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The critical period of weed control for cassava planted during the rainy season of Thailand

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Abstract Weed competition period in the farm production of cassava (*Manihot esculenta* Crantz) was investigated on the farmer field during May, 2019 to March, 2020. The major weeds infested in this site were grass such as *Dactyloctenium aegyptium* (L.) Willd., *Digitaria ciliaris* (Retz.) Koeler., *Echinochloa colona* (L.) Link, *Eleusine indica* (L.) Gaertn., *Pennisetum polystachion* (L.) Schult. A maximum weed biomass was observed on July to October, 2020 about 120 – 160 g (dry weight) m^{-2}. In the weed-free plot, the root yield was 31.6 t ha^{-1}. While, the plot of weed infestation through the season was represented 53% loss of fresh roots. Gompertz and logistic equations fitted to yield data for increasing periods of weed control and weed interference showed that the critical period of weed interference, considering a 5 and 10% yield loss, which appeared between 20 and 114 days after planting, i.e., during the early canopy information and early tuberization stage. Thus, alternative weed management tools should be applied during this period to ensure a high yield of cassava roots.

Keywords: Weed competition, Weed interference, Critical weed-free competition, Yield loss

Introduction

Cassava (*Manihot esculenta* Crantz) is one of the five important crops in Thailand. Cassava production accounts for about 1.4 million hectares of land use, with an output of approximately 29 million tons in Thailand, the country with the highest production, followed by Nigeria and the Congo (FAO, 2021a). This crop is cultivated mainly by smallholders and medium-scale farmers in 37 countries (FAO, 2021b). In roots, cassava accumulates carbohydrates in roots in the form of starch, which accounts for about 70–80% of all carbohydrates in cassava (FAO, 2021b), thereby representing the cheapest source of carbohydrate food. Cassava-based products are sources of human consumption and industrial raw material for producing starch, bioethanol, and high-quality flour for pharmaceuticals, food, and beverages (Ekeleme *et al.*, 2020). Cassava

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is an easy crop to cultivate, with superior drought tolerance and growth on infertile soil and low associated economic costs (Howeler, 2021; Santiago *et al.*, 2020). However, the yields of cassava are low due to several factors such as drought and pests. One major contributory pest causes by weed interference. Weeds are a major pest that compete with crops for nutrients, water, light, and carbon dioxide, and some species even produce metabolites that inhibit crop growth and development (Santiago *et al*., 2020). Cassava yield loss due to weed interference was reported to be 60–80% in Nigeria (Ekeleme *et al*., 2020), 70% in Brazil (Santiago *et al.,* 2020), 80–85% in Laos (Khanthavong *et al*., 2016), and 25–50% in Thailand (Aye, 2002).

In Thailand, cassava is planted all year round, though around 59% of the total area of cassava is planted during the rainy season and around 27% in the dry season. The dry season in Thailand typically lasts from November to February and begins with the end of the rainy season. The dry season is currently characterized by higher yields and more convenient management but only occurs in a minority of areas in Thailand. The rainy season from March to June is a popular time for cultivation because suf-ficient water after planting is ensured due to rainfall (Aye, 2002). However, weed infestation is a significant risk during this season and is the primary competitive factor in cassava cultivation. At present, chemical weed control is a more common method than others in Thailand due to reduced manpower availability and high labor costs related to the alternatives. Tongglum *et al*. (1992) reported that a conventional practice for weed control in Thailand's dry and rainy seasons uses pre-emergence herbicides immediately after planting and post-emergence herbicides at 2–3 months after planting. However, the cost of herbicides and labor is continuously increasing. Decreasing the time of herbicide application is one approach for reducing costs. Thus, determining the precise timing for optimal weed control is important for decision making and management involving the use of weed control tools. Weed program management is an essential component of farm work. The critical period of the weed control (CPWC) program depends on many factors, such as the planted cultivar, planting season, weed species, weed density, seed emergence time, soil type, and rainfall in the region (Mirshekari *et al.*, 2010). This information is important in determining the period of weed competition and necessary for developing effective models to develop effective weed management programs in crop production (Singh, 2014). Moreover, the CPWC can help in determining the appropriate time for herbicide application or application of other tools toward reducing the impacts of a weed population on crops (Daramola, 2020). Onochie (1975) reported that the period for weed control in cassava covers about 3 months after planting or when a canopy is closed. de

Oliveira (2021) reported that the critical period for weed interference is responsible for about 5 and 10% loss in pineapple yield around 14–249 days after planting.

