



RESEARCH ARTICLE

Evaluation of critical crop-weed competition period in kharif sweet corn (*Zea mays* L. var. *saccharata* Strut) in North-Eastern Ghats of Odisha

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Abstract

A field investigation was undertaken at M S Swaminathan School of Agriculture, Centurion University of Technology and Management, in the rainy period of 2024 to estimate the duration of the critical period for weed control (CPWC) of green corn under the North-Eastern Ghats zone of the state, Odisha. This experiment was designed following randomised block design. Ten treatments with various periods of weed interference were chosen, involving weed-free and weed infested check. At 60 days after sowing (DAS), *Cyperus rotundus* L had a maximum relative weed density (13.16 %). Tank mix application of topramezone + atrazine 25.2 + 250 g ha⁻¹ at 20 DAS, i.e., T₁₀ (3.30 m⁻²), resulted in a significantly higher population of sedge weeds over atrazine, followed by one hand weeding, i.e., T₉ treatment (3.00 m⁻²) at 60 DAS. Surprisingly, the yield loss of green cobs was 48.04 and 53.99 % in T₉ and T₁₀ treatments, respectively, as compared to weed-free throughout the growing period, i.e., T₈ treatment. The CPWC was found to be 27–79 DAS, i.e., 53 days of green corn growth. T₈ treatment was recorded as most profitable by providing maximum benefit : cost (B:C). Weed-free up to 63 DAS treatment provided almost similar B:C. Therefore, effective weed control practices should be adopted by sweet corn growers to maintain the field weed-free from 27–63 DAS (i.e., 37 days) during kharif in the North-Eastern Ghats of Odisha.

Keywords: atrazine + 1 hand weeding; atrazine + topramezone; critical period for weed control; herbicide; sweet corn

Introduction

Sweet corn, being a crop of the Poaceae family, is a rich source of dietary fibre, some vitamins and minerals (1). Among the various corn species, green corn has gained more importance mainly because of its use as a vegetable. Thus, sweet corn or green corn is also called vegetable corn. The nutritional content and taste of sweet corn have enhanced its value in all countries and with a higher scope of production (2). In the world, the area, production and productivity of green corn or sweet corn were 1.07 million ha, 9.74 Mt and 9.09 t ha⁻¹, respectively, in 2023 (3). In 2021, the average productivity of green cob was 12.01 t ha⁻¹ in India (4). The sugar percentage of sweet corn varies with varieties, which is a quality parameter of this crop (5). Local sweet corn varieties have 9–11 % of sugar, whereas hybrid sweet corns contain 16–18 % sugar. Among the various factors, the most critical for the lower productivity of green corn is the weed infestation competing with the crop for the natural

resources and depriving the crop of necessary resources (6). Green cob yield loss was reported as 67.78 % of the sweet corn hybrid, Sugar 75, because of weeds in the spring season (7). Two key weed control methods are the mechanical and herbicidal methods followed in corn (8). To obtain high yield with a good quality crop while minimising time of weed interference and the harmful impacts of weeds, integrated weed management (IWM) is influential on ecological and economic bases (9). Critical period for weed control (CPWC) is a time gap between the critical timing of weed removal (CTWR) and the critical weed-free period (CWFP). The appearance of weed before and after CPWC must decrease green cob productivity non-significantly (10). The weeds need to be managed to restrict the loss of productivity < 10 % during CPWC to get its acceptance (11). Since, many experiments performed in various regions shows various durations of CPWC, it is important to find out CPWC in sweet corn for this region to adopt an efficient weed management strategy.

Materials and Methods

Site of experiment

The investigation was undertaken at the P.G. Research Farm (18°48' N latitude, 84°10' E longitude and 90 m above MSL) of M. S. Swaminathan School of Agriculture (MSSoA), Centurion University of Technology and Management (CUTM), Odisha. Meteorological data of the cropping phase were collected from the Meteorological Observatory, CUTM, Paralakhemundi. The average maximum temperature in the crop growth phase from 34.2–31.2 °C, while the average minimum temperature was from 27.8–23.6 °C (Fig. 1). The highest and lowest total rainfall occurred (179.6 and 6.2 mm, respectively) during 33rd and 30th standard meteorological week (Fig. 2). Sampling of soil was performed in the selected field at 0–20 cm through soil auger. The experimental soil was sandy loam textured. Soil pH was slightly acidic (6.0) with low organic C content (0.35 %). The soil was also in low mineralizable N (205 kg ha⁻¹), low exchangeable P₂O₅ (13.3 kg ha⁻¹) and medium in extractable K₂O (175 kg ha⁻¹).

Details of experiment

The investigation was undertaken in the rainy season of 2024 under randomised block design (RBD) and ten treatments were kept in each replication. Three replications were taken in this experiment. The rate of fertiliser was 150:75:50 kg ha⁻¹ N:P₂O₅:K₂O. The 6 treatments included weed-free and weed-infested periods at three different days after sowing (DAS), i.e., 21, 42 and 63 DAS. Additionally, four other treatments were included: weed-free and weed-infested throughout the growing period, one integrated weed management treatment, i.e., Atrazine at 1 kg ha⁻¹ at 1 DAS *fb* 1 hand weeding at 40 DAS and another one was a chemical weed management treatment i.e., topramezone + atrazine (tank mix) at 25.2 + 250 g ha⁻¹ at 20 DAS. The details of all treatments were described in Table 1.

Observations and calculations

Weed parameters, including density and dry matter of weeds at 30 DAS and 60 DAS, relative density of weeds and weed diversity index at 30 and 60 DAS, weed control efficiency at 30 DAS and 60 DAS and weed index. Plant growth attributing characters, including plant height at harvest, accumulation of dry matter and leaf area index, were recorded at 50 DAS and at harvest. Crop growth rate (CGR) and

relative growth rate (RGR) at 50 DAS-harvest were also calculated as secondary data computation. Yield attributing characters such as the number of green cobs plant⁻¹, cob weight without husk, cob girth, cob length, number of rows cob⁻¹ and number of grains row⁻¹ were also measured. Green cob and green fodder productivity were taken and the harvest index was calculated. To assess the density of weeds, a quadrat of 0.25 m² (0.5 m x 0.5 m) was kept randomly at three locations within a net plot area. Then weeds were categorised into grassy weeds, broadleaved and sedge weeds and expressed as weed density m⁻². The weeds were uprooted, roots washed and sun-dried, followed by oven-drying at 65 °C to a static weight to find out dry matter of weeds (g m⁻²) under a separate category.

