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Original Research Article

Determination of the critical period for weed control of sweet corn under tropical organic farming system

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Abstract

An understanding of the critical period of the crop for weed control (CPWC) is needed before making a decision on weed management. A field experiment to study a CPWC of sweet corn was carried out at the highland of Bengkulu Province, Indonesia from October 2015 to January 2016. The objective was to determine the CPWC of sweet corn under the tropical organic farming system. Weed infestations in the research plots including 14, 28, 42, 56, 70, and 84 days after planting (DAP) of weedy and weed-free periods were arranged in a completely randomized block design (CRBD) with three replications. Results showed that the plant height, leaf area, and yield of sweet corn descended and ascended due to the increase of weedy and weed-free periods, respectively. The biomass and yield losses due to weed competition during the growing season reached 49.5 and 54.7 %, respectively. The relative yield descended or ascended in logistic equation curves due to the increase of weedy or weed-free periods, respectively. Based on the acceptable yield loss (AYL) of 5 %, the CPWC of sweet corn under organic farming system was determined from 2 to 77 DAP, and with the AYL of 10 %, the CPWC was determined from 3 to 53 DAP.

Keywords: Sweet corn, CPWC, Tropical organic farming, Weed control

Introduction

Sweet corn (*Zea mays saccharata*) is a horticultural crop cultivated over the world. The consumption of sweet corn in Indonesia continues to increase because of its nutrition and naturally sweet taste, but production remains low. Efforts to optimize the yields of sweet corn were done intensively using many synthetic inputs such as fertilizers and pesticides (Johnson et al., 2010; Akintoye and Olaniyan, 2012). But, using of synthetic inputs intensively may cause adverse impacts to the environment due to the deterioration of soil and water quality (Mulvaney et al., 2009; Savci, 2012; Ruark et al., 2012). Therefore, the organic farming system, known as an environmentally friendly practice without using synthetic materials, becomes a wise choice not only to save soil environment but also to produce healthy food (Hue and Silva, 2000; Taguling, 2013). An organic farming system is trending over the world today, especially for horticultural crops (Ruark et al., 2012; Muktamar et al., 2017).

Organic farming can be interpreted as a crop production system based on biological recycling of nutrients. Soil fertility can be improved not only by recycling the organic material in-situ but also by using the organic materials from the outside of the farming areas, such as composted forage plants and animal manures (Taguiling, 2013). However, some organic materials such as cattle manure and forage composts may carry weed propagules (Barberi, 2002). The number of weed populations in planting area may increase because of the emerging weeds both from animal manure and from soil seed bank (Carr et al., 2013). Weeds will be very detrimental to the crops if they are not controlled by the right measures at the appropriate time. Since organic farming does not use any synthetic chemicals such as herbicides, the choice of weed control practices may be limited to cultural, mechanical, biological, or integrated control practices by combining those methods (Barberi, 2002). An appropriate weed management should be carried out when the presence of weeds is harmful to the crops through a significant reduction of yield known as the CPWC (Knezevic at al., 2002; Johnson et al., 2010). According to Zimdahl (2004), CPWC is the growth stages of the crop where weeds must be controlled to prevent the apparent losses of crop yields. An understanding of the CPWC is very useful to make timely decisions for specific weed control on each plant species (Knezevic and Datta, 2015).

Determination of the CPWC can be approached by investigation of the weedy and weed-free periods on a specific crop. The limit of the acceptable yield loss (AYL) in general varies from 5 to 10 % (Knezeviz and Datta, 2015). The yield or relative yield of weedy and weed-free trials are described in logistic equation curves, where the intercept of the weedy and weed-free curves at the AYL on x-axis can determine the maximum of weedy periods and the minimum of weed-free periods of crop growth stages to weed competition, respectively (Juraimi et al., 2009; Mekonnen et al., 2017).

Some researchers have reported the CPWC among crops worldwide that included corn (Evans et al., 2003; Gantoli et al., 2013), soybeans (Knezevic et al., 2003), rice (Juraimi et al., 2009; Chauhan and Johnson, 2011; Mekonnen, 2017), peanuts (Everman et al, 2008), and sweet corn (Williams II, 2006). The CPWC varies due to climates factors, environmental conditions, cropping system, and cultivation technology such as row spacing, planting date, and fertilizer application (Williams II, 2006; Juraimi et al., 2009; Chauhan and Johnson, 2011). A field experiment was carried out at the highland of tropical areas to determine the critical periods of sweet corn to weed competition under a closed organic farming system.

