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SHADE MANAGEMENT AND PRUNING IN TWO COFFEE VARIETIES VS. PLANT GROWTH AND LEAF RUST IN THE PERUVIAN AMAZON

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ABSTRACT

Coffee leaf rust (CLR) is a fungal infection which is devastating susceptible coffee plantations throughout the South American region in the last years. The objective of this study was to analyze the effects of shade trees management and pruning in two coffee varieties against coffee leaf rust in the Peruvian Amazon. The experimental design was a randomized complete block with factorial scheme 2A×2B×4C with 16 treatments and four repetitions, making a total of 64 experimental units, in which each experimental unit had 16 coffee plants. The studied factors were agroforestry system (A), coffee varieties (B), and pruning methods (C). The data were statistically examined by analysis of variance and mean comparisons using Tukey test. It was found that plant growth was favored by the use *Inga* shade and recepa pruning in Typica variety. Also, the use of polyculture-shaded coffee with about 40 % of shadow, and recepa (cutting the stem of the plant at 40 cm from the ground), reduce the incidence and severity of CLR in coffee plants. The incidence and severity of CLR was lower in the Typica variety as compared to Pache variety. This study confirms that a shadow management and pruning coffee plants stimulate the growth of new branches and reduce incidence and severity of CLR in coffee plantations.
Additional keywords: Agroforestry system, CLR incidence and severity, *Coffea arabica*, recepa pruning

RESUMEN

Manejo de sombra y poda en dos variedades de café vs. crecimiento de la planta y roya de la hoja en la Amazonía Peruana

La roya amarilla del café es una infección fúngica que está devastando plantaciones de café susceptibles en América del Sur en los últimos años. El objetivo de este estudio fue analizar los efectos del manejo de árboles de sombra y podas de dos variedades de café contra la roya amarilla en la Amazonía Peruana. Se usó un diseño experimental de bloques al azar con arreglo factorial 2A ×2B×4C con 16 tratamientos y cuatro repeticiones, para un total de 64 unidades experimentales, en las que cada unidad experimental contó con 16 plantas de café. Los factores estudiados fueron sistemas agroforestales (A), variedades de café (B) y métodos de poda (C). Los datos se analizaron estadísticamente mediante análisis de varianza y las comparaciones de medias según la prueba de Tukey. Se encontró que la sombra de *Inga* y la poda de recepa favorecieron el crecimiento de la planta. Asímismo, el uso del sistema agroforestal de café sombreado con distintas especies de árboles, con aproximadamente 40 % de sombra, y recepa (corte del tallo de las plantas a 40 cm del suelo), redujo la incidencia y severidad de la roya amarilla en plantas de café. La incidencia y severidad de la enfermedad fue menor en la variedad Typica en comparación con la variedad Pache. Este estudio confirma que el manejo de la sombra y la poda de las plantas de café estimulan el crecimiento vegetativo y, al mismo tiempo, reducen la incidencia y severidad de la roya amarilla en cafetales.
Palabras clave: *Coffea arabica*, incidencia y severidad de la enfermedad, poda de recepa, sistema agroforestal

INTRODUCTION

Coffee is one the one of most important agro-export products in Peru (Vallejos et al., 2019), and its value chain involves, directly and indirectly, approximately two million Peruvians (Borjas et al., 2020). According to the last National Agricultural Census carried out in Peru (INEI, 2012), an approximate of 223 thousand families cultivate around 425 400 hectares of coffee. The limiting factors of coffee productivity in the Peruvian Amazon are the age of the plantations and poor management practices, which include fertilization, pruning, shade management, and pest and disease control.

