeding (93.42% WCE) (Table 1). The enhanced efficacy of these treatments likely results from extended residual activity and systemic translocation, ensuring sustained suppression of both annual and perennial weed species. Comparable efficacy has also been reported by Anusha *et al.* (2025) under similar tropical cropping conditions. Madhu *et al.* (2021) also demonstrated similar WCE values (~81%) under early post-emergence application of topramez one-based tank-mix treatments.

Soil physico-chemical properties: Post-harvest soil analyses indicated non-significant differences in *p*H, electrical conductivity, organic carbon, or available nitrogen, phosphorus and potassium across treatments. The stability of these parameters suggested that the tested herbicidal formulations, when applied at recommended doses, are environmentally safe and do not compromise soil health or nutrient availability. These findings support prior studies showing minimal impact of modern herbicide

Table 1 Effect of different weed control treatments in weed density, dry matter and weed control efficiency in sugarcane

Treatments	Weed density (Nos./m^2)			Weed dry weight (g/m^2)			WCE (%)		
	2023–24	2024–25	Pooled	2023–24	2024–25	Pooled	2023–24	2024–25	Pooled
2,4-D + ametryn + halosulfuron methyl @3.5 kg/ha	5.58 (30.67)	5.32 (27.78)	5.45 (29.22)	7.57 (56.80)	6.47 (41.34)	7.02 (49.07)	82.18	84.52	83.35
2,4-D + ametryn + halosulfuron methyl @4.5 kg/ha	3.37 (10.89)	3.26 (10.11)	3.32 (10.50)	3.51 (11.80)	3.55 (12.13)	3.53 (11.96)	95.32	95.35	95.33
2,4-D + ametryn + halosulfuron methyl @5.625 kg/ha	3.10 (9.11)	2.92 (8.00)	3.01 (8.56)	3.13 (9.28)	3.15 (9.44)	3.14 (9.36)	96.20	96.33	96.27
2,4-D 3.2 kg/ha	8.12 (65.44)	8.31 (68.56)	8.22 (67.00)	8.54 (72.45)	9.32 (86.43)	8.93 (79.44)	72.10	66.14	69.12
Ametryn @2.5 kg/ha	7.40 (54.33)	7.21 (51.44)	7.31 (52.89)	7.80 (60.31)	7.93 (62.32)	7.86 (61.31)	78.61	75.41	77.01
Halosulfuron methyl @0.09 kg/ha	10.04 (100.33)	9.89 (97.23)	9.96 (98.78)	12.71 (160.99)	12.41 (153.61)	12.56 (157.30)	48.23	43.81	46.02
Mesotrione + atrazine @3.5 L/ha	7.20 (51.32)	6.89 (46.99)	7.05 (49.16)	7.59 (57.05)	6.81 (45.85)	7.20 (51.45)	81.49	82.16	81.83
Hand weeding at 30 and 60 DAS	3.98 (15.33)	4.68 (21.44)	4.33 (18.39)	5.22 26.71)	5.41 (28.78)	5.31 (27.75)	94.58	92.26	93.42
Untreated control (weedy check)	13.85 (191.33)	13.99 (195.11)	13.92 (193.22)	17.99 (322.97)	16.79 (281.36)	17.39 (302.17)			
SEm±	0.12	0.12	0.12	0.14	0.13	0.14			
LSD (p=0.05)	0.35	0.35	0.35	0.41	0.40	0.41			

Data transformed to square root values $\left(\sqrt{(x+0.5)}\right)$. Original values are given in parentheses. WCE, Weed control efficiency; DAS, Days after sowing.

on soil physico-chemical properties when used judiciously in sustainable production systems. Ramesha *et al.* (2018) also reported similar findings wherein sulfonylurea and triazine-based herbicides showed negligible influence on post-harvest soil properties in sugarcane.