Table 1. Treatment details

Notations	Treatments
T ₁	Weed free up to 21 DAS
T ₂	Weed free up to 42 DAS
T ₃	Weed free up to 63 DAS
T ₄	Weed free throughout the growing period
T ₅	Weed infested up to 21 DAS
T ₆	Weed infested up to 42 DAS
T ₇	Weed infested up to 63 DAS
T ₈	Weed infested throughout the growing period
T ₉	*Atrazine at 1 kg ha ⁻¹ at 1 DAS followed by 1 hand weeding at 40 DAS
T ₁₀	**Topramezone + atrazine at 25.2 + 250 g ha ⁻¹ (tank mix) at 20 DAS

*In T₉ treatment, 1st flush of weeds came at 9 DAS and 2nd flush of weeds came at 47 DAS.

**In T₁₀ treatment, 1st flush of weeds came at 5 DAS and 2nd flush of weeds came at 33 DAS.

#Spray volume was kept at 400 L water ha⁻¹.

Weed control efficiency (%) =

$$\frac{\text{Weed dry weight in control plot} - \text{Weed dry weight in treated plot}}{\text{Weed dry weight in control plot}} \times 100 \quad (\text{Eqn 1})$$

Weed index (%) =

$$\frac{\text{Yield from weed free plot} - \text{Yield from treated plot}}{\text{Yield from weed free plot}} \times 100 \quad (\text{Eqn 2})$$

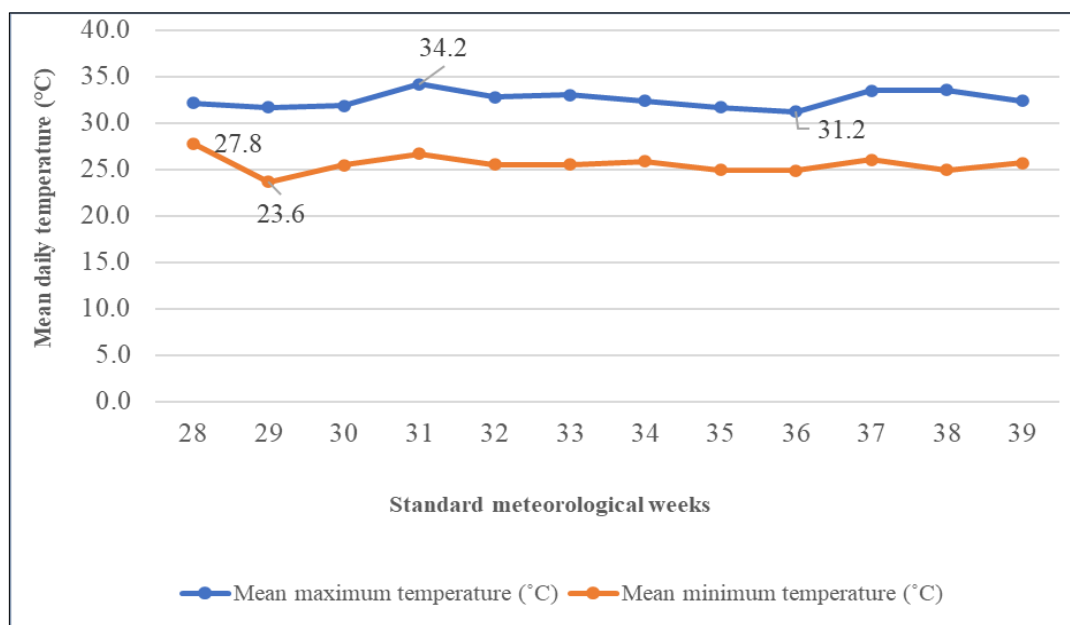


Fig. 1. Mean daily temperature (°C) during the cropping period of sweet corn.

$$\text{Crop growth rate (CGR)} = \frac{W_2 - W_1}{T_2 - T_1} \times 1/A \quad (\text{Eqn 3})$$

Where, W_2 and W_1 = Dry matter of the crop at times T_1 and T_2 , T_1 and T_2 = Corresponding time points, A = Unit area

$$\text{Relative growth rate (RGR)} = \frac{\ln W_2 - \ln W_1}{T_2 - T_1} \quad (\text{Eqn 4})$$

Where, W_2 and W_1 = Dry matter of the crop at times T_1 and T_2 , T_1 and T_2 = Corresponding time points

Relative weed density =

$$\frac{\text{Total number of weeds of a particular species}}{\text{Total number of weeds of all species}} \times 100 \quad (\text{Eqn 5})$$

Simpson's weed diversity index =

$$\sum \left(\frac{\text{Total number of weeds of a particular species}}{\text{Total number of weeds of all species}} \right)^2 \quad (\text{Eqn 6})$$

Harvest index (%) =

$$\frac{\text{Green cob yield}}{\text{Green cob yield} + \text{Green fodder yield}} \times 100 \quad (\text{Eqn 7})$$

Energy input = Energy from male and female worker + Energy from machineries + Energy from materials (i. e., seed, fertilizer, irrigation, chemicals, etc.) (Eqn 8)

Energy output = Energy from corn seed + Energy from dry stover (Eqn 9)

Net energy = Energy output - Energy input (Eqn 10)

Energy use efficiency = Total output energy / Total input energy (Eqn 11)

Specific energy = Energy input / Green cob yield (Eqn 12)

Energy productivity = Green cob yield / Energy input (Eqn 13)

Energetics

The energy input (MJ ha^{-1}) was obtained by multiplying the consumed amount of each input and its corresponding unit energy equivalent (12–15). Common input energy for weed management in sweet corn during kharif was 48110 MJ ha^{-1} . Energy output was obtained by multiplying the energy equivalents of sweet corn seed converted into corn seed and green fodder converted into dry stover. Energy input (MJ ha^{-1}), energy output (MJ ha^{-1}), net energy return (MJ ha^{-1}), energy use efficiency, specific energy (MJ kg^{-1}) and energy productivity (kg MJ^{-1}) were calculated by following the equations (15).

Economics

The common or fixed cultivation cost was obtained by adding the costs involved in field operations, i.e., tillage operations, sowing, irrigation, fertilisation, harvesting and post-harvesting works. and the costs of seeds and fertilisers. Treatment costs involved labour charges for weed removal and herbicide spray and the cost of the herbicide chemical. Gross return was obtained by adding the selling price of both green cob and green fodder. The market price of green cob was ₹15 per and the green fodder price was ₹0.30 kg^{-1} for each treatment. The net return for all the treatments was obtained by

subtracting the subtraction between total cultivation cost and the gross return. The benefit : cost (B:C) was obtained by dividing gross return and the total cultivation cost.

