Revista Facultad Nacional de Agronomía Medellín
ISSN: 0304-2847
ISSN: 2248-7026
Facultad de Ciencias Agrarias - Universidad Nacional de Colombia

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Revista Facultad Nacional de Agronomía Medellín, vol. 73, no. 3, 2020, September-December, pp. 9293-9303
Facultad de Ciencias Agrarias - Universidad Nacional de Colombia

DOI: https://doi.org/10.15446/rfnam.v73n3.80546

Research article

http://www.revistas.unal.edu.co/index.php/refame

Revista Facultad Nacional de Agronomía

Phenological patterns of defoliation and refoliation processes of rubber tree clones in the Colombian northwest

Patrones fenológicos de los procesos de defoliación y refoliación en clones de caucho en el noroeste de Colombia

UNIVERSIDAD NACIONAL DE COLOMBIA

doi: 10.15446/rfnam.v73n3.80546

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ABSTRACT

Keywords:
Hevea brasiliensis
Leaf area index
Phenology
Tropical species

The knowledge of the defoliation-refoliation process in rubber cultivation allows the development of management strategies in the production system to improve rubber yield. The objective of this study was to determine the intensity and duration of defoliation-refoliation of rubber clones FX 3864, IAN 710 and IAN 873 in the municipality of Tarazá and the FX 3864 and IAN 873 clones in the municipality of Nechí (northwestern Colombia). From October 2015 to June 2016, the measurements of the necromass were carried out in each location for each clone. The light environment was quantified, employing the hemispheric photographs technique to estimate canopy openness percentage (CO) and leaf area index. The assessed weeks were grouped by Principal Component Analysis (PCA) based on the original phenology and climatic variables. The defoliation-refoliation process was analyzed descriptively using graphical representations of the trend for the phenological variables that best described this process. The relationship between climatic and phenological variables in the period evaluated was evidenced; the rainfall was the most critical climatic characteristic in the induction of the defoliation process. The leaf area index was reduced to a minimum value in February, with values of 0.52 for IAN 710 clone in Tarazá, and 0.64 for the IAN 873 clone in Nechí, which corresponded to the highest defoliation stage in both locations. The refoliation period was short (4 to 6 weeks) and occurred during the dry season for all the clones in both places.

RESUMEN

Palabras clave:
Hevea brasiliensis
Índice de área foliar
Fenología
Especies tropicales

El conocimiento del proceso de defoliación–refoliación en el cultivo del caucho permite desarrollar estrategias de manejo en el sistema productivo encaminadas a mejorar el rendimiento de caucho. El objetivo de este estudio fue determinar la intensidad y duración de la defoliación-refoliación de los clones de caucho FX 3864, IAN 710 e IAN 873 en el municipio de Tarazá y los clones FX 3864 e IAN 873 en Nechí, ubicados en el noroccidente de Colombia. Durante el período de defoliación-refoliación entre octubre de 2015 y junio de 2016, la recolección y cuantificación de necromasa se llevó a cabo en cada plantación y para cada clon. El ambiente lumínico se cuantificó empleando la técnica de fotografías hemisféricas para estimar el porcentaje de apertura del dosel (CO) y el índice de área foliar en el cultivo de caucho. Para agrupar las semanas de medición por los procesos fenológicos ocurridos, se realizó un Análisis de Componentes Principales (PCA) basado en las variables de fenología y de clima. La evolución del proceso de defoliación-refoliación se analizó descriptivamente mediante representaciones gráficas de tendencia para las variables fenológicas que mejor describieron este proceso. Se evidenció la relación entre las variables climáticas y fenológicas en el período evaluado, siendo la lluvia, la característica climática más crítica en la inducción del proceso de defoliación. El índice de área foliar se redujo a un valor mínimo en febrero, con valores de 0.52 para el clon IAN 710 en Tarazá, y 0.64 para el clon IAN 873 en Nechí, que correspondió a la etapa de defoliación más alta en ambos lugares. La duración del período de refoliación fue corta (4 a 6 semanas) y se produjo durante la estación seca para todos los clones en ambos lugares.

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Received: October 31, 2019; Accepted: July 9, 2020

Rev. Fac. Nac. Agron. Medellín 73(3): 9293-9303. 2020

ISSN 0304-2847 / e-ISSN 2248-7026

Rubber tree [*Hevea brasiliensis* (Willd. Ex A. Juss.) Müll. Arg.] is a perennial plant species belonging to the Euphorbiaceae family and is native to the Amazon River basin. This zone is characterized by having an Intertropical environment with high rainfall, temperature, and radiation (Priyadarshan, 2017). The rubber tree is cultivated mainly in the equatorial zone between 10° S and 10° N (Meenakumari *et al*., 2018). In northwestern Colombia, one of the most important producing areas is called *El Cordón Cauchero-Cacaotero*. This zone has the largest number of producers (79%) in the department of Antioquia (Colombia), including the localities Tarazá and Nechí, which are representative of this area (CCC, 2015).

