



Impact of the timing and duration of weed control on the establishment of a rubber tree plantation

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Manuscript received on February 25, 2013; accepted for publication on November 11, 2013

ABSTRACT

Rubber tree production is reduced by weeds that compete for environmental resources; therefore, the timing and duration of weed control influences weed interference. The objectives of this study were to evaluate the growth of rubber tree (*Hevea brasiliensis*) plants, to determine the critical period for weed control, and to evaluate the growth recovery of rubber trees that coexisted with weeds for different periods of time after planting. Two groups of treatments were established under field conditions in the first year of the investigation: one group contained crescent periods of weed infestation, while the other contained crescent periods of weed control, also including a weed-free check and a total weedy check. In the second year of the investigation, the weeds were totally controlled. *Urochloa decumbens* was the dominant weed (over 90% groundcover). Crop growth was greatly reduced due to the weed interference. Plant height decreased more rapidly than did any other characteristic. Plant height, leaf dry mass, and leaf area decreased by 99%, 97% and 96%, respectively, and were the most reduced characteristics. Plant height also recovered more rapidly than did any characteristic when the period of weed control was lengthened. However, stem dry mass increased by 750%, making it the most recovered characteristic. The critical period for weed control was between 4 and 9½ months after planting in the first year; however, the rubber trees showed an expressive growth recovery when the weeds were controlled throughout the second year.

Key words: *Hevea brasiliensis*, weed interference, critical period for weed control, growth recovery.

INTRODUCTION

Hevea brasiliensis (Willd. ex. A.D. Juss.) Muell.-Arg., commonly known as the Brazilian rubber tree, is the most widely cultivated tree species in the production of natural rubber latex. The tree is a perennial, cross-pollinating and

monoecious species of the family Euphorbiaceae (Feng et al. 2009), native to South America and is cultivated worldwide, mainly in South East Asia (Venkatachalam et al. 2009). In Brazil, São Paulo State is the most important latex-producing area and is responsible for 55% of the Brazilian rubber production, totaling approximately 75,000 tons of rubber per year (IAC 2011).

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Brazil is not self-sufficient in rubber production; therefore, any factor affecting latex extraction can be very detrimental to rubber production. Latex production by rubber trees can be affected by biotic factors, such as microorganisms causing plant diseases, and other factors that increase the amount of time required for the plants to reach maturity, when latex can be extracted (Gonçalves et al. 2001). Thus, weed interference (the result of weed competition for light, CO₂, water, nutrients, and space, as well as of the allelopathic effects of some weed species) is an important issue reducing plant growth and, consequently, increasing the time required for the plants to reach maturity (Vollmann et al. 2010, Rabbani et al. 2011).

The degree of weed interference is influenced by many factors related to the crop (variety, population and distribution), the weed community (composition, density and distribution), the environmental conditions and management practices, and the period of weed-crop coexistence (Bleasdale 1960). Among them, many authors consider the period that weeds and crops coexist and compete for environmental resources to be the main factor influencing the degree of weed interference. Therefore, the study of the critical period for weed control is very important in establishing an efficient weed management program or/and in evaluating the efficacy of those previously established (Carvalho et al. 2010, Lemes et al. 2010).

Due to the importance and the lack of information regarding the effects of weed interference on rubber tree plantations, we conducted this research aiming (i) to evaluate the growth of rubber tree plants that coexisted with weeds for different periods of time, (ii) to determine the critical period for weed control during the establishment of a rubber tree plantation, and (iii) to evaluate the growth recovery of rubber tree plants after coexisting with weeds for different periods of time.

MATERIALS AND METHODS

SITE DESCRIPTION

The field trial was carried out from December 2008 to December 2010 in southeastern Brazil, at 20° 43' 05" S and 42° 32' 38" WGr. and at an altitude of 589 masl. The soil of this area is classified as a clay-textured Oxisol and its original vegetation was a degraded pasture that was dominated by *Urochloa decumbens* (Stapf.) Webster (up to 90% groundcover) and some weed species, such as *Sida* spp. and *Portulaca oleracea* L., among others. The local climate is tropical with a dry season (the Köppen-Geiger classification is Aw). The average historical daily maximum and minimum temperatures are 30.8 °C and 12.8 °C, respectively, and the mean annual rainfall is 1,408.9 mm and is concentrated from October to March.