Statistical analysis

The readings noted at certain intervals during the cropping phase and at the time of harvesting were subjected to statistical analyses, with the F-value measured at 5 % level of significance. Square root transformation [$\sqrt{(x+0.5)}$] of weed density and dry weight data was done and the transformed readings were analysed thereafter. Correlations among total dry matter of weeds at 30 and 60 DAS (g m^{-2}), green cob productivity (t ha^{-1}), green fodder productivity (t ha^{-1}), starch content (%) and sugar content (%) were assessed. A regression equation was made to estimate green cob yield loss (t ha^{-1}) and CPWC through the Gompertz regression model. The statistical analysis of research data was done in the R programming software.

Results and Discussion

Weed flora

The species of weeds noticed were *Dactyloctenium aegyptium* (L.) Willd (Crowfoot grass), *Digitaria sanguinalis* (Large crab grass), *Cynodon dactylon* (L.) Per (Dhub grass) and *Elusine indica* (L.) Gaertn (Goose grass) among the grassy weeds, *Cyperus rotundus* L. (Purple nutsedge) among the sedge weeds, *Trianthema portulacastrum* L. (Giant pigweed), *Commelina benghalensis* Forssk. (Benghal dayflower), *Phyllanthus niruri* L. (Stonebreaker), *Ludwigia octovalvis* (Wild clove), *Amaranthus spinosus* L. (Spiny pigweed) and *Synedrella nodiflora* (L.) Gaertn (Cinderella weed) among broadleaved weeds (Table 2).

At 30 DAS and 60 DAS, the relative density of broadleaved weed was noticed to be maximum (62.69 and 53.95 %, respectively). Among the broadleaved weeds, *Trianthema portulacastrum* L. had the highest relative weed density (17.91 and 12.50 % at 30 and 60 DAS, respectively) on both dates of observation. Overall, *Cyperus rotundus* had maximum relative weed density (13.16 %) at 60 DAS (Table 2). *C. rotundus* was also found to be the most dominant in conventionally tilled green gram under the corn-wheat-moong system in the previous report (16). At 30 and 60 DAS, Simpson's weed diversity index values were 0.107 and 0.092, respectively, which indicated a more diverse population of weeds during the later period of crop growth. Similar results were noticed earlier in kharif maize (17).

Density of weeds and dry matter of weeds

The T_5 option (0.71 m^2 and 0.71 g m^{-2} , respectively) showed minimum population and dry matter of grasses, sedge and broadleaved weeds at 30 and 60 DAS. Among T_1 , T_6 , T_7 and T_8 treatments, minimum population and dry weight of grasses (2.54 m^2 and 2.88 g m^{-2} , respectively), broadleaved (4.10 m^2 and 4.67 g m^{-2} , respectively) and sedge weeds (1.76 m^2 and 2.07 g m^{-2} , respectively) were recorded in T_1 at 30 DAS. T_2 treatment showed the lowest density and dry weight of sedges (1.94 m^2 and 2.19 g m^{-2} , respectively) and broadleaved weeds (6.95 m^2 and 7.83 g m^{-2} , respectively) among T_1 , T_2 , T_7 and T_8 treatments at 60 DAS. Interestingly, the density and dry matter of grasses obtained in the treatment, T_1 and T_2 at 60 DAS remained statistically similar, which indicated the fact that T_1 could be a better option than T_2 in controlling the grassy weed infestation in sweet corn due to lower labour involvement (Fig. 2).

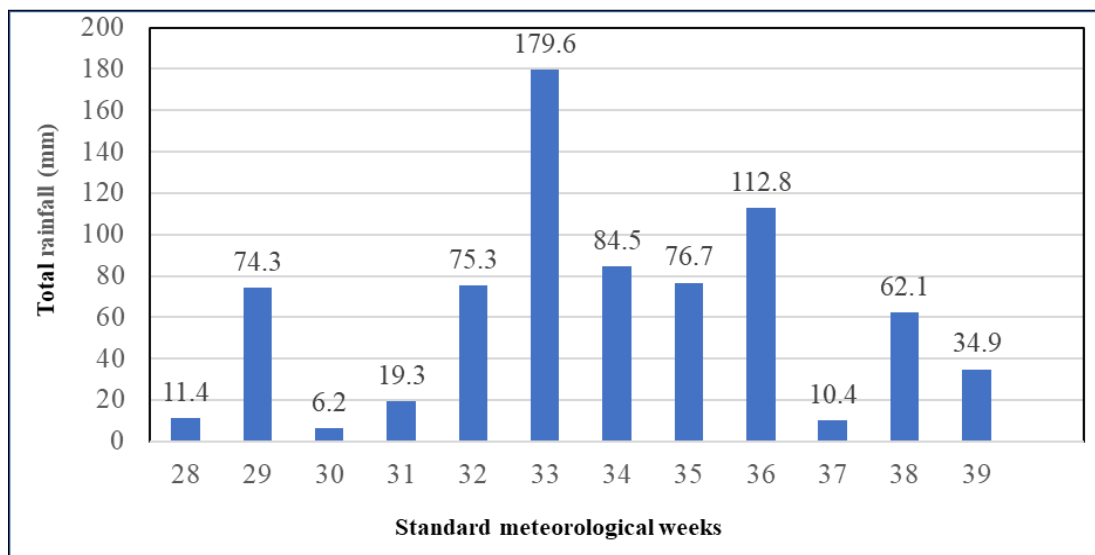


Fig. 2. Total rainfall (mm) during the cropping period of sweet corn.

Table 2. Relative weed density and Simpson's weed diversity index in sweet corn at 30 DAS and 60 DAS

Types of weeds	Relative density (%)		Simpson's weed diversity index (λ)	
	30 DAS	60 DAS	30 DAS	60 DAS
Grasses	25.37	32.89		
<i>Dactyloctenium aegyptium</i>	7.46	8.55		
<i>Digitaria sanguinalis</i>	5.97	8.55		
<i>Cynodon dactylon</i>	7.46	7.89		
<i>Elusine indica</i>	4.48	7.89		
Sedge weeds	11.94	13.16		
<i>Cyperus rotundus</i>	11.94	13.16		
Broadleaved weeds	62.69	53.95	0.107	0.092
<i>Trianthema portulacastrum</i>	17.91	12.50		
<i>Commelina benghalensis</i>	13.43	9.87		
<i>Phyllanthus niruri</i>	10.45	9.21		
<i>Ludwigia octovalvis</i>	5.97	6.58		
<i>Amaranthus spionus</i>	7.46	7.89		
<i>Synedrella nodiflora</i>	7.46	7.89		