There is little literature on the critical period of crop–weed competition for cassava in Thailand. The objective was to evaluate the depressive effects of weeds on cassava yield for the entire period and specific periods during the growth in the rainy season.

Materials and methods

The investigations were conducted from May 2019 to March 2020 on a farmer's field in Northern Thailand's Phitsanulok province, located at 17°03'26.7"N 100°22'20.9"E. The rainfall was 769 mm throughout the experimental period and was evenly distributed from June to September 2019 (Figure 1). The air temperature was a maximum of 38 ℃ on 26 May 2019, and the minimum was 12 ℃ on 9 December 2019. The average maximum and minimum temperatures during the experimental period were 33.3 ℃ and 23.1 ℃, respectively. Prior to the study, the experimental field had been in a cassava–maize rotation cycle for previous 2 years. The soil type was sandy-clay. The soil properties were pH 4.7–6.3; organic matter, 0.5–0.8%; P2O5, 45.9–158.6 mg kg^{-1}; and K_2O, 24–32 mg kg^{-1}. Land preparation involved 3-disked plowing and 1.2 m row ridging. A cassava stem variety with a length of 50 cm, called Kasetsart 80, was planted by cutting in ridges with a single 20 cm depth row with a spacing of 50 cm and mixed with fertilizer containing 47 kg ha^{-1} of N, P_2O_5, K_2O using a cultivator machine. The fertilizer was applied again by laborers at 2 months after planting. The plot size for the harvested area was 6 rows (7.2 m) x 8 m with 2 rows x 6 m at the center of the plot.

The experiment was designed as a randomized complete block design with four replications. There were two sets of treatments conducted at different times of weed operation after planting. The first set was a weed-free period in which weeds were allowed to compete with the cassava from 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 months after planting (MAP). Plots in which weeds were controlled throughout this period served as the check plot for this first set of treatments (weed-free). The second set of treatments was a weed-infested period in which weeds were manually removed at 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 MAP. Plots where weeds were allowed to grow throughout this period serve as a check plot for this second set of treatments (weed-infested). The plots were weeded in appropriated time at two-week intervals by hoeing. The weeds were randomly sampled and identified in guard rows for each plot by four quadrants of 50 cm x 50 cm at the time of weed removal for the weed infestation set. Weeds from weed removal during the weed-free period set were collected at the end of 10 MAP for recording of species and biomass, whereby samples were dried at 70 ℃ in an oven for 72 h. Data were analyzed using SPSS version 21 software. The treatment means were separated using Duncan's multiple range test (DMRT) at the *P* = 0.05 level.

The curves for estimating the critical period of crop–weed competition were fitted using SigmaPlot 12.5. According to Mekdad *et al*. (2021), the form of the Gompertz equation was used to model the effect of the weed-free period on grain yield, whereas the logistic equation was used to model the influence of weed duration on yield. The critical period for 95 and 90% of the maximum yield was obtained from the fitted curves.