Material and Methods

The research was carried out at the Closed Agricultural Production System (CAPS) Research Station of the University of Bengkulu located at District of the Rejang Lebong, Bengkulu Province, Indonesia from October 2015 to January 2016. The field is positioned at 1020 36' 56" E, 30 27' 37" S, and the altitude of 1,054 meters above the sea level. The soil type is Andept and the soil texture is classified as sandy loam. The site was regularly cultivated for organic vegetable production since 2009.

Weed assessment on the research site was conducted in 3 blocks based on weeds stratification. Weeds were enumerated in 5 sampling plots for each block using a wooden square plot size of 0.5 m x 0.5 m each, following the methods of Simarmata et al. (2015). Data observed were density, frequency, and dry biomass weight of weed species in each sampling plot. The rank of dominant weed species was determined based on the values of summed dominance ratio (SDR) calculated from the average of relative density, frequency, and dry biomass weight as modified from Janiya and Moody (1989) (Eq. 1).

$$SDR = \frac{Dr+Fr+Br}{3} \qquad (1)$$

Where, SDR is summed dominance ratio; Dr is relative density calculated from density of one species divided by total density of all species; Fr is relative frequency calculated from frequency of one species divided by total of frequency of all species; and Br is relative biomass calculated from biomass of one species divided by total biomass of all species.

Land preparation was started by cutting the weeds and land was cultivated twice using hoes.The experimental site was formed for 36 plots (12 trials with 3 replications) with sizes of 3 m x 1.5 m each. Organic fertilizer was applied one week before planting using composted solid cow's manure of 10 ton ha^{-1}. The manures were mixed homogeneously within 20 cm depth of soil surface. Seeds of sweet corn var. Secada were planted in a hole of 3 cm depth with planting spaces of 75 cm x 25 cm.

Sweet corn plants were maintained regularly by watering and pest were controlled mechanically as needed. In addition to the manure fertilizers, liquid organic fertilizer (LOF) was sprayed on soil surface at 1 and 6 WAP at the rates of 5 ml m^{-2}. The LOF was produced at the University of Bengkulu, consisted of dairy cattle feces, dairy cattle urine, soil containing local microorganism, green leaves of *Tithonia diversifolia*, and solution of EM-4, diluted and fermented in water for 10, 10, 1, 2.5, 10 %, respectively (Muktamar et al., 2017). Weeds were controlled by physical control method (PCM) in accordance with weedy and weed-free periods (Table 1). The CPWC of sweet corn under tropical organic farming systems was evaluated by variations of weed infestations in the research plots including 14, 28, 42, 56, 70, and 84 DAP of weedy and weed-free periods.

The weed-free periods were maintained by manually removing weeds that appear in the specified weed-free period trial, likewise, the weedy periods were allowing weeds to grow within the specified period trial and after that period, the emerged weeds were manually removed from the plots. The experiment was arranged in a completely randomized block design (CRBD) with three replications.

Table 1. Periods of weed infestations on sweet corn under tropical organic farming system.

No.	Treatment	0-14 DAP	0-28 DAP	0-42 DAP	0-56 DAP	0-70 DAP	0-84 DAP
1.	Weed-free 14 DAP	Weed-free	Weedy	Weedy	Weedy	Weedy	Weedy
2.	Weed-free 28 DAP	Weed-free	Weed-free	Weedy	Weedy	Weedy	Weedy
3.	Weed-free 42 DAP	Weed-free	Weed-free	Weed-free	Weedy	Weedy	Weedy
4.	Weed-free 56 DAP	Weed-free	Weed-free	Weed-free	Weed-free	Weedy	Weedy
5.	Weed-free 70 DAP	Weed-free	Weed-free	Weed-free	Weed-free	Weed-free	Weedy
6.	Weed-free 84 DAP =Weedy 0 DAP	Weed-free	Weed-free	Weed-free	Weed-free	Weed-free	Weed-free
7.	Weedy 14 DAP	Weedy	Weed-free	Weed-free	Weed-free	Weed-free	Weed-free
8.	Weedy 28 DAP	Weedy	Weedy	Weed-free	Weed-free	Weed-free	Weed-free
9.	Weedy 42 DAP	Weedy	Weedy	Weedy	Weed-free	Weed-free	Weed-free
10.	Weedy 56 DAP	Weedy	Weedy	Weedy	Weedy	Weed-free	Weed-free
11.	Weedy 70 DAP	Weedy	Weedy	Weedy	Weedy	Weedy	Weed-free
12.	Weedy 84 DAP =Weed-free 0 DAP	Weedy	Weedy	Weedy	Weedy	Weedy	Weedy