Biological events in plants are sensitive to climatic changes (Richardson *et al*., 2013), and their phenological behavior is influenced by factors such as temperature, rainfall, radiation, and soil nutrients (Zhai *et al*., 2017; Fu *et al*., 2015). In the specific case of rubber, its growth is annual, and the defoliation period can vary depending on the genetic material, planting density (Righi *et al*., 2001), and altered environmental conditions (Priyadarshan, 2017). According to Guyot *et al*. (2008), the period of refoliation lasts approximately one month. It includes the emergence of the leaf to the mature leaf stage described by Lieberei (2007) as stage D.

Paranjothy (2018) mentioned that rubber trees respond to drought stimuli, which generate variation in leaf phenology at different times and locations. However, Priyadarshan (2017) indicated that the phenological phases respond to the latitudinal position where plantations are located. In the north of the equator, the defoliation occurs in February-March, mainly associated with low humidity and high transpiration rate, while in the south of the equator in September-October, after winter with low temperature and water deficiency.

According to Carr (2012), defoliation occurs in trees older than three years. It is induced by dry or less humid climates where trees can remain almost leafless for up to four weeks. In addition, radiation in tropical areas can cause defoliation and refoliation (Borchert *et al*., 2015).

In tropical climates, rubber plants produce latex throughout the year with a marked reduction in the defoliation and refoliation periods since photosynthesis is restricted (Righi *et al*., 2001), which decreases the amount of reserves (carbohydrates) and total production (Simbo *et al*., 2013). The periods of defoliation, refoliation and subsequent rubber tree flowering occur at the same time of the year for all clones. Still, the precocity, homogeneity and speed of the event diverge substantially (Guyot, 2008).

It is necessary to know the behavior of natural rubber plantations and the functioning of different genotypes in rubber-producing zones of Colombia (Córdoba-Ganoa *et al*., 2018) to determine relationships between climatic characteristics with defoliation-refoliation patterns and their dynamics with the occurrence of diseases. According to Guyot and Le Guen (2018), refoliation is the phenological phase that is most susceptible to the South American Leaf Blight (SALB) caused by the fungus *Pseudocercospora ulei* (P. Henn.) V. Arx (Hora Junior *et al*., 2014), which is a major limiting factor for latex production by significantly reducing the tree leaf area (Jaimes and Rojas, 2011). It is hypothesized that the defoliation – refoliation process occurs at the same time for all the studied clones and localities but showing different durations and intensities, with the rainfall regime as the principal trigger for phenological events. That is why this study aimed to evaluate the intensity and duration of the defoliation-refoliation processes of rubber tree clones FX 3864, IAN 873 and IAN 710 in the productive stage in two northwestern Colombian municipalities (Tarazá and Nechí).

MATERIALS AND METHODS

This research was conducted as an observational study in two rubber tree commercial plantations under production, in the locality of Tarazá, administrative section of Santa Clara, and the locality of Nechí, administrative section of Quebrada La Cienaga, in Antioquia (Colombia).

In Tarazá (7°30' N, 75°30' W, 130 masl) monoclonal plots of 0.3 ha with the rubber clones FX 3864 (FX: Ford Cross), IAN 873 and IAN 710 (IAN: Instituto de Pesquisas Agropecuarias do Norte) were monitored. These were planted at 2.8 m between plants and 7 m between rows in the year 1998 and are under tapping since 2011. In Nechí (7°53' N, 74°50' W, 70 masl) monoclonal plots of 0.3 ha with the rubber clones FX 3864 and IAN 873 were monitored. These were planted at 2.8 m between plants and 7 m between rows in the year 2006, and are under tapping since 2015.

In both localities, the rainfall regime is monomodal with an annual mean rainfall of 4079 mm in Tarazá and 4058 mm in Nechí, the dry period occurs from December to March and the rainy season occurs from April to November. The rubber plantations are in Tarazá's flatlands and in Nechí's hilly landscape. In both locations, the soils are classified as Ultisols, with high acidity and low natural fertility (Villa *et al*., 2017). During this study, the rubber trees were tapped downward on half spiral cuts, at three daily frequencies, six days in tapping followed by one day of rest, without stimulation.

During the defoliation-refoliation period between October 2015 and June 2016, the collection and quantification of the necromass (leaves, flowers, fruit peels, branches and seeds) were carried out in each plantation and for each clone. The collection was performed in five sampling units randomly distributed, each consisting of three necromass collector nets of 1 m^2, 0.7 m from the soil surface, collecting necromass from four rubber trees, as shown in Figure 1. The collected necromass was dried in a Thermolab TO 90 S/G oven at 50 °C until a constant weight was reached. The dry weight (g) of leaves (DWL), flowers (DWF), fruit epicarp (DWP), branches (DWB) and seeds (DWS) were established independently. The quantification of the foliar area (FA) trapped in the collector nets was carried out employing the leaf area portable meter Licor® 3000C.

