VALIDATION OF THE CHEMICAL CONTROL FOR COFFEE LEAF RUST IN THE SUSCEPTIBLE VARIETY CATURRA IN THE SOUTH OF THE DEPARTMENT OF HUILA, COLOMBIA

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Abstract

CLR (*Hemileia vastatrix*) is the disease with the greatest economic and social impact on coffee production in the world, causing losses of up to 50% of productivity in susceptible varieties without proper and timely management. The department of Huila is the current largest producer with approximately 19% of production, going from 136,000 ha planted in 2012 with 61% in susceptible varieties, to about 150,000 ha in 2020 and 30% in susceptible varieties, mainly in the southern area of the department, indicating the advancement of the department's coffee sector. However, there is still an important area under threat from coffee rust, which must be controlled and reduced. The objective of this work was to validate the chemical management strategy for rust in commercial crops of the susceptible variety Caturra in the south of the department of Huila (Colombia). The evaluation was carried out in two commercial crops of var. Caturra at two altitudes at 1,410 and 1,280 m, where each batch was divided into three plots to monitor the blooms and the percentage of incidence of the disease from 2016 to 2018. The validation criteria consisted of: fixed calendars (CC1), adjustment of the main flowering (CC2), farmer (CA3), and finally without disease control (SC4). The incidence in critical periods was above 30% of the level of economic damage, directly accompanying the physiology of production. The criteria (CC1-CC2) and with the use of the recommended fungicide showed a lower incidence (AUDPC) compared to the other criteria evaluated, presenting a positive effect on the control of the disease, allowing a retention of foliage and delaying the curve of the disease reducing to 30% the incidence in critical periods. In addition, the risk of Colombian coffee growing has increased in recent years, especially due to the climatic variability that generates advances or delays in the peaks of the disease and generating reductions in the incubation periods.

keywords: Diseases, CLR, Coffee, Chemical control, main flowering.

Introduction

The coffee crop is considered one of the most important and valuable agricultural products in the world, ranking second in market value as a raw material after oil. In Colombia, coffee (*Coffea arabica*) contributes to the national economy, contributing approximately from 0.6 to 0.9 of the national GDP from 15 to 25% of agricultural GDP, depending on international prices and the exchange rate, and from which subsist about 540,000 families that cultivate some 660,000 farms in 603 municipalities in 23 of the 32 departments of the country, being the third world producer of coffee with approximately 9% of the international market (FNC - Cenicafé, 2018). Despite the global economic importance of coffee, there are several factors that can seriously limit production, including diseases, where CLR stands out.

Coffee leaf rust (CLR), caused by the fungus *Hemileia vastatrix* Berk & Br., continues to be the disease of greatest importance and economic impact for the coffee world, directly affecting the leaves, reducing photosynthetic capacity, and consequently generating severe defoliation and fruit production. of low weight and quality, impacting the productivity and sustainability of the crops strongly affected in the following years. In Colombia, the losses in quality and quantity are evaluated from 23 to 50% of the production in susceptible varieties such as Típica, Borbón, Caturra, Geisha, Maragogipe and some introduced Catimores, among others of unknown origin of the *Coffea arabica* species; In addition, when they do not have adequate and timely management, these losses can reach up to 90% in other countries (Kushalappa & Eskes, 1989; Rivillas *et al*., 2011, 2017; Avelino *et al*., 2015; Zambolim, 2016).

When CLR arrived in Colombia in 1983, the National Federation of Coffee Growers of Colombia and Cenicafé counted on the development of improved varieties with durable resistance to CLR based on genetic diversity, generating composite varieties such as Colombia (Moreno and Castillo, 1984), and then Castillo® varieties (general, regional and zonal), Tabi and Cenicafé1 (Moreno,2002; Alvarado *et al*., 2005; Alvarado, 2011; Flórez *et al*., 2016, 2018) as a productive strategy, widely adapted and sustainable. During the period from 2008 to 2011, the events of the “winter wave” such as the climatic variability of “La Niña”, along with the high incidence of CLR, nutritional deficiencies due to high costs of fertilizers and aging of crops, caused estimated losses of 30% or more of the harvests (Avelino *et al*., 2015). Therefore, the FNC, with the support of the National Government, established plans for the restructuring and renewal of coffee farming based on planting mainly the Castillo® variety, resistant to CLR with greater productivity and regional adaptability.

CLR is a disease that accompanies the physiological development of the crop, therefore, the epidemic within a production cycle begins shortly after flowering and reaches its maximum before harvest. The main source of inoculum lies in the affected leaves remaining from the past epidemic of the crop itself or neighboring crops. In susceptible varieties such as Caturra, incidence levels of 5 to 10% at the beginning of phase II of the epidemic is the economic threshold for action and is sufficient to initiate management through chemical control of the disease, and up to 20% incidence between 30 and 60 days prior to harvest, to stay below a 30% economic damage level. This requires the protective or curative action of fungicides based on copper, triazoles or strobilurins that are applied according to three criteria: 1) levels of infection or incidence, 2) fixed calendars based on historical regional flowering and harvest patterns, and 3) adjustments to the date of occurrence of the main flowering of the lot. Additionally, average daily CLR increase rates of 0.19% and higher from 90 days after flowering are considered severe and will cause damage and production losses (Sierra and Montoya, 1995; Rivillas *et al*., 2011, 2017, 2018).

However, coffee growing in Colombia, being influenced by the behavior of climatic variables in the different agroecological zones of each region, affects water availability in the soil, air temperature, sunlight and relative humidity. generating changes in flowering and harvest patterns. The strategies for the integrated management of CLR in susceptible varieties must be adjusted under application criteria to advance timely control actions, considering the agronomic management of the crop, the distribution of the harvest, the evaluation of the development of the disease, climatic conditions and adequate chemical control with fungicides with appropriate application technologies (Rivillas *et al*., 2011, 2017). Therefore, this study aimed to validate the chemical control strategy for CLR in commercial lots of the susceptible variety Caturra in the south of the department of Huila, Colombia, comparing the recommendations of Cenicafé based on previous scientific research, with the autonomous criteria by the owner coffee grower, versus a control without any control of the disease.

Altitude m.a.s.l.	Village	Age (year)	Planting Distance (m)	Planting density (pl./ Ha)	Effective trees
1.282	El Maco	1.4	1.40 x 1.50	4.762	2.381
1.410	Cabeceras	2.2	1.20 x 1.40	5.952	5.357

Table 1. Description of the commercial crops with the Caturra variety selected for monitoring the methods of integrated management of CLR.

Material and Methods

Experimental area

The study was carried out between the period from April 2016 to December 2018, in the municipality of Pitalito (Huila). Colombia two commercial crops of coffee variety Caturra highly susceptible to rust were selected; Starting the monitoring at 1,410 m.a.s.l. as of April 2016, and at 1,280 m.a.s.l., as of April 2017. (Table 1).

Each area was divided into three similar plots, and the weekly recorded of blooms and CLR incidence percentage was followed up and monitored. For all the lots, the agronomic management of the crops was unified under the general recommendations of Cenicafé, supervised by personnel assigned to the project, and the integrated CLR management methods validated were the following:

Cenicafé Management (CC1) - *fixed calendar criteria*: Chemical control based on the history of the main flowering periods according to the harvest area, in this case with the main harvest in the second half of the year, making applications on recommended fixed dates. in the first week of May, third of June and between the first and third of weeks August, depending on the recommended fungicides (Rivillas *et al*., 2011).

Cenicafé Management (CC2) - *adjustment criteria for main flowering*: Chemical control based on the date of the main flowering according to the relative quantification of the flowering, making the applications from 60 days after the main flowering occurred, continuing the applications with intervals of 45 to 60 days, completing two or three applications before 180 days, depending on the recommended fungicides, their composition and interval of action (Rivillas *et al*., 2011, 2017).

Farmer Management (CA3) - *Farmer Control*: Chemical control under the farmer's own decision criteria, with applications on variable dates with fungicides that the farmer considered autonomously, both recommended and not recommended.

No Treatment Control (SC4) - *NTC*: To verify under natural inoculum the complete development of the disease and its epidemic in the lots evaluated during the study period. A commercial lot of Caturra variety coffee was selected for each altitude (1,280 and 1,410m), without the use of fungicides to control CLR.

