Prevention and control of coffee leaf rust

Handbook of best practices for extension agents and facilitators

Elias de Melo Virginio Filho
Carlos Astorga Domian

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Foreword

Coffee leaf rust has been a threat to coffee for more than 100 years. It is one of the most important diseases that affect coffee production across the American continent. The frequent lack of access to resources is one of the central factors that has led to the continued devastation caused by the disease, which has affected the livelihoods of farmers throughout the region.

CATIE, one of the few institutions dedicated to regional research, is proud to have partnered with the Borlaug Institute and the World Coffee Research to launch this handbook on coffee rust, which was derived from CATIE's extensive data collection on coffee rust. It will serve as a comprehensive guide for researchers and extension agents in Central America in understanding and controlling the pathogen. More importantly, the handbook will serve as a training tool so that field agents can convey critical information to their most important audience: coffee producers in Latin America.

Elsa Murano, Ph.D.
Borlaug Institute for International Agriculture

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To Promecafé and the coffee institutes of Central America, for their collaboration over the last few years in implementing measures to understand and control the coffee leaf rust epidemic affectin the region.

Acronyms

Anacafé	National Coffee Association of Guatemala
ARS-USDA	Agricultural Research Service. US Department of Agriculture
CATIE	Tropical Agricultural Research and Higher Education
CENTA	National Center for Agriculture and Forest Technology Enrique Álvarez Córdoba, El Salvador
CIFC	Coffee Leaf Rust Research Center
CIRAD	Centre de Cooperation Internationale en Recherche Agronomique pour le Developpment
EWS	Early Warning System
FAO	Food and Agriculture Organization
Icafé	Costa Rican Coffee Institute
Ihcafé	Honduran Coffee Institute
IICA	Inter-American Institute for Cooperation on Agriculture
Magfor	Ministry of Agriculture and Forestry, Nicaragua
MIDA	Ministry of Agricultural Development, Panama
OIRSA	International Regional Organization for Plant and Animal Health
Procafé	Foundation for Coffee Research, El Salvador
Promecafé	Regional Program for the protection and modernization of coffee production in Central America and Panama
Sagarpa	Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food, Mexico
USAID	United States Agency for International Development

Relevance and how to use the handbook

The creation of this handbook grew out of a need to prevent and control the coffee leaf rust epidemic (*Hemileia vastatrix*) that occurred in 2012 and 2013. This epidemic affected the coffee production cycle across the Central American region, reducing coffee production by 20% and generating important repercussions on coffee producing families that depend directly or indirectly on the activity. As a result, the amount of labor for coffee harvesting was reduced, creating unemployment and putting food security at risk for many families.

Historical trends show that coffee leaf rust experiences epidemic cycles that are repeated over time, although each cycle shows specific particularities. We must be permanently prepared to establish preventive or control measures that are applied in a timely and effective manner. For the coffee producing countries of the American continent, the epidemic cycle of 2012-2013 had an unprecedented peculiarity since it affected several countries of the region at the same time.

The handbook aims to give a detailed description of the coffee leaf rust disease, including its causal agent (fungus), life cycle, reproduction and incidence in coffee production, as well as analyses, interactions and discussion of how environmental factors affect its development until it transforms into an epidemic. Understanding these interactions is crucial in the work of extension agents that provide training and technical assistance, but also for the producer families that make farm management decisions throughout the coffee productive cycle.

The Orton-CATIE/IICA Library has an important documentary database on coffee leaf rust (http://bibliotecaorton.catie.ac.cr/) and a specific portal in development where relevant information on this topic can be found: http://biblioteca.catie.ac.cr/royadelcafeto/

This handbook also presents the latest research results on different coffee production systems to understand how these influence the incidence of the disease. Management and environmental considerations are highlighted for different coffee production systems. Research findings also show the need to incorporate new knowledge into the agroecological management of the crop. There is still a need to do further research to understand the factors that affect the development of coffee leaf rust. However, research findings show new basic points that can help achieve long-term sustainability in coffee production. An example of this is the shade grown coffee - leaf rust relationship. In the past, the negative aspects of shade (almost always in terms of poor design and poor handling) were emphasized, but positive relationships have been found between shade and coffee leaf rust control, depending on climatic conditions.

This handbook is a tool to help technical staff and extension agents disseminate new knowledge and develop theoretical and practical learning approaches with coffee farmers in order to strengthen and increase their technical capacities.

For the development of the training sessions, use of the zig zag and/or the field school methodology (Virginio Filho 2009) is recommended. The curriculum should be designed based on the state of the coffee plantations and the objectives of the participating families.

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1 For a detailed description of the methodology, see chapter 7 “MIP en manos de familias rurales”, 2004, Staver C., CATIE: http://repositorio.bibliotecaorton.catie.ac.cr/bitstream/11554/3138/1/MIP_en_manos_de_familias_rurales.pdf

2 Also see “Las escuelas de campo del MAP-CATIE”, 2012, Gutiérrez-Montes et al, CATIE: http://orton.catie.ac.cr/repdoc/A9230E/A9230E.PDF

Section I.

Disease characterization

Chapter 1. Origin, epidemics and impacts of coffee leaf rust

Coffee leaf rust is considered one of the most severe diseases affecting coffee plants since it was first reported in 1869. The disease has caused major losses in coffee production areas in the countries of Asia, Africa and America. Once the disease is introduced and takes hold in an area, it is difficult to eliminate, despite multiple strategies that can be implemented by coffee farmers. Therefore, farmers must learn to cope with it and implement practices to prevent and manage the disease. However, due to climate variations, crop management and other conditions we will be discussing in the following chapters, severe and widespread epidemics have occurred in different countries and regions that weakened plantations and generated crop losses. These effects are not only significant within a production cycle but also in subsequent years (two or three years following). When crop exhaustion occurs, a common practice is to heavily prune the coffee plants, which greatly reduces coffee production in the short term.

1.1 Origin and distribution of coffee leaf rust in the world

In 1869, the first coffee leaf rust outbreak was reported on the Asian continent, specifically in Sri Lanka (previously known as Ceylon). That same year, British plant pathologist Miles Joseph Berkely described the fungus responsible for the disease and gave it the scientific name: *Hemileia vastatrix* (Avelino and Rivas 2013).

According to Leppik (1970), a disease generally occurs for the first time in or near the center of origin of the species it affects. The emergence of coffee leaf rust in Asia was a matter of discussion due to its distance from the center of coffee origin (Africa). McCook (2006) proposed a hypothesis about coffee leaf rust, indicating it might have been introduced by accident in Sri Lanka from East Africa through diseased plants. British expansion towards Sri Lanka facilitated the movement of people and goods as well as plants with their pathogens. Once it reached Sri Lanka the fungus found conditions suitable for its growth because of the abundant rainfall caused by monsoonal which favors various disease processes.

Additionally, the European settlers in Sri Lanka had grown coffee in homogeneous plantations with susceptible materials and full sun exposure, other factors that contribute to the development of the disease. It is worth noting that during that period the possibilities of using chemical control to treat the disease were very limited. For example, the fungicidal properties of alternatives such as the Bordeaux mixture were disseminated in 1885, that is, 16 years after the first report in Sri Lanka of orange leaf rust (Avelino and Rivas 2013).

It is well known that coffee shows different degrees of resistance to coffee leaf rust, especially the wild coffee varieties from Ethiopia, thereby showing that, indeed, the disease first originated in Africa. The first report of the fungus could have taken place in 1861, just before the first report in Sri Lanka. This report was made by a British explorer, who observed the disease in wild coffee bushes in the Lake Victoria region of East Africa (Wellman 1952). In this region, coffee plants that were most susceptible to the disease were naturally rare, which may explain why the disease went unnoticed for many years (Saccas and Charpentier 1971). After the report of the first coffee leaf rust appearance, the crop expanded to many regions of the Asian continent, as did the disease (Table 1).

Table 1. Distribution of coffee leaf rust (*H. vastatrix*) around the world and its main effects on coffee production from 1869-1993.

Year	Presence of the disease	Observations and impacts on coffee production
1869	Sri Lanka (Ceylon)	First report of coffee leaf rust.
No date	Java and Sumatra	Coffee production decreased 30 to 50% in one coffee harvesting season. The disease expanded rapidly to low elevations in Asia and in Java all coffee plantations at an elevation of 1000 masl were abandoned.
1880 - 1890	Reunion Island	The exact date when the disease appeared is unknown. Coffee production decreased by 75% during the decades 1880 – 1890.
1889	Philippines	Fourth largest coffee exporter in the world (7000 t).
1892	Philippines	Coffee production ceased almost entirely.
1966	Angola	First report of coffee leaf rust in a West African country.
1970	Bahia State, Brazil	First report of coffee leaf rust on the American continent. The strongest hypothesis is that coffee leaf rust was dispersed from Africa by trade winds.
1976	Nicaragua	First appeared in the region between San Marcos and Masatepe on the Pacific side of the country.
1976	Panama	Low impact when it first appeared, but impact was severe in 2012 (Promecafé et al. 2013).
1979	El Salvador	Severe damage in 2010 and 2011. The year 2012 showed the strongest epidemic since its first appearance (Procafé 2013).
1980	Honduras and Guatemala	In Guatemala in 2010 and 2011, coffee leaf rust was present in an altitudinal gradient at 1219 - 1524 masl; in 2012, the disease expanded to other regions (Anacafé 2013).
1981	Chiapas, Mexico	Damages were not as severe as when the disease first appeared. But in October 2012, coffee production was reduced by 30%.
1983	Costa Rica	Damage was not as severe since the first appearance of the disease, but impacts were severe in 2012.

In the Philippines, coffee production decreased dramatically because of the disease. In a three-year period, the country went from being the world's fourth largest coffee exporter to almost null production in 1892. The losses produced by the disease resulted in the substitution of coffee for tea (Rayner 1972), and *Coffea arabica* coffee for *C. canephora* Robusta coffee. The latter is a coffee species better adapted to high altitudes and it shows stronger resistance to coffee rust (McCook 2006). Nevertheless, Asian countries continued producing coffee at altitudes higher than 1,000 masl, where the crop was less susceptible to the disease due to unfavorable environmental conditions for the fungus.

The dispersal of coffee leaf rust on the African continent was much slower, until it reached the West African region. The first known account was in 1966 when the disease first reached Angola. According to McCook (2006), the slow progress made by the disease was due to the small amount of coffee production development in Central and Western Africa since these countries were experiencing severe economic crises during the first half of the 20th century (the Great Depression and the Second World War).

The arrival of coffee leaf rust to the American continent occurred in 1970 and it was first reported in Brazil. Bowden et al. (1971) suggested that the uredospores (reproductive structures) of coffee leaf rust were transported by trade winds coming from Western Africa to Brazil. On the other hand, Waller (1972) suggests that the disease was accidentally introduced by contaminated plant material or clothing. From the time of its discovery in the American continent and within a period of thirteen-years, coffee rust spread rapidly to all the coffee producing countries from the southern part of Latin America region (Bolivia and Peru) to the northern part of the region (Mexico).

1.2 Epidemics and impacts of coffee rust on production and economy

There has been increasing concern in the coffee sector since most land under coffee is susceptible to coffee leaf rust disease. The greatest concern has been the occurrence of an epidemic of coffee leaf rust across various Asian countries at the end of the 19th century and early 20th century which generated a gradual reduction of coffee production until it almost disappeared.

The first measures to eradicate the disease were implemented in Brazil (Muller 1971), Nicaragua (Schuppener et al. 1977) and Mexico (Gutiérrez and Carreón 1982). These measures were based on Papua New Guinea's experiences. In this territory, there were three instances (1892, 1903 and 1965) where attempts to eliminate the disease were implemented with temporary results. In 1986, it was finally recognized that the disease had become established (Avelino and Rivas 2013).

Since the emergence of coffee leaf rust in Brazil, the ministries of agriculture and agencies in charge of the coffee sector in the Central American region initiated research aimed at evaluating Brazilian genetic materials with tolerance to coffee leaf rust. In 1978, the Regional Program for the Protection and Modernization of Coffee Production in Central America and Panama (Promecafé) was established. This program generated a significant change in the mentality of researchers in countries within the region which started a new phase in the modernization and improvement of coffee production in Central America (Avelino and Rivas 2013).

The appearance of coffee leaf rust in Central America did not produce the great losses that were feared. Coffee producers and technical staff implemented measures to improve management and learned to cope with the disease. The presence of coffee leaf rust was first reported in Nicaragua (Schuppener et al. 1977) in 1976, but since then no severe damages were reported. In fact, no reductions in production due to coffee leaf rust were quantified (Table 2). But in 2010, coffee leaf rust incidence began to increase, and in the 2012-2013 harvest, the feared epidemic occurred causing crop losses, reduced income and increased unemployment (Cristancho et al. 2012).

The impact of the coffee leaf rust attack on the Central America region in 2012-2013 caused a 15% reduction in crop production on average. Honduras and El Salvador were the countries that experienced the highest percentage of crop loss (Table 3). Another factor that contributed to the development of the disease was the decline in coffee prices in the international market in 2010

Sun grown coffee plantation devastated by coffee leaf rust in Santo Domingo, Heredia, Costa Rica (February 2013). Photo: Jacques Avelino

Table 2. Summary of the main coffee leaf rust attacks reported in the Central American region.

Year	Epidemic	References
1989 - 1990	Severe epidemic in Costa Rica (low coffee prices)	Aguilar Vargas 1990; McCook 2009
1995 - 1996	Increased incidence in Nicaragua, no damages were reported	Avelino 1996; McCook 2009
2002 - 2003	El Salvador (epidemic related to coffee overproduction in 2000)	McCook 2009
2008 - 2011	Colombia (favorable climatic conditions for the development of the disease)	Cristancho et al. 2012
2012 - 2013	Central American countries, Mexico, the Caribbean, Peru and Ecuador	Avelino and Rivas 2013; Cristancho et al. 2012

Table 3. Estimated crop losses due to the coffee leaf rust epidemic in 2012-2013a

Country	Harvest 2011-2012 (millions of 46-kg bags)	Losses in 2012-2013 (thousands of 46-kg bags)	Percentage of crop loss	Declared state of emergency
Honduras	7.10	2192 *	31 *	Yes
Guatemala	4.85	730 *	15 *	Yes
Costa Rica	2.01	97 **	5 **	Yes
Nicaragua	2.00	58 **	3 **	No
El Salvador	1.50	442 **	23 **	No
Panama***	0.287	38.6**	13.5**	Yes
Total	17.75	3557.6	Prom. = 15 %	

a. Data provided by the coffee institutes of the region (Ihcafé, Anacafé, Icafé, Magfor, Procafé) within the framework of the CATIE-CIRAD-Promecafé Proyect “Control of coffee leaf rust in Mesoamerica” financed by the Government of Norway

* Coffee production reduction experienced in 2011-2012, mainly attributed to coffee leaf rust

** Coffee production reduction in 2012-2013, mainly attibuted to coffee leaf rust

*** Information presented by the Ministery of Agricultural Development of Panama (Promecafé et al. 2013).

and 2011. As a result, coffee farmers reduced management practices in their plantations, the age of coffee plantations exceeded 25 years, and climatic variations increased the incidence of the disease. Increased disease incidence led to a reduction in crop production and generated negative side effects, particularly socioeconomic impacts.

Close to 1.9 million people depend on coffee for their livelihood, including some of the poorest landless workers in the region. Promecafé and IICA (2013) indicate that coffee sector losses in Central America have been estimated at more than 19% of the production, that is, 3.5 million coffee bags, weighing 60 kg each (representing a loss of 499 million USD). About 80% of affected coffee farmers were small-scale farmers who lacked alternative sources of income. It was estimated that 373,584 people (17.2% of the coffee sector's workforce) were displaced due to the disease attack.