SITE PREPARATION AND PLANTATION

Prior to planting the crop, the original site vegetation was desiccated with glyphosate at 1.08 kg ae ha⁻¹. One week after the desiccation, the land was tilled using a moldboard plough, disc plough and disc harrow, in sequence. The crop was planted on December 20, 2008 using seedlings of the rubber tree clone RRIM 600 that were obtained by normal-T-budding. The soil was fertilized using 150 g single superphosphate at planting and monthly for four additional months using in sequence 30, 40, 50 and 60 g ammonium sulfate per plant. Water was also supplied during the first-year investigation.

EXPERIMENTAL DESIGN AND TREATMENTS

Two groups of treatments were established after planting during the first year of the investigation: one group consisted of crescent periods of weed infestation, while the other contained crescent periods of weed control, also including a weed-free check and a total weedy check. The periods of weed infestation or weed control were established monthly via the application of glyphosate at

1.08 kg ae ha⁻¹ and complementary mechanical control when necessary until 360 days after planting (DAP). There were 11 treatments for each group (weed infestation and weed control) plus two checks, totaling 24 treatments arranged in a randomized block design with 3 replicates. The experimental plots composed of four lines 8 m apart with four plants 2.5 m apart. In the second year of the investigation, all of the experimental plots were maintained free of weeds by monthly glyphosate applications and complementary mechanical control if necessary until 720 days after planting.

MEASUREMENTS

All the measurements were taken within the area of the two central lines. The stem diameter (digital paquimeter) and plant height (yardstick) were measured monthly from 60 to 360 DAP during the first year of the investigation. At 360 DAP, just one plant per replicate was cut close to the ground for the leaf count and leaf area measurement (Li-Cor, Li-3000A, USA). The aboveground material was separated into stem and leaves and was dried to a constant weight in a forced-air convection oven at 70 °C and weighed to determine the dry mass of the stem and leaves. At 720 DAP, the stem diameter and plant height of three rubber trees were measured.

DATA ANALYSIS

Data from the first year of the investigation were fitted to a non-linear, log-logistic regression model as follows:

$$Y = c + \{(d - c) / [1 + (x / g)^b]\},$$

where Y is the value of a rubber tree characteristic; c and d are the coefficients corresponding to the lower and upper asymptotes, respectively; b is the slope of the line; g is the point of inflection halfway between the upper and lower asymptotes; and x is the number of days.

In addition, the critical period for weed control was estimated based on a non-linear regression

model that was adjusted to the accumulation of aboveground dry mass accepting 5% yield losses.

Data from the second year of the investigation were analyzed using an ANOVA and a Tukey test at 5% probability.

Regression analyses were performed using SigmaPlot software (Systat, version 10.0, USA), while the ANOVA and the Tukey test were performed using STATISTICA software (StatSoft, version 8.0, USA).

RESULTS AND DISCUSSION

In the first year of the investigation, four monocotyledon species, including *U. decumbens*, *Cyperus rotundus* L., *Eleusine indica* (L.) Gaertn. and *Panicum maximum* Jacq., and at least nine eudicotyledon species, including *Amaranthus* spp., *P. oleracea*, *Indigofera hirsuta* L., *Ipomoea* spp., *Malva* spp., *Mimosa pudica* L., *Richardia brasiliensis* Gomes, *Sida* spp. and *Spermacoce latifolia* Aubl., infested the rubber tree plantation. Among these species, *U. decumbens* showed the highest relative importance (over 90% groundcover), mainly after 90 DAP, while *P. oleracea* and *Sida* spp. were also prominent species up to 90 DAP (data not shown). Because the experimental field was a degraded pasture of *U. decumbens*, this plant was expected to be the dominant species.

Grasses and herbaceous broad-leaved weed species are commonly found during crop establishment and constitute a major impediment to the successful early growth and development of tree crops (Knowe et al. 1985, Boomsma and Hunter 1990, Richardson 1993, Savill et al. 1997, Adams et al. 2003). Weed interference can range from the significant suppression of crop growth to widespread crop mortality (Adams et al. 2003). Crop productivity may be subsequently reduced throughout the rotation (Lewis and Ferguson 1993) and the benefits of using fertilizer and genetically improved seedlings can often be reduced (Waring 1972,

Flinn et al. 1979). Furthermore, the stress that is caused by weed interference can increase the crop susceptibility to attacks from pests and diseases (Nambiar 1990).