CLR incidence

Determined by the number of leaves with sporulated rust divided by the total number of leaves present, according to the equation (Campbell & Madden, 1990). For each monitored plot, 60 trees (1/K) were randomly and systematically selected monthly, and from each of them a branch of the productive third with high production and with more than 10 leaves present was evaluated, determining the percentage of rust incidence.

$$\textbf{Incidence (\%)} = \frac{\mathrm{NLR}}{\mathrm{NTL}}\ x\ 100$$

Where: **NLR:** Number of leaves with CLR in 60 trees evaluated; **NTL:** Number of total leaves present in 60 trees evaluated

Daily Incidence Progress Rate

It is calculated as the difference between the intensity of the disease between each pair of evaluations and divided by the number of days between each pair of points or adjacent evaluations (Vanderplank, 1963), comparing the speed of development of the disease under each method of control.

$$r = \frac{(Y_1 - Y_0)}{(X_1 - X_0)}$$

Where: ***Y_0*:** Evaluation of the initial incidence percentage.; ***Y_1*:** Final incidence percentage evaluation.; ***X_0*:** Initial day of the evaluation.; ***X_1*:** Final day of evaluation.

Area under the disease progress curve

Estimating the area under the disease progress curve (AUDPC), calculating the average intensity of the disease between each pair of adjacent time points between evaluations (Madden *et al*., 2007). The AUDPC stabilizes the variance of the incidence values of the disease measured in percentage within the control or control treatments throughout the measurement season within the crop.

$$\text{AUDPC} = \sum_{i=1}^{n-1}\left(\frac{Y_i + Y_{i+1}}{2}\right) x\ (t_{i+1} - t_i)$$

Where: ***n*:** Number of evaluations.; ***Y*:** Incidence of rust in percentage.; ***t*:** Evaluation period.; ***Y_i*:** The percentage of incidence of CLR (%) in the ith evaluation.; ***$Y_{(i+1)}$*:** The percentage of incidence of CLR (%) in the following evaluation to the ith.; ***$t_{(i+1)}$*:** The evaluation time or period following the ith.; ***t_i*:** The ith time or evaluation period.

Control effectiveness

Due to the highly variable or heterogeneous incidence among trees of the lot under study, the formula of Henderson & Tilton (1955) was used. In this case, it was only calculated for the year 2018 when the control was made with the adjustment criteria for the main flowering date, as shown in Supplementary Tables 1 and 2.

$$\text{Efficacy (\%)} = \left[1 - \left(\frac{\text{Ca}}{\text{Ta}}\right) x \left(\frac{\text{Td}}{\text{Cd}}\right)\right] x\ 100$$

Where: ***Ta:*** Incidence in the treated plot before applying the treatment.; ***Ca:*** Incidence in control plot without control before applying the treatment.; ***Td:*** Incidence in the treated plot after applying the treatment.; ***Cd:*** Infestation in control plot without control after applying the treatment

Foliage retention

It was determined based on the total number of leaves present in a branch of each of the 60 trees evaluated monthly in each treatment during the validation period. The opposite variable would be defoliation or loss of foliage, which is a direct consequence of CLR.

Climatic data

The meteorological data used in this study were obtained from Campbell® micro-meteorological stations located in the municipality of Pitalito, in the coffee lot where the research is carried out at 1,280 m.a.s.l. and on a farm adjacent to 1,347 m.a.s.l., which are part of the coffee meteorological network of the National Federation of Coffee Growers (FNC) and Cenicafé established for this project with the General System of Royalties and the Dept. from Huila.

Statistical analysis

The data for AUDPC of incidence and foliage retention were processed to determine the differences between management criteria, performing a comparison of means through the Tukey test ($p < 0.05$), under the packages lme4, emmeans, easyanova, PerformanceAnalytics, agricolae, viridis, and tidyverse, using codes on the RStudio platform (RStudio, 2019).

Results and Discussion

Flowering Registry

The historical periods of flowering in the Department of Huila have been established between January to March and between August and October, with variations depending on climatic aspects that determine the times of high and concentrated flowering in the different agroecological zones characterized (Salazar *et al*., 2019) (Figure 1A). During the evaluated periods there were alterations in the productive cycles (flowering to harvest) represented in advances or delays in the main blooms compared with the regional historical ones. The monthly behavior of flowering during the period from April 2016 to December 2018 in the municipality of Pitalito in the two altitudes evaluated, in the susceptible variety Caturra presented the main harvest pattern for the second semester and the mitaca or of less magnitude in the first semester, relatively similar to the historical one (Figures 1B,1C). For the production cycle of 2017, the main flowering occurred at the end of December 2016, which is anticipated with respect to historical records, while for the years 2016 and 2018 there were blooms in the usual times, between February and March.

Some variations or changes in the flowering and harvest pattern were found, depending on the altitude, the year and the associated climatic conditions that generated changes in the magnitude and distribution of the blooms. For the plot at 1,280 m, the main flowering that occurred in December 2016 accounted for about 40% of the second semester harvest, and the dispersed blooms accumulated between February and March 2017 for about 30%, while the main blooms of the 2018, which occurred at the end of February, accounted for about 60% of the second semester harvest. Therefore, these changes and dates of occurrence marked the beginning of the slow phase of the respective CLR epidemic, and therefore affected the efficiency in decision-making of the application system on fixed dates or calendars, and validated the criteria of application under the adjustment of the main flowering period for 2018 (Rivillas *et al*., 2011, 2017) (Figure 1B,1C). The control periods and the fungicides used for the adopted Cenicafé recommendations are presented in Table 1.

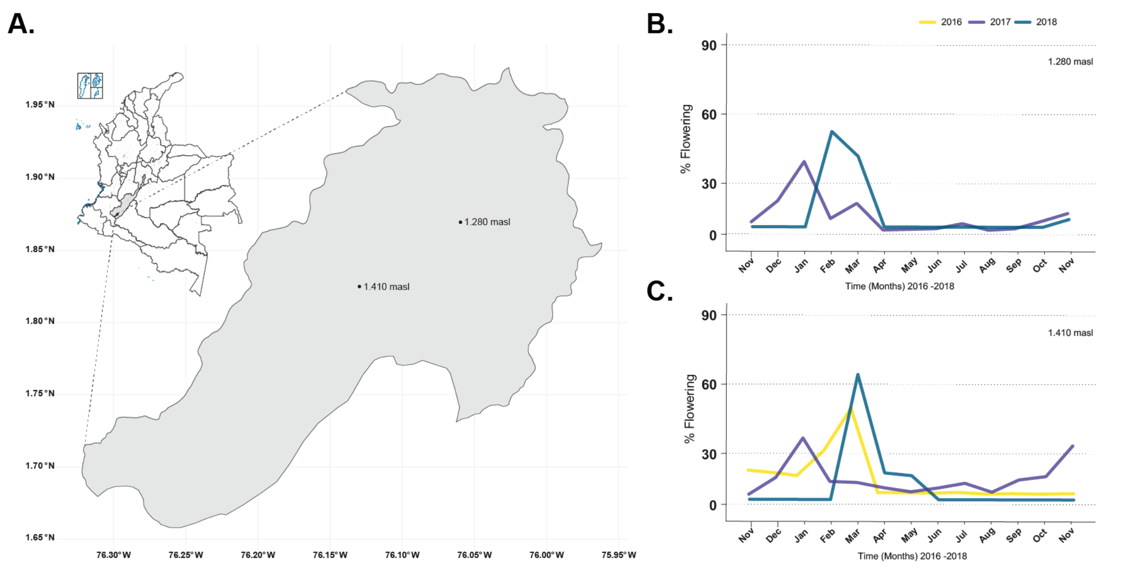

Figure 1. Dynamics of the relative percentage of flowering recorded in coffee crops var. Caturra susceptible to rust in the county of Pitalito (Huila), from October 2015 to October 2018 (blooms corresponding to the 2017-2019 harvests). **A.** Geographical location of the experimental area. **B.** at 1,280 m.a.s.l. **C.** at 1,410 m.a.s.l. The period for quantifying blooms for each harvest year, it was carried out between November 1 and the following October 31.

