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Critical period for weed control in *Stevia rebaudiana* (Bert.) Bertoni

[Tempoh kritikal pengawalan rumpai dengan *Stevia rebaudiana* (Bert.) Bertoni]

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Abstract

Knowledge on the critical period to conduct specific crop-weed interference is an important component for the development of an effective integrated weed management approach. The present experiment was carried out in a glass house at the Rice Research Centre, MARDI Serdang. Weeds were allowed to compete with the *Stevia* plants at different growth periods (after the *Stevia* plants were transplanted), before being removed manually. Full term weedy and weed-free treatments were included as controls for comparison. It was observed that the yield of *Stevia* decreased with increasing duration of weed competition. Based on the predicted Logistic equation and Gompertz response curve, the critical period for controlling weeds in *Stevia* was found to be as early as the first week after transplanting until the end of the third week. During this phase, the weeds have to be controlled in order to prevent losses that could exceed the economic threshold.

Keywords: critical period, *Stevia*, weed control, competition, yield loss

Introduction

Weeds are nourished by the same nutrients and environmental elements needed by a crop. Because of the limited supply of these vital elements, their association, therefore, leads to competition for these elements of survival (Mercado 1979). Weeds interfere with crop plants by severely reducing crop growth and lowering yield and quality (Zimdahl 1980; Qasem 2003). To reduce the cost and risks of intensive weed control, the frequency or intensity of operations should be reduced or optimised (Kavurmaci et al. 2010). The optimum period during which a crop must be free of the adverse effects of weeds (to prevent possible yield loss) is known as the critical period (Zimdahl 1993). This critical period represents the time interval between two separately measured components: the maximum weed-infested period, or the length of time that weeds emerging with the crop can remain before they begin to interfere with the crop growth; and the minimum weed-free period, or the length of time a crop must be free of weeds after planting to prevent yield loss. These components are experimentally determined by measuring crop yield loss as a function of successive periods of weed removal or weed infestation (Weaver and Tan 1987).

For increased productivity of crops, weeds have to be controlled before the onset

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of competition (Chancell and Peorters 1974). Almost all crops demand early control of weeds during growth, particularly for the first 1/3 to 1/2 of its life cycle (Mercado 1979). The critical period for weed control has been determined for several crops (Kavaliauskaite and Bobinas 2006). Pretimatilake et al. (1999) reported that the critical period of weed competition in young tea plants was 8 – 16 weeks after planting. For tobacco, Wan Zaki and Kamarudin (2005) reported it was from 20 – 40 days after transplanting to prevent 67% yield loss. In cowpea, yield losses can reach as high as 76% caused by weeds alone and a timely weed removal at the critical period (within 40 days after its emergence), would help to prevent unacceptable yield loss (Osipitan 2017). Another study by Mizan et al. (2009) showed that the critical period for weed control to prevent yield loss in sesame was 10 – 30 days after emergence. In Sweden, lack of weed control during the critical period of weed competition with cereal crops caused yield losses of up to 31.09% (Milberg and Hallgren 2004). While in Central Greece, studies found that weed competition reduced parsley dry weight of up to 93% and 95% in 2010 and 2011 respectively (Karkansis et al. 2012).

Stevia rebaudiana is a plant native to Paraguay, where it grows wild in sandy soils (Megeji et al. 2005). It is currently an alternative source of a calorie free sweetener. *Stevia* has attained worldwide importance because its leaves are used as a non-nutritive, high potency sweetener primarily in Japan, Korea, China and South America (Vikas et al. 2008). *Stevia* belongs to the Asteraceae family, which includes sunflower, marigold and chrysanthemum (Singh and Rao 2005). This herbaceous perennial plant is very slow to get established, does not compete well with weeds (Shock 1982) and the situation worsens after each consecutive harvest. Weeds are normally removed manually (hand weeding/hoeing) (Megeji et al. 2005), both of which are labour intensive and expensive. Accordingly, weed control has been identified as the biggest field management concern in *Stevia* cultivation. With a crop life span of three years, cost effective, on-going weed control is essential (Rank and Midmore 2006).