Rubber tree plantations are commonly established on the degraded pastures of grass species such as *U. decumbens*, *U. brizantha*, and *P. maximum*, among others. These species can have differing potentials for the infestation of and capacities for competition with rubber tree plants. In Brazil, *U. decumbens* is one of the most common species present in degraded pastures. This species reduces the growth of tree crops such as *Coffee* spp. (Dias et al. 2004, Souza et al. 2006, Marcolini et al. 2009) and *Eucalyptus* spp. (Brendolan et al. 2000, Toledo et al. 2000). Consequently, *U. decumbens* has the potential to infest and influence the growth of rubber tree plants under establishment in field conditions.

During the first year of the investigation, all the measurements taken during periods of weed infestation were the same as those taken during periods of weed control. However, during the second year of the investigation, when the period of weed infestation lengthened, the plant height, stem diameter, leaf number, leaf area, stem dry mass, leaf dry mass (Figure 1) and aboveground dry mass (Figure 2) reduced logistically. Additionally, when the period of weed control increased, these characteristics also increased.

During periods of weed infestation, some rubber plant characteristics reduced more rapidly than did other characteristics, indicating a higher sensitivity to weed interference. This sensitivity can be visualized graphically and by the analysis of equation parameter *b*. In the latter, a higher *b* value indicates that a rubber plant characteristic reduced more slowly than did characteristics with lower *b* values. The resulting sequence of the velocity of growth reduction was as follows: plant height > stem diameter > leaf dry mass > leaf area > leaf number > aboveground dry mass > stem dry mass (Table I).

During periods of weed control, some rubber plant characteristics increased more rapidly than did other characteristics, indicating a more rapid growth recovery. This rapid recovery can also be visualized graphically and by the analysis of equation parameter *b*. In the latter, a more negative *b* value indicates that a rubber plant characteristic increased more slowly than did characteristics with less negative *b* values. The resulting sequence of the velocity of growth recovery was as follows: plant height > leaf area > stem diameter > leaf dry mass > leaf number > aboveground dry mass > stem dry mass (Table I).

From the analysis of equation parameters *c* and *d*, we can estimate the theoretical potential of rubber plant growth reduction and growth increase. During periods of weed infestation, the plant height, leaf dry mass, leaf area, aboveground dry mass, stem dry mass, leaf number and stem diameter were reduced by 99%, 97%, 96%, 83%, 82%, 72%, and 63%, respectively, illustrating the sequence of growth reduction of rubber plant characteristics due to weed coexistence. During periods of weed control, the stem dry mass, aboveground dry mass, leaf area, leaf dry mass, leaf number, plant height and stem diameter were increased by 750%, 504%, 503%, 230%, 122%, 106%, and 96%, respectively, illustrating the sequence of growth increase of rubber plant characteristics due to weed control.

Equation parameter *g* indicates the period required to reduce or increase a rubber plant growth characteristic by 50%. Equation parameter *g* has been used as an indirect factor to estimate the actual sensitivity of plants to some biotic or abiotic factor. As such, when we compare a value of equation parameter *g* attributed to some rubber tree characteristic with that showing the lowest *g* value, we can identify the sequence of rubber tree characteristic sensitivity due to weed interference.

During periods of weed infestation, plant height showed the lowest *g* value (Table I), being the most sensitive rubber tree characteristic.