DAP = Days After Planting; hatched bar = Weedy; open bar = Weed-free

Ten sample plants from each plot were harvested at 84 DAP and data recorded for plant height, leaf area, and yield of unhusked cob's weight, cob's length, cob's diameter, and biomass weight. Residual of weed biomass were collected from 2 sampling plots (sizes of 0.5 m x 0.5 m each) of weed-free period trials. Biomass of sweet corn and weeds were oven-dried at 70 C for 72 hours. Data were subjected to one-way analysis of variances (ANOVA) and further separated by Duncan's multiple range test (DMRT) at 5 % level. Data of the yield were converted to relative yield as a percent of control and further analyzed using non-linear regression model. The equation with the highest determination factor (R^2) was judged as the most appropriate model to determine critical periods of sweet corn (Williams II, 2006; Juraimi et al., 2009). The intercept of weedy and weed-free curves on the x-axis at 5 % and 10 % of acceptable yield loss (AYL) were chosen arbitrarily to determine the CPWC of sweet corn under the tropical organic farming system (Knezeviz and Datta, 2015).

Results and Discussion

Weed analysis

Weed vegetation in the experimental site was identified before and after the experiment. Initial analysis was conducted in 3 blocks based on visual views of weed stratifications. Weed assessment in block I (Fig. 1A) identified 11 species of weeds in which 4 species have SDR > 10 which were *Ageratum conyzoides*, *Mimosa invisa*, *Echinochloa colona*, *Stachytarpeta jamaicensis*, respectively with SDR of 26.0, 18.0, 14.6, and 13.2 %. In block II (Fig. 1B) there were 7 species of weeds in which 5 species have SDR > 10 which were *Stachytarpeta jamaicensis*, *Cyperus kyllingia*, *Echinochloa colona*, *Ageratum conyzoides, and Mimosa invisa* with SDR of 29.4, 16.8, 16.4, 15.1 and 14.7 %, respectively. In Block III (Fig. 1C) there were 8 weed species but only 3 species have SDR > 10 which were *Echinochloa colona*, *Ageratum conyzoides*, *Stachytarpeta jamaicensis* with SDR of 40.9, 25.6, and 10.7 %, respectively. Based on the differences in weed distributions in the three blocks before the experiment, the study was designed in a randomized block design (RBD) with 3 replications as blocks.

Weeds that grew at the end of the study as residuals of the treatment were only observed in the plots of weed-free periods. There were 9 species that grew at the harvested time but only 3 species had SDR > 10 which were *Euphorbia prunifolia*, *Ageratum conyzoid*es, *Echinochloa colona* with SDR of 24.0, 22.7, and 15.6 %, respectively. Compared to the initial analysis, two new weed species were *Amaranthus spinosus*, *Borreria latifolia* with SDR of 4.4 and 3.7 %, while five weed species were absent were *Cyperus kyllingia*, *Phyllanthus niruri*, *Syndrella nodiflora*, *Spilanthes acmella*, and *Stachytarpeta jamaicensis* (Fig. 1D). The presence or absence of weed species indicated the shifting in weed vegetation due to manipulated microenvironment such as the different periods of weed infestation (Simarmata et al., 2015). Newly emerging weeds may be carried away from the manure or emerged from dormant seed or from the soil seed bank (Barberi, 2002). Weed residue harvested at the end of the study as the total weed biomass was only observed in weed-free trials because there was no weed residue in the weedy trials (William II et al., 2008). The heaviest weed residue in the weed-free trials reached 656 g m^{-2}. The weed residue decreased with longer periods of weed-free and there was no weed residue if the plot was free from weeds during the season (Fig. 2).