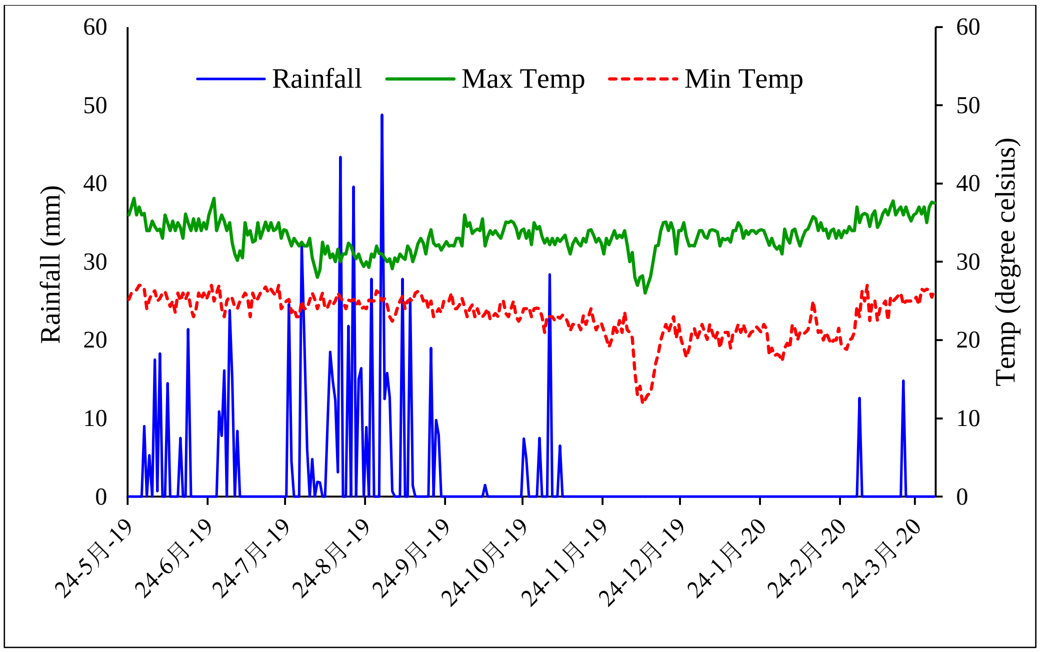

Figure 1. Rainfall, maximum and minimum temperatures during the experiment period; May 24, 2019 to March 31, 2020

Results

Weed species and biomass

The major weed species observed in the experimental sites included five grass and broadleaf species and a single sedge species. The major broadleaf species found were *Alysicarpus vaginalis*, *Oldenlandia corymbose*, *Phyllanthus amarus*, and *Praxelis clematidea*. The major grass species found were

Dactyloctenium aegyptium, *Digitaria ciliaris*, *Echinochloa colona*, *Eleusine indica*, and *Pennisetum polystachion*. The major sedge species found was *Cyperus iria*. The density of major weeds was estimated between 5 and 20 plants m^{-2}. Minor weeds species were *Ageratum conyzoides*, *Cleome viscosa*, *Commelina benghalensis*, *Corchorus aestuans*, *Eclipta prostrata*, *Gomphrena celosioides*, *Gymnopetalum integrifolium*, *Ludwigia hyssopifolia*, *Mimosa diplotricha*, *Portulaca oleracea*, *Sida acuta*, and *Tridax procumbens* and found at a rate of around 0.5–2 plant m^{-2} (Table 1). The timing of weed occurrence in this experimental site was around June–October 2019, after which weed species wilted and died. There were two broadleaf species found specifically during the experimental period (10 months), *P. clematidea* and *T. procumbens* (Table 1).

Table 1. Major and minor weed species commonly found in plots through experimental period

Scientific name	Family	Weed Classify [1/]	Occurrence time										
			2019							2020			
			May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Major weeds													
Alysicarpus vaginalis (L.) DC.	Fabaceae	Br											
Cyperus iria L.	Cyperaceae	Se											
Dactyloctenium aegyptium (L.) Willd.	Poaceae	Gr											
Digitaria ciliaris (Retz.) Koeler.	Poaceae	Gr											
Echinochloa colona (L.) Link	Poaceae	Gr											
Eleusine indica (L.) Gaertn.	Poaceae	Gr											
Oldenlandia corymbose L.	Rubiaceae	Br											
Pennisetum polystachion (L.) Schult.	Poaceae	Gr											
Phyllanthus amarus Schumach. & Thonn.	Phyllanthaceae	Br											
Praxelis clematidea R.M King & H. Rob.	Asteraceae	Br											

Table 1.(Con.)