In 2013, the "Action Plan with Immediate Measures: An Integrated Program to Combat Coffee Rust and Recovery of Production Capacity in Central America" (Plan de acción con medidas inmediatas: Programa integrado de combate a la roya del café y recuperación de la capacidad productiva en Centroamérica) was announced, with the participation of the region's coffee institutions, agricultural ministries, IICA, Promecafé and CATIE. This was the basis for establishing "Coffee Leaf Rust Control in Mesoamerica," financed by the Government of Norway (Avelino and Rivas 2013).

1.3 How to develop a technical session with coffee farmers

We suggest using the information contained in this chapter to start a technical session with coffee farmers. Prepare a summary with the following consolidated information:

- Origin of the disease and world distribution, including the American continent.
- Epidemics or severe damage seen on the American continent as a byproduct of an increased incidence of leaf rust disease as well as the impacts of coffee leaf rust.
- References indicating when coffee leaf rust first appeared in various countries and the impacts it caused.
- A discussion with the farmers in terms of their experiences coping directly with coffee leaf rust.

For training sessions with coffee farmers, it is very useful to rely on personal stories and experiences related to coffee leaf rust, particularly within the same area. Videos and printed material with photographs can be used in addition to farm visits to illustrate the scope of both the negative impacts and prevention methods that could be used as well as control measures.

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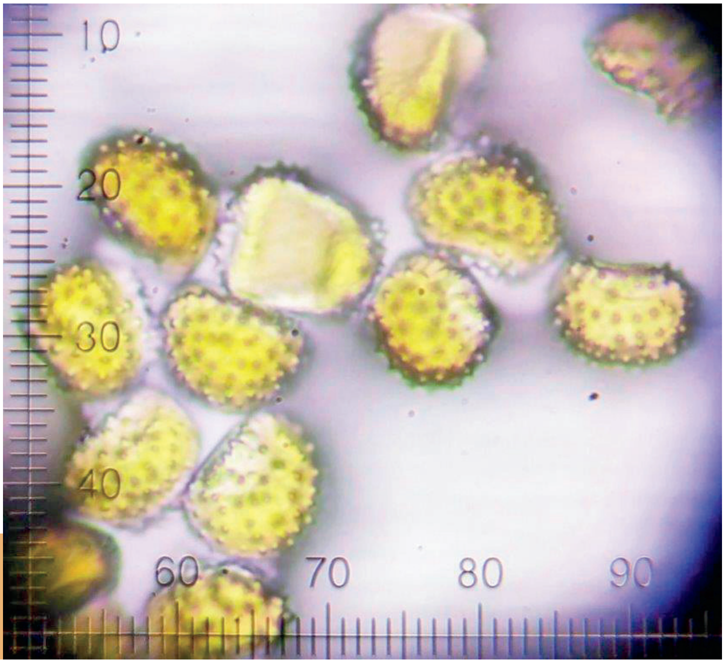
Chapter 2. Description and characterization of coffee rust´s life cycle

Foto: Shirley Orozco

2.1 Taxonomic classification of the *Hemileia vastatrix*

Coffee leaf rust is caused by a fungus in the Urediniomycetes class, belonging to the genus *Hemileia* (which means ‘half smooth’ due to a trait of the uredospores). The complete taxonomic classification of the fungus is in Avelino and Rivas 2013.

Phylum: *Basidiomycota*
Class: *Urediniomycetes*
Order: *Uredinales*
Family: *Chaconiaceae*
Genus: *Hemileia*
Specific epithet: vastatrix



Magnification of the uredospores of coffee leaf rust (x400).
Photo: Isabelle Merle

2.2 Description of the fungus

Hemileia vastatrix infects the leaves of the coffee plants. The first signs or symptoms observed are small, pale-yellow stains that appear on the upper side of the leaves (Figure 1A). These stains gradually increase in size until they produce yellow masses on the underside of the leaves, which correspond to the infectious entities of the fungus called uredospores, which are the reproductive structures of the fungus (Figure 1B). The fungus does not rupture the leaves of the epidermis, as most leaf rusts do; instead it sporulates through the stomatas. In other words, this fungus does not form pustules typical of common leaf rusts (Figure 1C). Powdery lesions on the leaf undersides may have a yellow-orange to red-orange color with considerable variation from region to region (Arneson 2011).

The lesions may occur on any part of the leaf, although they will mainly be found on the edges where raindrops and dew are concentrated (Figure 2A). The center of the lesions eventually dry out, turn brown and the edges continue to expand in order to produce the uredospores. At the beginning of the rainy season, the leaf lesions emerge from the leaves on the lower part of the plant, slowly advancing further up the coffee plant. Infected leaves fall prematurely, leaving long defoliated areas on coffee-bearing branches (plagiotropic branches) (Figure 2B).

Figure 1. Coffee leaf rust development in coffee leaves (Source: Arneson 2011)

A. Initial lesion observed on the leaf
B. Initial stage of uredospore production that takes place under the leaf
C. Advanced stage of coffee leaf rust lesion

Figure 2. A- Coffee leaf rust lesions concentrated on the edge of the leaves
B- Defoliated coffee-bearing branches (plagiotropic branches) (Source: Arneson 2011)

Hemileia vastatrix is a biotrophic organism (a parasite that feeds on living cells), also known as an obligate parasite on leaves of the *Coffea* genus, which means that it feeds and completes its life cycle in living cells (Avelino et al. 1999, Zuluaga and Céspedes 2009). The most susceptible species to coffee leaf rust is *C. arabica* (Avelino and Rivas 2013). There are no reports that the fungus survives in the soil substrate or in dead plant tissues. The reproductive structures of the fungus are the uredospores (sexual reproduction), which are their means of reproduction and dispersion. These structures are kidney-shaped and are rough on their upper half and smooth ventrally (Coutinho et al. 1995, Fernándes et al. 2009).

Rajendren (1967) was the first to observe that the uredospore could actually undergo meiosis, which has recently been verified. This hidden sexual reproduction is known as cryptosexuality (Carvalho et al. 2011).

2.3 Life cycle of the fungus and development stages in the coffee plant

The *Hemileia* fungus cycle begins with the process of releasing and landing a spore on the coffee leaf; subsequently, the spore germinates and the infection process begins (Avelino and Rivas 2013). In the third stage of the infection, disease symptoms appear, when pale yellow spots appear on the underside of the leaves that, with time, increase in size and join together, forming the characteristic yellow or orange spots with fine yellow dust that produces new fungal spores (Rivillas et al. 2011). According to Barquero Miranda (2013), the time between spore germination, internal leaf tissue penetration and the beginning of spore production varies from 20 to 40 days. With more favorable temperature conditions and the permanence of water on the leaf, it could take less time for the fungus to complete the reproductive cycle.

Spore germination requires specific environmental conditions such as constant rain that falls for at least six hours, a temperature of 21-25° C, and a dark environment (Sagarpa 2013, Avelino and Rivas 2013). A period of 5.3 to 8.5 hours is required to form the appressorium (a modification of the hyphae to infect an epidermal host cell). Germination is inhibited by the presence of light and dry conditions of 24-48 hours (Avelino and Rivas 2013). When evaporation or water availability on the leaf is reduced, the germination process stops, since this affects the growth of spore germination tubes (Sagarpa 2013). After germinating, the fungus penetrates the leaves through the stomata (natural openings used by plants for transpiration) located on the underside of mature leaves (Rayner 1961). Once the fungus has penetrated the interior of the leaf, it develops structures called haustoria, which come into contact with the cells of the plant to extract the nutrients necessary for its growth. Avelino and Rivas (2013) pointed out that in order for an infection to occur, there must be an optimal concentration of 15-30 fungal spores per square centimeter; if the spores are too scattered, the infection does not occur.

After 30 days of colonization, the fungus is considered to be mature enough to differentiate into structures called sori which are responsible for producing new uredospores. The latency period is the period of time between the infection and the production of spores. Coffee leaf rust can complete 6 to 8 cycles within 30 days depending on the precipitation pattern and region (Barquero Miranda 2013). Rivillas et al. (2011) pointed out that in the Colombian coffee region, the latency period can fluctuate between 34 and 37 days under sun, while under shaded conditions this varies from 31 to 35 days. Avelino and Rivas (2013) depicted the life cycle of the fungus and the factors that affect it in a flow diagram in which they indicated the conditions that can favor or inhibit the development of the disease (Figure 3.).

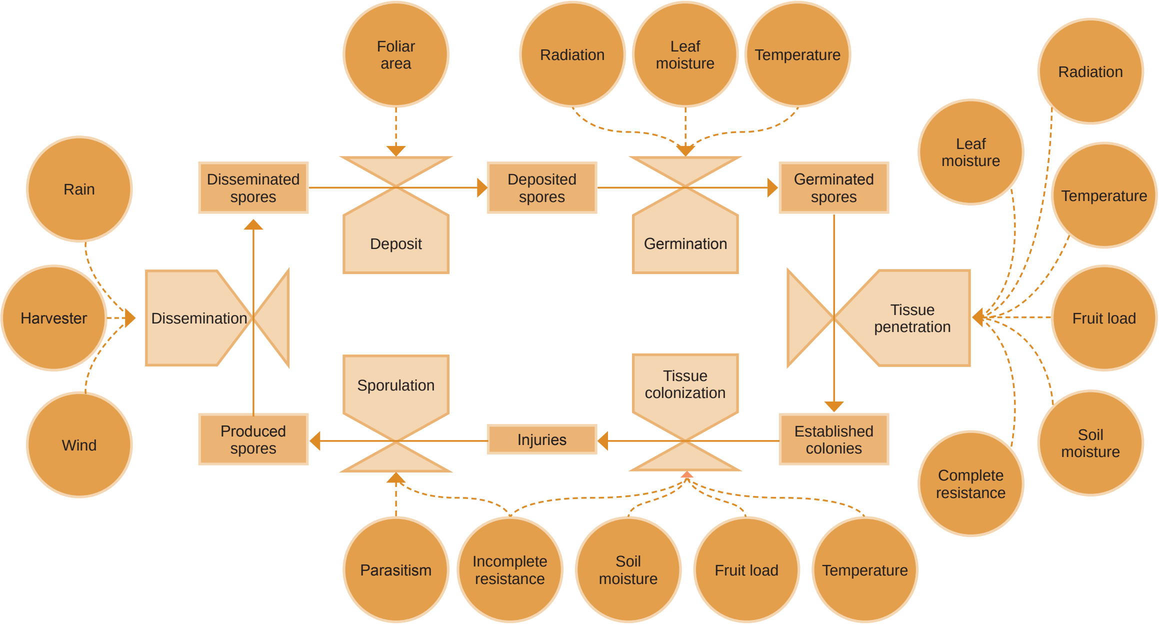


Figure 3. Diagram showing the life cycle of *Hemileia vastatrix* and factors that affect it (Avelino and Rivas 2013).

The coffee leaf rust life cycle usually lasts 30 days. It is after 24 days that translucent, pale yellow spots begin to appear. The typical signs of the disease are orange spores, which become visible on the 27th day of the life cycle, when 90% of the time has elapsed. Once leaf lesions or leaf rust spots start to appear, the structure remains active while the leaf continues to adhere to the plant. This can last for several months. Another aspect to consider is the survival of the inoculum from one year to the next, as it plays a very significant role in epidemic dynamics. Plantations that suffered moderate or mild disease attacks will have more leaves with coffee leaf rust lesions, which will remain in the plant during the dry season and will begin sporulation with the onset of the rains. Consequently, the possibilities of infection increase on new leaves if no protection measures are implemented (Avelino and Rivas 2013, Barquero Miranda 2013).

2.4. How to develop a technical session with the farmers

The technical session should consider the phenological life cycle of the plant, climatic conditions, and the presence of the fungus. If the training session is implemented at the beginning of the rainy season, coffee leaf rust lesions may be observed, which are the source of inoculum for the next life cycle. If the session takes place late in the rainy season, it is imperative to look under the leaves to detect advanced leaf lesions.

Suggested activities to implement:

- Gather coffee leaves that show the different phases of the coffee leaf rust cycles starting from the first pale yellow damage to well-sporulated coffee leaf rust.
- Explain the fungus' life cycle in the different stages beginning with the release of spores to when the spores have infected a leaf and pale yellow spots are observed. Make sure it is clear that when the first yellow spots appear, this means that the spores have germinated and penetrated the leaf tissue and are now feeding on the plant; this process started at least 24 days before.
- It is crucial that coffee farmers know about the gateway for the fungus. To explain this, prepare a sheet with illustrations or photographs showing the stomata found on the underside of the leaf. Using this tool helps explain leaf structures and processes that are not visible to the naked eye.
- Provide details of the temperature, light and humidity conditions the fungus requires to continue its life cycle.

- Introduce the concept of 'obligate parasite', that is, a fungus that develops its entire life cycle in a living plant and cannot survive in other places, such as in the soil. This means that when infected leaves fall to the ground, after a few days they dry up and the fungus dies. Generally, the fungus can stay in old leaves that remain attached to the coffee plant.
- Prepare a sheet with the diagram proposed by Avelino and Rivas (2013) to explain the cycle of the fungus in the coffee plant and in the coffee plantation. Highlight the factors that affect the development of the disease. For example, highlight the importance of temperature, shade and solar radiation conditions that favor fungal growth. What other conditions are beneficial for the fungus? What are the unfavorable conditions?

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Chapter 3. What we know about coffee leaf rust strains


Foto: Shirley Orozco

In 1917, on the island of Timor, a natural coffee hybrid from crosses between C. arabica and C. canephora was found. This hybrid is known as the 'Timor hybrid'. It has the morphological and agronomic characteristics of *C. arabica*, and the resistance of *C. canephora.* This hybrid has been used in genetic improvement programs to develop coffee varieties more resistant to coffee leaf rust (Cristancho-Ardila et al. 2007).

Studies conducted with *H. vastatrix* have shown that the fungus has evolved and developed genetic variants (fungus strains). The fungus strains attack different coffee species and varieties in a distinct way, depending on the coffee plant genes for resistance and the genetics of fungus virulence (Cristancho 2011).

In 1955, the Coffee Leaf Rust Research Center (CIFC, Portuguese acronym) was established to conduct research on coffee leaf rust and improve the resistance of coffee varieties. The CIFC has described more than 50 leaf rust strains from 3,500 samples collected from coffee-producing countries around the world (Barquero Miranda 2013; Várzea 2013). The highest diversity of strains is from Asian countries, mainly India, while in America, Strain II is the one that predominates (Várzea 2013).

Currently, the coffee regions that are free of coffee leaf rust are Australia and Hawaii. The disease exists and the number of leaf rust strains present varies in different coffee-producing regions around the world.

The highest number of coffee leaf rust strains are found in India; these strains are considered the most virulent, according to various surveys that were conducted by the CIFC. For example, two descendants of the Timor hybrid that initially were resistant to the disease became susceptible due to the evolution of the pathogen, which has managed to overcome the resistance of coffee plants over the years (Várzea 2013).

Isolation **CIFC 3302** (v1,2,4,5,6,7,8,9, ?) – HDT 832/1
Isolation **CIFC 3305** (v1,2,4,5,6,7,8,9, ?) – HDT 832/2

3.1 Actions and reactions to leaf rust attack

One of the biggest questions is why the highest number the highest number of coffee leaf rust strains, and the most virulent ones found in India? Part of the answer is because, in this country, coffee varieties resistant to the disease have been grown for many years, which has induced the fungus, in its process of evolution, to produce mutations (natural genetic modifications) that allow it to create new physiological groups (new strains) and infect plants that are more resistant.

The relationship between the host (the plant) and the pathogen, based on the gene-to-gene theory, will be discussed later in this chapter.

The pathogen, in its struggle for survival, begins the process of adaptation to new conditions and it evolves to attack the resistant varieties, so it can continue its life cycle (Várzea 2013). Researchers, for their part, are striving to develop and improve new varieties resistant to the fungus.