To prevent yield loss due to competition from weeds, it is necessary to control the weeds before the critical period. The establishment of the critical period of specific weed interference is an important step in the development of an effective, economic and sustainable integrated weed management strategy (Begum et al. 2008). Accordingly, the current study was undertaken to determine the critical period for weed control in *Stevia* and to determine the effect of the timing of weed removal and the duration of weed interference on *Stevia* yield.

Materials and methods

Site description

The experiment was conducted in a glasshouse at the Rice and Industrial Crop Research Centre, Malaysian Agricultural Research and Development Institute (MARDI) in 2009 and repeated in 2010. Forty rectangular plastic containers (40 cm x 20 cm x 58 cm) were filled with 40 kg of soil collected from the *Stevia* field at Serdang. The soil was clay loam (Serdang Series) consisting of 42.38% sand, 35.76% clay and 24.96% silt with a pH of 4.72.

Crop management

The S*tevia* variety MR 007 was used. Two to three node cuttings were taken from plants which had not flowered, raised under 25% shade in 104 trays (with plugged holes). The cuttings were then transplanted after one month at 24 cm apart between rows and 20 cm apart within rows. All containers received an initial basal application of processed chicken dung (@1 t/ha), followed by maintenance of commercial fertiliser application after alternate harvests. Fertiliser (NPK green at a ratio of 15:15:15) was applied along planted rows and covered lightly with soil by hilling. Water was supplied using sprinkler irrigation, once daily for 15 min.

Experimental design

Field experiments were carried out over two successive yearly periods. Weeds were allowed to compete with the *Stevia* plants at different growth periods after transplanting prior to removal by hand. In order to evaluate the onset of the critical period for weed infestation (WI), containers were left with weeds for 7, 14, 21 and 28 days after transplanting, then the weeds were removed and the containers were maintained weed-free until harvest. To determine the end of the critical period, another set of containers were kept weed-free (WF) for 7, 14, 21 and 28 days after transplanting and subsequently weeds were allowed to grow until harvest. Full term weedy and weed-free treatments were included as controls for comparison. All removed weeds were identified and recorded. All treatments were laid out in a randomised complete block design (RCBD) with four replicates.

Weed measurements

Weed species composition and density were assessed by categorising and counting weeds from each container. At the end of each period as described above, weeds were harvested and dried in an oven for 48 h at 65 °C and the dry matter content was determined.

Stevia measurements

The growth data (height, canopy width, leaf number, number of branches and presence of flowers) were determined at weekly intervals. When 50% of the *Stevia* plants started to produce buds, the plants were then harvested (using scateurs) at 5 – 10 cm above ground. The yield data was obtained by weighing the dried plant biomass and recorded as g/m^2.

Statistical analysis

All yield and growth data were analysed using the Statistical Analysis System (SAS) software and significant differences were tested using the LSD at the 5% level of probability. The relative yield of each treatment was calculated as a percentage of the corresponding yield of the weed-free treatment. A logistic equation was used to describe the effect of increasing the duration of weed interference on relative yield to determine the onset of the critical period (Knezevic et al. 2002; Johnson et al. 2004).

The form of the logistic equation used was:

$$RY = \frac{y_0 + a}{1 + (x/x_0)^b}$$

where, RY = relative yield, y_0 = lower limit, a = upper limit, x_0 = days giving 50% yield, x = days and b = slope. The Gompertz model was programmed to predict the relationship between relative yield, as influenced by the increasing length of the weed-free period (Knezevic et al. 2002, Johnson et al. 2004). The form of the Gompertz equation used was:

$$RY = y_0 + a^* \exp\{-\exp[-(x - x_0)/b]\}$$

where, RY = relative yield, y_0 = lower limit, a = upper limit, x_0 = days giving 50% yield, x = days and b = slope.

The onset and end of the critical period were determined by substituting the yield loss levels in the Logistic and Gompertz equations. To determine the critical period of weed interference, three yield loss levels of 2%, 5% and 10% were chosen arbitrarily to provide a realistic target range for weed management in *Stevia*.