At 30 and 60 DAS, T_9 treatment (3.75 and 5.50 m^2 , respectively) resulted in statistically similar grassy weed density with T_{10} treatment (3.48 and 5.07 m^2 , respectively) (Table 3). In the context of dry matter of grasses, T_{10} treatment (3.89 $g\ m^{-2}$) had significantly lesser result than T_9 treatment (4.23 $g\ m^{-2}$) at 30 DAS, but both

treatments were statistically similar in respect to dry weight of grasses (6.03 and 5.76 $g\ m^{-2}$ under T_9 and T_{10} treatment, respectively) at 60 DAS (Table 4). The treatment, T_{10} (6.40 m^2 and 7.08 $g\ m^{-2}$), was statistically similar to T_9 (6.04 m^2 and 6.81 $g\ m^{-2}$) in density and dry matter of broadleaved weeds at 60 DAS. At 30 DAS, the density of broadleaved weeds in the T_{10} treatment (4.73 m^2) was found to be significantly lower than in the T_9 treatment (5.24 m^2). In the context of sedge density, T_9 treatment (2.26 m^2) recorded significantly higher results than T_{10} treatment (2.03 m^2) at 30 DAS, but T_{10} (3.30 m^2) recorded significantly higher results than T_9 treatment (3.00 m^2) at 60 DAS. The density and dry matter of sedges at 60 DAS under the options, T_9 (3.40 $g\ m^{-2}$) and T_{10} (3.86 $g\ m^{-2}$), followed a similar trend. The treatment, T_{10} was unable to reduce population and dry matter of weeds than T_9 treatment in the later stages of sweet corn growth because the chosen herbicides had the short period of residual activity in soil after their application due to herbicide leaching under high rainfall and herbicide being washed off in proportion to the amount of excess rainfall runoff in kharif season though this herbicide mixture had better result in controlling weeds when applied in kharif maize than others (18, 19). These results also revealed that the chosen integrated weed management (IWM) option controlled the sedges more effectively during the later period of crop growth in kharif than the chemical weed management option taken.

Table 3. Impact of weed interference period on density of weeds (number m^{-2}) in sweet corn

Treatments	Density of weeds at 30 DAS (number m^{-2})			Density of weeds at 60 DAS (number m^{-2})		
	Grassy weeds	Sedge weeds	*BLWs	Grassy weeds	Sedge weeds	*BLWs
T_1 : Weed free up to 21 DAS	2.54 (6.00)	1.76 (2.67)	4.10 (16.33)	3.96 (12.67)	2.41 (5.33)	8.07 (64.67)
T_2 : Weed free up to 42 DAS	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	3.61 (15.33)	1.94 (3.33)	6.95 (48.00)
T_3 : Weed free up to 63 DAS	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T_4 : Weed free throughout the growing period	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T_5 : Weed infested up to 21 DAS	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T_6 : Weed infested up to 42 DAS	4.05 (16.00)	2.74 (7.00)	6.39 (40.33)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T_7 : Weed infested up to 63 DAS	4.14 (16.67)	2.86 (7.67)	6.41 (40.67)	7.12 (50.24)	4.19 (17.09)	9.15 (83.33)
T_8 : Weed infested throughout the growing period	4.18 (17.00)	2.91 (8.00)	6.51 (42.00)	7.19 (51.33)	4.45 (19.33)	9.08 (82.00)
T_9 : Atrazine at 1 $kg\ ha^{-1}$ at 1 DAS + 1 hand weeding at 40 DAS	3.75 (13.67)	2.26 (4.67)	5.24 (27.00)	5.50 (29.78)	3.00 (8.52)	6.04 (36.00)
T_{10} : Topramezone + atrazine at 25.2 + 250 $g\ ha^{-1}$ (tank mix) at 20 DAS	3.48 (11.67)	2.03 (3.67)	4.73 (22.00)	5.07 (25.33)	3.30 (10.41)	6.40 (40.67)
S.Em. ($\pm$)	0.14	0.10	0.13	0.16	0.09	0.17
CD ($P=0.05$)	0.43	0.30	0.39	0.48	0.28	0.52

BLWs: Broadleaved weeds. Values in the parentheses are original. Data subjected to ($\sqrt{x + 0.5}$) square root transformation.

Table 4. Impact of weed interference period on dry weight of weeds (g m^{-2}) in sweet corn

Treatments	Dry weight of weeds at 30 DAS (g m^{-2})			Dry weight of weeds at 60 DAS (g m^{-2})		
	Grassy weeds	Sedge weeds	*BLWs	Grassy weeds	Sedge weeds	*BLWs
T ₁ : Weed free up to 21 DAS	2.88 (7.87)	2.07 (3.80)	4.67 (21.33)	4.06 (16.07)	2.67 (6.75)	9.05 (81.61)
T ₂ : Weed free up to 42 DAS	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	4.59 (20.93)	2.19 (4.33)	7.83 (60.88)
T ₃ : Weed free up to 63 DAS	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T ₄ : Weed free throughout the growing period	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T ₅ : Weed infested up to 21 DAS	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T ₆ : Weed infested up to 42 DAS	4.63 (20.94)	3.39 (11.03)	7.16 (50.80)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T ₇ : Weed infested up to 63 DAS	4.75 (22.05)	3.68 (13.07)	7.27 (52.40)	7.62 (57.61)	4.87 (23.40)	10.12 (102.04)
T ₈ : Weed infested throughout the growing period	4.79 (22.46)	3.72 (13.43)	7.65 (58.20)	7.85 (61.20)	5.19 (26.47)	10.04 (100.61)
T ₉ : Atrazine at 1 kg ha ⁻¹ at 1 DAS + 1 hand weeding at 40 DAS	4.23 (17.49)	2.95 (8.33)	6.13 (37.33)	6.03 (35.85)	3.40 (11.07)	6.81 (46.17)
T ₁₀ : Topramezone + atrazine at 25.2 + 250 g ha ⁻¹ (tank mix) at 20 DAS	3.89 (14.68)	2.80 (7.37)	5.74 (32.53)	5.76 (32.88)	3.86 (14.40)	7.08 (49.83)
S.Em. ($\pm$)	0.10	0.12	0.19	0.20	0.14	0.25
CD ($p = 0.05$)	0.30	0.35	0.56	0.59	0.41	0.76

BLWs: Broadleaved weeds. Values in the parentheses are original. Data subjected to ($\sqrt{x + 0.5}$) square root transformation.

