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Research Article
Estimation of Critical Period for Weed Control in Soybean on Agro-forestry System with Kayu Putih

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Abstract

Background and Objective: The critical period for weed control is the period in the crop growth cycle in which weeds must be controlled to prevent yield losses. This study aimed to determine the critical period for weed control (CPWC) in soybean on the agro-forestry system with kayu putih. **Materials and Methods:** The experiment was conducted in Menggoran Forest Resort, Playen Forest Section, Gunung Kidul Regency, Special Region of Yogyakarta from February, 28-May, 9, 2015. The experiment was arranged in randomized complete block design (RCBD) with single factor of treatment with three blocks as replications. The treatments were weedy periods 0, 14, 28, 42 and 56 days after planting (dap) and weed-free periods 0, 14, 28, 42 and 56 dap. Statistical analysis was done by using one-way analysis of variance (ANOVA), structural equation modeling (SEM), Gompertz and logistic equations. **Results:** The soybean yield decreased significantly when the weedy period was done after 14 dap upto 42 dap. The soybean yield was influenced by the dry weight of annual weeds (DRAW), heterogeneity of weed (HET), soil moisture (SM), phosphorus (P) and potassium (K) concentration in the tissue. **Conclusion:** The CPWC in soybean for acceptable yield loss (AYL) of 5, 10, 15 and 20% began 16, 21, 24 and 27days after emergence (DAE) and ended 61, 55, 53 and 49 DAE. This study provides weed management control information on soybean in the agro-forestry system with kayu putih on Lithic Haplusterts soil type with ustic soil moisture regime.

Key words: Agro-forestry, critical period for weed control, integrated weed management, Lithic Haplusterts, soybean

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Over the last 5 years, soybean production has been continuously declining due to the shortage of suitable land for crop production[1]. One solution to tackle the problem above is the utilization of available space among forest plants, which is called agro-forestry. Moreover, agro-forestry has become one of the land management systems to enhance land productivity[2].

An ideal practice of seasonal crops cultivation can be found in kayu putih plantations intercropping. In the kayu putih plantation, intercropping can be done for several crop rotations with rice, corn, soybeans, peanuts and other locally developed species. Those comodities are possible because the kayu putih trees are routinely being pruned for harvesting. Therefore, shade factor does not interfere in the cropping system. Intercropping in kayu putih plantations can be done continuously upto 30 years[3].

The vacant space between kayu putih in a forest has the potential for growing annual crops. Therefore, by employing alley cropping, the land productivity will be improved. The benefit of the combination between kayu putih and the annual crop is the resources sharing, such as light, nutrition and water since soybean can make use of those resources[4]. The establishment of agro-forestry systems can increase land value by implementing appropriate cultivation techniques. An intercropping system is a valuable system for improving land productivity and a farmer's income/unit area in the time unit. Besides, an intercropping system can provide an optimum yield since it is composed of several commodities that build a sustainable system[5].

Nevertheless, there is a drawback of combining kayu putih and soybean, which is the weed. Weed can decrease the production, which then leads to a lower income of farmers. The competition offered by the crop can affect the degree of weed control achieved by other methods or herbicides. It has been estimated that enhancing crop competitiveness against weeds could reduce weed control costs by 30%[6]. Recently, interest has been increasing in the application of cultural approaches in integrated weed management systems[7-9].

Therefore, realising the maximum yield potential of these crops is important for the uninterrupted growth and development of the agriculture sector, as well as for the capacity utilization and growth of industries dependant on agriculture for raw materials[10]. Thus, weed control is considered as a key factor for successful soybean production and various weed management systems have been developed for that purpose[11].

Soybean and weed are both competing for solar radiation, water and nutrients. As pointed out by Moenandir[12], the exact timing on weeding might reduce the number of weeds and lessen the competition. In the plant life cycle, not all the growth stages of a crop are susceptible to weed competition. For instance, approximately around 25-33% of the life cycle of the annual plant is the most critical competition period to weeds. However, there is a misinterpretation that weeding at any time during plant growth will overcome the problems of competition with weeds[11].