Results and discussions

Effect of the duration of weed competition on crop growth and yield

The yield of *Stevia* refers to the dry weight of the harvested whole plants of *Stevia* including the leaves, branches and flowers. From the the study, all weed-free treatments showed higher yields compared to weed infested treatments. *Table 1* shows yield loss of up to 45% when the plots were kept weed-free for only the first week after transplanting, and could reach up to 50% if no weed control was done. The percentage yield loss fluctuated with weed infestation treatments from 28.6%, followed by 16.2, 21.9, 37.4 and 50% at 1WI, 2WI, 3WI, 4WI and 5WI respectively. This was caused by slow initial growth of *Stevia*. The high percentage obtained at 1WI shows that a short period of weed competition resulted in more production. Similar results were obtained by Ngouajio et al. (1997), where the yield of *Phaseolus vulgaris* L. decreased by up to 50% with increase in the weed infestation period and increased when the treatments were kept weed-free for a longer period. Meanwhile, studies in cowpea (*Vigna unguiculata* L.) found that allowing weed to interfere for up to 50 days after crop emergence (DAE) reduced yield by 26 to 75% (Olorunmaiye and Ogunfolaji 2002; Adigun et al. 2014).

Stevia growth was found to be influenced by weed competition. Overall, in weed-free treatments, plants were observed to have increased canopy width and higher numbers of leaves, branches and flowers. In weed-infested treatments, the width of canopy as well as the number of leaves, branches and flowers were lower depending on the length of the period of weed interference with the crop. Meanwhile, the height of *Stevia* seemed to fluctuate with weed infestation, whereby, the plants were taller based on the length of time the plots were kept weed-free (*Table 1*).

Weed interference affected the quality of the crop produced (Zimdahl 1980) and might also affect its chemical composition. The *Stevia* crop is used for the production of stevioside and rebaudioside, and the content of these compounds are correlated to the thickness of the leaf (Shyu et al. 1994). When competition between the crop and weeds occur, the nutrient uptake by the crop is less and the thickness of the leaf will decrease. Ramesh et al. (2006) reported that the yield (dry weight) of *Stevia* was significantly affected by plant height, number of branches and number of leaves per plant.

Critical period for weed control in Stevia

Predicted and observed *Stevia* yields as affected by the duration of weed-infested or weed-free periods are shown in *Figure 1*.

Table 1. Growth and yield of *Stevia* in weed-free and weed infested treatments

Treatment	Height (cm)	Canopy (cm)	Leaves (No.)	Branches (No.)	Flowering (No.)	Yield (g m^{-2})	Yield loss (%)
Weed free							
1WF	21.63^{a}	14.25^{ab}	32.80^{ab}	2.30^{a}	0.55^{ab}	0.14^{bc}	45.0
2WF	21.88^{a}	13.20^{ab}	33.00^{ab}	2.10^{ab}	0.45^{ab}	0.16^{bc}	38.4
3WF	21.14^{a}	14.88^{ab}	33.00^{ab}	1.90^{ab}	0.65^{ab}	0.16^{bc}	39.7
4WF	22.40^{a}	15.15^{a}	43.20^{a}	2.10^{ab}	0.55^{ab}	0.25^{a}	4.3
5WF	24.15^{a}	15.28^{a}	39.55^{a}	1.85^{ab}	0.75^{a}	0.26^{a}	0.0
Weed infested							
1WI	20.88^{a}	15.08^{a}	37.65^{ab}	2.20^{ab}	0.5^{ab}	0.19^{abc}	28.6
2WI	23.98^{a}	15.40^{a}	39.30^{a}	1.75^{ab}	0.75^{a}	0.22^{ab}	16.2
3WI	21.43^{a}	15.78^{a}	39.60^{a}	2.10^{ab}	0.7^{ab}	0.21^{abc}	21.9
4WI	18.45^{a}	13.93^{ab}	35.30^{ab}	1.90^{ab}	0.35^{b}	0.16^{bc}	37.4
5WI	23.13^{a}	11.55^{b}	26.35^{b}	1.50^{b}	0.45^{b}	0.13^{c}	50.0

Means within columns with the same alphabet were not significantly different at $p \geq 0.05$ (LSD), WF: Weed free, WI: Weed infested

