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RESEARCH ARTICLE

Determination of critical period of weed competition in Sugarcane (*Saccharum officinarum* L.) at Arjo Didessa sugar estate, western Ethiopia

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ABSTRACT

Weeds limit the sugar cane production. A field experiment employing cultivar NCO334 and Randomized Complete Block Design (RCBD) was done to assess weed competition crucial period. After planting, experimental plots were either weed-free or weedy (0, 25, 50, 75, 100, 125, and 150 DAP). Weed density, weed dry weight, sugarcane sprout, tiller number, cane height, millable cane number, girth, weight, and predicted cane and sugar production traits were evaluated. For different periods, weed competition affects tiller number, cane height, girth, weight, millable cane number, and cane and sugar yield. Tiller production, cane height, girth, weight, millable canes, and cane and sugar output rose with more extended weed-free periods. Weeds in sugarcane caused 90. 5% and 94.6% cane and sugar yield losses, respectively. Cane girth, height, weight, tiller number, cane and sugar production correlated positively and negatively with weed density and dry weight. weed crop competition begins between 17 and 131 DAP. To limit the impact of weeds on sugar cane yield, weed management measures should be implemented in sugarcane plantations during this important period.

Keywords: cane yield, critical period, sugarcane, sugar yield, weed competition.

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is not native to Ethiopia, but it was produced there before large-scale commercial plantations for direct consumption (Aregaw, 2002). In Ethiopia, sugarcane is grown industrially in sugar estates to make raw and refined sugar and its byproducts. The existing facilities encompass 102,741 acres of sugarcane and produce around 520,000 tonnes of sugar annually (ESC, 2019).

Sugarcane growth, productivity, and quality are hampered by weeds, illnesses, insects, farming techniques, and climate (Srivastava and Rai, 2012Weeds hinder sugarcane cultivation in Ethiopia

(Firehun et al., 2012). Thus, reducing weed damage could boost productivity (Meissle et al., 2010). Arjo Didessa sugarcane plantation weed management costs as much as 1.4 million ETB per year (1 USD = 52.59ETB on 31/05/2022), (ADSPAR, 2021).

Firehun et al. (2009) found that weeds reduced cane and sugar yield by 64 to 80% and 60 to 74%, respectively. In Wonji sugarcane plantation estate, Firehun et al. (2013) reported a cane yield loss of 83.5% for the erect cultivar NCO334. Compared to weed-free treatment, no weeding reduced sugar output by 90.5%. Weed management during critical crop growth phases helps prevent production loss.

Determining the critical period of weed competition might help decide whether to apply weed management and if it's cost-effective (Juraimi et al., 2013). The critical period of weed competition is the key information for weed control. Also, crop productivity losses owing to weeds in Arjo Didessa's sugarcane farm are unknown. This study determined the key period of weed competition and yield loss in Arjo Didessa Sugar Estate's sugarcane crop.

MATERIALS AND METHODS

Description of the study area

Field experiment was conducted during 2019/2020 at Arjo Didessa Sugar Estate which is located in East Wollega Zone of the Oromiya Region Ethiopia within the geographic boundaries of 8˚30' to 8˚40' N latitude and 36˚22' to 36˚43' E longitude at an average elevation of 1350 meters above sea level.

Edaphic and climatic conditions

Before conducting the field trial, five soil samples (0 - 30 cm depth) were randomly collected with an auger from the experimental area during experiment field lay out work. All five samples were mixed to form one composite sample to characterize its physical and chemical properties. The soil physical property of the study area is sand (37%), silt (14%) and clay (49%). The total N was determined by the modified micro kjeldahl method (Síez-Plaza et al., 2013) and available P by Olsen method (Olson et al., 1954). The available K, organic carbon and CEC were determined according to the procedure given by Zhang et al. (2009) and Sharma et al. (2015), respectively. Soil pH was also determined by the pH meter. The area receives an average annual rain fall of 2002 mm falling with unimodal distribution pattern lasting over the period of May to October and with annual average maximum and minimum temperatures of 30.85˚c and 18.43˚c, and mean temperature of 24.64^{0}c. The relative humidity of the area is ranging from average maximum of 92.92% to average minimum of 65% with an average of 79%.