The critical period of weed control (CPWC) indicates the optimum time for applying the weed control measure[13]. Hence, information on these periods can be used to improve the efficiency of weed management practices[14-16]. To gain a better yield and quality, controlling weeds during the critical period of crop growth is crucial. Identification of critical period of weed control in the main crops is the 1st step in designing a successful integrated weed management programme[17,18]. Moreover, the critical period threshold model will assist the decision for the exact weeding time[19,20].

The CPWC is the length of time that the crop must be kept weed-free to prevent yield losses at a certain level[18,21]. The CPWC is determined by measuring the time interval between 2 separately measured crop-weed competition components: (i) The critical period of weed interference and (ii) The critical weed-free period[18,21].

The critical period of weed interference is defined as the maximum length of time of the initial emerging weeds that can interfere with the crops without causing a significant yield loss[18,21]. The critical weed-free period, which is usually less concerned, is defined as the minimum length of time required for the crop to be maintained weed-free before yield loss, which is caused by late emerging weeds[18,21]. From the practical point of view, crop yield losses from weed interference before or after the critical period for weed control is trivial[18].

Many studies have been conducted worldwide to determine the critical period for weed control in various crops under diverse environmental conditions[18,22-28]. Studies conducted in different crops under diversified environmental conditions might not be applicable to all kind of systems due to different conditions of each location, including soil and climatic conditions, as well as weed populations[16,18,22,23,27,28]. Hendrival *et al.*[29], mentioned that the critical period of soybean grown in the post-rice cultivation field occurred on day 26 after planting.

The objectives of this study were to determine the critical period for weed control (CPWC) in soybean in the agro-forestry system with kayu putih and to ascertain the factors that influence the soybean yield. The knowledge of the critical timing of weed removal, critical weed-free period and subsequently the critical period of weed control in soybean on agro-forestry system with kayu putih could help producers to improve their weed management strategies and to prevent yield loss resulting from weed interference while reducing the amount of herbicide use.

MATERIALS AND METHODS

Study site: The research was conducted during February-August, 2015 in Menggoran Forest Resort, Playen Forest Section, Yogyakarta Forest Management District, Indonesia. Soybean varieties used Grobogan from a Research Institute of Bean and Tuber, Malang, Indonesia. No irrigation, chemical fertilizers, herbicides or pesticides were used throughout the growing seasons.

Experimental design: The experiment was arranged in randomized complete block design (RCBD) with single factor treatment and three blocks as replications. The treatments were the duration of weedy and weed-free periods in soybean, which consisted of ten levels as shown in Table 1.

Soil sampling and analysis: The samples were collected at depths of 0-60 cm. The Observations were made on the site and in the General Soil Laboratory, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, Indonesia.

Environment variables: An environment variable was taken from each treatment. The environment variables observed were soil moisture (SM)[30,31] and soil Temperature (ST)[31].

Weeds sampling: The weed composition was taken from each block of treatment by taking three samples of weeds randomly with a modified square method[32]. The sample ring size to pick the weeds was 70×40 cm adjusted with the soybean planting distance in 35×20 cm. To determine the dry weight of weed were cut at the soil surface and dried at 110°C for 48 h. The weed observed were the type of weeds species, dry weight of annual weeds (DWAW), dry weight of perennial weeds (DWPW), diversity of weeds (DIV)[33] and heterogeneity of weeds (HET)[33].

Soybean variable: The soybean variables observed were leaf area (LA), light interception (LI)[34], root surface area (RSA) and root length (RL)[35], nitrogen-phosphorus-potassium concentration in the tissue (N,P,K)[36], nitrogen-phosphorus-potassium uptake (NU,PU,KU)[36], total chlorophyll content (TC)[37], proline content (PRO)[38], photosynthesis rate (PR)[31], root dry weight of soybean (RDW), stem dry weight of soybean (STDW) leaf dry weight of soybean (LDW) and seed dry weight of soybean (SEDW).