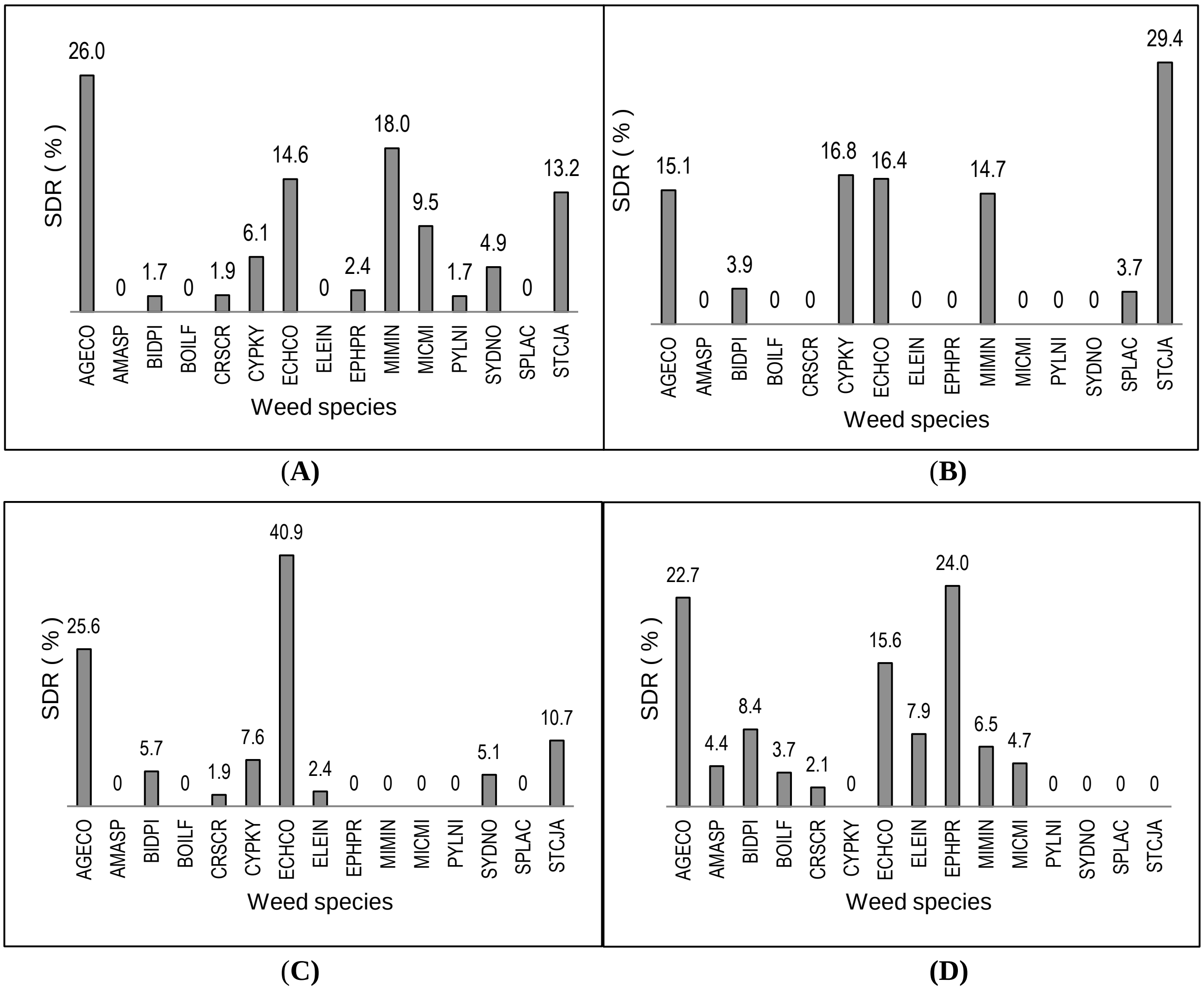

Fig. 1. Initial assessment of weed vegetation in research sites (A, B, C) , and final assessment at the end of the growing season (D) counted as summed dominance ratio (SDR); AGECO = *Ageratum conyzoides*, AMASP = *Amaranthus spinosus*, BIDPI = *Bidens pilosa*, BOILF = *Borreria latifolia*, CRSCR = *Crassocephalum crepidioides*, CYPKY = *Cyperus kyllingia*, ECHCO = *Echinocloa colona*, ELEIN = *Eleusine indica*, EPHPR = *Euphorbia prunifolia*, MIMIN = *Mimosa invisa*, MICMI = *Mikania micrantha*, PYLNI = *Phyllanthus niruri*, SYDNO = *Synedrella nodiflora*, SPLAC = *Spilanthes acmella*, STCJA = *Stachytarpheta jamaicensis.*

Growth, yield and biomass production

The sweet corn seeds germinated and grew at 99 %, so seedlings were thinned become one plant per planting hole. With low rain in October 2015, 35 mm in 5 days of rain categorized as a dry month, seedlings were watered every day. But in November, December 2015, and January 2016, the rainfalls were 355, 592, and 391 mm with rainy days of 23, 26, and 19 days, respectively. These rainfalls were optimum for sweet corn growth (Fig. 3). Overall, the crops grew well and there was no evidence of diseases and insects in the experimental plots.

Data on the growth variables, yield, and plant biomass are presented in Table (2). The period of weed infestations significantly affected plant height, leaf area, yield, and biomass production, but no effect was found on the yield components of cob's diameter and length. The longer the weedy period, the lower the height and the less the leaf area of sweet corn was. If the plots were weedy during agrowing season, the plant height and leaf area were depressed