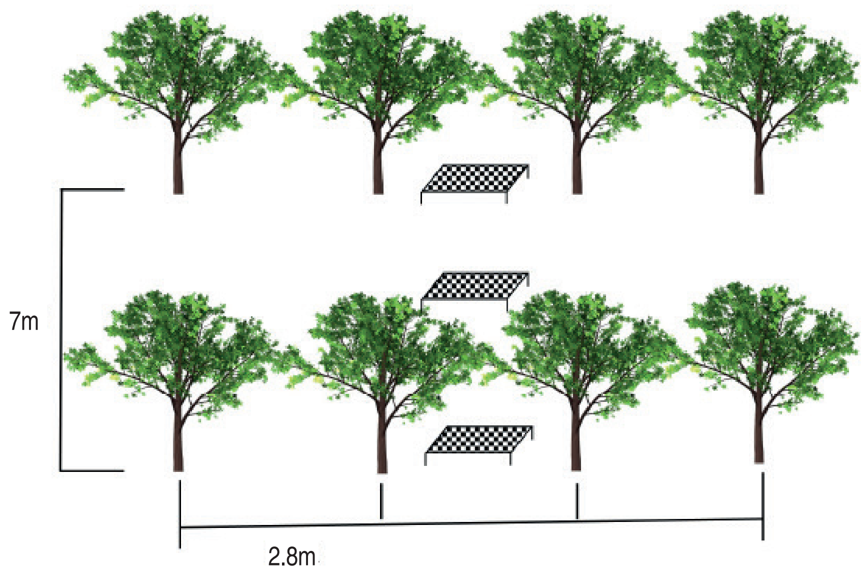

Figure 1. Graphic representation of the location of the necromass collector nets in each sampling unit.

The light environment was quantified, employing the hemispherical photography technique to the canopy of the crop (Chazdon and Field, 1987). A GoPro Hero + ® camera (GoPro Inc.) was used on each of the necromass capturing sites (meshes). The photographic records were directed to the canopy. The photographs taken were analyzed with the Gap Light Analyzer software (GLA) (Frazer *et al*., 1999) to estimate the canopy openness percentage (CO) and leaf area index. These measurements were made by inserting a circle into each photography and dividing it into six concentric rings and evaluating the variables on ring 4 (LAI4) and 5 (LAI5). The evaluations were conducted monthly between October 2015 (week 44 of 2015) and June 2016 (week 24 of 2016), except between October and February, where the frequency was biweekly due to the accelerated increase of necromass.

The following climatic variables were recorded in each location: average relative humidity (HR) (%), minimum relative humidity (%), maximum relative humidity (%), average temperature (TEM) (°C), minimum temperature (°C), maximum temperature (°C), photosynthetically active radiation (PAR) (μmol photon m^{-2} s^{-1}) and accumulated rainfall (RAINF) (mm $week^{-1}$), through the weekly recording in Spectrum® portable weather stations of the Watchdog 2900 ET series., the evapotranspiration was calculated using the Hargreaves equation (Allen *et al.*, 2006) to perform the climatic characterization of each locality, where evapotranspiration (ETo) was equivalent to ETc because according to Carr (2012) the coefficient of rubber crop is 1.

In order to group the assessed weeks by the occurring phenological processes, a Principal Component Analysis (PCA) was carried out based on the original phenology and climatic variables described above. From this, a biplot representation with 95% confidence ellipses was elaborated, using the statistical procedure "ggbiplot" of the statistical software R Project (R core Team, 2017).

The evolution of the defoliation-refoliation process was analyzed descriptively using graphical representations of the trend for the phenological variables that best described this process, for each clone and locality. The observed co-occurrence of phenological and climatic events was discussed.

On the other hand, to compare the defoliation and refoliation processed by clone (considered as fixed effects) in each location, the following response variables were used: dry weight of leaves, flowers, seeds, and leaf area index. For their analysis, the non-parametric Kruskal-Wallis rank test (95% confidence level) and the post hoc tests for multiple comparisons were implemented by the Conover method (Conover, 1999; Pohlert, 2014), using the statistical package "agricolae" of the statistical R Project software (De Mendiburu, 2013).

RESULTS AND DISCUSSION

From the PCA (Figure 2), all data contained in 14 variables were summarized in two principal components (PC1 and PC2). However, this reduces the amount of information and it improves interpretability by plotting all variables in two dimensions, allowing a better comprehension of a complex biological phenomenon such as phenology with multiple factors involved. The amount of variance explained for the components PC3 to PC14 does not compensate the interpretability lost because of the increased dimensionality. The PCA showed an important relationship between climatic and phenological variables