Table 1: Weedy and weed-free periods of treatments

Treatments	Remarks
W-0 dap	Weedy until 70 day after planting (dap)
W-14 dap	Weedy after 14 until 70 dap
W-28 dap	Weedy after 28 until 70 dap
W-42 dap	Weedy after 42 until 70 dap
W-56 dap	Weedy after 56 until 70 dap
WF-14 dap	Weed-free after 14 until 70 dap
WF-28 dap	Weed-free after 28 until 70 dap
WF-42 dap	Weed-free after 42 until 70 dap
WF-56 dap	Weed-free after 56 until 70 dap
WF-0 dap	Weed-free until 70 dap

Statistical analysis: Comparative analysis of soybean yield was analyzed using one-way analysis of variance (ANOVA) with a 5% and proceeded to Dunnett's t-test with a 5% as the *post-hoc* analysis. ANOVA, Dunnett's t-test and error bars was performed using Prism 5 software[39].

The yield of soybean data was used to parameter the logistic and Gompertz equations, used PROC NLMIXED. The logistic model was fitted to the data for increasing the duration of weedy periods on soybean yield. The logistic equation is a simplified form of the Richards model. The model used was[14]:

$$Y = [(1/\{exp[c*(T-d)]+f\})+[(f-1)/f]]*100$$

where, Y is the yield (% of season-long weed-free yield), T is the time (x-axis expressed in Growing Degree Day [GDD] or days after emergence [DAE]), d is the point of inflection (GDD), c and f are constants[14]. The calculate of logistic equation in this study was:

$$Y = [(1/\{exp[-0.02*(T-5.08)]+(-5.22)\})+[(-5.22-1)/-5.22]]*100]$$

The Gompertz model has been applied to predict the relationship between relative yield, as influenced by the increasing length of the weed-free period. The model used was[14,40]:

$$Y = a*exp(-b*exp(-kT))$$

where, Y is the yield (% of season-long weed-free yield), a is the yield asymptote, b and k are constants and T is the time (x-axis expressed in GDD or DAE)[14]. The calculate of Gompertz equation in this study was:

$$Y = 191.21*\exp(-1.08*\exp(-0.023*T))]$$

In this study, the CPWC was determined by arbitrarily chosen yield loss levels of 5, 10, 15 and 20%. The logistic and Gompertz equations were performed using Statistical Analysis Software (SAS) (version 9.1.3 for Windows, SAS Institute Inc., Cary, NC, USA).

RESULTS

Characteristics of location: The study site has ustic soil moisture regime. The interpretation of soil horizons in each soil profile at the site identified the soil type of Lithic Haplusterts. Based on the field observation and laboratory test, the soil in the research location was dominated by clay fraction for 75.17%, which concluded that the soil has a clay texture. The bulk density was 1.14 g cm^{-3} with a slow permeability, i.e., 0 cm h^{-1}, due to the high clay content that resulted in very low porosity. The nutrient content in the study location ranged from the very low to very high level with neutral pH.

Weed community characteristics: Based on the relative dry weight, it indicates that there are dominant weeds in the research location such as *Spigelia anthelmia*, *Panicum distachyum*, *Panicum muticum*, *Leptochloa chinensis*, *Lindernia crustacea* and *Eleutheranthera ruderalis*. The total of weed relative weight of the 6 types of weeds was 81.66% of the total of weed relative weight (Table 2).

Weeds in the research site are dominated by broadleaf type with annual life cycles. The weed relative dry weight indicate that the broadleaf with the annual life cycle (2.05 t ha^{-1}) is higher than the grass type with a perennial life cycle (1.65 t ha^{-1}). Soybean is included in the broadleaf one with leaf architecture that tends to be horizontal so that light intensity is low. Broadleaf type tends to be more adaptive than grass type.