to 161.9 cm and 567.5 cm^2 compared to weed-free in a season, the plant height and leaf area were 230.9 cm and 786.6 cm^2, respectively. On the other hand, the opposite was found on the weed-free trial, where the longer the weed-free period the higher the plant height and the more the leaf area. If the plots were free from weeds during a season the plant height increased from 161.6 to 230.9 cm and the leaf area increased from 567.6 to 786.6 cm^2. The responses of plant growth to weed infestations can be explained by the competition periods between crop and weeds to the life necessities such as nutrition, growing space, water, and CO_2 (Zimdahl, 2004). If weeds were suppressed by increasing the weed-free periods then the crop growth and yield increases (Williams II et al., 2008).

The decrease and increase of the plant height and the leaf area on weedy and weed-free trials affected the yield and plant biomass production. The yield decreased when the weedy period increased and the yield increased when the weed-free periods increased (Table 2). If the plot was free from weeds during a season, the yield of unhusked cobs was 463.5 g $plant^{-1}$. But, when the plots were weedy during the season, the yield decreased to 209.9 g $plant^{-1}$. The decrease or increase of yield was not correlated to the yield components of the diameter and length of the cob, but it was suspected due to the size and the number of seeds. The more opportunities the crops free from weeds, the higher the growth and yield of crops that were harvested (Zimdahl, 2004; Williams II et al., 2008).

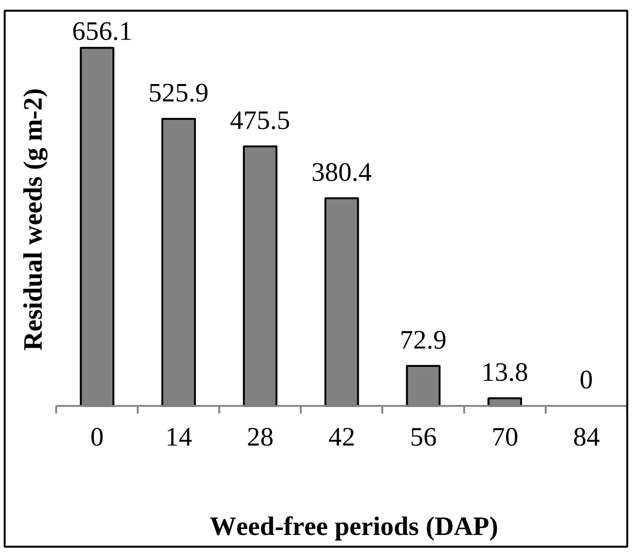

Fig. 2. Residual weeds of in sweet corn plots harvested at the end of experiment.