Weed control efficiency and weed index

The treatment, T₉ (32.3 %) had lower weed control efficiency WCE than T₁₀ (41.3 %) at 30 DAS but the treatment, T₉ (50.1 %) had higher WCE than T₁₀ (48.0 %) at 60 DAS (Fig. 3). Previously, research indicates that 88.0 and 83.7 % WCE, respectively in sweet corn grown in Rabi season under the IWM option, atrazine at 1 kg ha⁻¹ as pre-emergence followed by 1 hand weeding at 40 DAS (7, 20). This result revealed that the chosen IWM option is not suitable for weed management in sweet corn during kharif in the north-eastern ghats zone of the state, Odisha. The WI recorded under the treatment, T₉ was 44.6 %, which was much higher than the earlier findings in spring sweet corn (21). This result indicated poor yield performance of T₉ treatment in the kharif than spring season.

Growth attributes

The highest results of the major growth attributing characters, i.e., plant height at harvest, leaf area index (LAI) at 50 DAS and harvest, above-ground dry matter accumulation (DMA) at 50 DAS and harvest, CGR and RGR at 50 DAS-harvest, were recorded in T₄ treatment (Table 5). T₃ option was statistically similar to T₄ in case of LAI at harvest (3.08 and 3.21, respectively), above-ground DMA at 50 DAS (717 and 763 g m⁻², respectively) and RGR at 50 DAS-harvest (16.95 and 19.19 mg g⁻¹d⁻¹, respectively). The LAI obtained at harvest under T₉ treatment was 2.83, which was supported by the earlier report of (20). Further, plant height, LAI and above-ground DMA at harvest noticed under T₉ option (185 cm, 2.83 and 652 g m⁻²,

respectively) were significantly greater than T₈ option (127 cm, 2.50 and 419 g m⁻², respectively). Similar results were noticed from a previous finding (20). All the above-mentioned growth attributes at the lowest result in the T₈ treatment.

Yield attributes, yields and harvest index

T₃ option recorded statistically similar results with T₄ option for number of green cobs plant⁻¹ (1.37 and 1.53, respectively), number of rows cob⁻¹ (13.67 and 14.67, respectively) and number of grains row⁻¹ (36.00 and 38.00, respectively). Length of cob (16.17, 17.10, 17.47, 16.63, 16.60 and 16.43 cm under T₂, T₃, T₄, T₅, T₉ and T₁₀ options, respectively) and girth of cob (4.33, 4.47, 4.73, 4.37, 4.57 and 4.30 cm under T₂, T₃, T₄, T₅, T₉ and T₁₀ options, respectively) obtained under the treatment, T₂, T₃, T₄, T₅, T₉ and T₁₀ were statistically similar (Table 6). Findings regarding the length of cob under T₄ and T₉ treatment conformed with the earlier report (21). In the context of cob weight without husk, T₁ (121 g), T₂ (125 g), T₃ (129 g) and T₄ (126 g) treatments showed statistically similar results, which revealed the superiority of weed-free in different intervals over other treatments. Cob weight without husk recorded under T₄ treatment (126 g) was also significantly higher than T₉ treatment (105 g), which was similar to the previous report of (21). Further, cob weight without husk, cob length and cob girth noticed under T₉ treatment (105 g, 16.60 and 4.57 cm, respectively) were significantly higher than T₈ treatment (71 g, 14.97 and 3.53 cm, respectively). Similar results were noticed earlier (20).

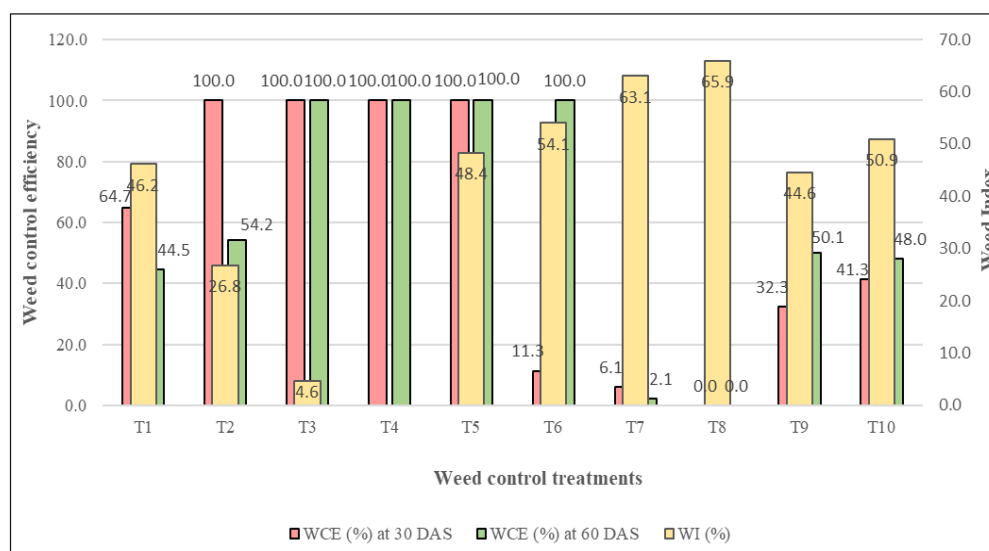
**Fig. 3.** Impact of weed control options on WCE (%) and WI (%) in sweet corn.

Table 5. Impact of weed interference period on growth attributing characters in sweet corn

Treatments	Plant height at harvest (cm)	LAI at 50 DAS	LAI at harvest	Above-ground DMA at 50 DAS (g m ⁻²)	Above-ground DMA at harvest (g m ⁻²)	CGR at 50 DAS-harvest (g m ⁻² d ⁻¹)	RGR at 50 DAS-harvest (mg g ⁻¹ d ⁻¹)
T ₁	167	3.36	2.82	464	640	6.09	11.12
T ₂	189	3.58	2.89	539	792	8.73	13.28
T ₃	199	3.70	3.08	717	1169	15.58	16.95
T ₄	233	4.10	3.21	763	1335	19.70	19.19
T ₅	162	3.76	2.88	453	613	5.50	10.40
T ₆	143	3.68	2.73	403	556	5.28	11.05
T ₇	135	3.10	2.67	305	484	6.16	15.91
T ₈	127	2.96	2.50	300	419	4.10	11.45
T ₉	185	3.49	2.83	400	652	8.70	16.78
T ₁₀	176	3.54	2.86	390	589	6.87	14.29
S.Em. (±)	8.49	0.11	0.09	20	34	1.14	1.52
CD (p = 0.05)	25	0.33	0.26	59	102	3.40	4.51

Table 6. Impact of weed interference period on yield and yield attributing parameters in sweet corn