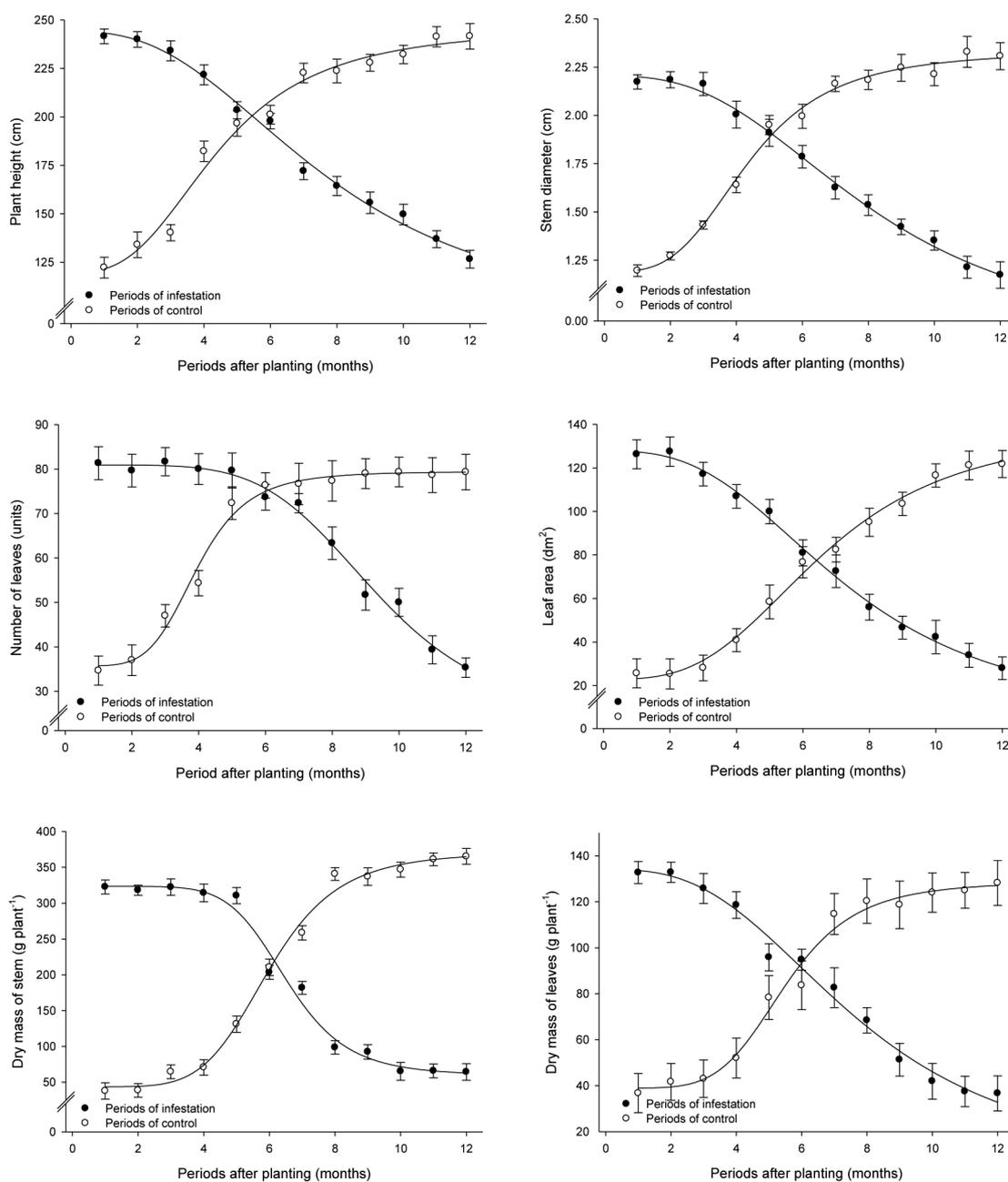


Figure 1 - Plant height, stem diameter, leaf number, leaf area, stem dry mass and leaf dry mass 12 months after planting of *Hevea brasiliensis* submitted to crescent periods of weed infestation or weed control. Vertical bars indicate the standard error of the means.

Comparing this value with that of the other characteristics, we identified the sequence of rubber tree characteristic sensitivity due to increased weed interference as follows: plant height > stem dry mass > aboveground dry mass > leaf area > leaf

dry mass > stem diameter > leaf number. The stem dry mass, aboveground dry mass, leaf area, leaf dry mass, stem diameter, and leaf number were 1.46, 1.49, 1.64, 1.73, 1.81, and 2.09 times, respectively, more sensitive than was the plant height. In