Biomass production of sweet corn also showed the same pattern with the growth parameters because biomass was the accumulation of the plant height and leaf areas of the plant. Biomass production decreased from 104.7 to 52.9 g $plant^{-1}$ if the plots were weedy during the growing season and vice versa occurred if the plots were weed-free during the season. The biomass production was also an important variable of sweet corn because it can be utilized for industries such as bioethanol or for local needs as fresh ruminant food (Barros-Rioss et al., 2015).

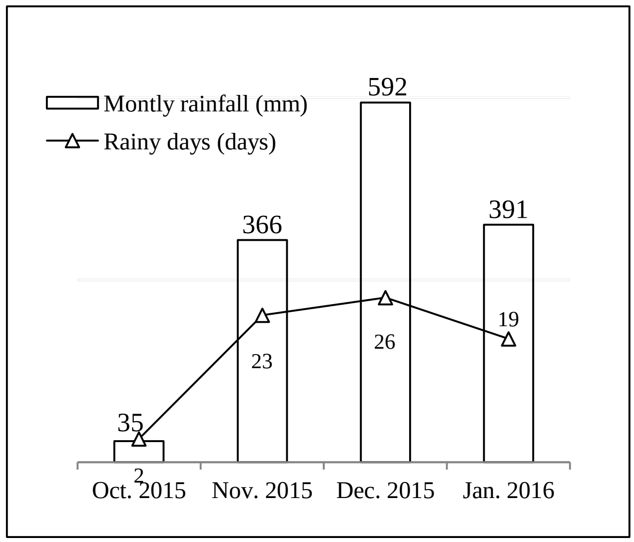

Fig. 3. Montly rainfall and number of rainy days in the research location from October 2015 to January 2016.

Determination of the CPWC

The yield and biomass relatives of sweet corn expressed in the percent of control are presented in Table 3. It appeared that the yield losses increased or decreased when the weedy or weed-free period increased, respectively. The highest yield loss of sweet corn grown under tropical organic farming reached 54.7 % if the weeds were not controlled during the season (84 days of weedy). Similarly, the highest biomass loss reached 49.5 % due to uncontrolled weeds during the season (84 days of weedy).

The logistic equation curves of relative yield of weedy and weed-free periods were used to determine the CPWC (Knezevic et al., 2002; Gantoli et al., 2013). The AYL due to adverse effects of weeds varies from 5 – 10 % (Knezevic and Datta, 2015). Determination of the critical period was judged by analysis of non-linear curves of the relative yields of weedy and weed-free treatments. In some publications, the critical periods of crops to weed control were fitted to Gompertz and logistic equation curves (Juraimi et al., 2009). In this study, a logistic equation was used to determine the CPWC with determination factors (R^2) reaching 94.9 and 85.8 % on the weedy and weed-free curves, respectively (Fig.4).

Based on the intercept of the curves on the x-axis with the AYL of 5 %, the maximum weedy period was 2 DAT, and the minimum of the weed-free period was 77 DAP. Thus, the CPWC of sweet corn under the tropical organic farming system with the AYL of 5 % was from 2 to 77 DAT (Table 4). If the AYL become 10 %, then the maximum weedy period was 3 DAT, and the minimum of the weed-free period was 53 DAP. Thus, the CPWC of sweet corn under the tropical organic farming system with the AYL of 10 % was from 3 to 53 DAT (Table 4).

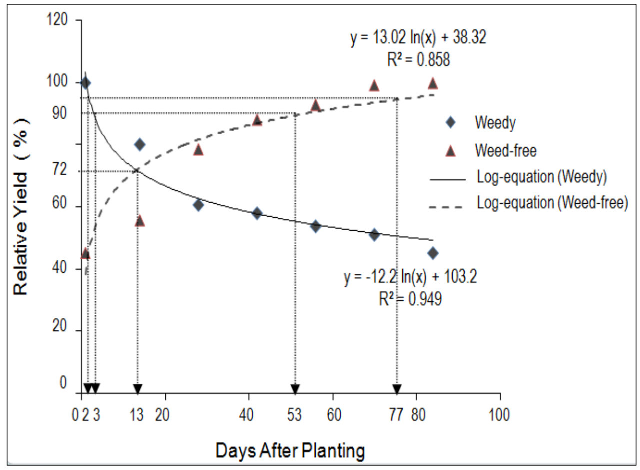

Fig. 4. The critical periods for weed control (CPWC) of sweet corn under tropical organic farming system.