Scientific name	Family	Weed Classify 1/	Occurrence time										
			2019								2020		
			May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Minor weeds													
Ageratum conyzoides L.	Asteraceae	Br	■	■	■	■	■	■	■	■	■		
Amaranthus viridis L.	Amaranthaceae	Br	■	■	■	■	■	■					
Cleome rutidersperma DC.	Cleomaceae	Br	■	■	■	■	■	■					
Cleome viscosa L.	Cleomaceae	Br	■	■	■	■	■	■					
Commelina benghalensis L.	Commelinaceae	Br	■	■	■	■	■	■	■	■	■	■	
Corchorus aestuans L.	Malvaceae	Br	■	■	■	■	■	■	■	■	■		
Eclipta prostrata (L.) L.	Asteraceae	Br	■	■	■	■	■	■					
Gomphrena celosioides Mart.	Amaranthaceae	Br	■	■	■	■	■	■	■	■			
Gymnopetalum scabrum (Lour.) W.J. de Wilde & Duyfjes	Cucurbitaceae	Br	■	■	■	■	■	■					
Ludwigia hyssopifolia (G.Don) Exell	Onagraceae	Br	■	■	■	■	■	■					
Mimosa diplotricha C.Wright ex Sauvalie	Fabaceae	Br	■	■	■	■	■	■	■	■	■		
Portulaca oleracea L.	Portulacaceae	Br	■	■	■	■	■	■	■	■			
Sida acuta Burm.f.	Malvaceae	Br	■	■	■	■	■	■	■				
Tridax procumbens L.	Asteraceae	Br	■	■	■	■	■	■	■	■	■	■	■

1/Br = Broadleaves, Gr = Grass, Se, = Sedge

Characterization of the weed biomass of the weed-free periods revealed that grass species accounted for more of the biomass than the broadleaf and sedge species. The weed biomass of the weed-free periods at 1 to 2 MAP was not significant differed upon weed check, while the weed biomass showed a tendency to decrease with the prolongation of the weed-free period. As a result of the treatments in the weed-free periods, there was zero weed biomass recorded at 8 to 10 MAP (Table 2). In another set of weed-infested periods, low weed biomass was observed after the first month (1 MAP), which increased at 2 to 3 MAP. The highest weed biomass was observed for the weed infestation treatment at 4 to 7 MAP, which decreased from 8 to 10 MAP (Table 3).

Table 2. Influence of the weed-free periods on weed biomass

Weed-free periods (MAP)	Weed biomass ($g\ m^{-2}$)		
	Total	Grass	Broadleaves
Weedy check	81.2 a	46.8 a	34.4 a
1	88.4 a	47.9 a	40.5 a
2	84.6 a	54.4 a	30.2 a
3	36.7 b	24.6 b	12.1 b
4	16.9 c	7.6 c	9.3 b
5	9.3 c	3.4 cd	5.9 b
6	10.2 c	3.2 cd	7.0 b
7	0.1 d	0.0 d	0.1 c
8	0.0 d	0.0 d	0.0 c
9	0.0 d	0.0 d	0.0 c
10	0.0 d	0.0 d	0.0 c

Means for four replicates. The different letters along a column indicate significant differences using DMRT at $p<0.05$.

Table 3. Influence of the weed-infestation on weed biomass

Weed-infested periods (MAP)	Weed biomass ($g\ m^{-2}$)			
	Total	Grass	Broadleaves	Sedge
1	1.7 e	1.1 e	0.5 c	0.1 e
2	52.9 d	34.6 d	16.5 b	1.8 bc
3	66.7 d	44.6 cd	17.9 b	4.2 a
4	168.5 a	126.4 a	36.7 a	5.4 a
5	164.2 a	119.9 a	39.5 a	4.8 a
6	142.4 ab	99.7 ab	40.5 a	2.2 b
7	135.9 ab	91.1 ab	43.6 a	1.2 cd
8	120.1 bc	78.3 bc	41.3 a	0.5 de
9	90.5 cd	54.3 cd	36.2 a	0.0 e
10	84.2 cd	46.3 d	37.9 a	0.0 e

Means for four replicates. The different letters along a column indicate significant differences using DMRT at $p<0.05$.