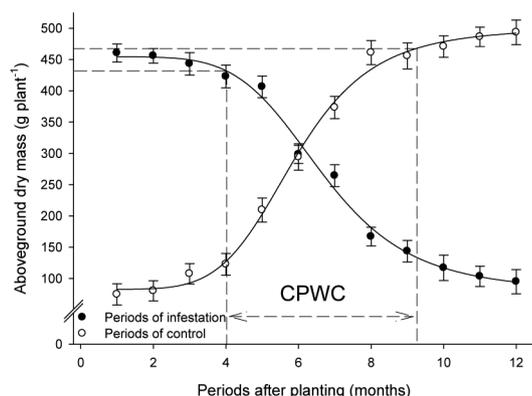


Figure 2 - Aboveground dry mass 12 months after planting of *Hevea brasiliensis* submitted to crescent periods of weed infestation or weed control. CPWC is the critical period for weed control. Vertical bars indicate the standard error of the means.

contrast, during periods of weed control, the leaf number showed the lowest g value, being the least sensitive rubber tree characteristic. Comparing this value with that of the other characteristics, we identified the sequence of rubber tree characteristic sensitivity due to increased weed control as follows: leaf number > stem diameter > plant height > leaf

dry mass > aboveground dry mass > stem dry mass > leaf area. The stem diameter, plant height, leaf dry mass, aboveground dry mass, stem dry mass, and leaf area were 1.11, 1.13, 1.39, 1.49, 1.52, and 1.68 times, respectively, more sensitive than was the leaf number.

Among the characteristics that were studied in this research, Toledo et al. (2000, 2003) reported that the stem diameter and plant height were the eucalyptus plant characteristics that were the most influenced by *U. decumbens* interference, being reduced by 69-71% and 62-68%, respectively. Tarouco et al. (2009) also observed a reduction by 33% of the stem diameter of eucalyptus plants that were submitted to crescent periods of weed infestation. Souza et al. (2006) observed that the plant height and stem diameter of coffee plants were reduced by 92% and 94%, respectively, when the tree crop coexisted with *U. decumbens* for 614 days after transplanting. While no scientific papers were found in literature regarding the effect of

TABLE I
Parameters of the non-linear, log-logistic equation[#] adjusted to different growth characteristics of *Hevea brasiliensis* submitted to crescent periods of weed infestation or weed control.

Characteristics	b	c	d	g	R ²	F	p
<i>Periods of weed infestation</i>							
Plant height	2.57	0.99	244.02	4.47	0.99	381.46	< 0.001
Stem diameter	2.73	0.82	2.20	8.10	0.99	700.00	< 0.001
Leaf number	5.19	22.96	80.93	9.34	0.99	273.16	< 0.001
Leaf area	2.86	4.38	127.76	7.31	0.99	785.61	< 0.001
Stem dry mass	7.10	59.45	323.39	6.54	0.98	190.49	< 0.001
Leaf dry mass	2.82	3.43	134.04	7.74	0.99	233.94	< 0.001
Aboveground dry mass	5.41	79.35	454.28	6.67	0.99	417.83	< 0.001
<i>Periods of weed control</i>							
Plant height	- 2.86	119.82	246.27	4.47	0.98	169.54	< 0.001
Stem diameter	- 3.41	1.19	2.33	4.39	0.99	384.75	< 0.001
Leaf number	- 5.19	35.71	79.46	3.95	0.99	244.79	< 0.001
Leaf area	- 3.16	22.93	138.51	6.64	0.99	472.87	< 0.001
Stem dry mass	- 5.68	43.65	371.13	5.99	0.99	468.87	< 0.001
Leaf dry mass	- 5.09	38.97	128.79	5.51	0.98	197.63	< 0.001
Aboveground dry mass	- 5.48	82.81	500.33	5.90	0.99	659.71	< 0.001

[#] Equation: $Y = c + \{(d - c) / [1 + (x / g)^b]\}$, where Y is the value of a rubber tree characteristic; c and d are the coefficients corresponding to the lower and upper asymptotes, respectively; b is the slope of the line; g is the point of inflection halfway between the upper and lower asymptotes; and x is the number of days.

U. decumbens on rubber tree plants, our results indicate the high potential for a negative effect of *U. decumbens* species on rubber tree plants.

Increased growth in response to weed control is usually explained in terms of improved access of the trees to water (Sands and Nambiar 1984) or nutrients (Ellis et al. 1985, Smethurst and Nambiar 1989, Örlander et al. 1996). This access leads to the enhancement of the trees' physiological activity (Boomsma and Hunter 1990, Richardson 1993, Mohammed et al. 1998), leading to an increase in the leaf area, light interception and photosynthetic activity of the crop (Adams et al. 2003). In this study, when the weeds were controlled during the first year of the investigation, the leaf number increased 122%. This result, when considered together with the 503% increase in the leaf area under the same growth conditions, illustrates how the increased light interception and photosynthetic activity of rubber tree plants is established.