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Altitude m.a.s.l.	Year	Management methods	Flowering Occurrence Month	Chemical product	Time of Application (fortnights)													
					Feb		Mar		Apr		May		Jun		Jul		Aug	
					1	2	1	2	1	2	1	2	1	2	1	2	1	2
1.410	2016	Fixed calendar	Feb (1st week)	Azoxystrobin+ Cyproconazole										X			X	
	2017	Fixed calendar	Dec (4th week) /16	Cyproconaloze Thiamethoxam + Cyproconazole		X					X					X		
	2018	Main flowering	Feb (4th week)	Azoxystrobin+ Cyproconazole						X			X		X			
1.282	2017	Fixed calendar	Dec (3rd week) /16	Thiamethoxam + Cyproconazole							X				X			
	2018	Main flowering	Feb (4th week)	Azoxystrobin+ Cyproconazole							X		X		X			

Azoxystrobin+ Cyproconazole (Amistar Ztra 28SC), Cyproconaloze (Alto 100SL), Thiamethoxam + Cyproconazole (Verdadero 600 WG)

Table 2. Schedule of applications to control coffee rust at 1,280 and 1,410 m.a.s.l. under two control criteria using fungicides recommended by Cenicafé (Rivillas *et al*., 2011)

Dynamics of the CLR Incidence in the field

In the study of the validation of the chemical management strategy for the control of CLR in commercial lots in the south of the department of Huila, a high intensity of the disease was observed in the two altitudes monitored from the beginning of the measurements, presenting variations in the treatments or criteria established during the evaluated period.

The dynamics of the progress of the incidence of CLR at 1,410 m.a.s.l. Since 2016 it was very high as a consequence of a previous year of “El Niño” characterized by a significant reduction in rainfall, lower relative humidity, higher temperatures and sunlight. The incidence for the control plot Without Control (SC4), registered values higher than the level of economic damage of 30% from early in the critical period of beginning of grain filling, in June, about 120 days after the main flowering, and reached the maximum peak of the epidemic in August with 75%, in full grain filling stage. The critical period closed above 46% of CLR incidence, at the end of the harvest in December the CLR was 51%, and the epidemic advanced until the first two months of 2017 with high levels (Figure 2B). This high incidence of CLR from early 2016 accelerated premature defoliation from the month of July, and continued to rise to severe levels of 30 to 50% between September and October 2016 when the harvest arrived, and was maintained until the first quarter of 2017 with values greater than 30% incidence.

As a consequence of the high epidemic of CLR and defoliation, the trees in the plot (SC4) registered continuous epidemics from 2016 to 2017, starting with the blooms in December 2016, and the decrease in incidence until April 2017 reflected significant leaf loss and new tissue development. As of April 2017, the increase in incidence is resumed until reaching the maximum peak in full harvest in September with 49%, an incidence that remained between 30 to 44% until the end of 2017 and the first two months of 2018. The Lower incidence is also related to the influence of the biennial cycle of coffee production, given that 2016 was a year of high production and the CLR epidemic increased, the following year it tends to decline.

In 2018 at 1,410 m.a.s.l. The CLR epidemic began with a high inoculum remnant of 32% in January and 44% in February, and with an incidence of 28% when the main concentrated blooms and high numbers occurred at the end of February and the beginning of March. A clear accelerated increase in CLR was observed when the critical period of grain formation and filling and accumulation of dry matter reached

90 days after main flowering, exceeding the economic damage level of 30% of CLR from May of 2018 with 36%. Maximum incidence peaks were reached very early, from June and July with 57% to 62% incidence, sustaining these high levels of disease until the end of the critical period and the end of the 2018 harvest with a maximum peak in October with 65%. Consistent with the incidence dynamics, the defoliation percentage curve can be observed for the control plot without application (SC4) in 2018, where premature defoliation peaks are observed since May, in the middle of the critical period, reaching levels close to 45 % just before harvest. All this accumulated premature defoliation affects the filling and accumulation of dry matter in the beans, causing losses in production and lower physical quality for coffee, which has been documented for CLR (Rivillas *et al*. 2011, 2017).

Under the Farmer's own criteria (CA3), it was not possible to adequately reduce the development of the disease in 2016, it barely delayed the incidence of CLR by one month from reaching 71% incidence values between September and October, at harvest arrived, but the maximum peaks occurred in November and December with about 82 and 76% respectively, as high as in the control plot Without Control (SC4) (Figure 2B). However, this high incidence, defoliation was low during 2016, and only at the end of the harvest did it reach almost 50%, which is expected. The delay in the epidemic and less defoliation could be due to the two fungicide applications between the months of May and July, one of them recommended by Cenicafé, although they were unable to lower the epidemic curve due to its late application.

For 2017, starting from the December 2016 blooms, the incidence of CLR in the CA3 plot started high with 40% and 35% in January and February respectively, and with the increase in incidence three months after flowering, affecting the critical period between 3 and 7 months of fruit and grain filling, all the time above the damage level of 30% incidence. The maximum peak of the epidemic was reached at the beginning of the harvest in August and September 2017 with 57% to 54% respectively. This increase in incidence since April 2017 was accompanied by normal defoliation close to 20% between May and July and remained relatively stable until the end of the year, which is also the effect of the high incidence of CLR and repeated harvest passes. , product of dispersed blooms of the first four months of 2017. Definitively, the applications of Cyproconazole fungicide by the coffee grower in April and at the end of August 2017 were not appropriate, nor did they use the formulation recommended by Cenicafé, therefore, they did not reduce the incidence, and that the reduction observed is due to the arrival of the harvest season due to the fall of affected leaves.

In 2018 for the plot at 1.410 m.a.s.l. of management of the coffee grower (CA3), the incidence of the first quarter was between 18 and 25% when the blooms arrived, an incidence that quickly reached 40% since April, exceeding the damage level, without yet starting the critical period of grain filling. This increase was generally maintained above 55 and 60% throughout the critical period between 90 and 210 days after main flowering, reaching the maximum peaks between 84 and 90% of CLR incidence at harvest and its end in December 2018. Therefore, it was possible to temporarily stabilize the daily CLR progress rate that exceeded 0.35%, which was very severe (Table 2), and that later, in the harvest period generated an increase of the incidence of the disease up to 90% that caused severe damage. The high incidence throughout the critical period was accompanied by defoliation greater than 25 and 30% all this time, premature defoliation that reduces the photosynthetic tissue responsible for filling fruits and

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grains. Once again, the two applications of Cyproconazole fungicide carried out at the coffee grower's own criteria in May and at the end of July, were neither sufficient nor capable of reducing the incidence of CLR below 50% given their lack of opportunity as they were late with respect to the main flowering, or use the recommended fungicide formulation.

Comparatively, the management given by Cenicafé for the plot at 1,410 m.a.s.l. in 2016 under the criteria of control by fixed calendars (CC1), where the fungicide was used with a combination of active ingredients Cyproconazole + Thiamethoxam applied to the soil in June and in August, it managed to significantly reduce the CLR epidemic, maintaining the incidence below or slightly higher than 30% during the middle of the critical period, reaching 34% and 38% in August and September prior to harvest, presenting the peak of incidence in the harvest period with average values of 46 in October and 68% in November (Figure 2B), which is expected at the end of the epidemic. However, due to the advanced stage of the epidemic coming from a strong "El Niño" event in 2015 and part of 2016, with accentuated periods of moisture deficit in the soil, which is required to absorb the applied fungicide, and Due to high previous production, they did not facilitate greater control of the disease, added to the weakening and wear of the crop.

With the same CC1 criteria, an attempt was made to manage in 2017, under a Neutral climatic condition, with more rainfall and therefore more moisture in the soil. The same CLR dynamics of the previous year was not registered, given the high levels of CLR incidence with which the lot came, higher than 44% when the main flowering occurred in December 2016. However, due to the defoliation registered close to 20% between January and February 2017, in order to decrease the daily CLR progress rate of 0.26%, and prevent further premature defoliation, an initial application of Cyproconazole was made, 45 days after flowering, in the second half of February 2017, earlier than recommended for a fixed calendar, and before starting the critical period. Then, the two applications were made in May and July of the fungicide Cyproconazole + Thiamethoxam to the soil recommended by the fixed calendar system. In this case, in 2017, the high inoculum pressure and the predisposing factors present did not allow us to wait until the first week of May for the application of a preventive control according to a fixed calendar, since the crop would be severely impacted by the disease. and faster. These two applications managed to maintain the incidence of CLR around 30% until the end of the critical period until July, reaching 51% in August as it was already in harvest, while defoliation with values lower than 15% remained stable or lower, which which is normal and adequate for the harvest season (Figure 2B).