Treatments and experimental design

The experiment comprised 14 treatments under the six weed-free periods (weed-free up to 25, 50, 75, 100, 125 and 150 days after planting) and six weed infestation periods (weed infestation up to 25, 50, 75, 100, 125 and 150 days after planting) along with two controls (checks) namely, completely weed free (kept weed free for season long) and weed infestation for season long (kept under weed infestation throughout crop period). The trial was conducted in a Randomized Complete Block Design (RCBD) with three replications. Each plot was 8.7 m × 5 m (=43.5 m^2) in size. There were six-planting furrows of 5.0 m length spaced at 1.45 m. The distance between blocks (replications) were 2.9 m and between plots were 1.5 m. How many plants in each plot? Therefore, the total area of the experimental field was 0.36 ha.

Crop husbandry

The soil was ploughed with a disc plough to remove the hard pan of the soil and create a fine seed bed. Land was levelled and furrowed precisely. After furrow rectification, disease-free, well-fertilized seed canes were chopped. Healthy two budded NCO-334 cultivar setts were made and used for planting. Dettol was used to prevent disease transmission when cutting and chopping. 10 ml Dettol was dissolved in one litre knife holder tube water for five minutes and swirled to dilute. A single stalk was chopped with a sterilised knife. After the setts were prepared, they were planted by overlapping two budded setts in the furrows and filling them with 2 - 5 cm of soil. The buds of all setts were put parallel to prevent bud damage, sun, and delayed germination. Each furrow has 352 budded setts overlapping by 5cm. All plots received 250 kg ha^{-1} NPS at planting and 150 kg ha^{-1}. Urea at tillering (75 DAP) according to site rate and time. All cultural practices except weed control followed the sugarcane production guidelines.

Data collection & Analysis

Data for density and dry weight of weeds were taken at each weeding period and at harvesting time from each plot of the four central furrows by counting individual plants of each of the weed's species in the 0.5m ×0.5m quadrat thrown at random on four sampling points.

The above ground biomass of mixed weed population was harvested and oven dried at 80°C for

72 hrs until constant reading was maintained to measure the above ground dry weights. Data for sugarcane sprout number count at 45th days after planting, tiller number count at 4th months after planting, number of millable canes taken at 14th months after planting, weight per stalk from 20 representative stalk per plot taken at harvest, cane height from10 representative stalk per plot taken at harvest, cane girth (diameter) from three cane positions (top, middle and bottom) from 10 representative millable stalks were taken from each plot of the four central furrows. Also cane weight, cane yield and sugar yield/commercial sugar yield were calculated as the formula described on analysis.

The collected data were subjected for analysis of DMRT using SAS 9.3 software.

RESULTS AND DISCUSSION

Weed composition in the experimental field

The experimental field was infested with predominant weeds species such as *Acalypha crenata*, *Achyranthes aspera*, *Aeschynomene aspera*, *Ageratum conyzoides*, *Allium neapolitanum*, *Amaranthus albus*, *Amaranthus hybridus*, *Bidens pilosa*, *Commelina benghalensis, Commelina diffusa, Commelina latifolia*, *Cynodondactylon*, *Cyperus assimilis*, *Cyperus eragrostis*, *Cyperus esculentus*, *Cyperus rotundus*, *Cyperus haspan*, *Cyperus iria*, *Digitariaciliaris*, *Digitarias anguinalis*, *Echinocloa colona*, *Eleusine indica*, *Eragrostic aspara*, *Eragrostis cilianensis*, *Galinsoga parviflora, Hydrocotyle binaries*, *Imperata cylindrica*, *Ipomoea sinensis*, *Nicandra physaloides, Paspalum scrobiculatum, Physalis minima, Sonchus asper* and *Sorghum halapense*. From the recorded weed communities in the experimental field, *Cyperus rotundus*, *Cynodon dactylon, Echinocloa colona, Eleusine indica, Sorghum halapense,* and *Imperata cylindrical* were considered as six of the top ten world's worst weeds (Holm et al., 1977).