Crop growth parameters: Significant improvements in sugarcane growth parameters were observed in response to effective weed suppression. The spraying of 2,4-D sodium salt 30% + ametryn 40% + halosulfuron methyl 1.33% WP @5.625 kg/ha yielded the tallest plants (475.2 cm), widest stalk diameter (2.87 cm), longest internodes (14.24 cm) and the highest number of nodes/cane (27.95), all of which were significantly superior to those recorded in the weedy check (440.3 cm, 2.17 cm, 11.42 cm and 21.84, respectively) (Table 2). These improvements reflect reduced inter specific competition, allowing for greater photosynthetic efficiency, nutrient uptake and biomass accumulation owing to importance of early-season weed management for optimal crop establishment and vigour. The present findings also corroborate the work of Raskar (2014) in Maharashtra, who observed similar increases in growth parameters with effective post-emergence herbicidal weed control, particularly under tank-mix and broad-spectrum herbicide programs.

Cane yield and yield attributes: Cane yield was markedly influenced by weed management regimes. The highest pooled cane yield (148 t/ha) and single cane weight (1.37 kg) were recorded under the 5.625 kg/ha treatment, which outperformed all other treatments including manual weeding (Table 2). However, it was at par with 4.5 kg/ha treatment. The untreated control yielded only 113 t/ha, highlighting the detrimental impact of unchecked weed competition. The yield advantage under herbicidal treatments is attributed to efficient resource allocation, increased tillering and greater assimilate partitioning towards reproductive sinks. These findings corroborate those of Aekrathok *et al.* (2021) which also reported enhanced cane yield (~130–140 t/ha) under similar post-emergence herbicide combinations, suggesting consistency in outcomes across similar ecosystems. A similar subtropical sugarcane trials using herbicide sequences with comparable magnitude of yield enhancement (~130–140 t/ha) were well documented in the studies conducted by Srivastava *et al.* (2005) and Choudhary and Singh (2015).

Juice quality: Juice quality showed significant enhancement under effective weed control treatments (Table 2). The highest pooled Brix value of 24.48% was recorded with the herbicide mixture 2,4-D + ametryn + halosulfuron methyl @4.5 and 5.625 kg/ha, closely followed by hand weeding (24.43%) and the 3.5 kg/ha dose of the same mixture (24.38%). These treatments significantly outperformed the weedy check (22.14%), where unchecked weed growth likely impaired assimilate partitioning and sucrose buildup. Enhanced canopy development and improved light interception under weed-suppressed conditions could explain the increase in photosynthetic activity and efficient carbohydrate translocation, culminating in higher sucrose accumulation. Similar findings were

Table 2 Effect of different weed control treatments on growth parameters, yield and yield attributes, brix (%) and net return of sugarcane at harvest (pooled data of two years)

Treatments	Shoot length (cm)	Cane diameter (cm)	Inter node length (cm)	No. of nodes/ cane	Single cane weight (kg/plant)	Green top yield (t/ha)	Cane yield (t/ha)	Brix (%)	Net return (₹/ha)
2,4-D + ametryn + halosulfuron methyl @3.5 kg/ha	470.33	2.69	13.31	26.01	1.23	18.03	141	24.38	3,81,841
2,4-D + ametryn + halosulfuron methyl @4.5 kg/ha	473.41	2.78	13.67	26.88	1.35	18.3	148	24.48	4,04,450
2,4-D + ametryn + halosulfuron methyl @5.625 kg/ha	475.2	2.865	14.24	27.945	1.37	18.5	148	24.48	4,05,260
2,4-D 3.2 kg/ha	452.05	2.33	11.8	23.99	1.09	14.7	132	23.94	3,51,023
Ametryn 2.5 kg/ha	450.33	2.43	11.69	23.86	1.14	15	125	24.28	3,23,300
Halosulfuron methyl @0.09 kg/ha	451.9	2.32	11.74	22.97	1.16	15.6	127	24.07	3,32,154
Mesotrione + atrazine @3.5 L/ha	452.11	2.43	12.22	23.795	1.09	16	133	23.39	3,48,833
Hand weeding at 30 and 60 DAS	466.82	2.65	12.93	25.165	1.21	18	139	24.43	3,68,150
Untreated control (weedy check)	440.33	2.17	11.42	21.84	0.99	14	113	22.14	2,85,561
SEM±	7.65	0.04	0.21	0.41	0.02	0.275	2.23	0.03	-
LSD (*p*=0.05)	22.96	0.125	0.63	1.235	0.06	0.82	6.7	1.20	-