Under the CC1 criteria, there were two successive epidemics at values of 50% incidence or more, and the applications were made at the time established in the fixed calendars (90 and 180 days after main flowering), but the control was relatively late due to the fact that early blooms had occurred in the month of December 2016, an advance with respect to the historical ones of at least 2 to 3 months. Therefore, the additional and early application of Cyproconazole at the beginning of the critical period of fruit filling, reduced the impact of the disease since the control by fixed calendar would not have been effective for the year 2017, because it had not started when phenologically it was due, and with CLR levels below 30%. The CLR incidence values in the Cenicafé management criteria (CC1) were lower with respect to the epidemic observed under the Farmer's criteria (CA3) (Figure 2).

Due to the climatic variability of the coffee zone, which has been more evident in recent years, the vegetative, reproductive and productive behavior in coffee cultivation has been affected (Vélez *et al*., 2000; Ramírez *et al*., 2011, Rendón and Montoya, 2015; Agroclima, 2020). Therefore, based on the record of the blooms in the evaluated lots, the management of the disease was adjusted for the year 2018 under the main blooming criteria CC2 for the commercial plot. The start of the applications was determined 60 days after they occurred; that is, adjusted to the date of the main flowering that occurred in the fourth week of February, beginning in the month of April and not in the first fortnight of May, as recommended in management under a fixed calendar criteria, with intervals of 45 days between the three applications of the combination of active ingredients Cyproconazole + Azoxystrobin (Rivillas *et al*., 2011).

In 2018, the blooms occurred at the beginning of February, and the increase in the CLR progress curve began, which reached 41% in April, just before starting the critical period, and at which time it was recommended. the first application of the fungicide Cyproconazole + Azoxystrobin 60 days after the main flowering, in mid-April. The CLR epidemic continued to rise until reaching a maximum peak in June with 53% and defoliation of 30%, in the middle of the critical period, at which time the second application of the fungicide occurred at 105 days after the main flowering, which reduced the disease progress curve and premature defoliation. Then the third and last application was made 150 days after flowering, to continue reducing incidence and defoliation below 40%, reaching harvest time in September and October with CLR in 32% and 34% respectively, and defoliation less than 20%, within expected normal ranges.

The impact of the epidemic on the CC2 criteria was lower in 2018 in terms of lower incidence values recorded and its progress within the critical period of grain filling and dry matter accumulation between 90 and 210 days after main flowering, with with respect to the highest CLR and defoliation values observed in CA3 and SC4 (Figure 2B).

In the next part of the validation in the management of CLR, it was carried out at a lower altitude, with greater favorability for the disease and under the same criteria adopted previously, it was started in parallel in April 2017 in a batch of var. Caturra at 1.280 m.a.s.l. In criteria SC4, CLR measurements began with an incidence of 19%, just at the beginning of the critical period of grain filling, after 90 days of flowering. The main blooms occurred at the end of December 2016 followed by other scattered blooms between February and March 2017 (Figure 1B), due to environmental conditions, coming from a 2016 “El Niño” event in the first semester, and entering in its first main crop after the renewal by zoca in November 2015. The CLR epidemic in general was not high, and the maximum peak of CLR within the critical period was 38% in July, closing with the maximum peak of the epidemic in September with 60% when the harvest arrived, and its end was around 25%. Regarding defoliation, the high peaks of CLR incidence in July and September marked the maximum defoliation values with values of 15% or less, which is normal for a crop in its first harvest (Figure 2A).

However, the low intensity of the 2017 epidemic, the next epidemic for 2018 began with higher values after the main flowering occurred at the end of February, indicating a 35% incidence of CLR in March, and already for the beginning of the period. critical fruit filling in May, the incidence was by 46% exceeding the damage level of 30%. This increase in the CLR progress curve continued reaching a maximum peak within the critical period in July (150 days after flowering), with 63% CLR, generating an important premature defoliation close to 45% that remained high until the end, affecting grain filling. The high values of CLR incidence reached up to 65% and defoliation above 45% that were maintained until the peak of the epidemic when the harvest arrived in October 2018.

In the criteria of Farmer CA3, fungicides not recommended by Cenicafé were used that managed to reduce the daily progress rate of the disease to 0.13% and in the harvest period it obtained incidences of less than 10%. For the year 2018, the farmer modified his criteria and carried out the control imitating the CC1 criteria, with applications in the months of April and July, but again using a non-recommended fungicide. Inefficiency in the control was observed, therefore, a reduction in the daily rate of progress of the disease was not achieved, which remained at 0.30%, which being higher than 0.19% considered as severe (Table 3, Figure 2A).

When comparing the CC1 fixed calendar criteria in 2017, a daily CLR progress rate of 0.66% was obtained, which is very high, due to the late control resulting from fungicide applications far from the appropriate date. according to the anticipated main flowering, presenting average CLR incidences of 50% in the harvest period. In 2018, the adjustment criteria for the main blooms that occurred at the end of February and the beginning of March were validated, with two applications of fungicides at 45-day intervals each according to the recommendation of Cenicafé for the combination of active ingredients Cyproconazole + Azoxystrobin (Amistar ZTRA 28SC). This management plan significantly reduced the rate of CLR progress and maintained lower incidence levels close to 30% during grain filling until harvest (Figure 2A).

During all the flowering to harvest cycles evaluated at the two altitudes, the disease progress curve represented by the control Without Control SC4 (natural development of the disease), presented the same trend and followed the physiology and phenology of the crop, observing variations in the daily progress rate of the disease between 0.19% and 0.61% incidence, which is severe, evidencing the effect of the lack of CLR control on the defoliation variable, according to studies carried out by Sierra and Montoya in 1994 (Figure 2, Figure 3).

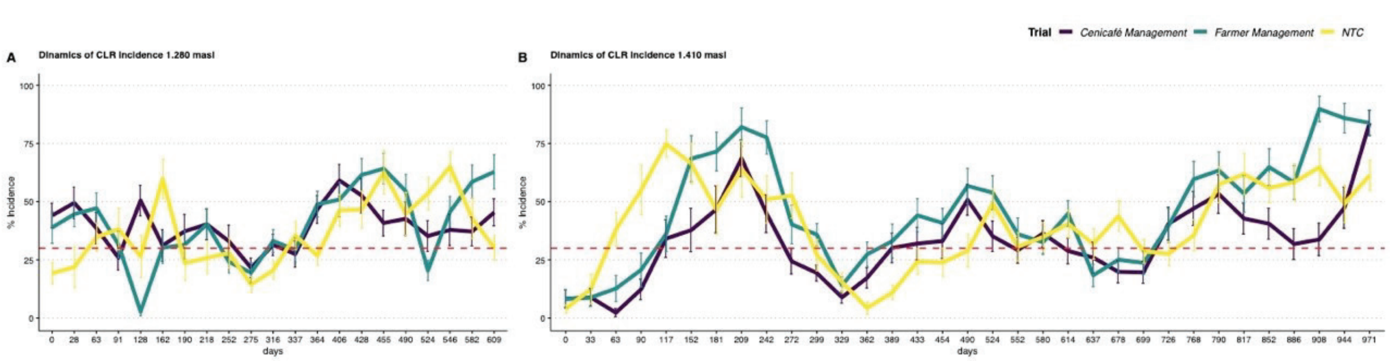
The disease progression curve is directly related to the physiology of coffee fruit production and the phenological state of the plant, starting from the blooms usually generated at the beginning of the rainy seasons. The development of the epidemic begins slowly when it infects mature and newly formed leaves, then goes through a phase of rapid or accelerated growth during the stage of formation and filling of the fruits, and ends in a maximum phase when it reaches the highest incidence. and severity in months prior to or during the coffee harvest (Kushalappa and Chaves, 1980a; Kushalappa and Martins, 1980b; Kushalappa, 1981; Rivillas, 2011; Avelino *et al*., 2015; Hinnah *et al*., 2018). In general, the greatest increase in the disease was observed during the months of grain filling and fruit maturation, and the maximum incidence during harvest, which consequently generates a greater impact if chemical control in susceptible varieties is not timely or adequate. technically.