3.1.1 Orange coffee leaf rust strains present in the American continent

According to studies that were carried out, the fungus' strain II arrived on the American continent around 1970 and spread rapidly into coffee-producing regions of southern Brazil. The coffee genetic improvement programs in Brazil produced varieties that incorporated disease resistance genes, resulting from the crossing of coffee varieties such as Caturra and Catuaí, with descendants of the Timor hybrid – giving rise to the Icatú variety. However, over the years, these varieties began to show decreases in coffee leaf rust resistance.

In 2000, 15 physiological strains of leaf rust were identified in Brazil: I, II, III, VII, X, XIII, XV, XVI, XVII, XXI, XXIII, XXIV, XXV, XXXI and XXXVII, but strain II was still the most widely distributed (Zambolim et al. 2005, Cabral et al. 2009). In 2007, Capucho et al. (2012) collected 64 samples of coffee leaf rust from different coffee-producing in Brazil and revealed the presence of strains I, II, III, XV, XXII and XXXIII. Strain II was present in 68.7% of the samples, while strains I, III, XV and XXII were present in six, four, one or two samples respectively. Strain XXXIII was reported for the first time and described in seven samples collected in several regions in the southern state of Minas Gerais.

In Colombia, more than ten leaf rust strains have been identified.Research showed that coffee leaf rust arrived in 1983 and the presence of strain II was reported as responsible for the impacts of crop loss for the Caturra variety. Subsequently, Cristancho et al. (2007) identified four strains of complex genotypes, as well as Strain XXII, and evidence of the presence of Strains XVII, XXIII, XXV and XXX, using derivative materials from the Timor hybrid. After the severe epidemic event that occurred between 2008 and 2011, generating 30% of crop production loss, molecular research was important in determining whether new disease strains were present. The study revealed that race II and its derivatives prevail in the country (Castro Caicedo et al. 2013, Cristancho et al. 2007).

Cristancho et al. (2007) pointed out that the available differential plants have not allowed the identification of new coffee leaf rust strains in Colombia in derivative materials from the Timor hybrid. However, they estimate that there must be more than ten strains that attack these derivative plants in the country.

Brazil and Colombia are the countries that have conducted the most research on coffee leaf rust and they have reported the presence of new fungus strains. Over the years, research institutes in these two countries have produced new disease-resistant varieties, from at least one parent of the Timor hybrid which give resistance to coffee leaf rust Strain II. However, the fungus *H. vastatrix* continues to evolve and adapt, affecting the new varieties.

Coffee leaf rust does not differ in terms of the symptoms and signs produced by the fungus strains at the plant level. To determine the presence of new leaf rust strains, it is necessary to take samples and send them to the CIFC in Portugal, where analyses are carried out in coffee plants called differentials. That is, they react in different ways to the different leaf rust strains.

3.1.2 Evolution of orange leaf rust strains in Central America

In 1976, coffee leaf rust was first reported in Nicaragua and subsequently dispersed to other Central American countries. The coffee leaf rust samples sent to the CIFC in 1977, 1984, 1992, 1993 and 1994, from Nicaragua, Honduras, Guatemala and Costa Rica, were identified as samples of Strain II.

In 2013, the analyses carried out by CIFC of coffee leaf rust samples collected in Costa Rica, also revealed the presence of Strains XXIV and XXXVI (Várzea 2013).

In Central America, the presence of new coffee leaf rust strains is limited. Perhaps this is because most of the coffee in the region is from coffee varieties susceptible to strain II, which has led to a lower level of evolution of the fungus. In 1997, a new strain was discovered in Honduras (Strain I; v2 and 5) from samples that were collected around the Yojoa Lake region. This same strain was later reported in El Salvador (Avelino et al. 1999). In 2012, the presence of two new strains (XXIV, v2, 4 and 5 and XXXVI, v2, 4, 5 and 8) was detected in Costa Rica, which implied either the fungus had evolved, or that these new strains had been introduced. Coffee institutes need to carry out frequent monitoring to determine the degree of dissemination of coffee leaf rust in coffee production areas, and whether these new strains are attacking coffee varieties with resistance to leaf rust, such as the Catimors and Sarchimors currently in production. Future responses of the new varieties that are in the research phase and later released should also be evaluated.

3.2 Coffee leaf rust resistance and virulence

For some years now, work has been done on leaf rust resistance in coffee plants. Currently, nine genes are known to be responsible for coffee leaf rust resistance, designated by the initials SH followed by a number that corresponds to a specific gene. Bettencourt and Noronha-Wagner (1971) reported that the resistance genes SH1, SH2, SH4 and SH5 come from the *C. arabica* species; the genes SH6, SH7, SH8, SH9 come from the *C. canephora* species, while the SH3 gene comes from the *C. liberica* species.

The coffee leaf rust fungus contains virulence genes, normally referred to with the letter ‘v’ followed by a number. It has been found that for each SH resistance gene found in the coffee plant, there is a v gene virulence. This is known as the gene-gene relationship (Avelino and Rivas 2013).

The varieties of *C. arabica*, such as Bourbon, Typica, Caturra, Catuaí and Pacas contain the resistance genes SH1, SH2, SH4 and SH5, which may exist in various combinations not yet fully identified. What is known is that these varieties are susceptible to strain II of leaf rust, which contains the v5 virulence gene. The aforementioned varieties contain the SH5 resistance gene, which explains why they are susceptible to the disease. As the combination of resistance genes now present in coffee varieties increases, rust strains develop more virulence genes that eventually attack coffee, known as a breakdown of resistance. That is, the fungus evolves and manages to infect coffee plants that were originally resistant.

The natural hybrid between *C. arabica* and *C. canephora* found on the island of Timor in 1917 opened the possibility of incorporating new genes resistant to coffee leaf rust. This hybrid integrated four resistance genes deriving from *C. canephora* (SH6, SH7, SH8 and SH9). The descendants 832, 1343 and 2570 of the Timor hybrid inherited the resistance genes of *C. canephora*. Consequently, the varieties created from the cross with the Caturra, Villa Sarchí and Catuaí varieties -known as Catimors and Sanchimors, respectively- contain eight resistance genes: four inherited from *C. arabica* and four from *C. canephora*. This has opened new possibilities for obtaining increased resistance to coffee leaf rust (Castro Caicedo et al. 2013).

However, it has already been shown that with time, the descendants of the Timor hybrid become susceptible to pathogen attacks. In India, for example, two previously immune descendants lost their resistance (Várzea 2013). Other research in Brazil has shown how resistant varieties developed by genetic improvement programs have already begun to show the presence of the disease (Hiroshi Sera et al. 2009).

The genetic improvement programs work to produce new varieties resistant to the disease, therefore, continuous work is required. Researchers are constantly looking for new sources of resistance that allow them to supply coffee producers with varieties showing greater resistance to the disease in order to delay the progress of the disease and minimize the damage it causes when present at epidemic levels. To do this, strategies must be used that combine plant resistant materials, on the one hand, and apply preventive and controlled measures appropriately and in a timely manner on the other.

3.3 How to develop a technical session with farmers

The session begins with a presentation to explain the coffee varieties that are present on farms. It is important to highlight the differences between the old varieties such as Typica, Borbón and Mundo Novo (taller varieties that are still grown in El Salvador, Honduras and Guatemala and, to a lesser extent, in Costa Rica and Nicaragua). Compare them with newer varieties, such as Caturra and Catuaí (varieties that are not as tall and introduced significant changes in Central American coffee production).

In preparing a technical session with coffee farmers, it is suggested that the technical staff and/or extension agents use the content of this chapter taking the following aspects into consideration:

- Make it clear that the varieties of coffee grown in the country are susceptible to coffee leaf rust. Explain the emergence of the Timor hybrid (a natural hybrid, product of the crossing of *C. arabica* and *C. canephora*, coffee). It is recommended that you show photographs of robusta coffee since many producers are not familiar with it. Explain that this hybrid incorporates resistance genes from both parents, which gives it greater resistance against the disease. The crossing of the Timor hybrid with varieties such as Caturra or Catuaí generates varieties that are more resistant to the disease; for example, catimors (some examples of catimor varieties are: CR95, Mida 96, Ihcafé 90, Lempira 98, Anacafé-14, Catrenic).
- It is recommended that you locate, in each zone, a farm or a coffee collection to see the different varieties of coffee and observe their response to coffee leaf rust attack.
- Bring to the meeting leaf samples infected with coffee leaf rust to explain the different aspects related to coffee leaf rust strains. Point out that the most widely distributed strain of coffee rust in the region is strain II, however, the presence of other strains has been reported in Honduras, El Salvador (strain I) and Costa Rica (strains XXIV (v2, v4, v5) and XXXVI (v2, v4, v5 and v8).
- Make it clear that at first glance, it is not possible to determine the type of leaf rust strain. This conclusion is only possible under controlled conditions in experimental stations where coffee plants known as “differential coffees” are used. These are plants that are susceptible

to a specific leaf rust strain; they only get sick when they are attacked by that particular strain. Differential coffees are not available for everyone and not just anyone can do the tests. In the experimental stations there are professional scientists and specialized personnel with a lot of experience who are in charge of the work.

- Make sure that the participants receive a very clear message: coffee leaf rust is not a static fungus. On the contrary, it is a fungus that is constantly evolving, so it is advisable to plant new coffee varieties with resistance to the disease. A greater diversity of coffee plants will make the evolution of the fungus more difficult, since, it will not find a homogenous group of plants of the same coffee variety, therefore it will lose the strength to continue its life cycle. Management practices that integrate prevention and control must be implemented constantly.

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Chapter 4. Environmental factors that influence coffee leaf rust

Foto: Silvia Chaves

In this chapter, we will address the main environmental factors that have either a positive or negative influence on the life cycle of the fungus that causes coffee leaf rust. The cited bibliographic information provides the evidence on how environmental factors such as temperature, precipitation, relative humidity, leaf dampness, dew point and solar radiation affect the development of the disease as well as how certain management practices can affect coffee growth and production. Therefore, we will analyze the results of recent research that aim to explain how these factors influence the behavior of the disease in sun-grown and shade-grown coffee agroforestry systems.

A set of minimum conditions are required in agro-ecological coffee regions for coffee to develop adequately and perform its vital functions. The most important condition is annual rainfall which should range from 1,200 to 2,000 mm per year. The cycle of rainy and dry periods is important for coffee plant growth, new foliage sprouting, flowering and fruit production of the plant. In addition to the amount and distribution of rain the coffee plants need, it is also important to consider other factors such as soil moisture retention properties, atmospheric humidity, cloud cover, and crop management practices (Fischersworring and Robkamp 2001).

Shade grown coffee represents 74.4% of all the coffee production systems in the Central American region. According to Castro et al. (2004), this type of coffee system is more compatible with the conservation of the environment, forest diversification and ecotourism, which mutually reinforce one another to contribute to agricultural sustainability. Shade generates certain microclimate conditions (relative humidity, temperature, solar radiation) that are optimal for coffee development, nonetheless, these conditions can also favor the level of infection and development of coffee leaf rust if the production systems do not have a proper design and shade management.

The effects of shade on coffee leaf rust are still debatable. Some authors claim that the level of coffee leaf rust infection is higher under shade-grown than under sun-grown conditions (Machado and Matiello 1983; Staver et al 2001; Avelino et al 2004; Avelino et al 2006), while others claim the opposite (Soto-Pinto et al. 2002). Avelino et al. (2004, 2006) suggested that the different results obtained could be explained by differences in coffee fruit loads.

We will now analyze the influence of environmental factors on the appearance and development of the fungus that causes coffee leaf rust under shade-grown and sun-grown conditions.

4.1 Temperature and altitude

The temperature is determined by latitude and altitude, although other factors might also affect it, such as the time of year and cloud cover. Additionally, the temperature of a site also varies depending on whether it is recorded under sun or under shade. This information is crucial to understanding the effect of temperature on the development of the fungus in shade-grown and sun-grown coffee systems.

The differences between air temperature and the temperature recorded on the coffee leaf depend mainly on the amount of solar radiation that the plants receive during the day. Warm and dry weather conditions show the greatest difference while in rainy and cold weather conditions, the air temperature and leaf temperatures tend to remain more in equal balance (Jaramillo and Gómez 1989). According to Orozco and Jaramillo (1978), differences between leaf temperature and air temperature will vary depending on the species and the water content of the leaf. In *C. canephora*, the temperature difference is greater (1 to 3° C) compared to *C. arabica*, which could be explained by the morphological, anatomical and physiological differences between the types of leaves (leaf area, thickness of the leaf, chlorophyll content, transpiration rate, amount of water content in the leaf and heat exchange) (Zahner 1968).

The optimal temperature for the development of coffee leaf rust is 22-23° C, which favors the uredospore germination process, tissue penetration and colonization of the leaf. The incubation period of *H. vastatrix* is therefore shortened with favorable temperatures for germination. In a study conducted in Honduras, Santacreo et al. (1983) demonstrated that, at 750 m above sea level, the latency periods of the fungus fluctuated between 29 and 62 days between February 1982 and January 1983; the shortest latency periods were found in August and September when the temperature remained between 18 and 27° C. At an altitude of 1,200 masl, the latency period lasted 40 to 80 days, due to the lower temperatures.

During the day, coffee plant branches and leaves remain at a warmer temperature than the air in the plantation and they are colder during the night (due to heat removal by convection and insufficient foliar evaporation to balance its temperature with the temperature of the air). The minimum air temperature occurs after the minimum temperature of the leaves and branches is reached (about 15 minutes later). The branches display intermediate heating and cooling between the coffee plant leaves and air. The closer the temperature remains to 22° C, the more likely it is that coffee leaf rust develops. The temperature of the fruits was similar to that recorded on the branches (Jaramillo-Robledo and Gómez-Gómez 1989).

The turbulent behavior of the wind within the coffee plantation depends on the wind speed, the architecture of the trees, the leaf area index, planting distance, management practices and the orientation of the furrows. Wind speed tends to increase logarithmically with tree height due to the decrease in leaf surface roughness and lower friction; this factor contributes to the dispersion of the fungus' uredospores.

In shade-grown coffee, the daily variations in temperature and humidity of the microclimate are lower than in sun-grown conditions because there is a decrease in the incidence of solar radiation due to shade (Jaramillo-Robledo and Gómez-Gómez 1989). The differences between minimum and maximum daily temperatures are also reduced, and there is a higher probability that the coffee leaf is exposed to greater moisture due to the shade conditions (Barradas and Fanjul 1986, Jaramillo-Robledo and Gómez-Gómez 1989, Caramori et al. 1996). Air temperatures within a shaded coffee system are affected by plant height, since lower temperatures are found closer to the ground. The greatest differences are found between ground level and 1 m in height; these differences can be up to 4 °C during the peak of highest exposure to solar radiation. Between 2 m and 4 m in height, temperature differences decrease by 1.0 to 1.5 °C. The air temperatures recorded at 1 m of height, at the middle level of the plant and within the foliage of the coffee plant were also similar, although results showed that in the period of time with the greatest solar radiation exposure in foliage, the air temperature was lower (Jaramillo-Robledo 1976).

Evaporation in a shaded coffee plantation was 50% lower compared to a coffee plantation with no shade. The wind speed was also lower (1.5-3 km/h) in relation to coffee plantations under full sun exposure (1.5-4 km/h). Higher wind speed provides favorable conditions for the development of the disease under full sunlight conditions (Orozco and Jaramillo 1978).

Studies carried out by López (2010) on the incidence and severity of coffee leaf rust showed that higher temperatures were not common during rainy days and temperature remained closer to the optimal temperature for uredospore germination. Coffee leaf rust was more likely to develop under shade-grown coffee temperatures since they were likely to reach an optimum level for the development of leaf rust (López 2010).

Table 1. Comparison of parameters that were evaluated in 2008 and 2009, during three periods of time during the day under three types of rainy conditions and two types of sunlight conditions (average and standard of error).