Weed density and biomass production

Weed density and dry weight statistically differed (p<0.01). Different weed infestation and weed-free periods caused the variances (**Table 1**). Weed density and dry weight dropped as weed-free periods rose. As weed competition or infestations rose, weed density and dry weight increased. When weed competition exceeded 125 days after sowing, weed plants decreased. State the result of all treatments. Identify the best economically profitable time to keep weed free based on the season long weed free treatment.

Effect of weed competition on sprouting and tiller production

Sprout percentage and tiller production of sugarcane as affected by different durations of weed competition and weed free periods were presented in Table 2. Accordingly, sprout percentage showed a non-significant difference ($P \leq 0.05$) in sprouting of buds from planted cane setts in different weed competition periods. However, there were highly significant differences among treatments of different weed infestation and weed free period in tiller production ($P \leq 0.01$) (**Table 2**).

Table 1. Weed density and dry weight as influenced by different durations of weed infestation and weed free periods.

Treatments	Weed density (m^{-2})	Weed dry weight (gm^{-2})
Weed free up to DAP		
25	94.67^{d}	269.3^{d}
50	68.67^{e}	222.7^{e}
75	56.67^{f}	127.2^{g}
100	55.33^{ef}	80.3^{h}
125	47.67^{fg}	34.9^{i}
150	19.00^{h}	25.7^{ij}
Season long (check)	0.00^{i}	0.00^{j}
Weedy up to DAP		
25	67.67^{e}	8.8^{ij}
50	144.33^{b}	85.4^{h}
75	178.67^{a}	180.7^{f}
100	120.00^{c}	332.0^{b}
125	99.00^{d}	298.8^{b}
150	43.67^{fg}	340.1^{b}
Season long (check)	38.00^{g}	398.8^{a}
CV	13.33	11.21

Note: Means with the same letters are not significantly different among each other. CV = Coefficient of variation.

Sprout percentage

The sprouting percentage of buds on planted cane setts was not significantly affected due to different weed competition and weed free periods.This result is in conformity with the result of Firehun et al. (2013) who reported weed competition had no adverse effect on the germination of cane under the prevailed conditions. Similar findings were also indicated by Welday et al. (2018a) in sugarcane.

Table 2. Sprout percentage and tiller production of sugarcane as influenced by different durations of weed infestation and weed free periods

Treatments	Sprout %	Tiller (ha^{-1})
Weed Free up to DAP		
25	66	66322^{de}
50	61	66437^{de}
75	63	127241^{abcd}
100	61	142759^{ab}
125	65	161954^{a}
150	66	148851^{a}
Season long (check)	64	177126^{a}
Weedy up to DAP		
25	65	136437^{abc}
50	58	148966^{a}
75	64	132644^{abc}
100	65	86897^{bcde}
125	66	80575^{cde}
150	67	59655^{e}
Season long (check)	62	51724^{e}
CV	7.05	16.86

Where, means with the same letters are not significantly different among each other. CV = Coefficient Variation

Tiller number

Tiller productivity varied greatly by treatment. In weed-free check, 177,126 tillers per hectare were generated, while in unweeded check, 51,724. Tiller productivity increased with weed-free periods and declined with weed infestations. Weeds competed for space, nutrients, and light, hindering tiller production. Zubair et al. (2011) reported weed-crop competition periods altered cane crop tillering. However, our study result is in contradiction with the result of Firehun et al. (2013) which reported that weeds did not affect the number of tillers produced. The reduction on tillering ability could be due to the over competitive effect of weeds on sugarcane for essential nutrients, light, space and moisture.

Effect of weed competition on sugar yield, cane yield and its components

Different weed infestation periods influenced cane height, girth, weight, millable cane number, and sugar production. Cane height, girth, weight, millable cane number, cane and sugar output all showed significant treatment effects ($p \leq 0.01$). Cane tiller production, height, girth, weight, millable cane number, cane and sugar output rose with weed-free periods. When weed infestation rose, tiller production, cane height, girth, weight, millable cane number, cane and sugar yield declined.