The variations in the dynamics and the peaks of the CLR epidemics generated by the changes in the main blooms with respect to the historical ones, presented an effect of the management strategies. Therefore, the CLR attacks immediately after the main flowering periods are the ones with the greatest impact, favoring early defoliation and the loss of photosynthetic area that feeds the young fruits (Villarraga and Baeza, 1987; Baeza and Villarraga, 1988; Sierra and Montoya, 1994; Chalfoun *et al*., 2015). The longer the start of chemical control takes place from the critical time, the greater the advance of the epidemic and therefore the greater the damage. There is therefore a direct relationship between the levels of CLR infection registered during the fruit filling period and the reduction in coffee production, the vegetative development of the plant is delayed and the production of the following year is negatively affected (Villarraga and Baeza, 1987; Baeza and Villarraga, 1988; Matiello *et al*., 2008; Rivillas *et al*., 2011; Chalfoun *et al*., 2015).

Although there was no reduction in fungicide applications, for both cases, the results reflect that the adoption of the adjustment criteria depending on the date of the main flowering, starting the CLR management 60 days after that flowering occurred and continuing with One or two applications at intervals of 45 or 60 days, depending on the recommended fungicide, is efficient in controlling the disease, reducing the daily rate of progress and reducing the incidence by almost 30%. With this management scheme, the infective processes of the pathogen are affected, which is positively reflected in lower defoliation and audpc (Figure 2, Figure 4, Figure 5). In the same way, the efficiency of chemical control is affected when applications are late or without adequate technical criteria, generating a greater accumulation of potential CLR inoculum and a higher percentage of leaf tissue affected with damage between epidemics, as it is a polycyclic disease. and polyetic, when conditions are favorable or in seasons closer to harvest time (Rivillas *et al*., 2011; Zambolim, 2016; Belan *et al*., 2019).

These results clearly indicate that, given the anticipation or delay of the blooms in relation to the historical patterns of the area, the CLR control should be adjusted at the beginning to a maximum of 60 days after the main blooming occurred, especially if it had been controlled. based on the recommended fixed calendars (Rivillas *et al*., 2011, 2017). Although chemical control measures are established (Figures 2A, Figure 3A), which have obviously had an impact on reducing the incidence of the disease, it is becoming more complex or difficult to reduce the percentages of CLR incidence in a highly susceptible variety such as Caturra of the indicated percentages of economic threshold and level of economic damage, which correspond to 5 and 10% at 60 and 90 days after flowering and 30% at 120 days, respectively (Villarraga and Baeza, 1987; Baeza and Villarraga, 1988; Sierra and Montoya, 1994; Rivillas *et al*., 2011). Hence, since the late 1980s, it has been indicated that applications based on incidence or levels of infection start from 5 to 10% of CLR incidence 60 days after the main flowering occurred. In addition to monitoring the blooms and the incidence of the disease before deciding to apply, precautions should be considered in the use of some fungicides due to their withdrawal periods and re-entry to the lot that must be maintained for each product and thus avoid impacts. health and the environment (Vasileiadis *et al*., 2017; FNC - Cenicafé, 2018).

Figure 2. Comparison of the dynamics of the percentages of incidence and defoliation caused by rust under two management criteria in the susceptible variety Caturra in the validation plots in the county of Pitalito (Huila). **A.** at 1,280 m.a.s.l. **B.** at 1,410 m.a.s.l.



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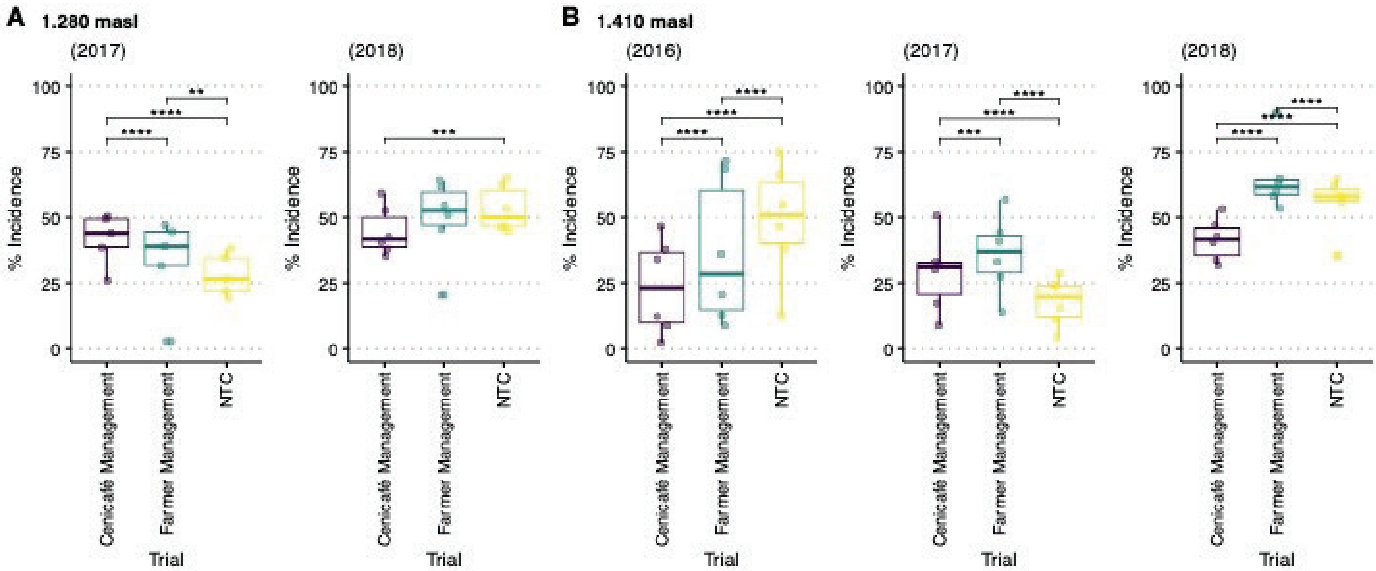


Figure 3. Boxplot of comparison of the percentages of incidence caused by Coffee leaf rust under two management criteria in the susceptible variety Caturra in the critical period critical period of evaluation starting 60 after days main flowering at the beginning of harvest (formation and filling of fruits) in the validation plots in the county of Pitalito (Huila). **A.** in the period 2017 - 2018 at 1,280 m.a.s.l. **B.** in the period 2016 - 2018 at 1,410 m.a.s.l.

Analysis of the area under the CLR progress curve.

The result of the variance analysis of the data related to the area under the incidence progress curve and the number of leaves with CLR for the different altitudes in which the management validation was carried out, showed significant differences ($p < 0.05$) (Figure 4). A significant effect was presented in the interaction criteria of control per year on the variables incidence of CLR, number of leaves with CLR, defoliation and number of total leaves, demonstrating that the chemical control criteria used affected the disease progress curve by altering the pathosystem.

When analyzing the incidence results for the validation at 1.410 m.a.s.l., a positive effect of the control criteria by Cenicafé CC1 was observed in the years 2016 and 2017 CC2 in 2018, due to the fact that there were fewer areas under the curve (AUDPC) with 23.46, 30.09 and 41.51 percentage incidence units respectively, when compared with the Farmer Control CA3 and Without Control SC4 (Table 3, Figure 4). Likewise, for the year 2018 at 1.280 m.a.s.l., adjusting the control based on the control criteria by Cenicafé at the date of the main flowering (CC2), an area under the curve of the progress of the incidence of minor CLR was obtained with respect to the Farmer Criteria (CA3), and although in some years there were no significant differences when compared with the No Control criteria (SC4), the fact is explained by the defoliation generated by the high incidence in previous years (Figure 4A) . In addition, the greater difficulty in controlling the high levels of CLR at lower altitudes is clear, where the adjustment of the criteria to the main flowering date CC2 was statistically different and better in AUDPC for the altitude of 1.410m compared to 1.280m where it was not obtained the expected effect (Figure 3, Tables 2) these results of the differences in control based on recommendations supported by Cenicafé research (CC1 and CC2) with respect to the farmer's own Criteria (CA3), which was not efficient in control, corroborate some works such as those of Almeida *et al*., (1998), Cunha *et al*., (2004) Rivillas *et al*. (2011) and Pereira *et al*. (2019), where the lowest CLR incidence values also depend on the active ingredient, dose and frequency of application.

Table 2. Dynamics of the area under progress curve the CLR incidence (standardized AUDPC) at 1,282 and 1,410 m.a.s.l.