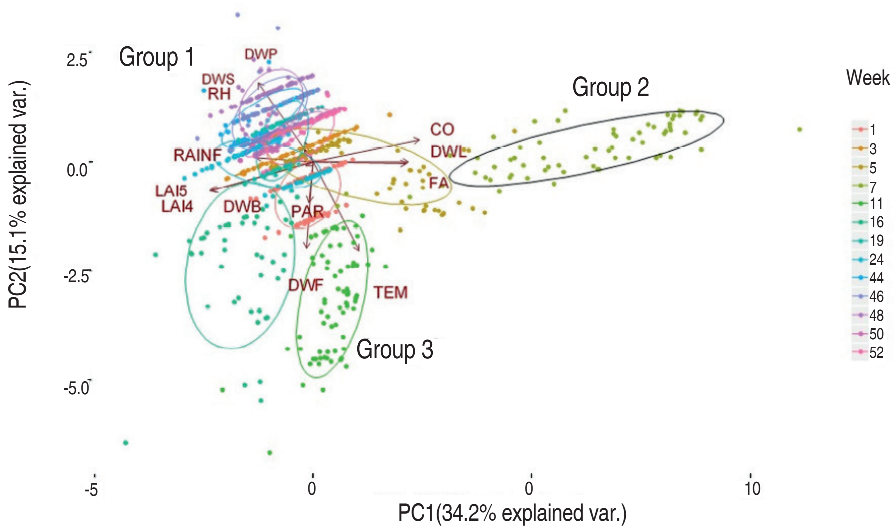

Figure 2. Biplot representation of the relationship between defoliation-refoliation processes variables and the climate variables in weeks 44, 46, 48, 50, 52 of 2015 and weeks 1, 3, 5, 7, 11, 16, 19 and 24 of 2016. LAI4 and LAI5 (leaf area index in the fourth and fifth ring), CO (canopy openness), FA (foliar area), DWL (dry weight of the leaves), DWB (dry weight of branches), DWF (dry weight of the flowers), DWP (dry weight of the fruit peel), DWS (dry weight of the seed), TEM (temperature), PAR (photosynthetically active radiation), RAINF (rainfall) and RH (relative humidity).

according to the evaluation period where the processes of defoliation, refoliation, flowering and fruit dehiscence occurred.

The PCA identified three stages: transition, maximum defoliation and refoliation, represented as groups of ellipses without interception between them (Groups 1, 2, and 3; Figure 2), that synthesize the behavior of the defoliation-refoliation period based on the two first principal components (PC1 and PC2), which explained 48.9% of the variation. The PCA findings were similar to those reported by Liyanage *et al*. (2018), who observed in five rubber clones studied in Southwest China (22° N) that defoliation occurred between December and January, refoliation between January and February and flowering in March to April, while the trees were in foliar stage D according to the scale proposed by Lieberei (2007) from April to December.

The first stage (1) comprising weeks 44, 46, 48, 50, and 52 of 2015 and 1, 3, 5, 16, 19, and 24 of 2016 corresponds to rainy seasons of high relative humidity and with a higher leaf area index. In this group, weeks 44-48 stood out due to seed fall, week 5 as a transition time towards the defoliation phase, and, in week 16, trees showed a higher leaf area index; moreover, these were in the foliar phenological stage D. Whereas Liyanage *et al*. (2018) found that precipitation is less critical than sunshine exposure time in determining the timing of rubber phenological phases, the rubber defoliation process in Tarazá and Nechí was influenced by the decrease in rainfall intensity. In the second stage (week 7), the highest canopy openness, dry weight and leaf area of the fallen leaves, as well as the lowest leaf area indexes, were obtained, which was associated with the highest defoliation period. Carr (2012) reported that this defoliation stage is induced by dry or less humid climates, where trees can remain almost leafless for up to four weeks. The third stage (week 11) was the refoliation period after the leaf loss and the flowering stage. This period is associated with a higher dry weight of flowers, high radiation, and high temperature; the main flowering season of rubber occurs between March and April in the northern hemisphere, preceded by the end of the defoliation – refoliation process, which happens in January to February, as was shown by Priyadarshan (2017).

In this work, rainfall was the most important climatic characteristic in the induction of the defoliation stage. The most significant foliage loss was generated from week 7. Similarly, Priyadarshan (2017) commented that the defoliation stage is a phenomenon in which the plant, in a stress condition due to water deficit, induces leaf fall as a strategy to reduce transpiration rates and ensures its reproduction. Furthermore, Li *et al.* (2016) reported that the foliar abscission and senescence are attributed to drought stress. Both the photosynthetically active radiation and temperature accumulated did not have a defined pattern. Therefore, the relationship of these two variables with a specific phenological process was not evident, although Borchert *et al*. (2015) and Priyadarshan (2017) mentioned that radiation and temperature have an important relationship in the phenology of the plant.