Soybean yield responses and critical periods of weed control: Structural equation modeling (SEM) was used to describe internal and external factors that influence the soybean yield. The SEM result shows that soybean yield is influenced by environmental factors, weeds and soybean physiology, while soybean morphology has no influence on soybean yield (Table 3 and Fig. 1).

Weed factors that significantly influence the soybean yield are the dry weight of annual weeds (DWAW) and heterogeneity (HET) of weeds. An environmental factor that has the significant influence on soybean yield is soil moisture (SM). Physiology factors that significantly influence the soybean yield are phosphorus (P) and potassium (K) concentration in tissue (Fig. 1).

One-way ANOVA results on the yield of soybean property showed a highly significant difference ($p<0.0001$). The yield of soybean showed the yield decrease significantly when weeding was done after 14 dap upto 42 dap (Fig. 2). The logistic equation was modified slightly from that proposed to describe the increasing duration of weedy periods on relative

Table 2: Weed species of the experimental field and their relative dry weights

Species	Life Cycle	Weed Type	Relative Dry Weight (t ha^{-1})
Ageratum conyzoides	A	BL	0.13
*Eleutheranthera ruderalis**	A	BL	0.29
Euphorbia hirta	A	BL	0.16
Euphorbia hypericifolia	A	BL	0.08
Ischaemum timorense	P	G	0.16
*Leptochloa chinensis**	P	G	0.38
Lindernia ciliata	A	BL	0.01
*Lindernia crustacea**	A	BL	0.37
*Panicum distachyum**	P	G	0.55
*Panicum muticum**	P	G	0.46
Panicum repens	P	G	0.02
Phyllanthus niruri	P	G	0.08
Phyllanthus virgatus	A	BL	0.01
*Spigelia anthelmia**	A	BL	0.97
Torenia violacea	A	BL	0.03

*Dominant weed species, A: Annual, P: Perennial, BL: Broadleaf and G: Grass

Table 3: Influence of environment, weed, physiology and morphology variables on soybean yield

	Total effect	Original sample estimate and standard deviation	T-stat
Environment	→ Physiology	0.875±0.229	3.814**
Environment	→ Morphology	0.685±0.208	3.300**
Environment	→ Yield of Soybean	0.862±0.230	3.749**
Weed	→ Environment	-0.759±0.208	3.653**
Weed	→ Physiology	-0.379±0.143	2.656**
Weed	→ Morphology	-0.607±0.189	3.210**
Weed	→ Yield of Soybean	-0.387±0.132	2.940**
Physiology	→ Morphology	1.217±0.189	6.450**
Physiology	→ Yield of Soybean	-0.055±0.068	14.945**
Morphology	→ Yield of Soybean	1.010±0.074	0.746^{ns}