Altitude m.a.s.l.	Criteria	Management methods	Standardized AUDPC		
			2016	**2017**	**2018**
1.410	CC1	**Fixed calendar Control**	**23,46** [a]	**30,09**[b]	**-**
	CC2	**Main flowering Control**	**-**	**-**	**41,51**[a]
	CA3	**Farmer Control**	**36,31**[b]	**36,18**[c]	**61,04**[b]
	SC4	**Without Control**	**53,53**[c]	**16,68**[a]	**57,12**[b]
1.282	CC1	**Fixed calendar Control**	**-**	**39,06**[b]	**-**
	CC2	**Main flowering Control**	**-**	**-**	**43,64**[a]
	CA3	**Farmer Control**	**-**	**35,11**[ab]	**49,74**[b]
	SC4	**Without Control**	**-**	**31,04**[a]	**52,58**[b]

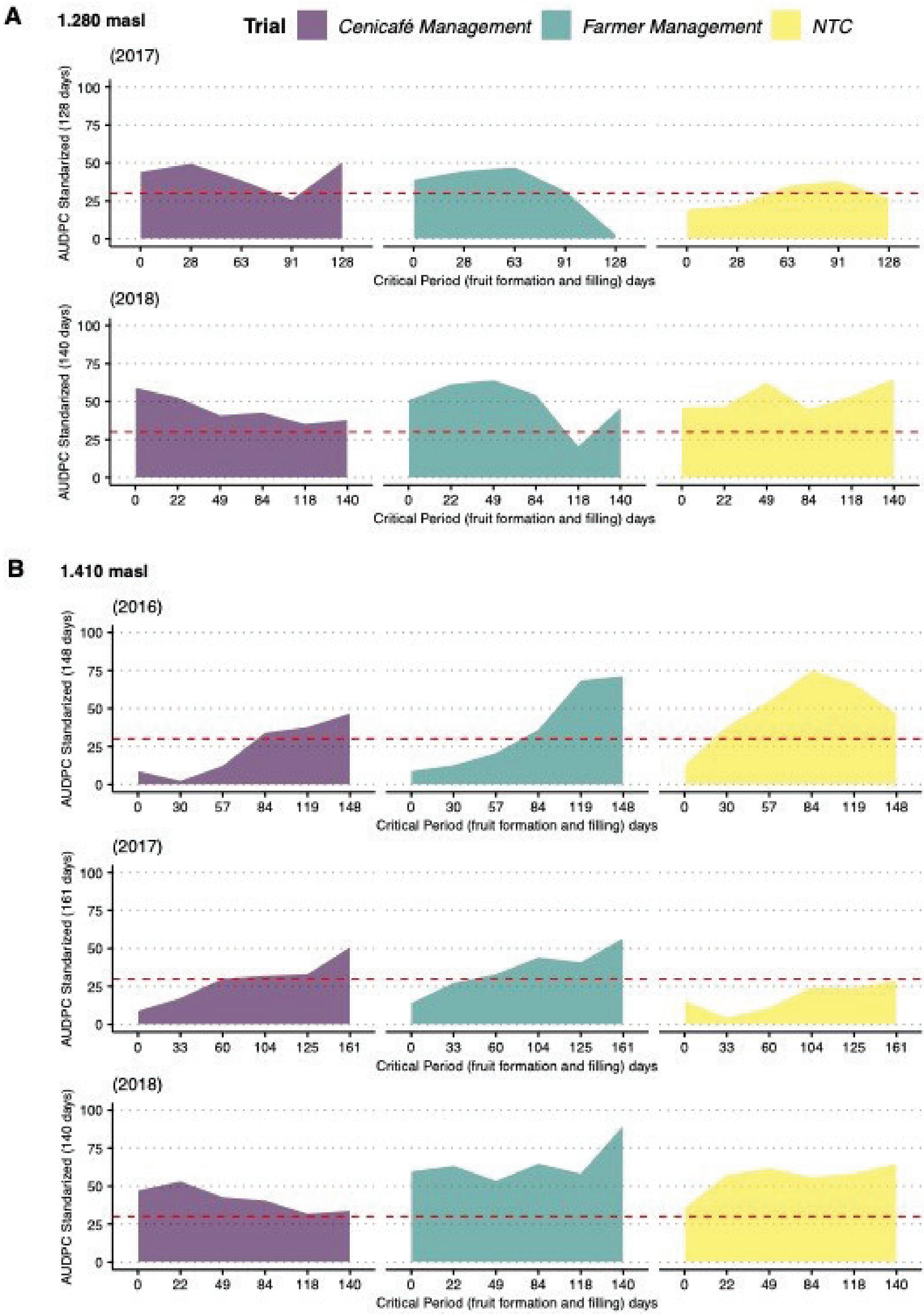
Standardized AUDPC=total epidemic area divided by the respective evaluation time period in days; * Numbers in bold represent significant differences (a=smaller epidemic area; b=intermediate value; c=larger epidemic area), based on Tukey's comparison test at 5%. Critical evaluation period: evaluation days beginning 60 days after main flowering at the beginning of harvest (fruit formation and filling)

Table 3. Dynamics of the area under progress curve average number of leaves (standardized AUDPC) at 1,282 and 1,410 m.a.s.l.

Altitude m.a.s.l.	Criteria	Management methods	Standardized AUDPC		
			2016	**2017**	**2018**
1,410	CC1	**Fixed calendar Control**	**19,75** [a]	**15,08** [a]	**-**
	CC2	**Main flowering Control**	**-**	**-**	**10,90**[a]
	CA3	**Farmer Control**	**20,57**[a]	**13,45**[b]	**10,59**[a]
	SC4	**Without Control**	**12,22**[b]	**14,56**[ab]	**10,98** [a]
1,282	CC1	**Fixed calendar Control**	**-**	**15,02**[a]	**-**
	CC2	**Main flowering Control**	**-**	**-**	**12,50**[a]
	CA3	**Farmer Control**	**-**	**16,04**[a]	**13,40**[a]
	SC4	**Without Control**	**-**	**15,84**[a]	**8,50**[b]

Standardized AUDPC=total epidemic area divided by the respective evaluation time period in days; * Numbers in bold represent significant differences (a=smaller epidemic area; b=intermediate value; c=larger epidemic area), based on Tukey's comparison test at 5%. Critical evaluation period: evaluation days beginning 60 days after main flowering at the beginning of harvest (fruit formation and filling)

Figure 4. Dynamics of the area under progress curve of CLR incidence (standardized AUDPC) under two management criteria in the susceptible variety Caturra in the critical period evaluation period from 60 days after the main flowering to the beginning of the harvest (fruit formation and filling) in the validation plots in the county of Pitalito (Huila). **A.** in the period 2017 - 2018 at 1,280 m.a.s.l. **B.** in the period 2016 - 2018 at 1,410 m.a.s.l.



Foliage Retention and Control Effectiveness

The foliage retention capacity generated by the criteria of Farmer Control (CA3), Cenicafé fixed calendars (CC1) and Cenicafé adjustment to main flowering (CC2), were evaluated by the opposite variable defoliation caused by the disease and by the number of leaves total, and revealed a lower leaf fall when compared with the control Without Control (SC4), in addition to the criteria of change in the evaluated branches when the average number of leaves was less than 10 leaves per branch. The results obtained show that for SC4 the change was made to 32% of the branches, for CA3 26% was changed and for CC1 and CC2 only 19% of the branches in the 1980 evaluations carried out at 1.410 m.a.s.l. The effect was similar for an altitude of 1.280 m.a.s.l., where in the control SC4 the change was made in 30% of the branches and for CA and CC1 and CC2 only 16% of the branches in the 1,260 evaluations. This effect is due to the higher incidence and severity of CLR present in the control treatment Without Control SC4, which caused the premature fall of a higher percentage of leaves (Figure 2, Figure 5). Defoliation was higher for all the plots with and without control at 1,280 m.a.s.l., therefore, it always presented a lower number of leaves compared to 1,410 m.a.s.l., reiterating the greatest problem due to CLR at lower altitude.

When the values of area under the curve (AUDPC) of CLR incidence were calculated for the control Without Control (SC4), the result of the defoliation generated by the effect of the disease during the first year of study in the period of September of 2016 to March 2017, generated defoliation close to 50% (Figure 2, Figure 4, Table 4), showing that the greater defoliation derives a greater number of new leaves without the presence of the disease, again validating that during the disease cycle the plants are in the vegetative process, replacing the leaves, eventually damaged by the initial attacks, but with a negative effect on production in later years (Villarraga and Baeza, 1987; Baeza and Villarraga, 1988; Sierra and Montoya, 1994; Matiello *et al*. ., 2008; Rivillas *et al*., 2011).