Time	Growing conditions	Daily precipitation	Air temperature*		Relative humidity		Leaf moisture	
			2008	2009	2008	2009	2009	
		No rain	26.26 ± 0.81	26.08 ± 0.37	81.22 ± 2.03	77.92 ± 1.30	30.00 ± 6.55	25.33 ± 5.42
	Full sun	<5 mm	24.76 ± 0.39	28.23 ± 0.41	84.92 ± 1.04	83.64 ± 1.00	45.55 ± 3.76	39.73 ± 4.43
8:43 am		>5 mm	24.35 ± 0.44	24.83 ± 0.28	88.39 ± 1.10	86.96 ± 0.93	62.76 ± 4.88	56.18 ± 5.00
		No rain	24.88 ± 0.75	24.25 ± 0.29	83.46 ± 2.41	81.76 ± 1.17	44.29 ± 12.44	78.00 ± 4.11
	Under shade	<5 mm	23.65 ± 0.35	25.81 ± 0.32	86.52 ± 1.06	86.88 ± 0.86	70.91 ± 4.93	87.57 ± 2.39
		>5 mm	23.45 ± 0.39	23.47 ± 0.21	88.10 ± 1.15	88.72 ± 0.84	81.38 ± 3.93	90.88 ± 2.23
		No rain	32.12 ± 0.61	31.10 ± 0.46	59.74 ± 1.36	66.49 ± 1.66	2.86 ± 1.94	3.13 ± 3.13
	Full sun	<5 mm	29.26 ± 0.41	30.56 ± 0.33	69.30 ± 1.42	69.00 ± 1.12	16.72 ± 4.31	11.20 ± 3.29
12:13 pm		>5 mm	26.90 ± 0.60	28.14 ± 0.44	80.09 ± 1.82	75.65 ± 1.52	45.86 ± 6.28	34.12 ± 5.45
		No rain	29.92 ± 0.57	28.22 ± 0.38	68.78 ± 0.99	75.31 ± 1.34	7.14 ± 3.98	39.38 ± 6.06
	Under shade	<5 mm	27.35 ± 0.36	27.58 ± 0.29	76.11 ± 1.11	78.04 ± 0.96	22.99 ± 4.47	57.07 ± 4.29
		>5 mm	25.60 ± 0.52	26.14 ± 0.36	84.01 ± 1.36	82.19 ± 1.19	53.45 ± 6.13	65.59 ± 4.64
		No rain	27.34 ± 0.44	27.52 ± 0.36	71.91 ± 1.73	75.69 ± 1.39	0.00 ± 0.00	3.13 ± 3.13
	Full sun	<5 mm	24.70 ± 0.25	26.52 ± 0.28	81.91 ± 0.87	79.47 ± 1.03	33.43 ± 5.18	36.80 ± 5.30
3:43 pm		>5 mm	23.21 ± 0.29	24.46 ± 0.28	89.20 ± 0.98	87.32 ± 1.02	72.76 ± 5.62	70.59 ± 5.17
		No rain	25.82 ± 0.34	26.00 ± 0.26	77.46 ± 1.13	81.61 ± 0.95	2.86 ± 2.86	46.88 ± 6.39
	Under shade	<5 mm	23.90 ± 0.22	25.17 ± 0.21	84.03 ± 0.71	84.57 ± 0.75	44.18 ± 5.47	68.00 ± 4.54
		>5 mm	22.69 ± 0.26	23.74 ± 0.22	89.99 ± 0.78	90.15 ± 0.77	77.59 ± 5.16	89.12 ± 3.42

* During 2008, 14 days without rain, 67 days with rain<5mm and 58 days with rain>5 mm were evaluated. During 2009 there were 32 days with no rain, 74 days with rain<5 mm and 69 days with rain>5mm. Source: López (2010).

Higher leaf temperatures were recorded under sun-grown (34° C) conditions compared to shade-grown (29° C) under rainy conditions (Figure 1). There were no differences in leaf temperature during the night for both types of coffee systems. The leaf temperature variable appears to behave independently from the rainy conditions, especially under shade-grown conditions. Only a slight decrease in temperature was observed in the afternoon when the sites experienced precipitation greater than 5 mm.

The temperature records (Figure 1) show how the optimum temperature for the development of leaf rust (22 to 23 °C) occurs from 2:00 p.m. until 11:00 a.m. on the next morning which, together with the factors of relative humidity and darkness, are the ideal conditions for the development of the disease.

4.2 Precipitation and dew

Precipitation has been one of the most studied environmental factors in relation to the development of coffee leaf rust over time. Plant´s water availability, is another factor that indirectly influences the development of the disease, due to its effect on the growth of the coffee plant. The

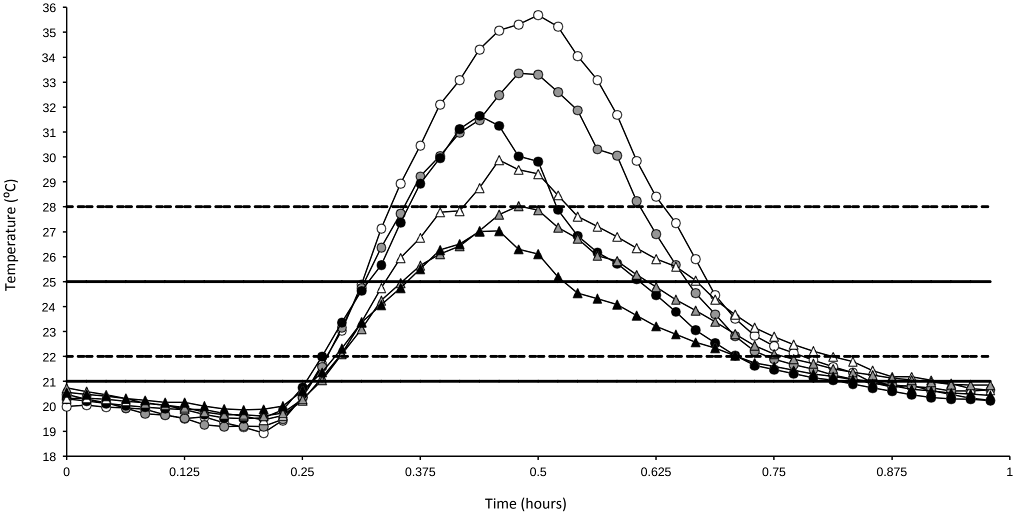


Figure 1. Temperature variations during rainy days under different conditions of daily rain (without precipitation: white, ≤5 mm: gray, > 5 mm: black) with coffee systems exposed under sun-grown conditions (O) and shade-grown conditions (Δ) during 2009. Source: López B. 2010.

production of new foliage, the growth of the branches, the flowering and the ripening of the fruits are tightly linked to water availability. Likewise, the number of infected leaves is related to the greater or lesser incidence of leaf rust disease, depending on the amount of tissue that is susceptible and available for infection (Subero 1970).

Precipitation is a very important factor in the development of a coffee leaf rust epidemic (increased intensity and severity). Precipitation acts as a determining factor in the germination and dispersion of the spores and, indirectly, on other environmental factors such as relative humidity, temperature and luminosity. When the intensity and frequency of the rains exceed certain levels, the coffee leaf rust infection tends to increase since precipitation acts at the level of sporulation (dissemination and transport), deposition, germination and penetration of the uredospores in the leaves. This explains why the epidemic develop during the rainy season (Gálvez et al. 1982; Santacreo et al. 1983; Holguin 1985).

Shade trees in coffee plantations intercept part of the rain (Imbach et al. 1989; Jaramillo-Robledo and Chaves-Cordova 1998). When the intensity and duration of the rain is light (0.25 to 1.00 mm/hour), the water may not reach plants under shade. However, when the rain is intense and long, the shade trees channels the water, and large droplets (up to 9 mm in diameter) are also formed that fall sparcely in the coffee plantation (Avelino et al. 2004). It is expected, therefore, that in low intensity rains shade trees contribute to limiting the dispersion of leaf rust spores; on the contrary, heavy rains encourage dispersion, due to the impact of large droplets of water on the leaves.

Coffee trees grow best when relative humidity is between 70 and 85%. However, very little is known about the effect of relative humidity in the development of coffee leaf rust. Avelino and Rivas (2013) stated that relative humidity and leaf moisture have an effect on the germination of the leaf rust's uredospore. When high relative humidity is present in the environment, water availability for plants improves and the tissues (leaves, fruits and branches) remain moist, which favors the germination of the uredospores and the proliferation of the infection.

Feliz (2003) indicated that a higher exposure to solar radiation can decrease relative humidity by 70% during the afternoon hours, between the rows of sun-grown coffee and in the shade of "madero negro" (Gliricidia sepium). This generates unfavorable conditions for the development of coffee leaf rust. Relative humidity remains high during the night, without variations between the different growing conditions, but it tends to fall during the day (Lopez 2010). Sun grown coffee had a lower level of humidity during the day compared to shade grown coffee, which generates adverse conditions for the development of the disease (Table 1).

Dew is a physical-meteorological phenomenon where the humidity of the air condenses in the form of droplets due to an abrupt decrease in temperature or contact with cold surfaces. Dew is often referred to as the condensation that takes place on a surface, usually on any plant cover on the soil. The dew point is the temperature at which water vapor contained in the air begins to condense to become dew, mist or another type of cloud. Under very low temperatures frost may occur. The dew point is reached when the air reaches its saturation (relative humidity equal to 100%). Saturation is caused by an increase in relative humidity with the same temperature, or by a decrease in temperature with the same level of relative humidity, or by a combination of both.

The study of López (2010) showed that during the period between 6:00 p.m. and 6:00 a.m., in rain-free, sun-grown coffee, there is a close relationship between the temperature of the leaf and the dew point (Figure 2), which favors the germination of coffee leaf rust spores. Under regulated shade conditions, the temperature of the leaf is above the dew point, which considerably reduces the formation of dew and, consequently, the possibility of fungus spore germination. The presence or absence of dew on the coffee leaves may be a determining factor in whether fungus spores develop or not.

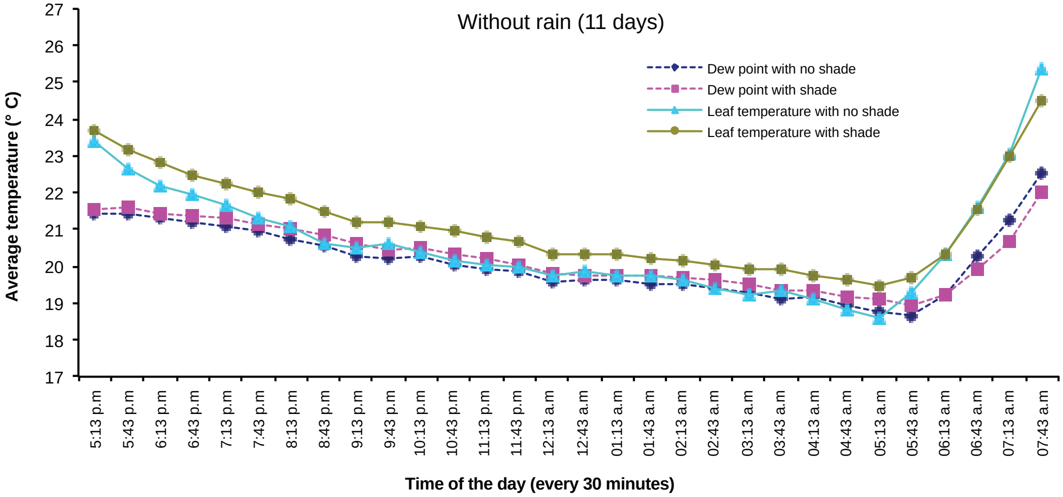
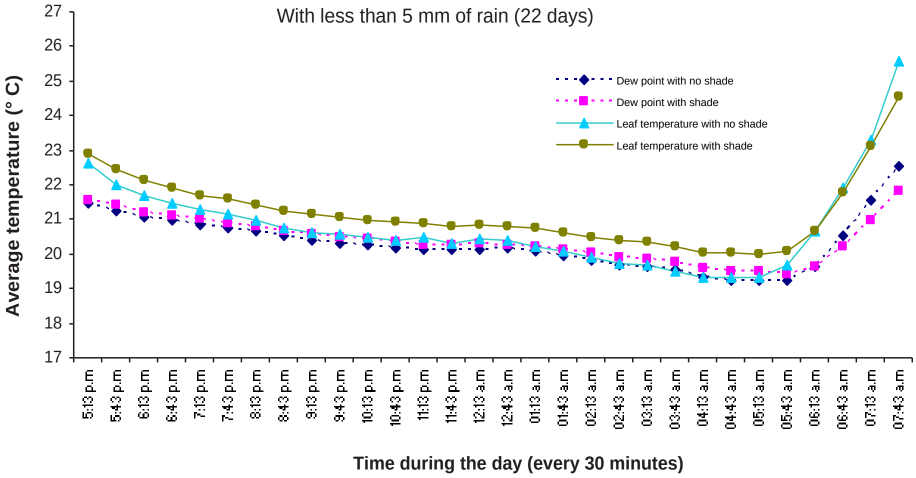


Figure 2. Comparison of leaf temperature (continuous line) and dew point (discontinuous line) under no rain conditions, for sun grown and shade grown trials in 2009
Source: López (2010).

Sun grown coffee with rainy day conditions (Figure 3) has a higher possibility of dew formation since the temperature of the leaf remains above the dew point. In regulated shaded growing conditions on days without rain, the dew point temperature is superior to that of the leaf and thus no water is condensed on the leaf.

Another factor that influences infection of coffee leaf rust is the moisture of the coffee leaf. Although no specific studies that document the effect of leaf moisture on the development of the



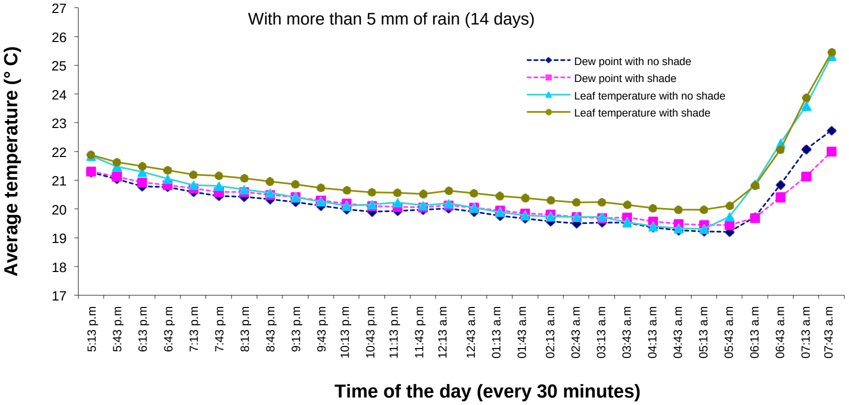


Figure 3. Comparison of leaf temperature (continuous line) and dew point (discontinuous line) under rainy conditions (<5 mm and >5 mm) for sun grown and shade grown trials during 2009.
Source: López (2010).

disease were found, Avelino and Rivas (2013) indicated that under shady conditions, free falling rain is retained inside the plantation, although under shade there is no dew, which would be the only source of water on days without rain. López (2010) pointed out that during his research there were no significant differences in the moisture content between sun grown and shade regulated coffee during the night. The data obtained show that moisture of the leaf remained above 15%, the threshold used to determine if the leaves remained wet or not. During the study period it was observed that between 8:43 a.m. and 3:43 p.m. leaf moisture level decreased; in sun grown conditions without rain, percentages of leaf moisture were observed below 15%; in all other cases, leaf moisture was above that value, therefore the leaves had enough moisture for the leaf rust fungus to carry out its life cycle under appropriate humidity conditions (Table 1).