Treatments	Number of green cobs plant ⁻¹	Cob weight without husk (g)	Cob length (cm)	Cob girth (cm)	Number of rows cob ⁻¹	Number of grains row ⁻¹	Green cob yield (t ha ⁻¹)	Green fodder yield (t ha ⁻¹)	HI (%)
T ₁	1.07	121	15.42	3.90	12.00	32.00	9.30	13.00	41.68
T ₂	1.20	125	16.17	4.33	12.33	33.00	11.20	14.63	43.38
T ₃	1.37	129	17.10	4.47	13.67	36.00	14.57	18.73	43.74
T ₄	1.53	126	17.47	4.73	14.67	38.00	16.30	21.47	43.15
T ₅	1.20	80	16.63	4.37	13.33	33.33	7.90	13.30	37.25
T ₆	1.13	78	15.43	4.07	12.67	33.33	6.60	11.63	36.18
T ₇	1.00	75	15.30	3.70	11.67	30.00	5.63	10.83	34.28
T ₈	0.87	71	14.97	3.53	11.00	29.33	3.90	8.23	31.95
T ₉	1.13	105	16.60	4.57	13.67	31.67	8.47	11.83	41.73
T ₁₀	1.10	101	16.43	4.30	13.33	30.33	7.50	10.20	42.36
S.Em. (±)	0.09	3	0.49	0.19	0.62	1.33	0.38	0.52	1.14
CD (p = 0.05)	0.26	9	1.46	0.57	1.85	3.96	1.13	1.54	3.39

Green cob and green fodder productivity were obtained at maximum under T₄ treatment (16.30 and 21.47 t ha⁻¹, respectively), which were also significantly greater than all others in both cases. The significant superiority of green cob yield under T₄ treatment over T₉ treatment was reported previously. Weed infestation throughout the crop growth in T₈ treatment resulted in 76.07 % reduction in green cob yield than weed free, i.e., T₄ treatment, which was corroborated by the previous findings (22). The harvest index calculated under T₁ (41.68 %), T₂ (43.38 %), T₃ (43.74 %), T₄ (43.15 %), T₉ (41.73 %) and T₁₀ treatment (42.36 %) was statistically at par, which disclosed the importance of weed control in sweet corn cultivation to obtain higher green cob and green fodder productivity. Research has also reported the statistical similarity of the harvest index obtained under T₄ and T₉ treatment (21).

Sugar and starch content

Weed-free throughout the growing period, the T₄ treatment had the highest sugar (16.70 % Brix) and starch content (11.90 %) in green cobs (Table 7). This treatment showed significantly higher sugar content than T₇ (15.27 % Brix) and T₈ (15 % Brix) treatment and significantly higher starch content than T₆ (11.10 %), T₇ (10.80 %) and T₈ (10.30 %) treatment. Sugar content in green cobs was reduced by 0.10 to 1.70 % due to the crop-weed competition. Research indicates that 1.60-2.00 % reduction in sugar content of sugarcane due to crop

-weed competition up to 3 weeks after sowing, which supported these results (23). Starch content in green cobs was also reduced by 0.80 to 1.10 % due to the crop-weed competition. Research has demonstrated that starch content can be reduced in potatoes due to crop-weed competition corroborated this result (24).

Correlation matrix

Total weed dry matter at 30 DAS had very strong negative significant correlation with green cob yield ($r = -0.808^{***}$), green fodder yield ($r = -0.810^{***}$), starch content ($r = -0.845^{***}$) and sugar content ($r = -0.818^{***}$) but strong significant positive correlation with total weed dry weight at 60 DAS ($r = 0.633^{**}$) (Table 8). Green fodder yield, starch content and sugar content had very strongly correlated with green cob yield ($r = 0.972^{***}$, 0.824^{***} and 0.879^{***} , respectively) and a strongly significant negative correlation with total dry matter of weeds at 60 DAS ($r = -0.694^{**}$, -0.755^{**} and -0.744^{**} , respectively). Green cob yield had a significantly negative correlation with total weed dry matter at 60 DAS ($r = -0.612^{*}$). Previously, research has reported a strongly significant negative correlation between total weed dry matter at 60 DAS and grain productivity of corn (25). Green fodder yield, starch content and sugar content also showed a very strong and significant correlation among themselves ($r = 0.780^{***}$ for green fodder productivity vs. starch content, $r = 0.854^{***}$ for green fodder productivity vs. sugar content and $r = 0.975^{***}$ for starch

Table 7. Effect of weed interference period on sugar content (% Brix) and starch content (%) of sweet corn

Treatments	Sugar content (% Brix)	Starch content (%)
T ₁ : Weed free up to 21 DAS	16.13	11.27
T ₂ : Weed free up to 42 DAS	16.33	11.40
T ₃ : Weed free up to 63 DAS	16.60	11.67
T ₄ : Weed free throughout the growing period	16.70	11.90
T ₅ : Weed infested up to 21 DAS	16.50	11.50
T ₆ : Weed infested up to 42 DAS	15.90	11.10
T ₇ : Weed infested up to 63 DAS	15.27	10.80
T ₈ : Weed infested throughout the growing period	15.00	10.30
T ₉ : Atrazine at 1 kg ha ⁻¹ at 1 DAS + 1 hand weeding at 40 DAS	16.00	11.23
T ₁₀ : Topramezone + atrazine at 25.2 + 250 g ha ⁻¹ (tank mix) at 20 DAS	16.23	11.30
S.Em. (±)	0.35	0.26
CD (p = 0.05)	1.05	0.77

Table 8. Correlation matrix among total weed dry matter at 30 and 60 DAS (g m^{-2}), green cob productivity (t ha^{-1}), green fodder productivity (t ha^{-1}), starch content (%) and sugar content (% Brix)

	Total weed dry matter at 30 DAS (g m^{-2})	Total weed dry matter at 60 DAS (g m^{-2})	Green cob productivity (t ha^{-1})	Green fodder productivity (t ha^{-1})	Starch content (%)	Sugar content (% Brix)
Total weed dry matter at 30 DAS (g m^{-2})	1					
Total weed dry matter at 60 DAS (g m^{-2})	0.633**	1				
Green cob productivity (t ha^{-1})	-0.808***	-0.612*	1			
Green fodder productivity (t ha^{-1})	-0.810***	-0.694**	0.972***	1		
Starch content (%)	-0.845***	-0.755**	0.824***	0.780***	1	
Sugar content (% Brix)	-0.818***	-0.744**	0.879***	0.854***	0.975***	1

*Correlation was significant at 0.10 level, **Correlation was significant at 0.05 level, ***Correlation was significant at 0.01 level.

content vs. sugar content). This was due to the harvesting of green cobs at 79 DAS, i.e., beginning of dough stage, when green fodder yield and sugar content attained their maximum level along with the continued increase of starch content during this stage.