Coffee leaf rust (CLR) is one of the diseases that

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causes the most damage to coffee plants (Gichuru et al., 2012) since it can cause from 30 to 100 % yield loss (Piato et al., 2020). CLR is caused by the fungus *Hemileia vastatrix*, a parasite that affects the coffee leaves by infecting the lower surface (Avelino et al., 2015), where it produces large colonies of orange spores, leading to premature leaf fall (Talhinhas et al., 2017). In recent years, high intensity coffee rust epidemics have affected several Latin American countries, including Peru in 2013 (Avelino et al., 2015), with losses of approximately 60 % of the total harvest (Julca et al., 2019). This crisis revealed the lack of technical training in the agronomic management of plantations for smallholder coffee farmers that allows them to implement measures against CLR (Borjas et al., 2020). Due to this situation, the National Agrarian Health Service of Peru (SENASA) implemented an emergency plan to mitigate the damage to coffee plantations caused by the CLR epidemic.

The severity of coffee rust epidemics has been associated with the elevation of the fields above sea level, being less intense at higher altitudes due to low temperatures (López et al., 2012). Zambolim (2016) mentioned that the rust epidemics are less severe at elevations above 1200 meters. Moreover, previous studies report that the impact of the CLR is related with the coffee variety, age of plants, environmental conditions, shade trees, pruning and fertilization (Alvarado et al., 2020; Márquez et al., 2014).

Coffee is a perennial crop that requires pruning to renew plants (Dufour et al., 2019). Aged coffee plants can be more affected by phytosanitary problems, being necessary to carry out a rejuvenation plan through pruning to facilitate harvesting practices and restore the yield (Gokavi et al., 2021; Morais et al., 2012). Pruning also helps improve aeration and light entry into the canopy, facilitates cultural management, recovers plants that do not meet desirable technical economic standards, and reduces plant height (Fernandes et al., 2012). Therefore, pruning is a rejuvenation technique aimed at removing non-productive stems and branches and at stimulating new vegetative growth, translocating nutrients to the producing branches (Baitelle et al., 2019; Gokavi et al., 2021), in order to restore the plant's productive capacity and lead to better fruit quality (Fernandes et al., 2012).

The main benefits of pruning in the control of CLR are the elimination of infectious lesions on coffee trees and the reduction of the foliage that can become a source of fungal spore inoculum (Baitelle et al., 2019). Thus, pruning reduces the amount of inoculum available for dispersal and infection of coffee plants. Therefore, the objective of this study was to analyze the effects of shade trees management and pruning of two coffee varieties against coffee leaf rust in the Peruvian Amazon.

MATERIALS AND METHODS

The study was conducted in 16 coffee plots belonging to different owners in the district of Jepelacio, in Moyobamba province, San Martin Region, Peru. The 10 to 14 years old coffee plantations of two varieties (Typica and Pache) were grown under two different agroforestry system and managed with three different pruning methods (high pruning or descope, medium pruning, and low pruning or recepa) and a control treatment without pruning (Table1).

Table 1. Geographical location of the plots under study

	Altitude (m)	Latitude	Longitude
Coffee var. Typica in Polyculture-shade plantation	1035	6º 09' 08" S	76º 54' 02" W
Coffee var. Pache in Polyculture-shade plantation	1107	6º 08' 49" S	76º 55' 44" W
Coffee var. Typica in *Inga*-shade plantation	1039	6º 08' 55" S	76º 54' 11" W
Coffee var. Pache in *Inga* -shade plantation	1060	6º 08' 51" S	76º 53' 13" W

The coffee plants were spaced 1 m and the distance between rows was 2 m. The shade trees are not evenly distributed in the plots since the farmers allowed them to grow naturally in the coffee plantation.

Experimental Design. The experimental design was a randomized complete block design with a factorial arrangement of three factors: 2A×2B×4C (Table 2). The study consisted of 16 treatments and four blocks per treatment, making a total of 64 experimental units, in which each experimental unit had 16 coffee plants.