Considering the aboveground dry mass of rubber tree plants as the primary characteristic in estimating the critical period for weed control and an acceptable growth reduction up to 5%, we found that the rubber tree plants showed no significant growth reduction when coexisting with the weeds until 4 months after planting. In addition, when the weeds were controlled until approximately 9½ months, the rubber tree plant growth was not significantly affected by those weeds that grew after the controlling efforts were abandoned. These results indicate that rubber tree plants may coexist with weeds up to 4 months after planting without significant growth reduction. Additionally, the prevention of weed interference for weed control is not necessary 9½ months after planting. Therefore, the critical period for weed control began 4 months after planting and continued until 9½ months after planting. The weed community must be controlled during this critical period to prevent weed interference and, consequently, to ensure crop growth.

There are no studies on the duration of periods of weed interference on the Brazilian rubber tree. However, Toledo et al. (2000) identified the critical period for weed control from 14 to 140 DAP, while Tarouco et al. (2009) estimated the critical period for weed control from 147 to 335 days after planting for eucalyptus plants. Differing critical periods for weed control between different years, regions or crops are common in literature because many factors can affect the duration of this period. The relative competitive ability of different weed species affects the duration of this critical period (Everman et al. 2008, Knezevic et al. 2002). Generally, the critical period for weed control for a given crop species varies greatly and depends on the density of weed infestation, weed species characteristics, crop species characteristics, climatic conditions, and environment (Knott and Halila 1986). The critical period for weed control can also differ due to planting densities (Ahmadvand et al. 2009), and the duration of this period can be affected by weed densities (Knott and Halila 1986).

Typically, the critical period for weed control concept assumes that weed emergence, species composition, and density are spatially homogenous across an environment (Knezevic et al. 2002). Environmental variability, crop characteristics, and other factors cause estimates of this critical period to be crop-specific within a given region. The critical period for weed control is unique for each crop and varies for each crop in differing environmental conditions. Because the critical period for weed control can vary by year and by environment, weed management practitioners should use the critical period for weed control as a guideline for recommendations (Knezevic et al. 2002, Everman et al. 2008). Therefore, because it is crucial to maintain a weed-free environment during the critical period for weed control to prevent unacceptable yield loss, research into this critical period in the Brazilian rubber tree is essential in the formation of weed management strategies.

After the first year of the investigation when the critical period for weed control was determined, all the rubber tree plants had grown free of weeds. At the end of the second year of the investigation, both the plant height and stem diameter of the rubber tree plants were maintained during coexistence with weeds for different durations during periods of both weed infestation and weed control (Table II). The plant height and stem diameter reduced significantly 11 months after planting during crescent periods of weed infestation when the weeds were not controlled, indicating that weeds

can coexist with rubber tree plants up to 10 months after planting without significantly reducing plant growth. However, during crescent periods of weed control, when the weeds were controlled until at least 7 months after plantation, both the plant height and stem diameter were not significantly reduced, indicating that if the weeds are controlled for 7 months after planting, rubber tree plants will grow similarly to those that are maintained weed-free.

These results indicate that some rubber tree plants showed growth recovery during the second year of the investigation when the weeds were

TABLE II
Plant height and stem diameter 24 months after planting of *Hevea brasiliensis*
submitted to crescent periods of weed infestation or weed control.