Cassava root yield

Weed competition throughout the duration of crop cultivation produced 14,653 kg ka^{-1} of fresh cassava root, corresponding to a 53.3% yield loss compared with weed-free conditions where the yield was 31,643 kg ha^{-1}. The yield for the weed-infested period of 1 month after planting (MAP) was not significant compared with the weed-free check, while weed-infested periods from 2 to 10 MAP showed a continuous decreased in yield, with losses of 17.0–53.3% (Table 4). In the set of weed-free periods, the root yield was not significantly different from that of the weed check after being weed-free for 1 month (1 MAP). From the third month to the end of the season (10 MAP), the weed-free periods did not show significant differences in root yield when comparing with the check plot.

The critical period of weed control (CPWC)

The Gompertz equation indicates the duration of the weed-free period required for a particular level of yield loss. Similarly, the polynomial equation showed the length of the period up to which weeds could remain in the crop. The CPWC, in terms of a 5% yield loss, is between (20–114 days after planting. The CPWC for a 10% yield loss is between 37 and 87 days after planting. The duration of the CPWC, considering the fresh root yield loss of 5 and 10%, is 3.1 and 1.7 months, respectively (Figure 2).

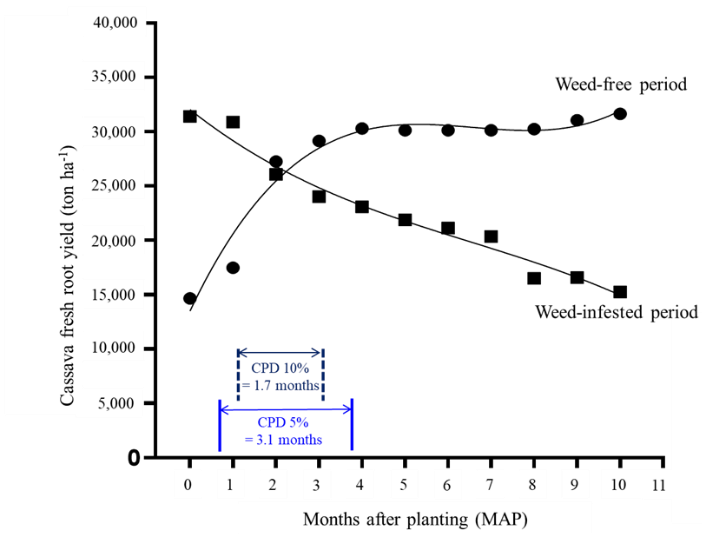

Figure 2. The relationship of the cassava yield with the weed-free period was best described by the polynomial equation, as follows: Y= 13486 + 8349X - 1317X^2 + 66.59X^3, R^2= 0.9534. A sigmoid (Gompertz) equation provided the best fit for the maximum weed-infested experiment. The model was as follows: Y= 32032 - 3136X + 291.4X^2 - 14.85X^3, R^2 = 0.9714. CPD, critical period duration at 5% or 10% yield loss; MAP, months after cassava planted

Discussion

The cassava variety in this experiment was Kasetsart 80, which is well studied and has been mentioned in publications dating back to 2004. This species can adjust to both drought and flooding stress and is thus popular and considered suitable among farmers in the lower area of Northern Thailand. It can be harvested in 8 months after planting. The canopy was observed to be completely closed for 4 months, according to the weed biomass represented in this result.

The weed biomass of the weed-free period at 1–2 MAP was not significantly different from that of the weed check because the cassava canopy was not closed. The canopy initially closed at 3 months; thus, the weed biomass of the weed-free period by 3 MAP was lower than that of the weed check. The weed biomass of the weed free-period at 4 MAP was significantly decreased (16.9 g m^{-2}) compared with the weed check (81.2 g m^{-2}) and weed-free period at 1–2 MAP (88.4 and 84.6 g m^{-2}, respectively), since the canopy was completely closed.