ns: Not significantly different, **Significantly different at a 1%. Mean±SD

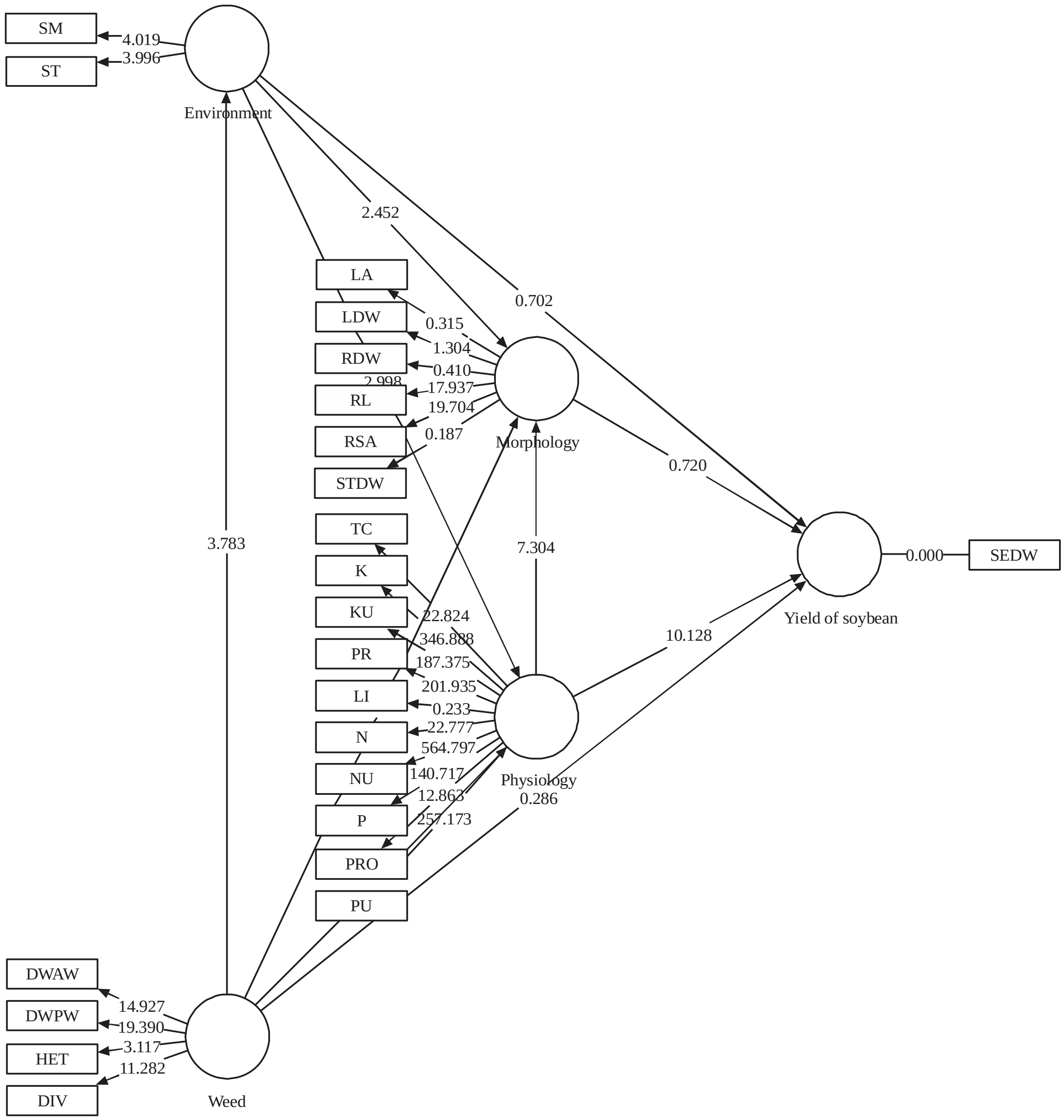

Fig. 1: Structural equation modeling (SEM) of the relationship between environment, weed, physiology and morphology on the soybean yield

Table 4: Critical period of weed control (CPWC) in soybean yield for acceptable yield loss (AYL) based on days after emergence (DAE)

AYL (%)	Beginning of CPWC	End of CPWC
5	16	61
10	21	55
15	24	53
20	27	49

yield. The Gompertz model has been shown to provide a good fit to yield as it is influenced by increasing length of the weed-free period[14]. The CPWC in soybean for acceptable yield loss (AYL) of 5, 10, 15 and 20% began 16, 21, 24 and 27 DAE and ended at 61, 55, 53 and 49 DAE (Fig. 3 and Table 4).

DISCUSSION

The competitive ability of crops and weeds is heavily dependent on the environmental conditions[41]. In addition to influencing the emergence patterns, the environment can play a large part in regulating the crop-weed competitive relationships. For example, weeds and crops respond differently to the variation in temperature, water availability and soil fertility[42].

The study site has ustic soil moisture regime and Lithic Haplusterts soil type. Ustic moisture is a soil regime containing limited moisture but is suitable for plant growth when the environmental conditions favour. Lithic Haplusterts is a vertisol soil type which has shallow solum and a lithic contact within 50 cm of the soil surface[43].