Table 3. Cane height (cm), girth (mm), weight (kg $stalk^{-1}$), millable cane number (ha^{-1}), cane yield (t ha^{-1}) and sugar yield (t ha^{-1}) as influenced by different durations of weed competition and weed free periods

Treatment	Height (cm)	Girth (mm)	Millable (ha^{-1})	Weight (kg $stalk^{-1}$)	Cane yield (t ha^{-1})	Sugar Yield (t ha^{-1})
Weed free up to DAP						
25	107.1^{fg}	17.51^{e}	60230^{ef}	0.27^{e}	16.11^{h}	1.20^{hi}
50	112.4^{f}	19.63^{d}	71149^{e}	0.47^{d}	33.16^{g}	2.80^{gh}
75	145.5^{d}	22.38^{c}	126322^{c}	0.77^{bc}	96.29^{d}	8.46^{e}
100	156.0^{cd}	22.66^{bc}	136897^{bc}	0.81^{ab}	110.27^{c}	10.33^{de}
125	173.3^{b}	23.15^{bc}	151034^{a}	0.83^{ab}	125.82^{ab}	12.73^{bc}
150	210.8^{a}	24.08^{abc}	152084^{a}	0.87^{ab}	131.82^{ab}	14.31^{ab}

Season long (check)	217.5[a]	25.02[a]	152169[a]	0.92[a]	138.81[a]	15.72[a]
Weedy up to DAP						
25	211.9[a]	24.48[ab]	140230[ab]	0.89[a]	124.31[b]	12.73[bc]
50	207.9[a]	23.58[abc]	142529[ab]	0.84[ab]	119.09[bc]	11.23[cd]
75	163.9[bc]	22.44[c]	95172[d]	0.68[c]	64.85[e]	5.66[f]
100	130.3[e]	22.47[c]	89080[d]	0.53[d]	47.61[f]	3.89 [fg]
125	108.7[fg]	18.88[de]	53678[f]	0.33[e]	18.02[h]	1.33[hi]
150	99.5[gh]	18.24[de]	52414[f]	0.30[e]	15.55[h]	1.03[hi]
Season long (check)	89.3[h]	17.29[e]	50115[f]	0.27[e]	13.25[h]	0.84[i]
CV	13.64	6.17	14.64	9.43	14.79	8.10

Means with the same letters are not significantly different among each other. CV = Coefficient of variation, MSE = Mean square error

Cane yield components

Cane height

Cane heights differed significantly ($p \leq 0.01$) depending on weed abundance (**Table 3**). Cane plant heights were not significantly different in WF up to 25, WF up to 50, and weed infestation up to 125 days after planting. The weed-free check had the tallest canes (217.5cm), while the weedy check had the shortest (89.3cm). Thus, weed-free period enhanced cane height and vice versa. This is because weed competition for light, nutrients, space, and moisture is reduced when weed-free times are extended, allowing the crop to flourish robustly. This result agrees with Zubair et al. (2011), Firehun et al. (2013), and Welday et al. (2018a), who reported the longest canes under weed-free conditions (zero competition) and the shortest under weed infestation (weedy check).

Cane girth

The treatments affected cane girths significantly. The thickest (25.02 mm) stalk was from a weed-free treatment, while the thinnest (17.29 mm) was from a weed-infested treatment (weedy check). Abubaker (1978) reported that weed competition doesn't alter cane girth.

Millable cane number

Presence and absence of weeds affects millable cane production ($p \leq 0.01$) (**Table 3**). As weed-free periods increased, millable canes rose. As weed competition rose, millable canes declined. Season lengthy weed free period (weed free check) produced the most millable canes (152,169 ha-1) while weed competition produced the least (50,115 ha-1) (weedy check). Compared to the weed-free testing, this showed 67.07 % millable cane loss. WF up to 125, WF up to 150, WC up to 25, and WC up to 50 treatments had more millable canes per hectare, although they were statistically equal. This study result is similar to Zubair et al. (2011), who found that protracted weed-crop competition suppressed millable canes to a minimum number in weedy check. Firehun et al. (2013) also found that weeds affect millable cane production.

Cane weight

Average cane weight differed significantly ($p \leq 0.01$) between weed infestation phases (**Table 3**). Weed-free periods enhanced cane weight. Cane weight reduced as weed infestations rose. Season long weed free treatments produced the heaviest (0.92 kg/stalk) and lightest (0.27 kg/stalk) cane stalks. Zubair et al. (2011) found that extended weed-crop competition lowered cane weight.