Figure 3 shows the evolution of the leaf area index of the canopy over time. The leaf area index was reduced, for all clones and localities, to a minimum value in week 7 (February) of 2016, with values of 0.52 for IAN 710 clone in Tarazá and 0.64 for the IAN 873 clone in Nechí. It corresponded to the highest defoliation stage in both locations. In Nechí for IAN 873, the reduction in the leaf area index occurred from week 5, reaching a minimum (0.63) in week 7 (Figure 4). Regarding FX 3864 clone, defoliation occurred specifically in week 7, which indicates that this clone is more efficient in terms of conservation of its leaf area than IAN 873; meanwhile, the recovery of its foliage was similar and occurred at week 11 for both clones. For week 7 in both clones, canopy openness of 60% and 50%, respectively, were obtained. The variables that best described the phenological behavior of the defoliation-refoliation processes of the rubber plants were the leaf area index of the fourth ring (LAI4), dry weight of the leaves, and percentage of canopy openness. These variables showed weeks 5 and 7 as the period of maximum defoliation, which was similar to what has been reported by Lin *et al.* (2018), who mentioned that the defoliation in rubber tree plantations of southeastern China was characterized by having a marked reduction in the leaf area index (0.5) during January.

The highest dry weight of the leaves for the FX 3864 clone was observed two weeks before IAN 873, without reflecting the decrease of the leaf area index. The defoliation stage in Tarazá was limited to week 7 for all

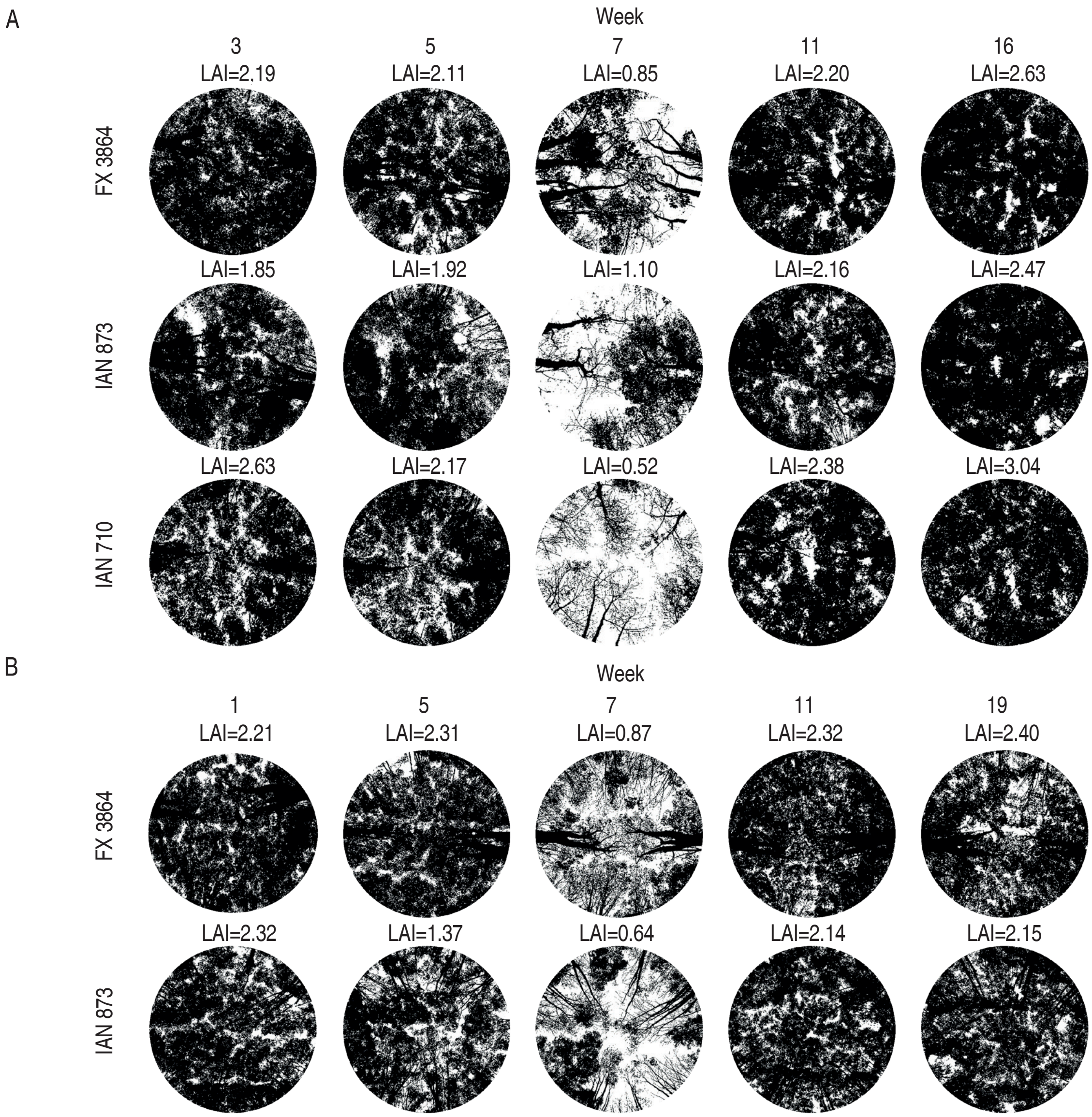

Figure 3. Evolution of the leaf area index (LAI) in the defoliation-sprouting season quantified in 2016 during the weeks (W) 3, 5, 7, 11 and 16 for clones FX 3864, IAN 873, and IAN 710 in A. Tarazá; and the weeks (W) 1, 5, 7, 11, and 19 for clones FX 3864 and IAN 873 in B. Nechí.