Weeds in the research site are dominated by broadleaf type with annual life cycles. This shading effect is more serious on seedlings that emerge later, thereby resulting in more competition for nutrients, which determines their growth and reproduction potential[44]. Crop canopy shading is an important mechanism of competition between crops and weeds. Early canopy formation limits the amount and quality of light penetrating through the canopy[45].

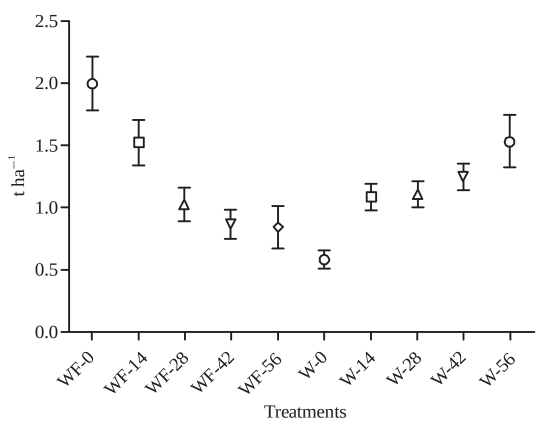

Fig. 2: Effect of increasing duration of weedy period and increasing weed-free period on soybean yield
W: Weedy after n dap, WF: Weed-free after n dap. The bar was indicated as standard error

Weeds competition with crop plants in several different ways. First, there can be interference competition where there is physical exclusion from some aspect of the shared habitat. Second, there is exploitation competition, which is indirect and takes the form of competition for a wide variety of resources such as light, water and nutrients. There may also be the allelopathic competition where the weed produces phytotoxins that reduce or inhibit the growth of the crop[46].

Several biotic and abiotic factors influence crop productivity. Weeds deplete limited resources essential for crop growth and persistent weed interference not only causes heavy yield losses, but increases production costs and reduces the quality of produce. Crop-weed competition is influenced by three major factors, time of emergence of weeds, weed density and type of weed species. Weeds that emerge before (or simultaneously) with the crop will be more competitive than weeds that emerge after crop establishment[47].

The increasing duration of weedy period causes a decrease in the availability of soil moisture and nutrients in the soil. It decreases physiological activity, morphology and soybean yield. Plant water deficits or water stress occur when transpirational water loss exceeds water absorption through the roots. This lowers stomatal guard cell turgor, thereby reducing stomatal conductance and CO_2 uptake. Water stress also reduces photosynthesis by interfering with chlorophyll synthesis, electron transport and photophosphorylation and the synthesis and activity of carboxylation enzymes. Because of its dependence on positive turgor as well as assimilate supply, the process of leaf expansion also is very sensitive to water stress[48].

According to Gibson and Liebman[49], water and nutrients are often in sufficient supply early in the season to support both the crop and weed seedlings and light competition does

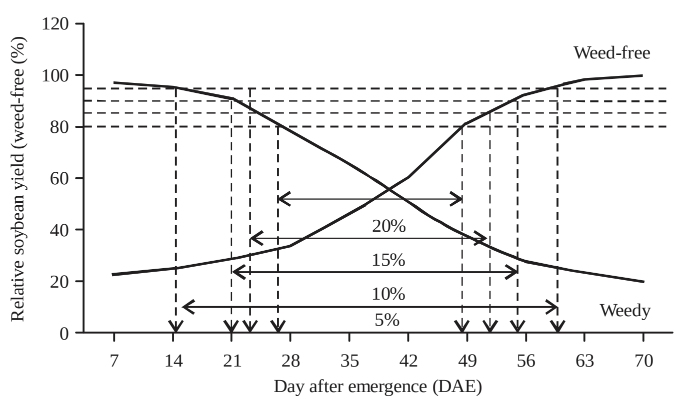

Fig. 3: Effect of increasing duration of weedy period and fitted curves as calculated by the logistic equation and increasing weed-free period and fitted curves as calculated by the Gompertz equation

not occur until the weed canopy shades the crop. In other crops, it has also been reported that weed interference can be tolerated up to a period before it causes irreversible yield loss[50,51].