Table 2. Factors evaluated in the study

Factor A: Agroforestry system	Factor B: Coffee variety	Factor C: Pruning method
a1: Polyculture-shade	b1: Typica	c1: Non pruning
a2: *Inga*-shade	b2: Pache	c2: Descope c3: Medium pruning c4: Recepa

Coffee agroforestry systems For this study two representative coffee growing systems were selected: 1. Polyculture-shaded coffee, a coffee system with shade trees of different species that includes fruits and timber trees, with about 40 % shade, and 2. *Inga* shaded coffee, a coffee system associated with legume species (*Inga edulis* Mart. and *Inga ruiziana* G. Don), with about 50 % shade. At the time of pruning, Pache variety plants had a mean height of 1.80 m, while Typica variety plants averaged 3.0 m.

Pruning methods The fruits are usually concentrated in the upper part of the plant and in the most distal part of the branches but considering that the age of the plantations ranged between 10 and 14 years, diseased and unproductive branches were observed, so the pruning will allow the renewal of productive branches. The average height of the pruning depended on the coffee variety, height of the plants and the maximum reach of the hands of the workers to carry out the pruning. In this study, we evaluated non-pruned coffee plants as a control, and performed three types of pruning: 1. Descope, which consisted in cutting the top of the coffee trees at 1.7 m and 1.5 m in height measured from the ground in Typica (tall variety) and Pache (dwarf variety) respectively. This type of pruning avoids the vertical growth of coffee plants and induces the development of secondary branches; 2. A medium pruning, which was done at 1.20 m and 1.00 m in Typica and Pache respectively, eliminating the upper part of the plants and the unproductive branches, and 3. Recepa, which consisted of making an inclined cut in the stem of all plants at 40 cm from the ground; with this pruning, the plant was completely renewed.

Sampling after pruning The evaluation was carried out 6 months after pruning. To measure the incidence, the diseased leaves were counted and divided by the total number of leaves in the evaluated branch. This procedure was carried out on one branch randomly selected in the lower, middle, and upper third of each one of the evaluated plants. To measure severity, a scale designed by Julca et al. (2019) was used, considering the level of damage in the leaf area, which ranges from 0 to 80 % (Figure 1). The same branch that was used to assess incidence was used to determine severity. The severity in each leaf was evaluated and then the average value for each branch was obtained. All branches of the coffee plants under analysis were labeled before being evaluated. Furthermore, in this study were evaluated the height of plants and number of branches.

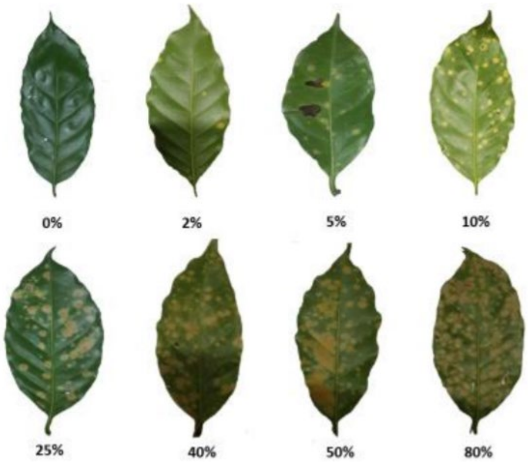

Figure 1. Scale used to quantify the severity of coffee leaf rust on *Coffea Arabica* (Julca et al., 2019)

Data analysis The data collected during the evaluation in fieldwork were recorded in an excel file. The data were subjected to an analysis of variance and the mean comparison test was performed using the Tukey test at 0.05, using R statistical software.

RESULTS

After six months of pruning, significant differences were observed with some factors under study and with some interactions between factors in all variables evaluated: plant growth, number of branches, incidence, and severity (Table 3). The incidence and severity of CLR in coffee plantations were linked to agroforestry system and pruning, which affected plant height, branch growth, and plant architecture.

The highest average values for the plant height were found in *Inga*-shaded coffee, and the interaction Typica variety*recepa pruning (Table 4). Although the plants under the polyculture-shade showed statistically lower results than those of the *Inga*-shade in the plant height variable, the development of them were within the standard of the region.