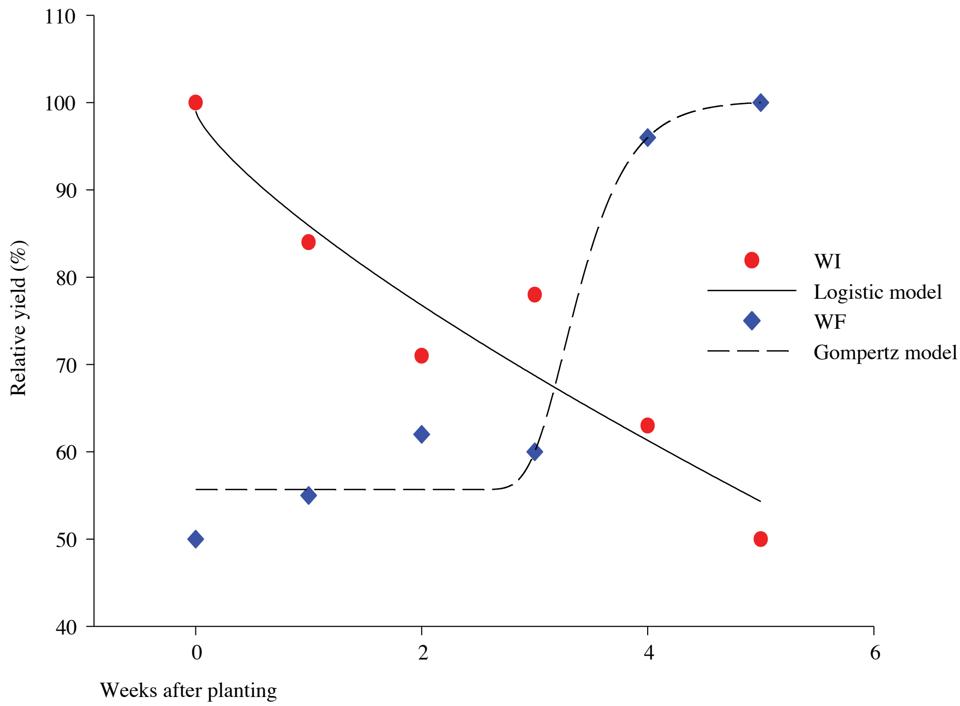

*Figure 1. The effect of weed infestation (WI) on Stevia yield based on Logistic model [Y= –144881.0 + 144977.1/(1+ abs (x/483.7))^1.7], R^2= 0.97; and weed free (WF) based on Gompertz model [Y = 47.8 + 53.2*exp (-exp(-(x-3.2)/0.5)], R^2 = 0.98*

This figure shows the most important period to keep free from weeds. As defined by Zimdahl (1980), critical period is a 'span of time between that period after seeding or emergence when weed competition does not reduce crop yield and the time after which weed competition will no longer reduce crop yield.'

The critical time of weed removal in *Stevia* as calculated using the logistic regression equations decreased as the pre-determined acceptable yield loss level decreased from 10% to 2% (*Table 2*). The end of the critical period of weed control using the Gompertz regression equation increased as the acceptable yield loss level decreased from 10% to 2% (*Table 2*). A 5% yield loss could be considered as an arbitrary standard for determining the critical period of weed control in *Stevia*. To prevent such loss, weeds should be removed from the field for at least 21.7 days after transplanting. At a 5% yield loss level, the predicted minimum weed-free period was 1.4 days after transplanting. Therefore, the critical period was between 1.4 and 27.3 days after transplanting or 25.9 days of weed control. The above results showed that the critical period observed was more than 1/2 of the crop's life cycle. It is important that early prevention or early control of weed interference is carried out. The results substantiate the finding of Mercado (1979), who opined that almost all crops demand early control of weeds during their growth, particularly in the first 1/3 to 1/2 of their life cycle.

Weed population

From the observations, 30 weed species from 15 families were recorded (*Table 3*). Among the species, seven were found dominant including *Digitaria ciliaris* (29%), *Cyperus iria* (12%), *Lindernea*

Table 2. Maximum weed-infested and minimum weed-free periods in the *Stevia* crop as calculated from the regression equation of three predetermined levels of crop yield loss

	Time (DAT) of indicated percentage yield loss		
	2%	5%	10%
The onset of the critical period from the Logistic equation	0.1	1.4	4.2
The end of the critical period from the Gompertz equation	29.3	27.3	25.9
The length of the critical period (days)	29.2	25.9	21.7