The effect of the chemical control criteria on the disease, represented by the efficacy of the control, shows that the application of the products Cyproconazole + Thiamethoxam (True 600 WG) and Cyproconazole + Azoxystrobin (Amistar ZTRA 28SC) used in the control recommended by Cenicafé (CC1 -CC2), compared with the products not recommended by Cenicafé and used under the CA3 farmer criteria, showed a greater efficacy between 15 and 35% when applied, and where this efficacy was more evident upon reaching the maximum peaks of the epidemic, especially at 1,410 meters above sea level, with higher efficacy in controls under Cenicafé management criteria (Figure 2, Figure 4, Figure 5). Furthermore, these data validate what was obtained by Grossmann and Retzlaff (1997); Yue-Xuan and Tiedemann (2001); Matos *et al*., (2016); Pereira *et al*., (2019), where they state that the use of strobilurins in systemic fungicides present a better response in the control of CLR and generate a delay in senescence and leaf fall, and that according to Venâncio *et al*., (2004), is favored for its ability to inhibit the synthesis of ethylene, ACC synthetase and AAC oxidase.

Regarding the productive cycle interaction per year, there was a significant effect in the management carried out under the three chemical control criteria on the area under the incidence progress curve and on defoliation (Figure 2, Tables 2 and 3). These results showed that the management criteria used affect the disease progress curve, changing the epidemiological cycle with a delay in reaching the maximum peaks in the curve, if fungicides are applied on time (Cunha *et al*., 2004; Zambolim, 2016; Hinnah *et al*., 2018; Belan *et al*., 2019). The above shows that the main objective of chemical control when it is applied in a timely manner is to preserve approximately 70% of the foliage on the tree and healthy in its productive zone during the critical period of grain filling until reaching the final phase of the epidemic before harvest (Villarraga and Baeza, 1987; Baeza and Villarraga, 1988; Rivillas *et al*., 2011; Pereira *et al*., 2019).

Although the effect of defoliation generated by the high incidence of the CLR epidemic in the three months prior to harvest was observed for the Farmer's Criteria (CA3) and the control Without Control (SC4), the one with the greatest negative impact was not controlling CLR SC4, which presented more than 50% defoliation for the evaluated cycles and lower AUDPC of the number of total leaves, leaving the plant with few leaves in the stage before harvest in the evaluated productive third (Figure 4). This fact was verified in some works that also associate the effect of defoliation to plant stress due to the productive load, water and nutritional deficit that generates a favorable environment for the residual inoculum from the previous cycle to modify the new epidemiological cycles under natural conditions. and without control criteria. (Mansk and Matiello, 1984; Cunha *et al*., 2004; Rivillas *et al*., 2011; Zambolim 2016; Pereira *et al*., 2019)

However, even if chemical control of CLR is carried out, integrating monitoring, selection of fungicides, doses and timely and adequate application in the susceptible variety Caturra, a difference of 7% less in production has been indicated in Cenicafé studies evaluating the elite progeny and components of CLR resistant varieties such as var. Colombia, where 21% of these progeny had better production than Caturra with adequate and timely chemical control (Aristizabal and Duque, 2007). In addition, Pereira *et al*. (2019) in Brazil show that under the use of different fungicides the severity of the disease in the variety Catuai vermelho (susceptible) does not decrease less than 20%, consequently affecting the following productions.

These data reiterate the challenge of carrying out a chemical control in highly susceptible varieties versus a resistant variety, and that the management under criteria of adjustment to the phenology of the crop according to the date of the main flowering in each productive cycle is the most efficient, where the behavior of the host, the pathogen and the environment is considered different (Kushalapa and Eskes, 1989; Rivillas 2011, 2017). However, the planting of varieties resistant to CLR is a transcendental decision for the coffee grower, in addition to being an efficient and profitable practice, it increases the benefit and reduces the environmental impact by not having to chemically control the disease (Van der vossen *et al*., 2015; Vasileiadis *et al*., 2017; FNC - Cenicafé, 2018).

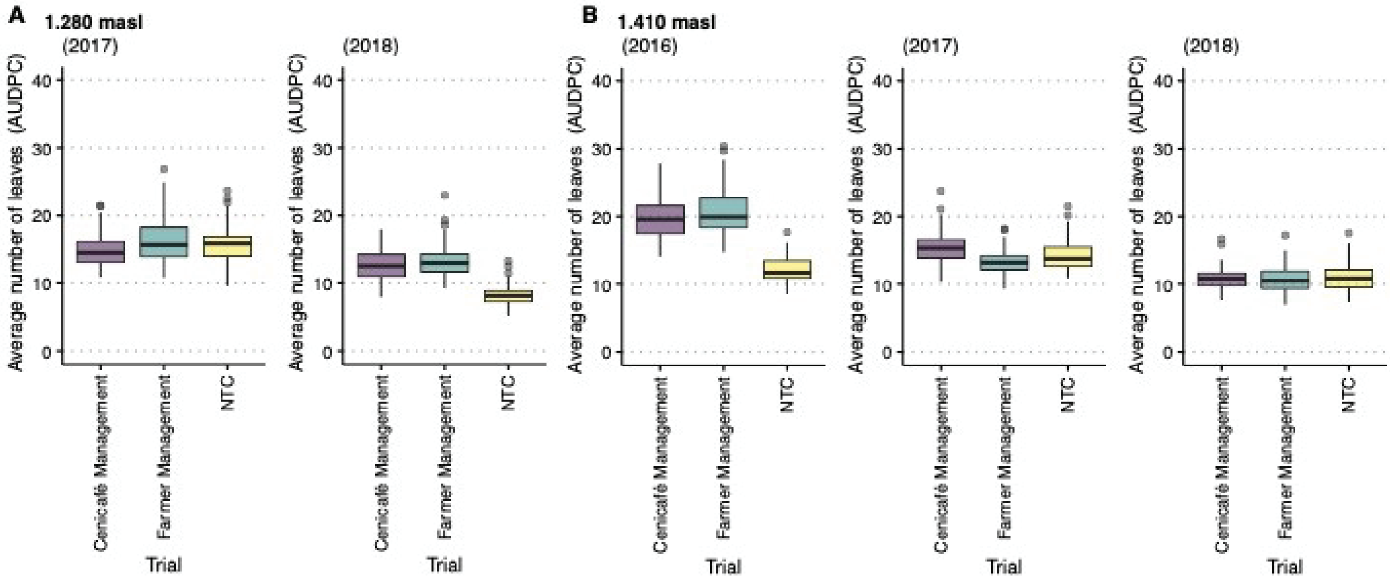


Figure 5. Boxplot of comparison of the AUDPC of average number of leaves under two management criteria in the susceptible variety Caturra in the critical period critical period of evaluation starting 60 after days main flowering at the beginning of harvest (formation and filling of fruits) in the validation plots in the county of Pitalito (Huila). **A.** in the period 2017 - 2018 at 1,280 m.a.s.l. **B.** in the period 2016 - 2018 at 1,410 m.a.s.l.