Inga-shade promoted higher number of branches than polyculture-shade regardless of the coffee variety. Likewise, *Inga*-shade combined with recepa pruning showed the highest number of new branches (Table 5). Also, it can be observed that recepa pruning always promoted the highest number of new branches regardless the shade type, either *Inga* or polyculture. These results indicated that the recepa pruning allowed to obtain a better morphological development of coffee plants.

Table 3. *P*-values of ANOVA results on all variables under study due to agroforestry system, coffee variety, and pruning method after six months of the installation of the study

Variation source	Plant height (cm)	N° of branches	Incidence (%)	Severity (%)
AS	0.0002	<0.0001	<0.0001	<0.0001
CV	<0.0001	0.9273 ns	0.0214	0.0009
PM	<0.0001	<0.0001	<0.0001	<0.0001
AS*CV	0.2144 ns	0.0325	<0.0001	<0.0001
AS*PM	0.0909 ns	<0.0001	0.7733 ns	0.0032
CV*PM	<0.0001	0.9932 ns	0.5590 ns	0.7852 ns
AS*CV*PM	0.3974 ns	0.0089*	0.2795 ns	0.0133*

AS: Agroforestry system; CV: Coffee variety; PM: Pruning method; ns: non significant

The factors agroforestry system and pruning method, and the interaction agroforestry system*coffee variety were significant ($P \leq 0.05$) when incidence of CLR was analyzed (Table 3). The recepa pruning and the interaction polyculture-shade*Typica variety stood out significantly with lower incidence of CLR (Table 6). The incidence of CLR in coffee plants pruned with the recepa method was significantly lower compared to the other pruning methods, with a value equal to 16.15 %, well below the 37.81 % observed in the non pruning treatment. Regarding the interaction agroforestry system*coffee variety, there were significant differences in the incidence of CLR, and polyculture-shade*Typica variety interaction (16.77 %) was the lowest and significantly different from the other interactions: polyculture-shade*Pache variety (25.83 %), *Inga*-shade*Pache variety (27.29 %), and *Inga*-shade*Typica variety (29.90 %). Furthermore, the variety Pache was affected more severely by CLR in polyculture-shade, sharing the same incidence percentages with the *Inga*-shade treatments (Table 6). When considering the CLR severity, the factors agroforestry systems and pruning method, and the interactions of agroforestry system with coffee variety and with pruning method were significant (Table 3). Polyculture-shade with Typica variety or with recepa pruning showed the lowest severity (Table 7).

Table 4. Effects of type of agroforestry system and interaction of coffee variety with pruning method on coffee plant growth

	Plant height (cm)
Agroforestry system	
Polyculture-shade	30.1 b
Inga-shade	36.4 a
Interaction coffee variety*pruning method	
Typica*non pruning	-
Typica*descope	42.3 b
Typica*medium pruning	49.3 b
Typica*Recepa	75.6 a
Pache*non pruning	-
Pache*descope	27.3 d
Pache*medium pruning	31.5 cd
Pache*recepa	39.9 bc

Means followed by different letters indicate significant differences ($P \leq 0.05$) among treatments according to Tukey test

Table 5. Effects of interactions of coffee variety with agroforestry system and with pruning method on number of new branches of coffee plants

	Number of branches
Interaction agroforestry system*coffee variety	
Polyculture-shade*Typica	4.2 b
Polyculture-shade*Pache	4.7 b
Inga-shade*Typica	6.9 a
Inga-shade*Pache	6.5 a
Interaction coffee variety*pruning method	
Polyculture-shade*non pruning	-
Polyculture-shade*descope	5.3 d
Polyculture-shade*medium pruning	5.3 d
Polyculture-shade*recepa	7.3 c
Inga-shade*non pruning	-
Inga-shade*descope	7.2 c
Inga-shade*medium pruning	9.1 b
Inga-shade*recepa	10.5 a

Means followed by different letters indicate significant differences ($P \leq 0.05$) among treatments according to Tukey test