According to the evaluated information, coffee trees growing under regulated shade management favors the development of the disease. Under shaded conditions, the leaves remain wet for a longer time which favors spore germination, the temperatures are close to optimum for germination and penetration of the fungus and there is a higher relative humidity. In addition, shade favors a lower light intensity which facilitates spore germination (Nutman et al. 1963). In sunny conditions, the increased light exposure inhibits spore germination and water droplets on the surface of the leaves evaporate faster (Rayner 1961).

4.3 Effect of coffee shade on environmental factors and its relationship to coffee leaf rust

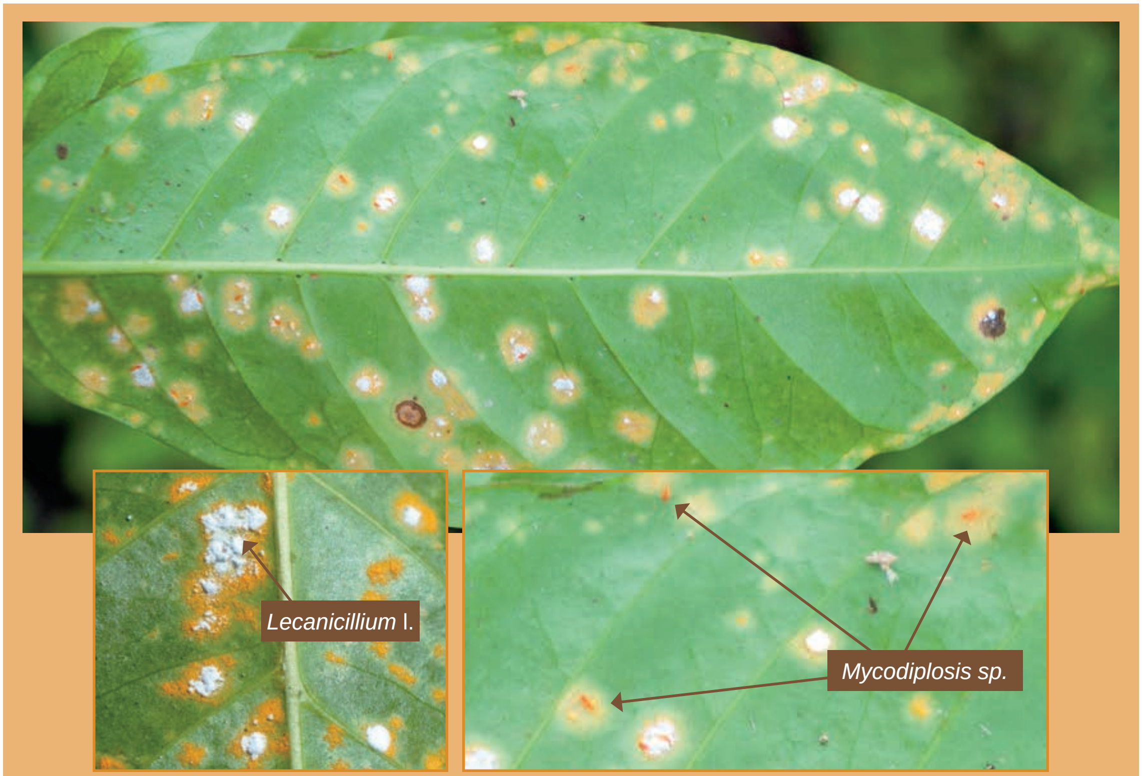
Several studies have shown precipitation, altitude, temperature, relative humidity and leaf moisture are closely related to the life cycle, behavior and development of coffee leaf rust. These studies have been implemented in sun grown or shaded coffee systems but there are no studies comparing the two coffee systems, which would allow a better understanding of the problems related to the development and behavior of the disease.

In 2000, CATIE established the “Long Term Coffee Experiment”, which integrated different coffee management systems from conventional high-input farming to basic organic management and various shade combinations, including full sun management as a control. In 2014, Pico Rosado completed a study on the effects of shade and coffee management on the incidence, severity, inoculum quantity and dispersion of *H. vastatrix* in Costa Rica, as part of the aforementioned experiment. The main objective of the study was to understand the effect of shade on the pre-infectious processes, colonization, sporulation and dispersion of coffee leaf rust.

During a one-year period, the study evaluated three levels of shade covers (*Chloroleucon eurycyclum* + *Erythrina poeppigiana*, *Erythrina poeppigiana*, full sunlight) combined with three agronomic management practices (conventional with fungicide, without fungicide, organic). The following aspects were analyzed during the research: percentage of diseased leaves, percentage of diseased area, amount of inoculum produced, area under the disease progress curve (in diseased leaves and diseased area), percentage of microparasitism by *Lecanicillium lecanii*, percentage of growth, and defoliation and fruit load of the host (coffee plant).

The results of the research provided answers to key questions raised, or reconfirmed previous findings. The results highlighted:

1. Coffee leaf rust in the presence of low fruit load (low production), does not generate the conditions that produce an epidemic.
2. Dense shade trees that have an open-crown (shade coverage greater than 40%) favor leaf moisture, maintained an otimum temperature and a higher relative humidity, all of which favor fungal spore germination.
3. Under sun grown conditions, the growth of coffee leaves was greater than in the shade; this fact could give the notion of a decrease of coffee leaf rust under full sunlight conditions, giving the impression that under shaded conditions the incidence is greater.
4. Shade favors the development of the fungus *Lecanicillium lecanii* coffee leaf rust's natural enemies (hyperparasite). The highest regulatory activity of *L. lecanii* occurred in the second part of the rainy season, when coffee leaf rust was abundant. This behavior allows us to understand that shade provides an important habitat for beneficial microorganisms that can contribute to the control of pests or diseases in a natural way.
5. During 2014, when coffee plants experienced a high fruit load, the intensity of the epidemic was reversed, meaning that there was a higher incidence of coffee leaf rust under sun grown conditions. As other researchers have explained, the greater the yield, the greater the presence of coffee leaf rust (Avelino et al 2004; Avelino et al 2006; Costa et al 2006; López et al 2012).
6. Conventional medium intensity management showed that fungicides were able to control coffee leaf rust at the beginning of the epidemic, but when fungicides were no longer used, the epidemic showed an increase. On the other hand, organic management was not able to control coffee leaf rust at the beginning stage, but it had an effect at a later stage of the epidemic, due to a greater presence of the natural coffee leaf rust regulator, *L. lecanii* (Pico Rosado 2014).



Lecanicillium l. (white fungi over the coffee leaf rust) and *Mycodiplosis* sp. (fly larvae found on top of the coffee leaf rust) natural biological control agents of the coffee leaf rust. Photos: Shaline Fernandes

Regarding the dispersion of coffee leaf rust, research showed:

1. In the presence of excessive rain, shade favors the dry dispersion of coffee leaf rust spores, up to 3.7 times more than under sun grown conditions.
2. During periods of time close to the beginning of and after a rain, a greater dispersion (0.17 times more) was observed under shade grown conditions possibly because the spores were washed by rain under sun grown conditions.
3. Shade intercepts the wind in the absence of rain; this discourages dispersion compared to sun grown conditions.
4. Shade can contribute to increasing the dispersion of coffee leaf rust when it rains hard. However, under rainy or light rain conditions, the opposite occurs. Interspersed dry periods during the rainy season could favor dispersion under sun grown conditions and partly explains the continental epidemic that occurred in 2012 (Pico Rosado 2014).

Studies conducted by Villarreyna Acuña (2014) in Tuma-La Dalia and San Ramón in Nicaragua, sought to better understand the effects of the coffee leaf rust epidemic that affected the country's coffee plantations in 2012, regarding the management of the crop. They found that the greatest impacts generated by the epidemic were related to the low levels of management and socioeconomic conditions of the coffee farmers. In hierarchical order, the variables with the greatest impact were plant nutritional status, fungicide application in 2011 and 2012, leaf rust monitoring, shade regulation in 2011 and 2012, and socio-economic aspects such as training, technical assistance and access to credits. This study confirms what has already been reported by Avelino et al. (2004), Avelino et al. (2006) and Avelino and Rivas (2013): that the incidence of leaf rust is the result of a combination of climatic conditions and management.

4.4 How to develop a technical session with the farmers

The following are the activities that extension agents and facilitators must develop during the meeting with coffee farmers:

1. Select plant material (coffee leaves) to explain the life cycle of the fungus; make sure you have leaves showing the initial as well as the more advanced stages of the disease (many well sporulated coffee leaf rust spots).
2. Select a site within a coffee plantation to explain the conditions that favor the development of the disease. In this site, address the following topics: temperature, relative humidity, leaf moisture, dew, solar radiation and specific conditions of the site.
3. Have the participants observe differences between sun grown and shade grown coffee.
4. Link the incidence of the disease and analyze the aspects related to production (fruit load) in both systems, as well as the relationships between production and abiotic factors (temperature, humidity, radiation, etc.).
5. Previously, select areas within the coffee plantation where shaded conditions exceed 40% and where there is full sun exposure. Promote dialogue among participants about the relationship between coffee leaf rust, coffee crop management and environmental conditions. When in the site, it is important to encourage field observation and, at the same time, motivate discussion with the coffee farm producers.

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Chapter 5. Physiological aspects of the host plant and their relationship to coffee leaf rust

Foto: Elias de Melo V.F.

Plant physiology is closely related to the functioning of plant organs and tissues, which may be affected or favored by interactions with climatic factors. The factors that directly influence the development and productivity of the coffee plants are temperature, precipitation, relative humidity, dew and solar radiation, which play roles in the processes of photosynthesis to produce food substances (sugars, proteins, etc.). In chapter 4, a detailed description was given of the environmental factors involved in the development of coffee leaf rust. As noted, the disease is based on an apparently simple infection cycle; however, during a period of time the fungus develops several disease cycles, which contribute to forming a polycyclic epidemic (several consecutive cycles) in successive periods. All the processes that follow are connected to a large number of environmental variables, and since coffee is a perennial crop, it is closely related to the plant's physiological crop production and performance.

Crop management, the varieties of coffee planted, planting density, the nutritional status of the plant, the use and management of shade, weed management , and especially the age of the coffee plant are other factors that also influence and impact coffee leaf rust's physiological functions and development. Studies conducted in Honduras have shown that crop management, different combinations of shade, coffee plant density in a given area, fertilization, and pruning may all strongly influence the development of the disease, depending on the microclimate and the plant's physiology, which indirectly exert an effect on the life cycle of the fungus (Avelino et al. 2004).

In this chapter, coffee plant nutrition and production (coffee berry load) will be addressed. These variables are closely related to the plant's physiology and can be related to the initial damage stage of coffee leaf rust.

5.1. Plant nutrition

Nutrition consists of a set of processes by which plants take substances from the external environment and transform them into food and energy. The plant's main nutritive element is carbon dioxide (CO_2) which it takes from the air through the photosynthesis process. Carbon (C) is the main food element that the plant produces to meet its nutritional needs and fruit production.

Nutrition is carried out through the process of CO_2 absorption and absorption of minerals in solution (in water) from the soil. The nutrients are absorbed through the roots and transported by the plant´s vascular system to the other organs to produce food substances that the plant needs to perform physiological functions such as maintenance, growth, and fruit and seed production.

Photosynthesis is carried out in the leaves. Under the leaves, stomata (small openings) allow the evaporation of part of the water absorbed, the release of oxygen (O_2) and the absorption of CO_2. There are two types of sap that move through the stem: the crude sap that moves through the xylem (internal part of the stem) and the sap moved through the phloem (external part of the stem).

Essential nutrients for a living plant fall into two categories: macronutrients and micronutrients. For its vital functions, a plant needs a greater proportion of macronutrients and a smaller amount of micronutrients. Macronutrients include hydrogen (H), carbon (C), oxygen (O2), nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P) and sulfur (S). The micronutrients are also known as trace elements and include chlorine (Cl), iron (Fe), boron (B), manganese (Mn), zinc (Zn), copper (Cu), nickel (Ni) and molybdenum (Mo).

For the coffee plant to perform its functions, the macro and micronutrients must be available in the soil in the appropriate quantities. To determine the concentration or availability of the elements in the soil, laboratory chemical analyses of soil must be done in order to quantify the amounts of the elements available. Coffee plants constantly absorb elements from the ground as they photosynthesize every day; for this reason, it is necessary to perform soil analyses periodically. It is advisable to do the tests at least every two years. Fertilization is applied when the results show limited availability of one or more of the elements. The fertilization programs to restore plant nutrients (Anacafé, no date) are done based on the availability of nutrients in the soil.

Analysis of the nutrient content of coffee leaves (foliar analysis) are as important as soil analysis. Foliar analysis informs us about the nutritional status of the plant and provides evidence as to whether the nutrients available in the soil are absorbed by the plant, or if nutrients delivered via foliar applications are assimilated by the coffee plant. A study of the nutritional imbalance in the leaves found that during the fruiting phase, large reductions in the concentrations of N, P and K in the leaves occur, with values below adequate levels (Acuña et al. 1992). This could be due to the fact that 80% of the N, P, K, Ca and Mg accumulates in the fruit during the first 120 to 150 days from the beginning of flowering season (Silva et al. 2000). The Ca and Mg levels were low after flowering, but gradually increased as the fruits began to mature (Chaves and Sarruge 1994). According to Correa et al. (1986), the greatest demand by fruits for nutrients occurs in the years of greatest production, while in years of lower production, the demand for nutrients is greater in the plant area.

A study on the application of N, P and K showed significant positive differences in the percentage of leaves attacked by leaf rust. Treatments that received the highest dose of K showed the least infestation compared to those that did not receive K. Likewise, in treatments where N and P were applied, there was no evidence of an increase in the attack of the disease (Koseoglu and Tokmak 1996). However, Figueiredo et al. (1974, 1976) found that excess N, P and K, as well as the non-application of N and P, favors the incidence of coffee leaf rust; N deficiency and K excess showed the highest incidence of the disease: in the form of a higher proportion of infected leaves and more pustules per leaf.

Silva et al. (2000) found a negative correlation between N content in the leaves and coffee leaf rust incidence. Similarly, there was an inverse relationship between K content in the leaves and the incidence of coffee leaf rust, which indicates that low K levels favor the disease. Other researchers obtained similar results with Boron: high levels of the micronutrient were measured in the periods of greatest coffee leaf rust development (Cruz and Chaves 1973). However, a correlation between boron content and the evolution of the disease was not demonstrated (Acuña et al. 1992; Carvalho et al. 1993).

The studies mentioned above determined that, in general terms, at the time of highest incidence of coffee leaf rust, there was a reduction in the foliar contents of N, P, K and S, and an increase in Ca and Mg (Acuña et al. 1992, López, 1976). However, variations in macronutrient contents are not related to the lower or higher severity of leaf rust attack, although this variation is physiological in nature and not a consequence of coffee leaf rust. Chaves Arias (2013) stated that there is no consensus regarding the specific influence of any nutrient on the development of coffee leaf rust, but highlights the importance of comprehensive fertilization programs to avoid nutritional imbalances caused by the nutrients' drainage from the leaves to the fruits.

Little research has been developed on aspects related to the synthesis of products from photosynthesis; in particular, the metabolites - mainly the phenolic compounds - that can act in plants as a source of resistance to pests and diseases. Some studies have shown that there is a reduction of these compounds in the leaves of coffee plants during the process of fruit production. It has been suggested that this could be one of the causes of the increased susceptibility to coffee leaf rust during this phase. Perhaps the origin is the product of the direct movement of the phenolic compounds from the coffee leaves to the fruits, or at least the primary metabolites essential for their biosynthesis (Chaves Arias 2013).

5.2. Fruit load

Coffee is a perennial crop in general and has a biennial production (bienality) phase; that is, the plants produce more fruits in one year and the next year fruit production decreases. It is assumed that this is because the plant must recover the food reserves it used during the year of greatest production.