DAS, Days after sowing.

reported by Banerjee *et al.* (2014) who observed significantly higher Brix values with metribuzin + almix compared to untreated plots. Likewise, herbicide treatments such as diuron effectively suppressed weeds and enhanced juice quality parameters including sucrose, brix and purity coefficient (Patel 2019). Research involving halosulfuron methyl in combination with metribuzin and 2,4-D also documented superior weed control efficiency and improved quality metrics in sugarcane (Sharma 2018).

Net return: Weed control strategies substantially affected profitability as evident in Table 2. The highest net return (₹4,05,260/ha) was achieved with the application of 2,4-D + ametryn + halosulfuron methyl @5.625 kg/ha herbicide treatment, closely followed by a dose of 2,4-D + ametryn + halosulfuron methyl @4.5 kg/ha application (₹4,04,450/ha). These returns exceeded those obtained through manual weeding (₹3,68,150/ha), underscoring the cost-effectiveness of chemical weed control. The lowest return (₹2,85,561/ha) was observed in the untreated plots due to suppressed yield and higher weed competition. These findings align with Anusha *et al.* (2025) who demonstrated that strategic herbicide application significantly improves economic outcomes in sugarcane production systems. Madhu *et al.* (2021) also found that well-timed herbicide application combined with one hoeing delivered the highest economic return and B:C ratio in sugarcane. Similar comparable magnitude of profitable return (BC~3.0) was documented in previous subtropical sugarcane trials using herbicide sequences by Choudhary and Singh (2015).

Correlation studies: A strong and significant positive correlation was observed between cane yield and all recorded growth parameters of sugarcane. Cane yield showed the highest association with shoot height (r=0.9608), number of nodes (r=0.9519), cane girth (r=0.9421) and green top yield (r=0.9321), indicating their substantial influence on yield formation. Internode length (r=0.9249) and single cane weight (r=0.9187) also showed significant correlations, though slightly lower (Table 3). The high inter-correlations among plant height, cane girth, internode length and number of nodes suggested the presence of multicollinearity, indicating that these traits are physiologically interdependent. These results underline the role of robust vegetative growth in achieving higher cane yield under effective post-emergence weed control measures.

Regression studies: Regression analysis revealed a significant quadratic relationship between cane yield and growth traits. Among them, number of nodes (R^2=0.9460) and shoot height (R^2=0.9452) recorded the highest

Table 3 Correlation coefficient (r) between growth parameters and cane yield of spring planted sugarcane

Pearson correlation	Cane yield (t/ha)	Shoot height (cm)	Girth (cm)	Inter node length (cm)	No. of nodes/cane	Single cane weight (kg/plant)	Green top yield (t/ha)
Cane yield (t/ha)	1						
Plant height (cm)	0.96083	1					
Girth (cm)	0.94210	0.97908	1				
Inter node length (cm)	0.92494	0.96633	0.97277	1			
No. of nodes	0.95192	0.96490	0.97851	0.96921	1		
Single cane weight (kg/plant)	0.91869	0.95251	0.95593	0.93064	0.95426	1	
Green top yield (t/ha)	0.93206	0.97709	0.96538	0.95663	0.91624	0.91611	1