Table 2. Effect of weed infestation on growth, yield, yield components, and biomass of sweet corn.

Periods of weed infestation (DAP)		Plant height (cm)	Leaf area (cm^2)	Unhusked - cob (g $plant^{-1}$)	Cob- diameter (cm)	Cob- lenght (cm)	Oven-dried biomass (g $plant^{-2}$)
Weedy	0	230.9 a	786.6 a	463.5 a	5.77	20.8	104.7 a
	0-14	233.2 a	775.8 a	371.8 b	5.88	20.8	93.0 ab
	0-28	189.1 ab	668.2 b	281.9 c	5.76	19.7	78.8 bcde
	0-42	190.4 ab	633.7 b	269.2 c	5.80	21.9	67.5 def
	0-56	196.9 ab	626.4 b	250.2 cd	5.54	19.2	60.9 ef
	0-70	189.9 ab	591.0 bc	237.2 cd	5.02	19.5	54.9 f
	0-84	161.9 b	567.5 c	209.9 d	5.00	21.5	52.9 f
Weed-free	0	161.9 b	567.5 c	209.7 d	5.00	21.5	52.9 f
	0-14	206.3 a	586.6 bc	258.4 bc	5.17	20.7	70.9 cdef
	0-28	215.2 a	742.8 a	364.6 b	5.13	21.4	83.9 bcd
	0-42	221.2 a	749.6 a	405.0 b	5.23	21.3	90.8 abc
	0-56	226.8 a	760.4 a	431.1 a	5.25	21.8	91.3 abc
	0-70	222.6 a	772.1 a	460.4 a	5.84	21.3	96.2 ab
	0-84	230.9 a	786.6 a	463.5 a	5.77	20.8	104.7 a
ANOVA ($P<0.05$)		*	*	*	NS	NS	*

*** = Significant effect; NS = Non-significant effect; Numbers followed by the same letter in one column are not significantly different by DMRT (P<0.05).**

Table 3. Effect of the weed infestations on yield and biomass losses of sweet corn.

Period of weed infestation (DAP)		Relative Yield (%)	Yield losses (%)	Relative biomass (%)	Biomass losses (%)
Weedy	0-14	80.2	19.8	88.8	11.2
	0-28	60.8	39.2	75.3	24.7
	0-42	58.1	41.9	64.5	35.5
	0-56	53.9	46.1	58.2	41.8
	0-70	51.2	48.8	52.4	47.6
	0-84	45.3	54.7	50.5	49.5
Weed-free	0	45.3	44.7	50.5	49.5
	0-14	55.8	44.2	67.7	32.3
	0-28	78.7	21.3	80.1	19.9
	0-42	88.2	11.8	86.7	13.3
	0-56	93.0	7.0	87.2	12.8
	0-70	99.3	0.7	91.9	8.1
	0-84	100	0.0	100	0

DAP = days after planting

Table 4. Determination of the CPWC of sweet corn based the AYL 5 and 10 % of weedy and weed-free curves.

Relative Yield (%)	Yield Loss (%)	Maximum weedyperiods (DAP)	Minimum weed-free periods (DAP)
95	5	2	77
90	10	3	53

CPWC = critical periods for weed control; AYL = acceptable yield loss; DAP = days after planting.

Conclusion

The periods of weed infestations influenced the growth and yield of sweet corn cultivated under tropical organic farming systems which ascended or descended with the non-linear curves of the logistic equations due to the increase of weedy or weed-free periods, respectively. Based on the AYL of 5 %, the CPWC of sweet corn under tropical organic farming was from 2 to 77 DAP and with the AYL of 10 %, the CPWC was from 3 to 53 DAP.

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