The triple interaction of the factors showed that the combination of *Inga*-shade*Pache variety*non pruning exhibited the highest percentage of CLR severity, with a value of 33.65 %, while the combination of polyculture-shade*Typica variety*recepa pruning had the lowest severity, with 6.39 % (Table 8)

Table 6. Effects of type of agroforestry system, coffee variety and pruning method on incidence of coffee leaf rust

	Incidence (%)
Pruning method	
Non pruning	37.81 a
Descope	23.44 b
Medium pruning	22.40 b
Recepa	16.15 c
Interaction agroforestry system*coffee variety	
Polyculture-shade*Typica	16. 77 b
Polyculture-shade*Pache	25.83 a
Inga-shade*Typica	29.90 a
Inga-shade*Pache	27.29 a

Means followed by different letters indicate significant differences ($P \leq 0.05$) among treatments according to Tukey test

Table 7. Effects of interactions of coffee variety with agroforestry system and with pruning method on severity of coffee leaf rust

	Severity (%)
Interaction agroforestry system*coffee variety	
Polyculture-shade*Typica	12.1 b
Polyculture-shade*Pache	22.6 a
Inga-shade*Typica	24.9 a
Inga-shade*Pache	22.6 a
Interaction coffee variety*pruning method	
Polyculture-shade*non pruning	18.2 bc
Polyculture-shade*descope	19.0 b
Polyculture-shade*medium pruning	20.8 b
Polyculture-shade*recepa	11.5 c
Inga-shade*non pruning	32.3 a
Inga-shade*descope	22.4 b
Inga-shade*medium pruning	23.3 b
Inga-shade*recepa	16.9 bc

Means followed by different letters indicate significant differences ($P \leq 0.05$) among treatments according to Tukey test

Table 8. Effects of type of agroforestry system, coffee variety and pruning method on severity of coffee leaf rust

	Severity (%)
Interaction agroforestry system*coffee variety*pruning	
Polyculture-shade*Typica*non pruning	17.12 cdefg
Polyculture-shade*Typica*descope	11.87 fg
Polyculture-shade*Typica*medium pruning	13.19 efg
Polyculture-shade*Typica*recepa	6.39 g
Inga-shade*Typica*non pruning	30.97 ab
Inga-shade*Typica*descope	25.24 abcd
Inga-shade*Typica*medium pruning	24.93 abcde
Inga-shade*Typica*recepa	18.51 cdef
Polyculture-shade*Pache*non pruning	19.38 bcdef
Polyculture-shade*Pache*descope	26.18 abcd
Polyculture-shade*Pache*medium pruning	28.33 abc
Polyculture-shade*Pache*recepa	16.63 cdefg
Inga-shade*Pache*non pruning	33.65 a
Inga-shade*Pache*descope	19.58 bcdef
Inga-shade*Pache*medium pruning	21.63 bcdef
Inga-shade*Pache*recepa	15.45 defg

Means followed by different letters indicate significant differences ($P \leq 0.05$) among treatments according to Tukey test

DISCUSSION

Average CLR incidence for each treatment ranged from 16.15 to 37.81 %. These values are within the incidence range previously reported in Peru by Ehrenbergerová et al. (2018) who found 10-60 % incidence of CLR in Villa Rica, Pasco region, Peru, but Soto et al. (2002) reported in Mexico lower incidence of CLR with values that ranged between 5.1 and 20.2 %. Likewise, the average CLR severity ranged from 6.39 to 33.65 %, with higher values than those reported by Borjas et al. (2020), who indicated a range of severity between 1.3 and 15.9 % in coffee plantations in Chanchamayo, Junin region, Peru. In this study, the pruning, different combinations of shade, and coffee varieties influenced the level of disease damage. Additionally, other authors found that incidence and severity of CLR are influenced by edaphoclimatic conditions, geographic location, and fruit load (Maia et al., 2017; Toniutti et al., 2017).