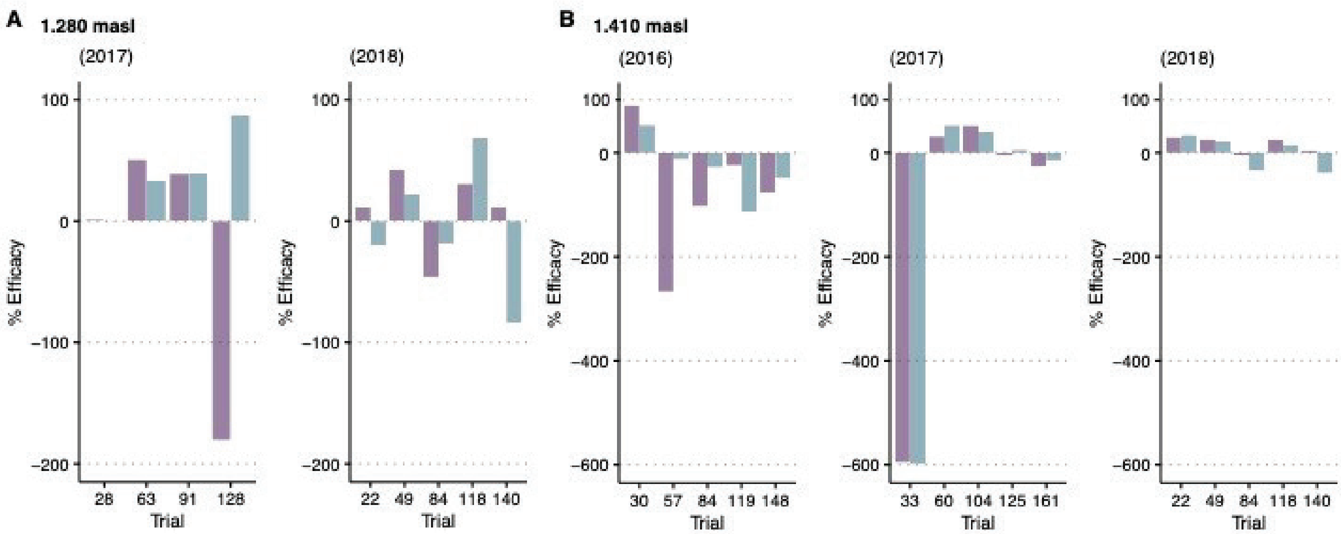


Figure 6. Dynamics of the Efficacy of the control in the critical period starting 60 days after main flowering at the beginning of harvest (fruit formation and filling) under two management criteria in the susceptible variety Caturra, in the validation plots in the municipality of Pitalito (Huila). **A.** Dynamics of the efficacy of Control per Farmer management (CA3) vs. Cenicafé management (CC1 – CC2) at 1,280 m.a.s.l. **B.** Dynamics of the efficacy of Control per Farmer (CA3) vs. Cenicafé Control (CC1 – CC2) at 1,410 m.a.s.l. in red box represents

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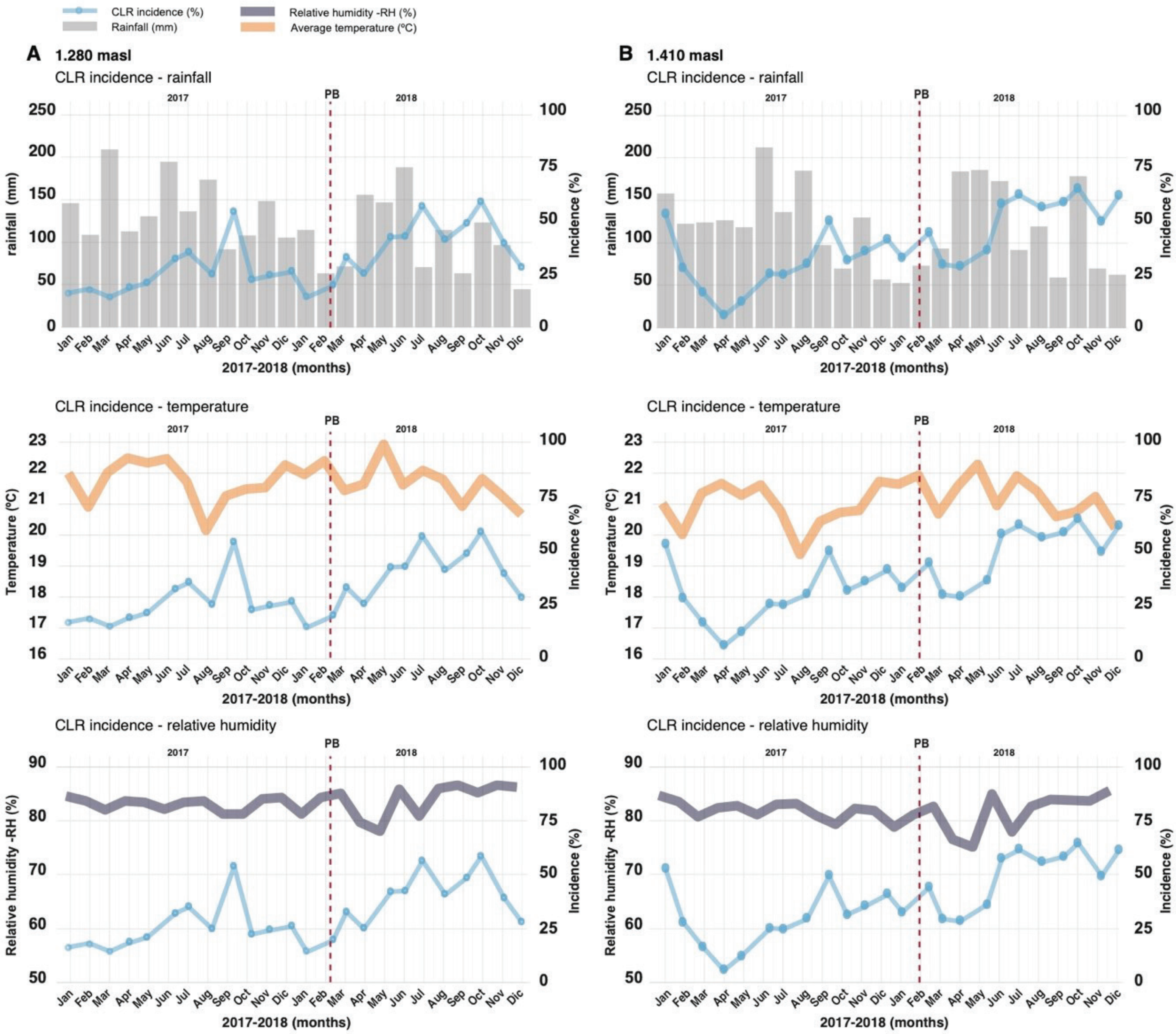

Figure 7. Dynamics of the incidence of coffee leaf rust in the susceptible variety Caturra in the county of Pitalito, in the period between January 2017 and December 2018, in relation to climatic variables **A.** monthly precipitation or rain (mm) , monthly average temperature (°C), and average monthly relative humidity (%) at 1,280 m.a.s.l. **B.** monthly precipitation or rain (mm) , monthly average temperature (°C), and average monthly relative humidity (%) at 1,410 m.a.s.l. Red dotted line represents principal blossom date.

Climatic conditions in the region

The period of least precipitation goes from December to February (Figure 7), which generates a water deficit in the soil sufficient to induce the blooms of the main crops. During the year 2017, alteration in the climatic conditions generated the main flowering in advance of the historical records, this fact affected the curve and the peaks of the disease, advancing the epidemic due to the increase in the maximum average monthly temperatures observed and the high precipitation. present during this year for both altitudes. Likewise, in 2018, although there were blooms in the usual times, between February and March, and under the evidence of the presence of inoculum that allows the spontaneous appearance of the disease in susceptible varieties and a trend of increased rainfall and variation of the temperature allowed to have peaks exceeding the damage level of 30%. Therefore, the knowledge of the climatic dynamics in the two altitudes, allows to differentiate and characterize the microclimate conditions of each altitudinal range, to adjust the management and adequate control under local conditions of the lot, farm or region.

Implementation of an Application to support decision-making for the control of CLR in the Department of Huila

Taking into account the results of this validation, and the characterization of the regional historical dynamics of the blooms in the department of Huila (García *et al*., 2019), an application was designed that incorporated into developments in information and communication technologies, helps you FNC extension workers and coffee growers to define the appropriate times to initiate and carry out chemical control activities of CLR in susceptible varieties in the department of Huila, based on the criteria for adjusting the main flowering dates for each zone and lot. https://agroclima.cenicafe.org/alerta-roya

Conclusions

In the implementation of a management alternative, the fundamental reason for the control of CLR mainly involves protecting the highest percentage of leaf area in a timely and adequate manner during the fruiting period. Therefore, the results obtained indicate that the CLR management criteria with adjustment to the occurrence of the main blooms was timelier and more effective than the fixed calendar for these years and region, when blooms are concentrated, while that of Fixed calendar is still in force in the case of scattered blooms and that agree with the historical ones. This adjustment of the disease management based on the occurrence, concentration and magnitude of the blooms is considered a more precise approach to the development of the epidemic related to the physiology of the coffee plant production, where both the “main blooms” or Those that produce the “traviesa or mitaca” harvest are experiencing advances or delays in relation to historical peaks due to regional climatic variability, altitude and “El Niño” or “La Niña” events.

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