Time after planting (Months)	Weed infestation		Weed control	
	Plant height (cm)	Stem diameter (cm)	Plant height (cm)	Stem diameter (cm)
1	383.3 ± 7.5 A	3.59 ± 0.11 A	276.3 ± 7.8 D	2.27 ± 0.17 E
2	378.9 ± 5.9 A	3.60 ± 0.17 A	275.2 ± 11.4 D	2.38 ± 0.19 DE
3	375.5 ± 9.1 A	3.57 ± 0.12 A	278.6 ± 11.4 D	2.37 ± 0.21 DE
4	364.5 ± 8.9 AB	3.48 ± 0.13 A	274.4 ± 9.9 D	2.54 ± 0.14 CDE
5	364.1 ± 7.8 AB	3.59 ± 0.12 A	296.0 ± 11.4 CD	2.57 ± 0.15 CDE
6	364.3 ± 6.8 AB	3.52 ± 0.10 A	302.9 ± 9.6 BCD	2.73 ± 0.12 BCDE
7	357.7 ± 7.9 AB	3.44 ± 0.14 A	327.9 ± 8.0 ABC	3.10 ± 0.10 ABCD
8	341.1 ± 9.9 AB	3.27 ± 0.12 AB	330.1 ± 5.5 ABC	3.10 ± 0.11 ABCD
9	351.1 ± 10.8 AB	3.20 ± 0.15 AB	332.0 ± 8.9 ABC	3.20 ± 0.12 ABC
10	347.8 ± 12.2 AB	3.20 ± 0.17 AB	347.5 ± 8.7 AB	3.38 ± 0.13 AB
11	320.0 ± 11.5 B	2.68 ± 0.11 BC	370.0 ± 7.3 A	3.53 ± 0.09 A
12	315.6 ± 13.9 B	2.33 ± 0.15 C	367.8 ± 5.9 A	3.57 ± 0.15 A
F	5.00	8.80	15.80	10.82
p	< 0.001	< 0.001	< 0.001	< 0.001

Means ± the standard error of the mean followed by the same letter in columns are not different by Tukey's test at 5% probability.

totally controlled. Therefore, the beginning of the critical period for weed control would be delayed and the end of this period would be advanced. So, rubber tree plants that coexist with weeds during the first year until 10 months after planting can show growth recovery if the weeds are controlled during the second year. The critical period for weed control began 4 months after planting during the first year, indicating that the rubber tree plants coexisting with weeds from 5 to 10 months after

planting during the first year could recover their growth in the second year. Additionally, plants that are maintained free of weeds during the first year until 7 months after planting can show growth recovery if the weeds are controlled during the second year. The critical period of weed control ended in the first year 9½ months after planting, indicating that plants coexisting with weeds during the first year from 7 to 9½ months after planting can recover their growth in the second year.

ACKNOWLEDGMENTS

The authors thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (Master, Research Productivity, and Universal Scholarship Programs) from the Brazilian Government and Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) (Post-Doc Scholarship Program) from the São Paulo State Government, Brazil, for jointly supporting this research.

RESUMO

A produção da seringueira é reduzida pelas plantas daninhas que competem por recursos ambientais; portanto, a época e duração do controle de plantas daninhas influencia a interferência das plantas daninhas. Os objetivos deste estudo foram: avaliar o crescimento de plantas de seringueira (*Hevea brasiliensis*), determinar o período crítico para controle das plantas daninhas e avaliar a recuperação do crescimento das seringueiras que conviveram com plantas daninhas por diferentes períodos de tempo após o plantio. Dois grupos de tratamentos foram estabelecidos em condições de campo, no primeiro ano de investigação: um grupo teve períodos crescentes de infestação de plantas daninhas, enquanto o outro teve períodos crescentes de controle das plantas daninhas, também incluindo uma testemunha livre de plantas daninhas e uma testemunha com infestação total de plantas daninhas. No segundo ano da investigação, as plantas daninhas foram totalmente controladas. *Urochloa decumbens* foi a planta daninha dominante (mais de 90% de cobertura). O crescimento da cultura foi grandemente reduzido devido à interferência de plantas daninhas. A altura de plantas decresceu mais rapidamente que qualquer outra característica. Altura de planta, massa seca de folhas e área foliar decresceram em 99%, 97% e 96%, respectivamente, e foram as características mais reduzidas. A altura de plantas também se recuperou mais rapidamente que qualquer outra característica quando o período de controle das plantas daninhas foi entendido. Contudo, a massa seca do caule aumentou em 750%, fazendo desta a característica mais recuperada. O

período crítico para o controle de plantas daninhas foi entre 4 e 9½ meses após o plantio, no primeiro ano; contudo, as seringueiras mostraram expressiva recuperação do crescimento quando as plantas daninhas foram controladas ao longo do segundo ano.

Palavras-chave: *Hevea brasiliensis*, interferência de plantas daninhas, período crítico para controle de plantas daninhas, recuperação de crescimento.

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