Although it can be difficult to prevent CLR infections, it is possible to reduce damage to coffee leaves by carefully monitoring crops and pruning when appropriate. Pruning is one of the most important cultivation techniques applied during coffee farming (Karim et al., 2021), and not all genotypes respond equally to pruning, as genotypes with vigorous growth may recover more promptly (Rodrigues et al., 2017). Pruning removes old and non-productive branches, stimulates new vegetative growth and increases light through the canopy. In this study, the recepa pruning promoted growth increase of coffee plants and reduced the incidence of CLR, while the interaction polyculture-shade*Typica variety*recepa pruning significantly reduced the severity of CLR. This pruning technique removed all infected leaves that could serve as inoculum for fungal spores and also reduced foliage that could potentially be infected with CLR spores. Recepa is recommended for aged plants, with advanced exhaustion and without lower branches, and should be done at the end of the harvest, preferably during the dry season or low rainfall period (Filho and Domian, 2019).

Ehrenbergerová et al. (2018) reported that approximately 70 % of coffee plantations in Peru are more than 20 years old and that CLR infection appears to increase substantially between 15 and 20 years. Pruning is recommended when the canopies of the coffee trees start to overlap and diseased branches appear, causing detrimental effects, so depending on the spacing, environment and growth, pruning should be done every four years (Rodrigues et al., 2017). The coffee plantations of our study were between 10 and 14 years old and they had not been pruned for at least the last 5 years, so they were at a recommended age to be pruned, allowing to renew the plantation and reduce CLR infection.

The genetics of coffee plants provide information that allows to identify CLR-tolerant plants (Diola et al., 2011). Typica and Pache are included between the most cultivated varieties in Peru (Díaz and Willems, 2017) and are susceptible to CLR (ANACAFE, 2019). In coffee plantations of Chanchamayo, Peru, Borjas et al. (2020) found that Pache and Typica did not show significant differences when severity was analyzed, with values ranging from 5.8 to 8.2 %. The interactions polyculture-shade*Typica variety and polyculture-shade*Typica variety*recepa pruning showed the lowest incidence and severity, inferring that Typica was the variety least affected by CLR.

The production of coffee under shade is a sustainable practice that has been considered as a mitigation strategy to face the effects of climate change (Piato et al., 2020). In this study, the shade percentage of *Inga*-shade was about 50 % and the shade percentage of polyculture-shade was about 40 %, with the lowest incidence and severity of CLR in polyculture-shade. This result might allow to infer that the dispersion of CLR spores is favored by a higher percentage of shade in the plantations. Shade trees influence the spread of CLR by protecting uredospores from rain, while in full sun, rain facilitates the depletion of CLR spores and limits their dispersal (Avelino et al., 2020). The shade trees regulate the presence of CLR spores, but they also have a reducing effect on the yield of coffee plantations (Perfecto et al., 2005).

CLR incidence is influenced by microclimate conditions and the incidence and severity of CLR in coffee plantations are correlated (Julca et al., 2019). Considering that damage estimation is an essential requirement to implement any plant protection program, better understanding of the interaction between agroforestry system, coffee variety and pruning methods will lead to greater effectiveness of the application of coffee management practices against infections caused by spores of *H. vastatrix*.

CONCLUSIONS

This study showed that pruning method and combination of shade influenced on CLR incidence and severity. The use of recepa pruning stimulated new vegetative growth and reduced the incidence and severity of infections of *H. vastatrix* in coffee plantations, being favored by the establishment of plantations under polyculture-shade with about 40 % of shadow. The cultivation of coffee associated with shade trees is considered a strategy for adaptation and mitigation to climate change, so it is necessary to continue with research and establish an adequate level of shade and identify suitable tree species. Moreover, according to the results, both varieties were susceptible to the infection for spores of *H. vastatrix* although Typica was the variety least affected. Coffee farmers should use CLR-resistant varieties and apply recepa type pruning to renew the plantations.

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