genetic materials. The lowest values (0.52) of the leaf area index and the highest openness of the canopy (67%) were found in IAN 710 clone. Concerning the accumulated leaf biomass, it was 3.2 and 1.6 t ha^{-1} for FX 3864 and IAN 873 clones, respectively, in Nechí. In Tarazá, it was 2.3 t ha^{-1} for both FX 4098 and IAN 873, and 2.0 t ha^{-1} for IAN 710. However, the accumulated biomass found during the whole defoliation process in this study was higher than what was reported by Meti *et al.* (2014), who mentioned that in a rubber plant production system in India with the RRII 105 clone, litter values ranged between 1.67-1.9 t ha^{-1} $year^{-1}$, which constitutes a contribution of minerals to the soil for the nutrient cycling process.

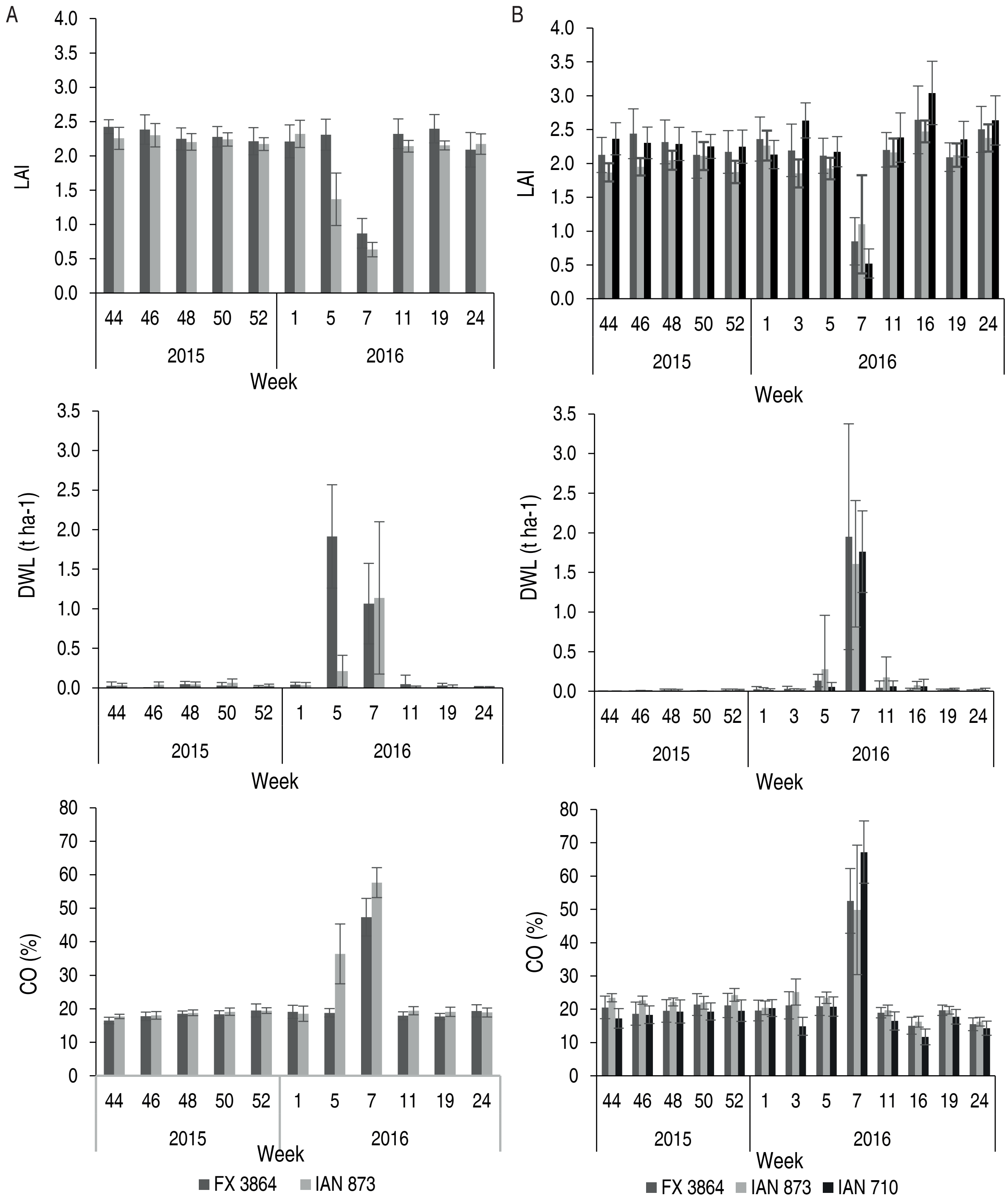

Figure 4. Behavior of leaf area index (LAI), dry weight of leaves (DWL) and canopy openness (CO) of rubber clones FX 3864, IAN 873, and IAN 710 in A. Nechí and B. Tarazá.