DAT: days after transplanting

Table 3. List of dominant weed species in *Stevia* cultivation

Weed species	Family	SDR (%)
Digitaria ciliaris	Poaceae	29
Cyperus iria	Cyperaceae	12
Lindernia crustacea	Scrophulariaceae	9
Echinochloa colona	Poaceae	8
Mitracarpus villosus	Rubiaceae	8
Ageratum conyzoides	Asteraceae	5
Ludwigia hysopifolia	Onagraceae	5
Cleome rutidosperma	Cleomaceae	4
Spermacoce exilis	Rubiaceae	4
Spermacoce latifolia	Rubiaceae	4
Mimosa invisa	Fabaceae	2
Eleusine indica	Poaceae	2
Centella asiatica	Mackinlayaceae	2
Galinsoga ciliate	Asteraceae	1
Hedyotis corymbosa	Rubiaceae	1
Lindernia sessiliflora	Scrophulariaceae	1
Phyllanthus niruri	Phyllanthaceae	1
Phyllanthus urinaria	Phyllanthaceae	1
Axonopus compresus	Poaceae	0
Cyperus rotundus	Cyperaceae	0
Eclipta alba	Asteraceae	0
Emilia sonchifolia	Asteraceae	0
Euphorbia geniculata	Euphorbiaceae	0
Euphorbia hirta	Euphorbiaceae	0
Fimbristylis miliacea	Cyperaceae	0
Ipomoeabatatas	Convolvulaceae	0
Melochia conchorifolia	Sterculiaceae	0
Mikania micrantha	Asteraceae	0
Murdannia nudiflora	Commelinaceae	0
Oxalis corniculata	Oxalidaceae	0

SDR: Summed dominance ratio

crustaceae (9%), *Echinochloa colona* (8%), *Mitracarpus villosus* (8%), *Ageratum conyzoides* (5%) and *Ludwigia hysopifolia* (5%). All these types of species belong to grasses, sedges and broad leaves. From the results obtained, *Digitaria ciliaris* and *Echinochloa colona* were the most dominant weeds giving the highest values of 29% and 12 %. The differences in morphology, physiology and development are the factors for the grasses to be the dominant weeds. The grasses have a rapid growth, many root hairs and good seed germination. Adaptation to the surrounding gives a good succession for the grasses as well. However, the grasses can be controlled by using plastic mulch as reported by Awdoyin et al. (2007),where weed control efficiencies of the mulches ranged between 91% and 100%.

Conclusion

The highest yields were obtained from treatments that were weed-free for 28 days after transplanting and for the whole season-long. The yield was reduced by 50% with season-long weed competition. The competition between the weeds and *Stevia* resulted in decline in the number of leaves, branches and flowers, as well as decrease in the width of the canopy. Based on the results of the present study, it can be concluded that to prevent 50% yield loss, the crop has to be free from weeds from 1.4 to 27.3 days after transplanting. Meanwhile, the grasses need to be controlled so that in the subsequent seasons, the seeds are not setting up and the population will decrease. The data of this experiment provided a basis for herbs producers to make a decision with respect to timely weed control.

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Abstrak

Pengetahuan tentang tempoh kritikal persaingan rumpai dan tanaman adalah komponen penting dalam pembangunan pengurusan rumpai bersepadu yang efektif. Eksperimen ini telah dijalankan dalam rumah kaca Pusat Penyelidikan Padi dan Beras di MARDI Serdang. Rumpai dibiarkan bersaing dengan *Stevia* pada tempoh pertumbuhan yang berbeza (selepas tanaman *Stevia* dipindahkan), sebelum dicabut secara manual. Rawatan kawalan yang terdiri daripada merumpai sehingga tuai dan rumpai dibiarkan tumbuh sehingga tempoh penuaian turut disertakan sebagai perbandingan. Didapati bahawa hasil *Stevia* berkurangan dengan peningkatan tempoh persaingan rumpai. Berdasarkan persamaan logistik yang diramalkan dan keluk tindak balas Gompertz, tempoh kritikal untuk mengawal rumpai di kawasan *Stevia* didapati seawal minggu pertama selepas pemindahan sehingga hujung minggu ketiga. Semasa fasa ini, rumpai perlu dikawal untuk mengelakkan kerugian yang boleh melebihi ambang ekonomi.