When studying the process of productive bienality in coffee plants and its relationship with coffee leaf rust attacks, Chaves Arias (2013) found that there is a nutritional imbalance in plants that have a high production year, which could be one of the causes of the greater susceptibility to the disease. This imbalance could be caused by the movement of nutrients from the leaves to the fruits.

The leaves' predisposition to the attack of coffee leaf rust varies depending on the production (fruit load), probably because during the fruiting period, phenolic compounds move from the leaves to the fruits (Avelino et al. 1993; Chaves Arias 2013). In a study conducted by Avelino et al. (1993) in Guatemala, they corroborated the existence of a highly significant positive relationship (probability 0.01%) between the fruit load of coffee, which was evaluated after the physiological fall of the fruits, and the subsequent infection suffered by the plants; 50% of the variability of the observed infection was attributed to the fruit load.

Coffee leaf rust attacks tend to be more severe as production increases. In a trial done in Brazil, Miguel et al. (1977) evaluated the percentage of coffee leaf rust in coffee plots with various productivities, with and without the application of copper-based fungicides. The results showed that in all cases, the fungicide reduced the percentage of infection, although it was always considerably higher in plots with higher productivity (Table 1).

Table 1. Percentage of leaves infected by coffee leaf rust in plots with high, medium and low production; with and without fungicides.

Production	Percentage of leaves with coffee leaf rust	
	W/o fungicide	W/ fungicide
Low	36.5	11.5
Medium	54.0	17.0
High	77.5	28.0

Source: Miguel et al. (1977).

The predisposition of coffee to a leaf rust attack seems to increase not only in plants with high a high fruit load, but also in the same plant as the fruit develops (Avelino et al. 1991). In a trial conducted in Brazil, Miguel and Matiello (1985) confirmed the importance of coffee production in relation to the incidence of coffee leaf rust. The authors found that within the same plant, the percentage of leaves attacked was positively related to the number of fruits branch (bandola).

In another study conducted in Mexico between March 1988 and April 1989, Avelino et al. (1991) observed that the onset of the disease coincided with the start of the coffee harvest. The accelerated growth of the epidemic occurred when the harvest was well established, and the maximum infection was found at the end of the harvest. After the harvest, the epidemic began to decline. However, another factor that could affect this behavior are the movements of the people picking the coffee, which favors the dissemination of uredospores.

López et al. (2012) evaluated the effects of shade on the behavior of coffee leaf rust. Their results are controversial because, on the one hand, shade helps prevent high fruit loads, which decreases the susceptibility of the leaf to the pathogen, but on the other hand, shade offers better microclimate conditions for the germination and colonization of the fungus. These two antagonistic models are probably combined under natural conditions. To clarify the individual effects and dissociate these two factors, research was carried out where the fruit loads were homogenized manually under two conditions of light exposure: under shade and full sun exposure. The trial was conducted in Turrialba, Costa Rica at 600 masl, under shade, using the species Erythrina poeppigiana as the main shade species; with two crown prunings per year.

The trial was subdivided into two sub-plots; in one the shade was maintained and in the other it was eliminated. In each sub-lot the fruiting nodes of 40 plants were removed to leave four levels of productive nodes: 0, 150, 250 and 500 productive nodes per coffee plant. For two years, the incidence and severity of the coffee leaf rust attack, as well as plant growth and defoliation in the 40 coffee plants were evaluated. The temperature of the air and the coffee leaves, the wetting of the leaves and relative humidity were also monitored.

The results obtained showed that the intensity of the coffee leaf rust epidemic increased linearly with respect to the fruit load. An increase of 28.9% in the incidence of the disease and a 192% increase in the severity was found in plants that had 500 productive nodes with respect to the plants without productive nodes. With the homogenization of the fruit load, the intensity of the coffee leaf rust epidemic was greater in the shaded lot with a 21.5% increase in incidence, and a 22.4% increase in severity (Table 2).

Table 2. Maximum percentage of accumulated growth of leaves and foliar area in relation to the fruit load and sungrown exposure conditions (average values)

Descriptor	Trial and treatments	Leaves				Foliar area			
		2008		2009		2008		2009	
	Sun grown coffee	47.06	b	120.13	b	19.62	ns	201.45	b
PMCA	Shade grown coffee	33.08	a	84.04	a	12.09	ns	133.95	a
	0 np	42.37	ns	111.55	ns	12.61	ns	159.62	ns
	150 np	42.16	ns	105.81	ns	16.9	ns	155.22	ns
	250 np	34.11	ns	103.03	ns	13.17	ns	187.93	ns
	500 np	41.64	ns	87.96	ns	20.75	ns	168.01	ns

PMCA = maximum percentage of accumulated growth. np = productive nodes.
LSD Fisher Test <= 0.05. Different letters indicate significant differences between the trials and treatments.
Source: López-Bravo (2010).

The study found that, under sun grown conditions, the growth of new leaves increased by 25.2% as did new leaf areas (37.5%). Likewise, it was determined that the microclimate under shade grown conditions was more favorable for the development of coffee leaf rust, due to a greater variation of the temperature during the day, lower maximum temperature and higher frequency of leaf moisture. This shows that shaded conditions indeed have antagonistic effects on coffee leaf rust. The service provided by the shade to control coffee leaf rust is necessarily associated with a service that consists of a reduction of production in the short term.

5.3 How to develop a technical session with the farmers

In order to develop the technical session with coffee farmers, the extension agent and/or facilitators must prepare the necessary materials in advance to explain and discuss the following issues:

- Explain how the coffee plant gets its nutrients; describe that the plant needs to get nutrients from the air and soil.
- Describe the elements that the plant takes from the air through the leaves; point out where the microscopic structures (stomata) are located to enable gas exchange (CO_2, O_2, hydrogen). It is advisable to present an enlarged photograph or illustration of the stomata.

- Mention that the plant absorbs water and nutrients from the soil through its roots. Show the fine roots of a coffee plant in a picture, or in the field remove the leaf litter to show the roots. Make sure that the farmers understand the absorption process.
- Describe the process of photosynthesis: water and nutrients are transported to the leaves, where structures (cells) inside the leaf, contain smaller structures called chloroplasts which are responsible for photosynthesis. The main ingredients to allow photosynthesis to occur are sunlight + CO_2 + water + nutrients.These ingredients are transformed by photosynthesis to form sugars, proteins and other important plant substances. Prepare in advance a demonstration with two coffee plants in separate bags or pots (same age, size, variety, vigor, soil and humidity); keep one plant in total darkness for about 7 or 10 days and expose the other to a normal environment. In this way producers can see the effects of the lack of full sunlight and the reduction of the photosynthesis process. The procedure can be documented using photographs, so farmers can see the changes experienced by both plants.
- Highlight the importance of shade regulation and good plant nutrition so that the plant can develop its vital functions: maintenance, growth and production.
- Explain that when the plant starts producing coffee fruits, it will decrease the levels of N, P, K and S, and that this decrease makes the coffee plant more susceptible to a coffee leaf rust attack. In other words, the plant is weaker and thus the coffee leaf rust enters with greater ease, making the plant more susceptible to infection.
- Talk about the phenols, substances that are produced in the coffee leaf and are necessary for the filling out of the fruits. Some studies have shown that these compounds, when in the leaves, act as a defense against the coffee leaf rust attack. During the plant's process of filling out the fruits, the presence of phenols in the leaves decreases and thus coffee leaf rust can develop more easily. To demonstrate the presence of phenolic substances, take a coffee leaf, mash it a little with your fingers and after a few minutes, the leaf starts to take on a dark color; that's where an oxidation effect of the phenolic substances takes place.

For the second part of the session, be sure to have at least one plant under full sun exposure, or at least more exposed to the sun, and another under shade.

- Explain the biennial cycle of coffee production. Make it clear that this effect is more pronounced in sun grown coffee than in shade grown coffee
- Explain the process that happens in both conditions with respect to microclimate conditions: temperature, relative humidity, radiation and leaf wetting.
- Talk about the results that have been obtained in different studies on the antagonistic effect that occurs when coffee is grown under shade: the attack of coffee leaf rust may be greater under shade (mainly denser) but, at the same time, the shade regulates the fruit load (decreasing peaks between high and low production) and thus the incidence of the disease is reduced.

- It should be clear that under the same conditions (full sunlight or shade) and with the same fruit load, the attack and severity of leaf rust may be greater under shade because microclimate conditions (temperature, humidity, leaf moisture and darkness) favor its germination and development in the coffee leaf.
- Remind the coffee farmer that shade reduces the dispersal of coffee leaf rust spores under mild rain conditions but increases with heavy rains. Similarly, under adequate shade conditions there may be a better natural control of coffee leaf rust, since the microorganisms that attack coffee leaf rust develop better in shady conditions. Practices can be done to observe the incidence in coffee plots with contrasting conditions (very dense coffee shade and coffee with regulated shade).

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Section II.

Evaluations and control practices

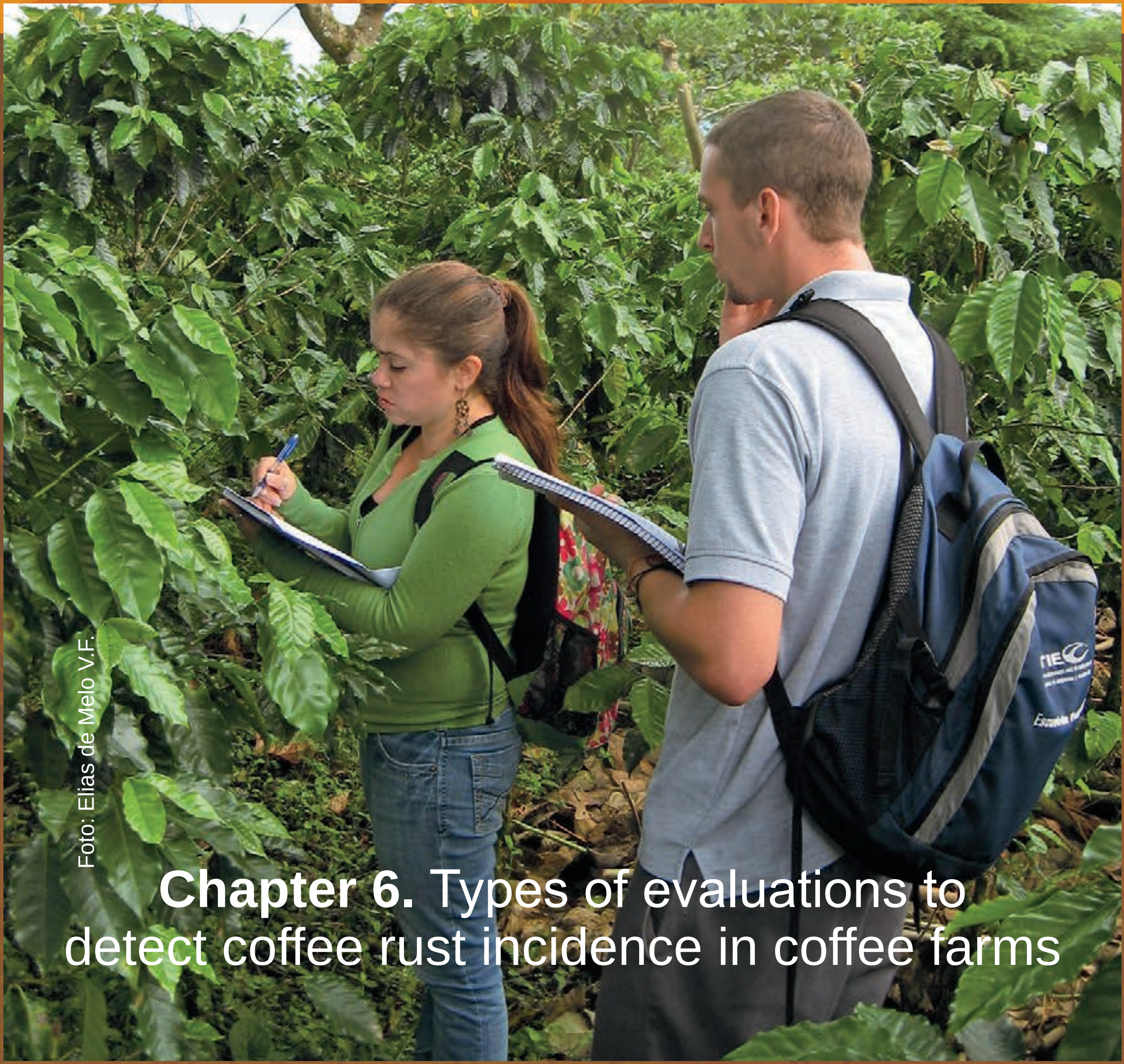

Foto: Elias de Melo V.F.

Chapter 6. Types of evaluations to detect coffee rust incidence in coffee farms

The rainy and dry periods have different effects on coffee plants and on the evolution of the disease. During the rainy season, the coffee plant develops the phenological cycles that allow it to grow, generate new leaves and produce fruit; simultaneously, coffee leaf rust also develops its life cycle in the leaves because it is the time of the year where it finds the best conditions for its establishment and growth.

During dry periods, the fungus finds adverse conditions and thus remains inactive on the coffee leaves, but it adheres to the plant until a new rainy period starts again. The amount of fungus or the number of infected leaves that remain on the plant during the dry period is called the residual inoculum.

In coffee production it is important to evaluate the coffee leaf rust condition at the beginning of the rainy season, in order to estimate the amount of inoculum that might be present in the coffee plantation. With a high degree of probability, it is possible to estimate disease behavior projections taking into consideration the optimum conditions based on the development of its life cycle. These projections will provide important information to manage and control the advance of the coffee disease.

It is necessary to use a sampling method that allows collecting representative data on farm conditions or about a specific lot in order to implement an effective evaluation. With the information generated, the percentage of disease incidence can be determined. Once the percentage of incidence and/or severity of the disease is known, management and control methods are selected to keep the coffee leaf rust at the lowest possible level. Doing so, we can assure that leaf damage is kept to a minimum and consequently good coffee production is achieved during the crop cycle.

In Central America, some coffee institutes have conducted research to define sampling methodologies that allow the collection of reliable information on coffee leaf rust status at the time of the evaluation. In some countries, two samplings are recommended (one at the beginning of the rainy season and the other two or three months after the rainy season starts) to determine whether the disease management program is producing the expected effect and, if not, to make the adjustments necessary to maximize disease control.

The evaluation protocols used by some of the coffee institutes in the region and by research institutions are presented below. The coffee producer must decide, together with the extension agent and/or facilitator, which is the best sampling methodology to be used, based on the coffee cultivated area, resources and time available to carry out the sampling. The information must be recorded in order to make decisions on how to implement the annual coffee leaf rust prevention and management program of the disease. The sampling methodologies and practices presented here are reliable and have been useful in supporting farmers' decisions. Any of the methods can be used. If there is a desire to compare coffee leaf rust incidences between regions or farms in the same country, it is recommended that the same methodology be used for all the evaluations in order to reduce control differences that may occur with the use of various methods.

6.1 Anacafé´s method for evaluating coffee leaf rust

Anacafé’s research team in Guatemala carried out a study to determine the most appropriate coffee leaf rust sampling method for commercial coffee plantations in order to make the disease control programs more efficient (Campos et al. 2013).

The proposed sampling method consists of establishing 20 sampling plots in an area of 5 mz (3.75 ha) or less (thus each site should have an area of 0.25 mz or 1750 m^2). It is recommended that the sampling sites be numbered and located on a map, following the location of the plots in the field to facilitate their location. At each site, 14 random coffee plants should be selected and from each plant, ten leaves should be collected from the lower, middle and upper part of the plant using the four cardinal points (north, south, east and west) (Figure 1).