In addition, it was observed that the weed biomass of the weed check in the weed-free set (81.2 g m^{-2}) was lower than the biomass of the weed-infested set, especially 4–8 MAP (120.1 – 168.5 g m^{-2}). Some species, especially annual species in the weed check, wilted and died before collecting the samples at the end of the season. These data are related to the rainfall, as seen in Figure 1, where the maximum rainfall of the season was from August to September 2020. Afterward, the rainfall amount declined, and the season shifted to winter. This result is in agreement with Ramella *et al.* (2020), who reported that the dry weight accumulation of weed was the highest around 155 days after cassava planting in Brazil from 2014 to2016.

The percentage of cassava yield loss varied with the timing of weed removal, showing differences between the set of weed-infested period and the set of weed-free periods. The set of weed-infested periods continuously declined with the prolongation of weed-infested time, for which the graph displayed a straight line trend. These results are in agreement with Onochie (1975), who reported on weed-infested cassava in Nigeria and showed that the root yield continuously decreased with extension of the time of weed infestation and similarly with sesame in Turkey (Karnas *et al*., 2019). However, this weed-infested set was different from the weed-infested period of the other annual crops, in which the graph was curved, similarly to those for peanut (*Arachis hypogaea* L.) (Everman *et al*., 2008) spring maize in Northwest India (Singh *et al*., 2016), and three corn species in Turkey (Tursun *et al*., 2016).

The set of weed-free periods showed that there was significant cassava yield loss at 1 to 3 months after planting (MAP), whereas the weed-free period from 4 MAP onwards showed no significant differences. Thus, the graph showed a curve. The graph of weed-free periods in our study showed the same trend as those reported by others (Mirshekari *et al*., 2010; Singh *et al*., 2014; Karnas *et al*., 2019; Everman *et al*., 2008, Singh *et al*., 2016, Tursun *et al*., 2016).

The CPWC at 5 and 10% began from 20 to 37 days after planting (DAP) or 3–5 weeks after planting (WAP) until 87– 114 DAP or 12–16 WAP. These results are in agreement with Onochie (1975), who reported that the weed competition period in cassava is between 1 to 3 months after planting in Nigeria. Two periods in which weed competition causes decreases in cassava yield were identified: The first is in the early canopy-formation stage from 3 to 12 WAP. The second is after the third month, when the bulking of storage roots commences (Ekeleme *et al*., 2020; Howeler, 2021; Aye, 2002; Tongglum *et al*., 1992).

Our study results are also of benefit for decision making regarding tools for weed management. Pre-emergence herbicides should be used to control weed emergence for 3 months after planting. However, the toxicity of different herbicide residues in the soil affecting root transformation must be considered (Ekeleme *et al.*, 2020; Santiago *et al.*, 2020). In addition, post-emergence should apply between 3 weeks and 2 months after planting. However, our decision to select herbicides depended on rainfall. Early rainfall always results in more weed emergence than late rainfall, and in this case, post-emergence herbicides should be applied sufficiently early. Paraquat is a post-emergence herbicide popularly used by most farmers to control weeds in the rainy season of cassava production in Thailand (Rungmekarat *et al.*, 2021). It is always applied 1–3 months after planting, depending on the weed size related to the rainy period. However, the Thailand government has prohibited paraquat since on 1 June 2020 due to concerns regarding human poisoning (Kriengsoontornkij *et al.*, 2020). Thus, the selection of post-emergence herbicides should necessarily accord only with the right time for critical weed competition and the efficacy of weed control but also regarding its toxicity. Based on results, it concluded that to maximize the root yield of cassava planted in the rainy season in the lower area of Northern Thailand, the critical period of weed control (CPWC) is from 20 to 114 days (3–16 weeks) after planting.

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