The availability of essential nutrients is one of the many site-specific factors which directly influence the outcome of crop-weed interference of a particular site[22,52,53]. Evaluation of the nutrients absorption such as N and P affecting the crop-weed competition can be effective in developing better weed management decision[27,54,55,56].

The P and K concentration in tissue by soybean also significantly decreased with increasing the weedy periods. This phenomenon is in agreement with Karkanis *et al.*[57] and Stagnari and Pisante[58], who observed an increase in total weed biomass with increasing weed competition duration.

The soybean yield decreased significantly when weeding was done after 14 dap upto 42 dap. The ages of 14-42 dap are critical phases in determining the growth and development of plants, where at that age there is a vegetative phase, flowering and filling of seeds. Flowering and seed filling phases are a very critical phases that determine the soybean yield[59].

According to Tursun *et al.*[28], increasing periods of weed interference significantly reduced yields in three corn types in both years. The weed competition throughout the crop growing season could cause about 51-72% yield losses in field corn, 50-79% in popcorn and 47-54% in sweet corn. These results are similar to Dogan *et al.*[60], who also reported lower corn yields with increasing weed interference.

Therefore, a CPWC based on AYL of 5% may, in reality, result in a yield loss that is slightly greater than 5% of the weed-free condition. Also, because two separately measured components are used to determine the CPWC, it is possible that these two elements will not overlap in such a way that a single discrete weed control period can be defined[23,61,62]. This occurs when a yield loss of more than 10-20% is used to calculate the CPWC but has been observed at yield loss levels as low as 2%[14].

The CPWC in soybean for AYL of 5, 10, 15 and 20% began 16, 21, 24 and 27 DAE and ended 61, 55, 53 and 49 DAE. The critical period of weed control can vary in a wide range between years and locations, even when the same genotypes and agronomical practices are adopted, because the crop-weed competition for light, water and nutrients is influenced by factors such as the diversity of weed species, climatic variation, soil properties and time of weed emergence[63-68].

Integrated weed management (IWM) is a weed management program based on a combination of preventive, cultural, mechanical and chemical practices. A single weed control measure is not feasible due to the number of different weed species and their highly diverse life cycles and survival strategies. Also, controlling weeds with one or two methods provides the weeds with a chance to adapt to those practices[69]. In essence, the development of an IWM program is based on a few general principles that can be used at any farm: (1) Use agronomic practices that limit the introduction and spread of weeds (preventing weed problems before they start), (2) Help the crop compete with weeds (help 'choke out' weeds) and (3) Use practices that keep weeds 'off balance' (do not allow weeds to adapt)[69].

Implementation of IWM has the potential to decrease reliance on herbicides and tillage, with potentially high environmental gains, including improved soil conservation, lower CO_2 production and increased farm bio-diversity because of reduced impacts on non-target organisms[70,71].

CONCLUSION

The soybean yield decreased significantly when the weedy periods was done after 14 dap upto 42 dap. The soybean yield was influenced by the dry weight of annual weeds (DRAW), heterogeneity of weed (HET), soil moisture (SM), phosphorus (P) and potassium (K) concentration in the tissue. The CPWC in soybean for acceptable yield loss (AYL) of 5, 10, 15 and 20% began 16, 21, 24 and 27 days after emergence (DAE) and ended at 61, 55, 53 and 49 DAE.

SIGNIFICANCE STATEMENTS

The results of this study are expected to enrich the scientific references concerning critical period for weed control (CPWC), especially in soybean on the agro-forestry system with kayu putih. This study also provides information about the relationship between environment, weeds, physiological of soybean, the morphology of soybean with soybean yield.

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