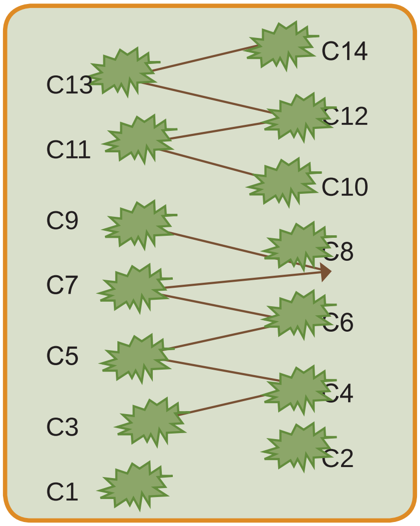

Figure 1. Scheme showing random sampling of 14 coffee plants
Source: Campos et al. (2013)

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1 La manzana es una unidad de medida de superficie de la tierra equivalente a 7500 m^2.

The equation for determining the percentage of infection is:

$$\%\ \text{coffee leaf rust infection (IR)} = \frac{\text{N° of leaves infected with coffee leaf rust X 100}}{\text{Total number of leaves collected (140)}}$$

In order to record the information from the 20 sampling plots, it is advisable to prepare a form like the one shown in Table 1.

Some of the advantages of Anacafé´s sampling method for monitoring coffee leaf rust infection coffee leaf rust infection are (Campos et al. 2013):

- It allows evaluation of the spraying quality and the performance of the fungicides used to control the disease.
- It allows the implementation of a sampling system for coffee leaf rust control programs.

Table 1. Table format to record the information on leaves infected with coffee leaf rust in each sampling plot

Farm				
Lot and/or coffee sector:			Area (mz):	
Sampling date:		Days after main flowering period:		
Responsible for the sampling:				
Plot	Size of the sampling (no. leaves)	Healthy leaves	Infected leaves	% of infection
1	140			
2	140			
3	140			
.	.			
.	.			
20	140			
Total				
% infection*				

*% of infection in the 20 plots (5Mz)= Total column % of infection divided by 20.
Source: Campos et al. (2013).

- It reccomends sampling evaluations of the disease starting 60 to 70 days after the main flowering period.

6.2 CATIE's method for evaluating coffee leaf rust and other coffee diseases and pests

This methodology allows evaluation of the incidence of coffee diseases, such as iron spot (*Cercospora coffeicola*), American leaf spot (*Mycena citricolor*), also known as ojo de gallo, and pests such as the leaf miner (*Perileucoptera coffeella*) and the coffee borer (*Hypothenemus hampei*). Additionally, it allows determination of the presence of natural controlling organisms such as *Beauveria bassiana*, a fungus that controls the coffee borer; and *Lecanicillium lecanii*, a fungus that controls coffee leaf rust. In this section we will focus on the proposed methodology for evaluating the incidence of coffee leaf rust.

The methodology proposed by Virginio Filho et al. (2009) was developed by the CATIE-MIP-AF-NORAD project (Guharay 2000) and is designed for comprehensive integrated analysis of coffee plantations (weeds, macrofauna, and shade).

The methodological process consists of the following steps:

- Divide the farm into plots with similar characteristics.
- Within each plot, select a square area containing 100 coffee plants. At the center of the square area, select ten coffee plants - 5 in one row (Station 1) and 5 in another row (Station 2).
- On each coffee plant, select a branch (bandola) and count the infected leaves, the total number of leaves, total fruits, fruits with coffee borers, fruits with coffee borers with *Beauveria* and the total number of nodes.
- Each piece of information is recorded in the information sheet (Table 2). Each column corresponds to one branch per plant. Between one plant and another the height of the branch is alternated. For example, on the first plant an upper tier branch is chosen, on the second plant a center tier branch and on the third plant, a lower tier branch and so forth, until the count is completed on the tenth plant.

Table 2. Evaluation of pests and disease on coffee plants during the rainy season

Farm: ______________________________ Name of the farmer:____________________________________

Plot ____ Date: ___________________________________

	Station	Point 1	Point 2	Point 3	Point 4	Point 5	Total	Percentage
Leaves with coffee rust	1							
	2							
Leaves with coffee rust and *Lecanicillium*	1							
	2							
Leaves with iron spots	1							
	2							
Leaves with leaf miners	1							
	2							
Leaves with anthracnose	1							
	2							
Branch with anthracnose	1							
	2							
Total no. of leaves	1							
	2							
Fruits with coffee borer	1							
	2							
Fruits with *Beauveria*	1							
	2							
Fruits with chasparria (Cercospora leaf spot)	1							
	2							
Total no. of fruits	1							
	2							
Nodes with cochinilla (mealybug)	1							
	2							
Total no of productive nodes	1							
	2							

We will use the following equation to determine the percentage of coffee leaf rust incidence:

$$\text{\% of coffee leaf rust infection (CFRI)} = \frac{\text{Total number of infected leaves x100}}{\text{Total number of leaves in 10 coffee branches}}$$

The proposed methodology also includes a guide for recognizing the main diseases and pests that affect coffee plantations and a table to guide decision making. For example, it is considered that between 10 and 30% of the farms have a critical level of coffee leaf rust incidence; consequently, basic control and management actions should be implemented. These include natural control methods (*Verticilium* (*Lecanicillium lecanii*), *Cladosporium hemileiae*, *Glomerella ongulata*), as well as cultural controls (avoiding the use of excessive shade (maintain regulated shade), pruning and removing suckers from the coffee plant).

Use the number of sampling points in the farms suggested by Guharay et al. (2000) to implement a pest count in all the plots or just in some of them. The methodology must be applied during the rainy season. Depending on the possibilities, implement a pest count in all the lots or just in some of them. In order to make this decision, consider characteristics such as type of shade, level and presence of pests and diseases. If count is done in selected lots only, it should be made sure that they are located throughout the farm. Those lots are important since they provide information for making farm management decisions.

In each of the lots where pests and diseases are counted, locate five points that are evenly distributed. When sampling the lot, go to the first point and establish two counting stations. These stations should be located in opposite directions (to the right and to the left, to the north and to the south). Each station must have five plants and on each plant a plagiotropic branch (bandola) is counted according to the procedure previously described. For each branch, write down the data in the table (Table 2). The same procedure is performed for all the other points.

6.3 Icafé´s method for evaluating coffee leaf rust

The Coffee Institute of Costa Rica (Icafé) recognizes that implementing field sampling is one way to obtain accurate and timely information to understand the situation of the disease and its progress over time (Icafé 2013). Therefore, you can have technical criteria for the condition of the disease, and for determining the control measures that must be implemented in a timely manner.

To implement the sampling of the disease, Icafé recommends the following procedure:

1. Select 50 coffee plants per hectare or mz at random; strive towards an even plant distribution within the lot or farm.
2. For each plant, select a branch located in the middle part of the plant and count the total number of leaves, as well as the number of rust-infected leaves.
3. Apply the following equation to determine the disease rate incidence:

$$\text{Incidence of coffee leaf rust} = \frac{\text{Number of leaves with leaf rust on the branch x 100}}{\text{Total number of leaves on the branch}}$$

4. Once you have estimated the disease rate incidence for 50 plants, the results are added and divided by 50 to obtain the average incidence rate of the coffee leaf rust infection on the plot or farm. This individual calculation (per plant) allows us to determine the points on the farm where the highest disease incidence is present and also relate it to management aspects that could be favoring the development of the disease.
5. It is recommended that a field notebook or data sheet be used to record field data once while visiting the plots in the field.

Icafé recommends making an initial evaluation (sampling) at the beginning of the rainy season, when the growth of the branches and the sprouting of new leaves begins. Subsequently, a second sampling is recommended to determine the progress of the disease. In the case of Costa Rica, it is recommended that the second sampling be done at the beginning of the harvest season - between the months of June and July and between September and October in the coffee regions that experience early fruit maturation (low elevation areas).

For farm decision making, Icafé suggests considering the following parameters:

- If the incidence of coffee leaf rust is less than or equal to 5% during the beginning of the rainy season (April or May), the disease will grow very slowly so it is advisable to apply a protective (cupric) fungicide to further delay coffee leaf rust progress.
- With detected incidences between 10 and 15%, it will be necessary apply a systemic fungicide in curative doses as soon as possible in order to stop the advance of the coffee leaf rust that occurs on the leaves but is not yet visible. If it is not treated, and favorable weather conditions for the disease to advance occur, the incidence could increase to more than 35% after 30 days.

- Preventive programs for the disease should be applied at the beginning of the rainy season, while curative programs are applied during the periods of greatest precipitation. The purpose is to obtain greater protection on the new leaves being formed.
- It is recommended that a permanent disease monitoring system be implemented in large coffee farms, and establish a monitoring system that will be compensated by better agrochemical applications.

6.4 OIRSA´s method to evaluate coffee leaf rust

The International Regional Organization for Plant and Animal Health (OIRSA) published a guide on implementing evaluations of coffee leaf rust (OIRSA 2013). Different countries in Central America are using the following methods to evaluate coffee leaf rust:

Honduras

- Select five sites at random in each plot to be sampled.
- In each site, select five plants.
- On each plant, select six plagiotropic branches (bandolas): two on the upper part, two on the middle part and two on the lower part of the coffee plant.
- On each branch, count the number of leaves with coffee leaf rust present and the total number of leaves.

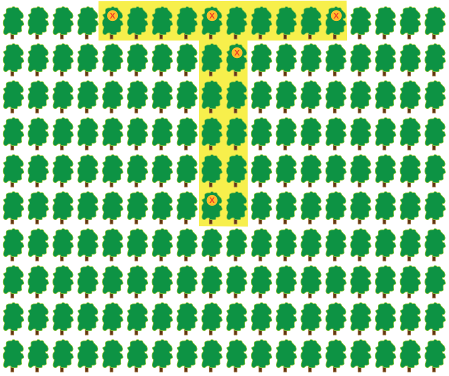
Nicaragua

- Select five points at random in each plot to be sampled.
- At each site establish two subplots (one on the left and one on the right).
- In each subplot select five plants.
- On each plant select a branch:
  - On each plant select a branch:
  - On plant 1: a branch between the middle and upper portion of the plant
  - On plant 2: a branch between the middle and lower portion.
- Continue the above sequence
- On each branch count:
  - Number of leaves with leaf rust present
  - Total number of leaves on the branch

This methodology is proposed by Guharay et al. (2000).

Mexico

According to OIRSA, a T-sampling method is used, which allows assessing the severity of the disease in 20 plants and on the leaves of five plants (Figure 2). Figure 3 shows the scale used in Mexico to determine the severity of the attack on the plant and in the coffee leaves.



Description of the method

- To evaluate coffee leaf severity, use the following scale:

Class	Foliar damage by coffee leaf rust
0	Healthy plant
1	3%
2	10%
3	30%
4	60%
5	Defoliation

- In the direction of the 4 cardinal points determine the % of plant damage using the scale in diagram 1.
- To evaluate the severity in the leaves present in each plant, use the scale of table 2 and diagram 2.

Figure 2. Establishment of the T-sampling method, a procedure that use the data and a classification scale to determine the severity of the disease on the plant
Source: OIRSA (2013).

Table 2

Class	Area of leaf damage
0	Healthy with no visible symptons
1	1-5%
2	6-20%
3	21-25%
4	>50%

Diagram 1

Scale of severity of coffee leaf rust (LANREF)

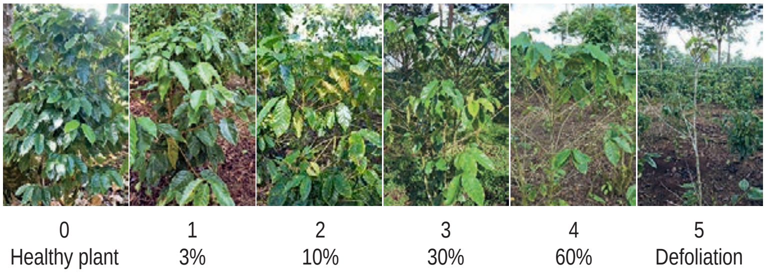
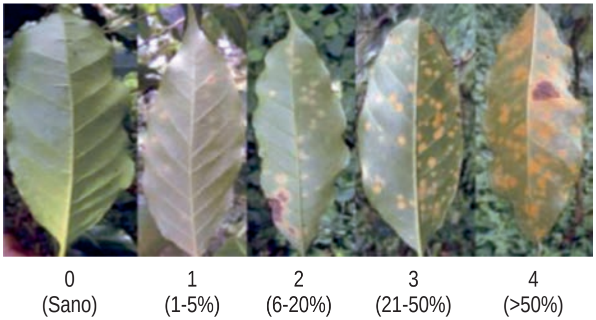


Diagram 2



Scale of coffee leaf rust severity in coffee plants (LANREF)

Figure 3. Evaluation scales that show coffee leaf rust infection severity in plants and leaves
Source OIRSA (2013).

For more details on evaluation methodologies consult the document **“Compilado sobre Métodos de Diagnóstico de la Roya [Compilation of Leaf Rust Diagnosis Methods]”** developed by the Coffee Leaf Rust Proyect CATIE-CIRAD-PROMECAFE/NORUEGA (Request it from http://bibliotecaorton.catie.ac.cr/).

6.5 How to develop a technical session with the farmers?

It is recommended that extension agents and/or facilitators use the content of this chapter to organize a technical session with coffee farmers. Plan to explain and discuss the following issues with coffee farmers:

- Explain what disease evaluation is and its importance in determining the status of a disease (coffee leaf rust) at a given time.
- Highlight that the results of the evaluation are of great help for decision making on a farm, at regional and national levels. The results will allow determination of the current status of the disease and the actions that should be implemented in the short, medium and long terms.
- Choose one of the evaluation methods and put it into practice on a farm. Develop the complete process. Include plot selection, definition of the evaluated site, field data collection, information processing and interpretation.
- Analyze the information together with the participating coffee farmers or farm owner, and then provide technical recommendations on managing the farm to control coffee leaf rust.
- It is advisable to use climate information, shade conditions of the coffee farm and fruit loads for the evaluation process. Make assumptions about the effects of variations in the conditions on the development of the disease. For example, what happens if it rains excessively or if the shade is very dense, etc.
- This session should have an integrated approach that incorporates information contained in the other chapters as well. It is advisable to compare the results from different plots to try to explain the factors that have influenced the differences in disease incidence levels such as shade, full sun exposure, and pruning. For training purposes, make sure you select plots that have contrasting shade conditions (plots with dense shade, intermediate shade and full sun exposure) to discuss possible leaf rust incidence differences and responses.

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Virginio Filho, E. de M; Barrios, M; Toruño, I. 2009. ¿Cómo podemos mejorar la finca cafetalera en la cuenca? Una guía de apoyo a procesos de reflexión-acción-reflexión participativos con familias productoras y promotores técnicos. Turrialba, Costa Rica, CATIE. 70 p.

Chapter 7. Early warning systems

Foto: Elias de Melo V.F.

An early warning system (EWS) is a set of actions that is developed to maintain the surveillance of a foreseeable event that take place at a specific time (Unesco et al. 2011). The EWSs help to know in advance and with a certain degree of certainty, in what time and space a threat or a natural event or an event caused by human interventions, can trigger a potentially dangerous situation. The events can have very different characteristics; for example, predicting floods or landslides. The EWSs can also be applied in agricultural production, to monitor climate conditions, crop management and many other variables that have a direct influence on crop production, such as diseases and droughts.

In establishing an EWS, it is important to define a series of protocols, instruments and equipment for permanent monitoring (surveillance) of the natural (biotic and abiotic) and anthropogenic (human) factors that contribute to the presence or absence of a specific event (Unesco et al. 2011).