Regarding the climatic factors (Figure 5), the minimum temperature was similar in both locations (approximately 24 °C). However, the photosynthetically active radiation averaged per week (1,145 µmol photon m^{-2} s^{-1}) and the maximum temperature (38.5 °C) were higher in Nechí compared to Tarazá (904 µmol photon m^{-2} s^{-1} and 36 °C) (Figures 5A and 5B). In Nechí, the dry period was between December to March (week 50-2015 to week

16-2016) with a negative water balance (Figure 5C). In Tarazá, the occurrence of rains did not have the same pattern; a dry season was identified with a negative water balance in February and March (Figure 5D). In Nechí, IAN 873 and FX 3864 clones were subjected to a reduction in rainfall intensity of 97% from November to January to reach the state of greatest defoliation. As for Tarazá, defoliation was synchronized in all clones, and only a 31% reduction in rainfall intensity in the same months was sufficient for its occurrence. The occurrence of the dry season (negative water balance) before maximum defoliation was evident

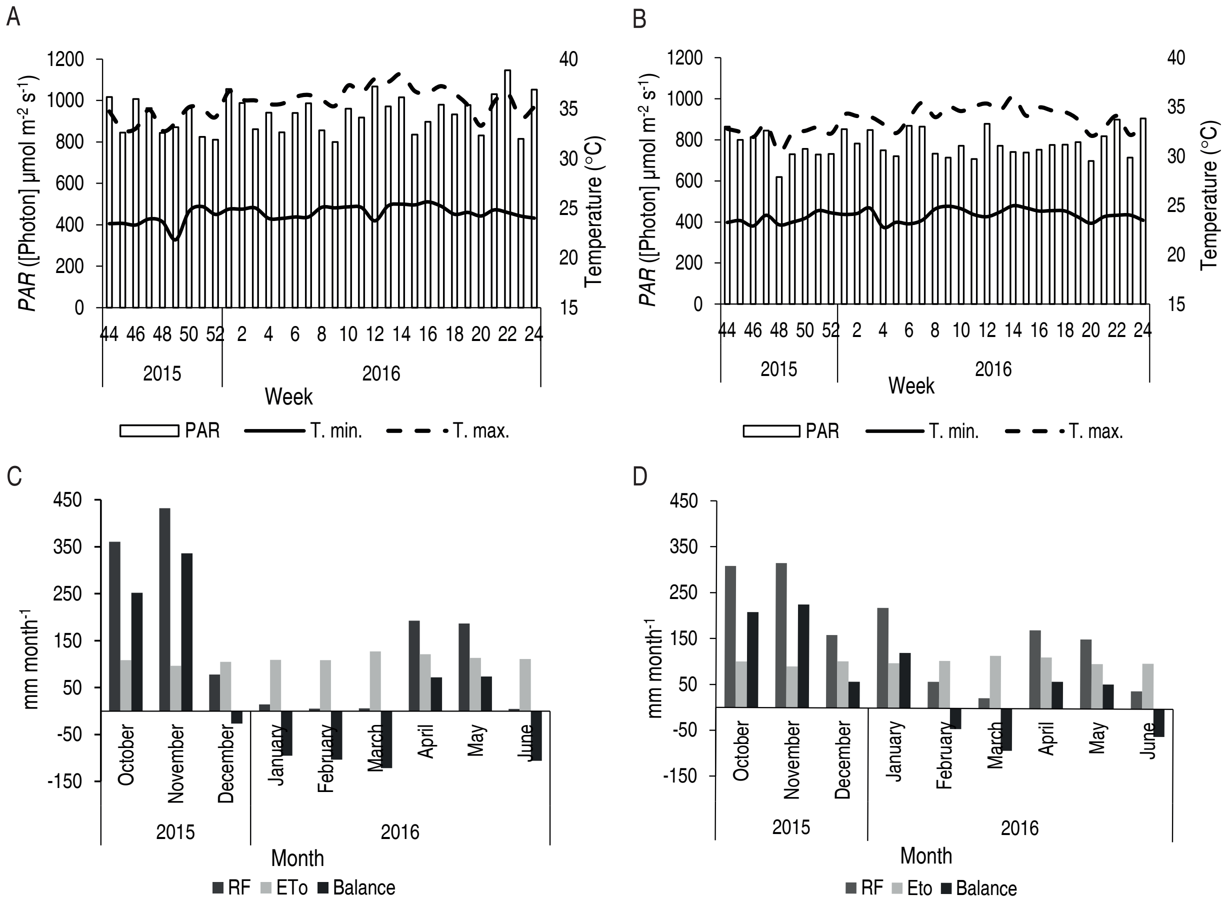

Figure 5. Behavior of photosynthetically active radiation (PAR), minimum and maximum temperatures in A. Nechí and B. Tarazá in weeks 44-52 of 2015 and weeks 1-24 of 2016. Rainfall (RF), evapotraspiration (ETo) and water balance in C. Nechí and D. Tarazá between October 2015 and June 2016.

in Nechí. However, a reduction in the intensity of rainfall was enough to trigger the phenological stage in Tarazá. This climatic factor could generate faster and more uniform defoliation (Gasparotto *et al.*, 2012).