Energetics

The treatment, T_4 exhibited the maximum results of extra input of energy (565 MJ ha^{-1}), total input of energy (48675 MJ ha^{-1}), output of energy ($192909 \text{ MJ ha}^{-1}$), net energy of $144234 \text{ MJ ha}^{-1}$, use efficiency of energy (3.96), specific energy (7.04 MJ kg^{-1}) and productivity of energy (0.14 kg MJ^{-1}) (Table 9). The minimum extra energy input was recorded under the chemical weed management option T_{10} (46.60 MJ ha^{-1}) where herbicide application was done once. This finding was in line with the previous report of (26). On another hand, weed infested throughout the growing period i.e., T_8 treatment had no extra input of energy (0.00 MJ ha^{-1}) with minimum total input of energy 48110 MJ ha^{-1} , output of energy (51430 MJ ha^{-1}), net energy (3321 MJ ha^{-1}), use efficiency of energy (1.07), specific energy (3212 MJ kg^{-1}) and productivity of energy (0.03 kg MJ^{-1}) showing the ill effect of the poor weed control on energy efficiency. Similar results were presented earlier under direct-seeding and transplanting of rice respectively (26, 27). Similar productivity of energy was noted under T_6 and T_7 treatment, which was supported by the result of statistically similar green cob yield under these two treatments.

Critical period for weed control (CPWC) estimation through the Gompertz regression model

Green cob yields in weed-free and weed-infested areas were predicted through the Gompertz regression model and green cob yield loss due to weeds was obtained by subtracting those two for the period of 21-79 DAS, i.e., collar of 4th leaf visible to the beginning of dough stage or V_4-R_4 growth stages of sweet corn. Green cob yield loss was predicted from 1.85 to 10.99 t ha^{-1} within the period of 27 to 79 DAS, i.e., collar of 5th leaf visible to the beginning of dough stage due to weed interference (Table 10). Weeds must be under control to

prevent a loss in productivity of less than 10 % (11). The CPWC at < 10 % acceptable yield loss was determined by this experiment to be 27-79 DAS, i.e., 53 days of sweet corn growth, though the CPWC ranged from collar of 8th leaf visible to physiological maturity (V_8-R_6 growth stages) in Turkey as per the earlier report of (28). This variation might be due to changes in environmental situation, density of weeds, species of weed, soil fertility, moisture and pattern of sowing (29). This relationship between green cob yield loss and weed interference period showed a logarithmic regression equation, $y = 8.7085 \ln(x) - 27.028$ (Fig. 4). The acceptable green cob yield loss due to weed interference was predicted from 0.20 to 1.58 t ha^{-1} within the period of 21-26 DAS, i.e., 6 days of sweet corn growth period (Table 11).

Economics

The common cost of sweet corn production was $\text{₹}62280 \text{ ha}^{-1}$ which was strengthened by the earlier reports (30). Maximum gross and net return as well as benefit: cost (B:C) were found with the treatment, T_4 ($\text{₹}235940 \text{ ha}^{-1}$, $\text{₹}157911 \text{ ha}^{-1}$ and 3.02, respectively) among all the treatments (Table 12). Treatment cost was also measured at the maximum ($\text{₹}15750 \text{ ha}^{-1}$) under T_4 treatment due to the maximum number of labour engagement for the hand weeding operation. The labour charge of a female labourer was kept at $\text{₹}350$ for 8 hr of work to make the field weed-free. On the other hand, no treatment cost was incurred under the T_8 treatment ($\text{₹}0.00 \text{ ha}^{-1}$). Further, B:C obtained by T_4 treatment was closely followed by T_3 treatment (3.01), underscoring the sufficiency of keeping the field weed-free up to 63 DAS instead of weed-free up to harvesting time for obtaining maximum profit. The IWM option, T_9 , recorded a lower treatment cost ($\text{₹}3850 \text{ ha}^{-1}$) and a higher gross return ($\text{₹}130550 \text{ ha}^{-1}$) than the chemical weed management option, T_{10} ($\text{₹}7075$ and 115560 ha^{-1} , respectively) due to the high market price of the herbicide, topramezone and better green cob and green fodder productivity, respectively, with this option.

Table 9. Impact of weed interference period on energetics in sweet corn

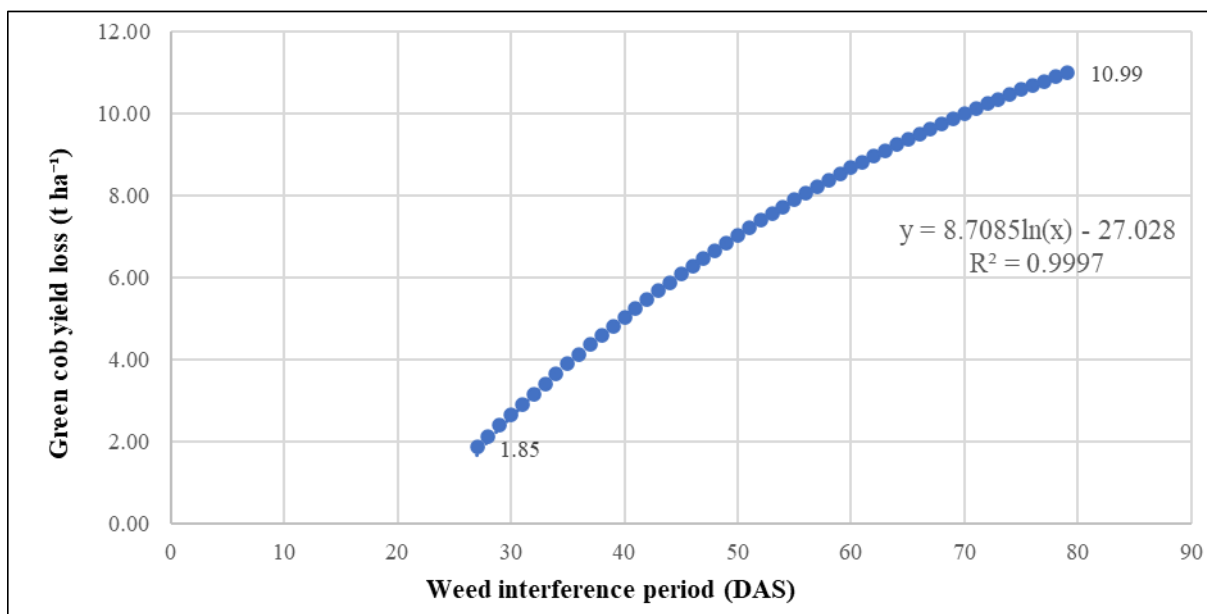
Treatments	Extra input energy (MJ ha^{-1})	*Total input energy (MJ ha^{-1})	Output energy (MJ ha^{-1})	Net energy (MJ ha^{-1})	Energy use efficiency	Specific energy (MJ kg^{-1})	Energy productivity (kg MJ^{-1})
T_1	163	48273	107670	59397	2.23	12.72	0.08
T_2	314	48424	125705	77281	2.60	10.60	0.09
T_3	440	48549	166435	117886	3.43	8.01	0.12
T_4	565	48675	192909	144234	3.96	7.04	0.14
T_5	490	48600	94974	46375	1.95	15.69	0.06
T_6	377	48487	83489	35002	1.72	18.37	0.05
T_7	276	48368	74650	26264	1.54	21.47	0.05
T_8	0.00	48109	51430	3321	1.07	32.12	0.03
T_9	138	48248	100518	52270	2.08	13.70	0.07
T_{10}	46.60	48156	83550	35394	1.73	16.05	0.06