Cane yield

The treatment effects showed a highly significant difference ($P \leq 0.01$) on cane yield (**Table 3**). The length of weed infestation or weed free period changed the sugarcane yield (Table 3 and Figure 1 & 2). The highest (138.81 t ha^{-1}) yield was recorded from the weed free check while the lowest (13.25 tha^{-1}) obtained from the weed competition check treatment. The yields obtained from WF (check), WF up to 150 DAP and WF up to 125 DAP were higher and statically similar to each other as compared to other treatments. On the other hand, yields obtained from weedy check, weedy up to 150 DAP, weedy up to 125 DAP and WF up to 25 DAP treatments were lower and statically similar.

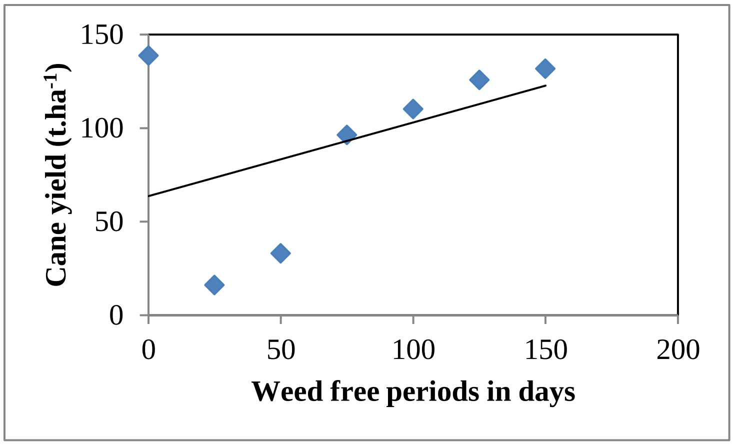

Figure 1. Relationship between cane yield and weed free periods

Increasing periods of weed infestation simultaneously reduced sugarcane yields. High yield reductions were observed due to treatments that had weedy period for more than 50 days and weed free for less than 75 days after planting (**Figure 1** and **Figure 2**). In this study, the cane yield obtained from weed infestation up to 25 DAP treatment was 124.31

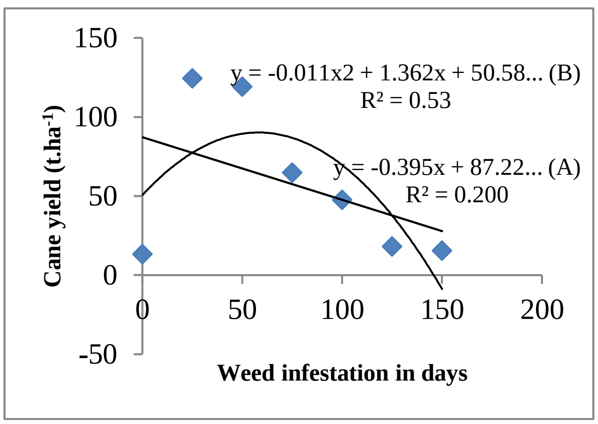

Figure 2. Relationship between cane yield and weed competition periods

Sugar yield

The treatments showed highly significant difference ($P \leq 0.01$) on sugar yield (**Table 3** and **Figure 3**). The highest (15.72 t ha^{-1}) yield was recorded from the weed free check treatment while the lowest (0.84 t ha^{-1}) was recorded from the weed competition check. The sugar yields obtained from WF (check) and WF up to 150 DAP were higher and statically similar to each other.

On the other hand, yields obtained from weedy check, weed infestation up to 150 DAP, weed competition up to 125 DAP, weed competition up to 100 DAP, weed competition up to 75 DAP, WF up to

t ha^{-1} which showed a yield loss of 10.5% as compared to the weed free check. This could be due to the higher weed seed bank of the soil, early on and lately germination of weeds caused by optimum moisture availability due to rainfall, and fast and vigorous growth of weeds due to their capability to take more growth resources than the crop before cane canopy development.

50 DAP and WF up to 25 DAP treatments were lower and statically similar. Further, high sugar yield reduction was observed in treatments that had weed competition period for more than 50 days and weed free for less than 75 days after planting (Figure 4). In this study, the sugar yield obtained from weed infestation up to 25 DAP and WF up to 125 DAP were 12.73 t ha^{-1}, showing a yield loss of 19.02% compared to the weed free check.