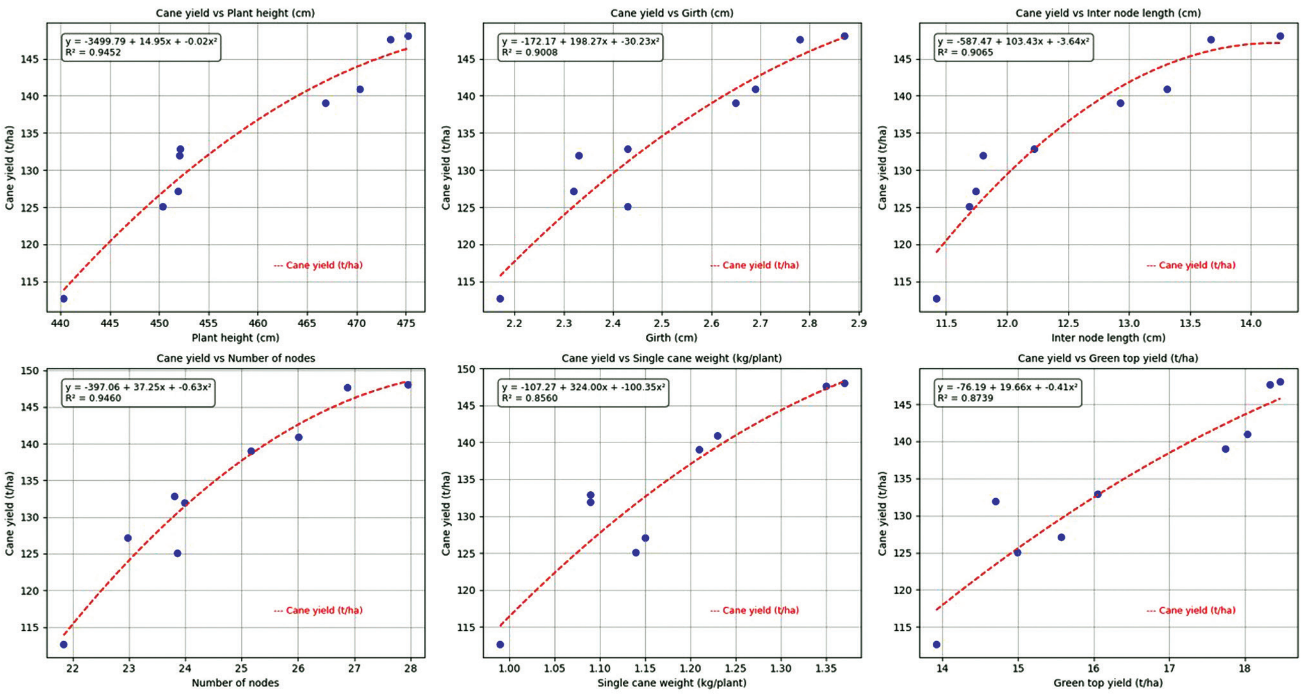

Fig. 2 Relationship between growth parameters and cane yield of spring planted sugarcane during both the years.

coefficient of determination, suggesting that these traits are the most reliable predictors of cane yield. Similarly, internode length (R^2=0.9065) and cane girth (R^2=0.9008) also contributed significantly to yield prediction. Single cane weight (R^2=0.8560) and green top yield (R^2=0.8739) showed moderately high predictability (Fig. 2). The overall regression pattern indicated that higher values of these growth parameters were positively associated with improved cane yield. These findings are in close agreement with the correlation analysis, reinforcing the importance of vegetative traits in determining productivity under different post-emergence herbicide treatments.

The present two-year study clearly demonstrated the superior efficacy of post-emergence herbicide combinations, particularly the premix of 2,4-D sodium salt + ametryn + halosulfuron-methyl @5.625 kg/ha in managing diverse weed flora in spring-planted sugarcane. This treatment achieved the highest weed control efficiency (96.27%), significantly reduced weed density and biomass and resulted in the most favourable growth parameters, including shoot height, internode length and cane girth. Consequently, it produced the highest cane yield (148 t/ha), single cane weight (1.37 kg), brix content (24.48%) and net return (₹4,05,260/ha), thereby surpassing both manual weeding and other herbicidal options. Correlation and regression analyses further validated the pivotal role of vegetative growth traits particularly shoot height and number of nodes in realising cane yield.

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