*Common input energy for sweet corn cultivation during kharif was 48110 MJ ha^{-1} ; Woman energy equivalent to $1.57 \text{ MJ women-hr}^{-1}$

Table 10. Prediction of green cob yield in weed free and weed infested condition and yield loss due to weeds as per Gompertz regression model

DAS	*Predicted yield in weed free (t ha ⁻¹)	**Predicted yield in weed infested (t ha ⁻¹)	Predicted yield loss due to weeds (t ha ⁻¹)	DAS	*Predicted yield in weed free (t ha ⁻¹)	**Predicted yield in weed infested (t ha ⁻¹)	Predicted yield loss due to weeds (t ha ⁻¹)
27	9.47	7.62	1.85	54	14.03	6.31	7.72
28	9.69	7.57	2.12	55	14.14	6.26	7.88
29	9.91	7.52	2.39	56	14.25	6.21	8.04
30	10.12	7.48	2.64	57	14.36	6.16	8.20
31	10.33	7.43	2.90	58	14.47	6.11	8.36
32	10.53	7.38	3.15	59	14.57	6.06	8.51
33	10.73	7.33	3.40	60	14.67	6.01	8.66
34	10.93	7.28	3.65	61	14.77	5.96	8.81
35	11.12	7.24	3.88	62	14.86	5.91	8.95
36	11.31	7.19	4.12	63	14.95	5.86	9.09
37	11.49	7.14	4.35	64	15.04	5.81	9.23
38	11.67	7.09	4.58	65	15.12	5.76	9.36
39	11.85	7.04	4.81	66	15.20	5.71	9.49
40	12.02	6.99	5.03	67	15.28	5.66	9.62
41	12.19	6.95	5.24	68	15.36	5.61	9.75
42	12.35	6.90	5.45	69	15.44	5.56	9.88
43	12.52	6.85	5.67	70	15.51	5.51	10.00
44	12.67	6.80	5.87	71	15.58	5.47	10.11
45	12.82	6.75	6.07	72	15.64	5.42	10.22
46	12.97	6.70	6.27	73	15.71	5.37	10.34
47	13.12	6.65	6.47	74	15.77	5.32	10.45
48	13.26	6.60	6.66	75	15.83	5.27	10.56
49	13.40	6.55	6.85	76	15.89	5.22	10.67
50	13.53	6.50	7.03	77	15.95	5.17	10.78
51	13.66	6.45	7.21	78	16.00	5.12	10.88
52	13.79	6.41	7.38	79	16.06	5.07	10.99
53	13.91	6.36	7.55				

*Multiple R squared for predicted yield in weed free is 0.9829; **Multiple R squared for predicted yield in weed infested is 0.9809

**Fig. 4.** Predicted green cob yield loss (t ha⁻¹) due to weed interference.**Table 11.** Acceptable weed interference period (days) as per Gompertz regression model

DAS	Predicted yield in weed free (t ha ⁻¹)	Predicted yield in weed infested (t ha ⁻¹)	Predicted yield loss due to weeds (t ha ⁻¹)
21	8.10	7.90	0.20
22	8.34	7.86	0.48
23	8.57	7.81	0.76
24	8.80	7.76	1.04
25	9.03	7.71	1.32
26	9.25	7.67	1.58

*Acceptable weed interference period: the period of green cob yield loss < 10 % due to weeds.

Table 12. Economic performance of sweet corn cultivation under various weed interference periods

Treatments	Treatment cost (₹ ha ⁻¹)	Gross return (₹ ha ⁻¹)	Net return (₹ ha ⁻¹)	Benefit cost ratio
T ₁ : Weed free up to 21 DAS	4550	126900	60071	1.90
T ₂ : Weed free up to 42 DAS	8750	172390	101361	2.43
T ₃ : Weed free up to 63 DAS	12250	224120	149591	3.01
T ₄ : Weed free throughout the growing period	15750	235940	157911	3.02
T ₅ : Weed infested up to 21 DAS	13650	122490	46561	1.61
T ₆ : Weed infested up to 42 DAS	10500	108490	35711	1.49
T ₇ : Weed infested up to 63 DAS	7700	87750	17771	1.25
T ₈ : Weed infested throughout the growing period	0	80470	18191	1.29
T ₉ : Atrazine at 1 kg ha ⁻¹ at 1 DAS + 1 hand weeding at 40 DAS	3850	130550	64421	1.97
T ₁₀ : Topramezone + atrazine at 25.2 + 250 g ha ⁻¹ (tank mix) at 20 DAS	7075	115560	46206	1.67

Common cost: ₹62280 ha⁻¹

Conclusion

The treatment, weed-free throughout the growing period, showed best results of all the growth and yield-attaining characters, green cob and green fodder productivity as well as sugar and starch content in grain. This treatment was found most energy efficient and most profitable by providing maximum gross and net return as well as B:C. The treatment, weed-free up to 63 DAS, provided almost similar B:C. Therefore, keeping the field of sugar 75 weed-free through efficient weed management practices in the period of 27–63 DAS, i.e., 37 days, instead of keeping the field weed-free up to the completion of CPWC during the kharif season in the North-Eastern Ghats of Odisha, could be recommended to the sweet corn growers.

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Authors' contributions

MS carried out the experiment and data collection. TM had the idea of this work and supervised this work, as well as the correspondence work. RSK had written the manuscript except for tables, figures and the reference list. AM had done weed identification and prepared the tables and figures of the manuscript. DS searched all the supporting references and wrote the reference list of the manuscript. CS participated in the laboratory analysis of samples. BG participated in the design of the study and performed the statistical analysis of the datasets. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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