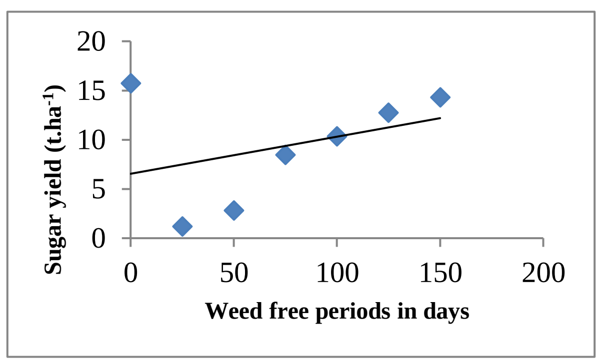

Figure 3. Relationship between sugar yield and weed free periods

Generally, a sugar yield loss of 19.02%, 28.56%, 63.99%, 75.25%, 91.54% and 93.45% were resulted due to weed competition up to 25, 50, 75, 100, 125 and 150 days after planting, respectively. In the same way, sugar yield losses of 92.37%, 82.19%, 46.18%, 34.29%, 19.02% and 8.97% were recorded as a result of weed free up to 25, 50, 75, 100, 125 and 150 days after planting, respectively, as compared to the yield recorded from weed free check. This result confirmed previous research findings by Taye (1991) that weeds were caused severe reduction in yield of sugar in the sugarcane plantations of Ethiopia. Similarly, Firehun et al. (2009) reported that crop-weed competition in the sugarcane plantations of Ethiopia inflicted a significant sugar yield loss that ranges from 60 to 74 %. According to the data analysis formula, the highest cane yield and sugar yield losses were 90.45% and 94.6%. This substantial output drop was linked to greater weed populations reducing millable canes, cane length, girth, and weight due to crop-weed competition for growth resources. This may be attributed to the appearance of a large number of weeds after an extended rainfall, resulting in rapid growth, intensive weed competition, and greater biomass.

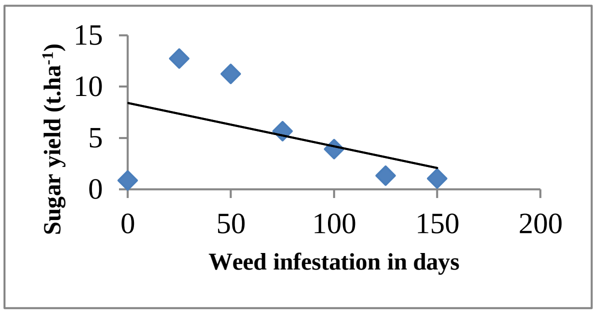

Figure 4. Relationship between sugar yield and weed competition periods

With 5% acceptable cane production loss, weed competition was critical between 17 and 131 days after planting. Therefore, weed competition in sugarcane for NCO334 cane cultivar in Arjo Didessa sugarcane plantation began 17 days after planting and lasted 131 days. Following 131 days after planting, crop canopy closure limits weed germination and growth.

Firehun et al. (2013) identified a critical phase of weed competition between 2.5 and 14 weeks after planting for the erect cultivar (NCO334) on Ethiopian sugarcane plantation estates. Welday et al. (2018a) reported a 16-to-126-day crucial timeframe for sugarcane weed management. Similar to this study, Lianming and Chuxiong (2003), Srivastava et al. (2003), and Seeruttun and Lutman (2004) found the key weed competition phase in sugarcane to be one to four months after sowing.

Correlation between weed density, weed dry biomass, cane yield, yield components and sugar yield

Critical period of weed competition and control in sugarcane

Using logistic and compertz equations, the critical period of weed competition at 5% tolerable yield loss was determined. Figure 4 shows the beginning and end of weed competition periods for NCO334 cultivar, i.e., the maximum time the crop should be weed-free and the shortest time weeds can persist in the crop field.