Concerning the comparison of genetic materials (Table 1), in Tarazá, the clone with the highest leaf area index was IAN 873, and the lowest was IAN 710. The smaller leaf area recorded in IAN 710 clone was the result of higher defoliation during the evaluation period. In Nechí, the clone with the highest leaf area index was FX 3864, although the dry weight of the detached leaves was similar among clones. The intensity of the flowering evidenced by the dry weight of flowers was similar in all the clones, albeit the dry weight of seeds was higher for IAN 873 in Nechí. In this sense, Righi *et al.* (2001) mentioned that the production of rubber has a high correlation with the leaf area index since a more extended period of defoliation would be associated with a decrease in latex production. According to Guyot (2008), homogeneous and short defoliation processes generate an escape condition from phytosanitary problems, especially the South American Leaf Blight (SALB) disease. However, clones with greater susceptibility to SALB with a lower percentage of retained leaves, at the end of the annual defoliation–refoliation, could present the most intense SALB signs and symptoms (Sterling *et al*., 2019).

Table 1. Comparison of mean ranges employing the Kruskal-Wallis test and the Conover post hoc tests for the variables dry weight of leaves (DWL), dry weight of flowers (DWF), leaf area index (LAI) and dry weight of seeds (DWS) of clones FX 3864, IAN 873 and IAN 710 in the localities of Nechí and Tarazá.

Location	Clone	DWL (kg m^{-2})		DWF (kg m^{-2})		LAI		DWS (kg m^{-2})	
		Mean	Range*	Mean	Range*	Mean	Range*	Mean	Range*
Tarazá	FX 3864	0.1740	275.92 b	0.0097	284.64 a	2.16	301.31 b	0.0009	292.01 a
	IAN 873	0.1736	284.82 b	0.0258	293.63 a	2.01	350.41 a	0.0004	296.49 a
	IAN 710	0.1569	318.26 a	0.0417	300.73 a	2.26	227.27 c	0.0013	290.49 a
Nechí	FX 3864	0.2856	156.06 a	0.0199	160.71 a	2.18	180.59 a	0.0005	155.51 b
	IAN 873	0.1035	163.86 a	0.0098	159.30 a	2.03	139.79 b	0.0037	164.41 a

* Different letters mean statistical differences with 95% confidence level for the variable's mean ranges within each location

The duration of the refoliation period was short (4-6 weeks) for all the clones in both locations. It occurred in the dry season, which was similar to Silva *et al.* (2012), who mentioned that despite a water restriction, the plants could develop their foliage. However, Rivano *et al*. (2016) indicated that the defoliation and refoliation process could be extended up to 20 weeks. This short period (4 to 6 weeks) required by rubber trees to complete the defoliation-refoliation cycle is considered an advantage of rubber cultivation in the subregion of Bajo Cauca since the trees quickly recover the foliage and have the capacity to increase the latex production. Similar results were found by Maeght *et al*. (2015), who also mentioned that although the growth of the secondary roots stops during the dry season, a variable quantity of the water demanded is supplied by deeper roots. However, it is important to continue with other studies that allow us to establish whether this duration affects the lifespan and the occurrence of the dry panel and total solids content in rubber trees, and its relationship with the most critical leaf diseases.

CONCLUSIONS

Rubber tree cultivation in northwestern Colombia showed three phenological stages that groups the defoliation and refoliation events, such as maximum defoliation (minimum leaf area index), the transition stage (beginning of abscission and leaf regrowth) and refoliation (maximum index of leaf area and flowering). The defoliation stage was mainly promoted by a reduction in rainfall intensity on the municipalities of Nechí and Tarazá. Furthermore, the refoliation stage in the plantations in Tarazá and Nechí took place in the dry season, was short (4-6 weeks) and synchronized for all the clones.

ACKNOWLEDGMENTS

The results and information of this publication were obtained from the development of the project "Sistemas de apoyo para el seguimiento y gestión del manejo en plantaciones de caucho, a partir de componentes climáticos, edáficos, fitosanitarios y fisiológicos de plantaciones establecidas en núcleos productivos", executed by the Corporación Colombiana de Investigación Agropecuaria - AGROSAVIA, within the framework of the *Agenda Dinámica Corporativa*, financed with public resources through the Ministerio de Agricultura y Desarrollo Rural (MADR). The authors thank Albert Julesmar Gutiérrez Vanegas as national leader of the mentioned project, the Laboratorio de Ecofisiología de Plantaciones en el Trópico, Departamento de Ciencias Agronómicas, Universidad Nacional de Colombia for its Eco physiological instruments, and to the rubber producers' associations ASCULTICAUCHO and ASCABIA for supporting this study.

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