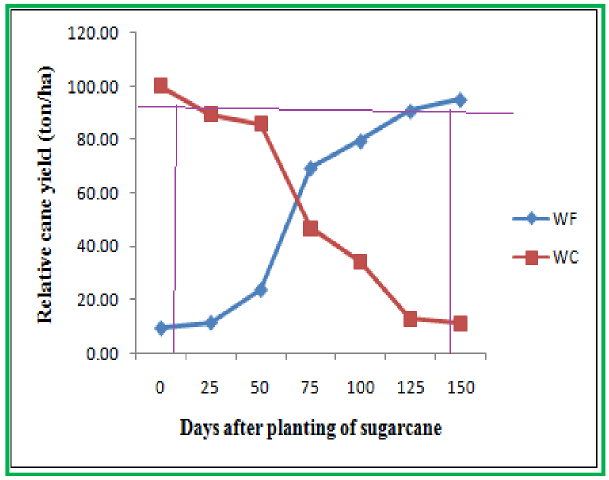

Figure 4. Beginning and last part of critical period of weed competition in sugarcane on NCO334.

The correlation coefficient between sprout percentage and other parameters viz., tiller, millable cane number, height, girth, weight, cane yield and sugar yield were non-significant (P≤0.05) (**Table 5**). Weed density showed negative and highly significant correlation with tiller, cane height, millable cane, cane girth, cane weight, cane yield and sugar yield. Similarly, weed dry biomass was negatively and highly significantly correlated with tiller, cane height, millable cane, cane girth, cane weight, cane yield and sugar yield.On the other hand, cane height showed a positive and highly significant association with millable cane, cane girth, cane weight, cane yield and sugar yield. Millable cane was also positively and highly significantly correlated with cane girth, cane weight, cane yield and sugar yield. Similarly, tiller number, cane girth, height, weight, cane yield and sugar yield showed a significant and positive correlation to each other. However, cane yield and sugar yield did not show any correlation with sprout percentage at p≤0.05, but, showed a negative correlation with both weed density and weed dry weight at p≤0.01. Cane yield and sugar yield showed a positive and highly significant correlation with the tiller number, millable cane number, cane height, cane girth and cane weight at 0.1% significance level.

Table 4. Simple correlation coefficient among weed density, weed dry biomass, sugar yield, cane yield and yield component parameters in sugarcane

	Sprout	Weed density	Weed dry weight	Tiller	Cane height	Millable cane	Girth	Cane weight	Cane yield	Sugar yield
Sprout	1									
Weed density	-0.155^{ns}	1								
Weed dry weight	0.115^{ns}	0.246**	1							
Tiller	-0.142^{ns}	-0.080**	-0.849**	1						
Cane height	-0.138^{ns}	-0.092**	-0.905**	0.833**	1					
Millable cane	-0.159^{ns}	-0.225**	-0.936**	0.894**	0.907**	1				
Girth	-0.057^{ns}	-0.054**	-0.818**	0.781**	0.879**	0.879**	1			
Cane weight	-0.164^{ns}	-0.132**	-0.915**	0.834**	0.906**	0.938**	0.932**	1		
Cane yield	-0.145^{ns}	-0.252**	-0.949**	0.874**	0.929**	0.985**	0.932**	0.971**	1	
Sugar yield	-0.112^{ns}	-0.322**	-0.949**	0.865**	0.936**	0.975**	0.878**	0.937**	0.988**	1

Where: ns = non-significant (p≤0.05), ** = highly significant (P≤0.01)

CONCLUSION

Weeds reduce sugarcane yields and production costs. Cane and sugar yield losses were 90.45% and 94.6%. The important period of weed competition in this study was 17-131 days following planting. As weed-free period decreased, weed density (m^{-2}) and dry biomass (g/m^2) grew significantly. Tiller productivity, cane height, girth, weight, quantity of millable cane, cane yield, and sugar yield differed between weed-free and weed-infested seasons. Tiller number, cane height, girth, weight, cane yield, and sugar yield are correlated. However, these parameters showed a negative correlation with both weed density and dry weight. This study reveals that sugarcane fields, especially with upright cultivars, should be weed-free from 17 to 131 days following planting to keep production loss below 5%. Further, luvisol and other cane cultivars should be tested for weed competition crucial period.

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COMPETING INTERESTS

The authors declare that they have no competing interests

DATA AVAILABILITY STATEMENT

The raw data used to support the findings of this study are available from the corresponding author upon request.

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