In the case of coffee leaf rust, an EWS integrates information related to meteorological variables agricultural practices and trends in the international coffee market to predict, with a certain degree of precision, the risk of a possible coffee leaf rust outbreak. It is well known that when coffee prices fall, producers reduce the implementation of management practices such as pruning, fertilization, shade management and disease monitoring, which often results in an increased incidence of the disease. The EWS helps foresee the possibility of an epidemic outbreak occurrence, such as the one that occurred in 2012. Crop management considerations are important in implementing the measures required to prevent or reduce the impact of a coffee leaf rust epidemic.

When an EWS is applied in agricultural production, the objective is to gather information that allows farmers to take actions to minimize the effects of a given event, for example, an increase in the incidence of coffee leaf rust due to favorable weather conditions. As a result, actions could be planned to protect the crop through the implementation of management practices and the application of alternatives for adequate treatment such as fungicides to reduce the impact of the disease in crop production.

7.1 EWS design and implementation for coffee leaf rust control in Central America

During 2012 and 2013, the Central American region suffered a strong coffee leaf rust epidemic. Promecafé, in collaboration with other research and development institutions such as CATIE, IICA, ARS-USDA, OIRSA, FAO and the national coffee institutes, raised awareness on establishing an EWS to prevent new epidemics that might affect coffee production and alleviate the socioeconomic effects caused by the epidemic.

In October 2013, the “First Regional Workshop on Early Warning Systems for Coffee Leaf Rust” was held in Guatemala (IICA 2013). The event brought together experts from different institutions including coffee sector representatives, international and regional organizations, and experts in coffee production with the purpose of designing an EWS for the region. This action was part of an initiative led by the “Integrated Program to Combat Coffee Leaf Rust”, which was endorsed by representatives of the region’s ministries of agriculture with the aim of recovering coffee production capacity in Central America and the Caribbean (IICA 2013).

A proposal was submitted from the workshop and presented to FAO (Hruska 2014). The proposal considered various data sources and information for the EWS, including:

- Important abiotic factors: temperature, humidity, solar radiation, crop phenology.
- A system of meteorological stations for collecting data.
- Prediction models for fungus outbreaks.
- Accurate recommendations for short- and medium-term farm management.

During May 2014, a second workshop on the coffee rust EWS was organized with the purpose of establishing a pilot experience in the region. The event took place in El Salvador and was organized by CENTA. A total of 30 technicians participated and the event had support from OIRSA.

The Honduran Institute of Coffee (Ihcafé) promoted the creation of an EWS specialized technical committee to work on the issues of coffee leaf rust affecting Honduras. The first bulletin issued by the committee presented the national results of the first coffee leaf rust sampling that took place in April 2014. The results showed that coffee leaf rust had a national incidence of 12% of residual inoculum and 1% severity (Figure 1). For 2014, good coffee production was expected since coffee was experiencing two important flowering seasons. The following recommendations were made to improve the coffee productive cycle:

- Implement a first preventive application of fungicides for coffee leaf rust control from April 30 until May 10, with dual-action systemic products validated by Ihcafé.
- Apply the second foliar fertilization (post-flowering) along with a fungicide to control coffee leaf rust.
- Manage the shade level in the plantation.
- Continue prunings within the coffee farm.
- Perform adequate weed control.
- Continue coffee leaf rust sampling to monitor disease presence (Government of the Republic of Honduras et al. 2014).

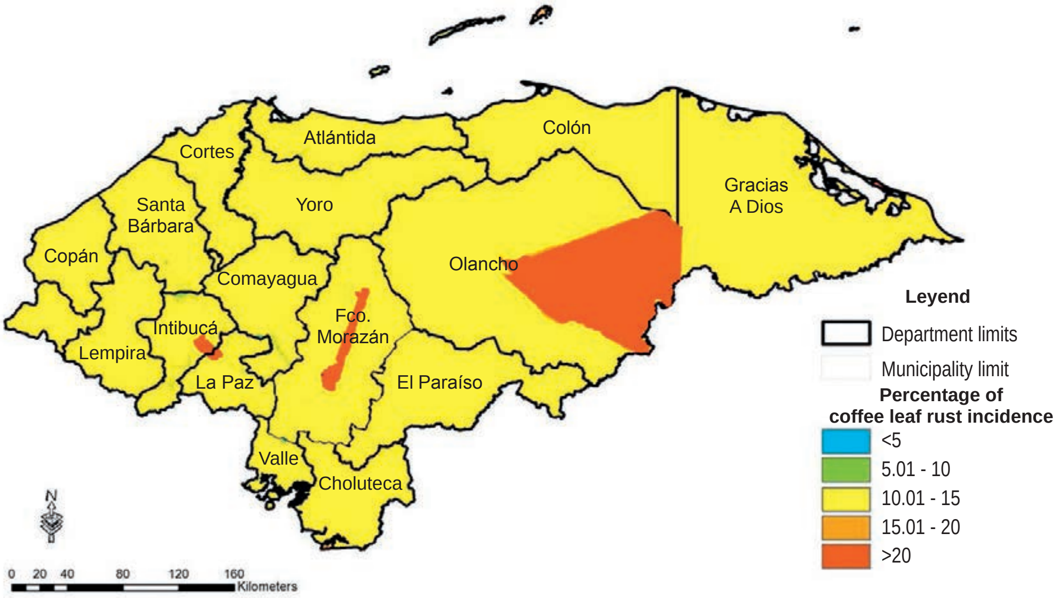

Figure 1. National map showing the incidence of coffee leaf rust
Source: Government of the Republic of Honduras et al. (2014).

EWS development and application for coffee leaf rust is a result of the multiple efforts coordinated by Promecafé, in collaboration with the national coffee institutes of Central American countries; regional and international research and development institutions, technical cooperation, and ministries of agriculture.

The links below contain information on coffee leaf rust early warning systems for the Central American region:

Guatemala: Página principal de Anacafé
http://www.anacafe.org/glifos/index.php/P%C3%A1gina_principal

Coffee leaf rust Bulletin published by Anacafé (April 2015)
http://anacafe.org/glifos/images/4/4f/Manejo_Integrado_de_la_Roya2.pdf

Special Bulletin: National Survellance and Monitoring System of Coffee Leaf Rust
http://anacafe.org/glifos/images/6/61/Boletin-Especial-Abril2015.pdf

Honduras: Ihcafé web site
http://www.ihcafe.hn/

Direct link to the EWS bulletins for Honduras:
http://www.ihcafe.hn/images/BoletinT%C3%A9cnico%20nacional_05%20Honduras%20final.pdf

El Salvador: Procafé web site
http://procafe.com.sv/menu/

PROCAFE´s Research program on coffee leaf rust
http://www.procafe.com.sv/menu/Investigacion/Roya.htm

Costa Rica: Icafé web site
http://www.icafe.go.cr/

Direct access to EWS bulletins:
http://www.icafe.go.cr/icafe/anuncios/roya/sistema_alerta_recomendacion_temprana/Actual/Seguimiento%20y%20recomendaciones%20Roya.pdf
http://www.icafe.go.cr/icafe/anuncios/roya/roya_del_cafe.html

7.4 How to develop a technical session with the farmers

It is recommended that extension agents and/or facilitators use the content of the previous chapter to organize a technical session with coffee farmers. In addition, it is important to consider the parameters that other countries use for climate information, crop management and monitoring protocols to evaluate coffee leaf rust incidence and severity as a basis for the EWS and decision-making processes. The information must be shared with the coffee farmers in order to prioritize the crop management actions they must implement to prevent the effects of a strong disease outbreak.

- Select one of the evaluation protocols presented in Chapter 6. Implement the evaluation together with the participants to obtain incidence percentages and disease severity in the coffee plantation.
- From the results obtained, make an analysis of the coffee plantation's phenological condition. It is recommended that you plan this session during the first month after the initial stage of the coffee flowering season in order to determine the results of the flowering and the expected harvest for that year according to the crop's biennial cycle.
- Analyze environmental variables such as: precipitation, humidity, and solar radiation, as well as management aspects such as type of shade, pruning and sucker removal, fertilization and plant weed controls. Infer from the preliminary results the practices that should be implemented for adequate crop management during the following months or productive cycle.
- Another option is to conduct training meetings to present the information and recommendations of the country's EWS. Remember to take into account the country's characteristics. Encourage those groups of coffee farmers that might have access to the internet and more updated and complete information. Urge them to regularly consult the sources of information available.
- Encourage those groups of coffee farmers that might have access to the internet and more updated and complete information to regularly consult the sources of information available.

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Gobierno de la República de Honduras; Secretaría de Agricultura y Ganadería; OIRSA; Ihcafé, Servicio Meteorológico Nacional Honduras; Infoagro. 2014. Sistema de alerta temprana para la roya del café en Honduras. Comité Técnico Especializado del sistema de alerta temprana para la roya del café en Honduras. Boletín 01: 4 p.

IICA (Instituto Interamericano de Ciencias Agrícolas). 2013. Crean sistema de alerta temprana para la roya del café. Consultado 10-12-2014. http://www.iica.int/Esp/prensa/IICAConexion/IICAConexion2/2013/N31/secundaria8.aspx

Hruska, A. 2014. Sistema de alerta temprana para la roya del café en Centroamérica. Propuesta presentada a la FAO. (PowerPoint presentation: 30 images).

Unesco; Comisión Europea; SICA; Cepredenac; Meduca. 2011. Manual sistemas de alerta temprana: 10 preguntas - 10 respuestas. Panamá. 60 p.

Chapter 8. Best practices for the prevention and control of coffee leaf rust

Foto: Elias de Melo V.F.

The main reason to control coffee leaf rust lies in the need to protect the foliage (leaves) during the fruit development season. Leaves play an important role since their fundamental function is to synthesize all carbohydrates needed for coffee plant maintenance, growth and reproduction. During the fruit production stage, foliage presence is necessary for up to 60 days after the main flowering, and up to 30 days before the harvesting season (Cenicafé 2011). If the coffee plant's foliage remains healthy, it ensures an adequate fruit harvest during the productive cycle and harmonious development of the crop for future harvests.

There are four factors that determine the appearance of coffee leaf rust: host, pathogen, environment and crop agronomic management. These factors need to be taken into consideration for adequate disease management in order to diminish epidemic development (Cenicafé 2011). The following sections highlight best practices that different countries are implementing to manage and control coffee leaf rust and reactivate the coffee sector. This information comes from country reports for different coffee regions that have been presented at various national and regional forums. It is encouraging to know that this set of proposed actions can help reduce the incidence of coffee leaf rust; however, the risk of a new epidemic remains latent, and very likely to occur due to climatic variability and coffee farm conditions in coffee-producing countries.

8.1 Agronomic management of coffee farming

8.1.1 Coffee pruning and sucker removal

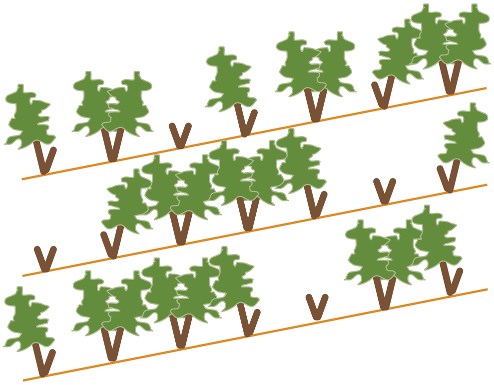
In Central America, one of the limitations for coffee production has been the advanced age of the coffee plantations. According to Anacafé (2013), 60% of coffee plantations in Guatemala are more than 15 years old; in Panama, according to the information provided by MIDA (2013), 61% of the coffee area is more than 20 years old and 23% is between 11 and 20 years old. In Costa Rica, of the 96,539 hectares of coffee, 14,592 hectares (15.1%) require pruning and 5,140 hectares (5.3%) require renewal. In both cases it is noticeable that crop management has not been the most appropriate, and the aging of the plantations is quite evident (Icafé 2013). In El Salvador, 10.5% (11,444 ha) of land under coffee does not receive adequate minimum management (Procafé 2013).

Further on we will discuss alternative options for renewing coffee plantations in Central America with more resistant and productive varieties. Coffee renewal is crucial in facing present and future challenges.

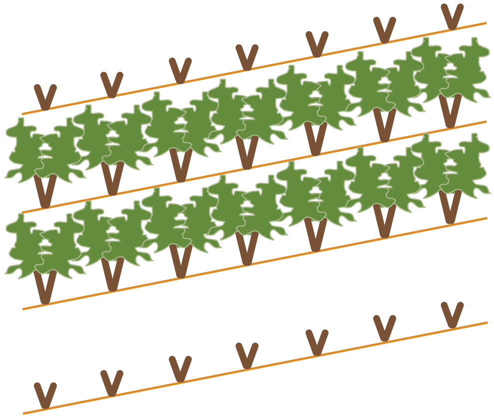
Coffee pruning should not be done until end of the coffee harvesting season, preferably during the dry season or low rainfall period. The purpose of coffee pruning is to eliminate diseased and exhausted tissue as well as any broken branches so that the plant can be renewed (Icafé 2011).

The coffee plant starts production in the third year after sowing. It is difficult to know when the right moment is to start the practice of pruning since it depends on the management given to the crop. Pruning should be done when the plant shows signs of exhaustion, around the third year of production - or six years after planting the crop.

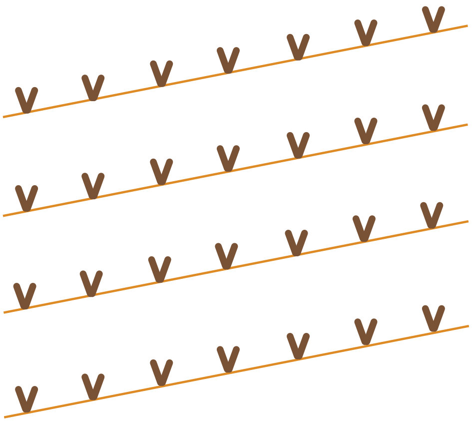
There are various pruning systems that can be applied to coffee. Among the most used are:



Selective pruning. This consists of observing the plant and determining which branches are exhausted and/or diseased in order to remove them. This way the plant maintain itself in a constant renovation process



Pruning by row. This consists of pruning all the coffee plants that are present in a given row. In general, the farmer decides when to prune, usually every three, four or five years. The farmer needs to follow a strict order in pruning. The aim of pruning by row is to create a cycle of pruning and to maintain at least 66% of the total crop area.



Pruning by plot. This consists of pruning all the plants present in a given coffee plot. The farmer chooses the area to be pruned in relation to total crop area and the phenological state of the coffee plantation. During the coffee plant recovery period, the farmer can use the space between the rows to plant other types of crops that have a short cycle, such as beans, corn, pepper, or tomatoes in order to reduce the maintenance costs of the area. The sale of these agricultural products can also generate an alternative source of income during a two-year period.

After pruning, mainly at the beginning of the rains, the coffee plant restarts its growth process and activates a large number of buds that produce many sprouts or shoots. This is the time to start implementing sucker removal, which consists of selecting two or three vigorous suckers that are well distributed on the plant's trunk; these will become the future productive branches. All other suckers should be eliminated to decrease competition and allow selected shoots to develop vigorously. The suckering removal practice is usually applied twice a year. The first sucker removal takes place two or three months after pruning and the second, 2 or 3 months after that. This is done because the increased incidence of light helps activate the buds and stimulates the production of shoots.

Pruning and suckering practices help maintain the branches and stimulate leaf growth. They also improve aeration within the crop and improves space distribution between the plants; this in turn promotes adverse conditions for the development of coffee leaf rust, such as a lower level of relative humidity and higher sunlight penetration that limit the development of the disease. Additionally, pruning and suckering improve the application and, thus, the effectiveness of foliar products that are applied on the leaves (Barquero Miranda 2013; Anacafé 2013; Icafé 2013; Ihcafé 2013; Magfor 2013; MIDA 2013; Sagarpa et al. 2013).

After the coffee leaf rust epidemic of 2012, the institutions in charge of the coffee sector strongly encouraged the use of pruning as a mechanism to control the disease. The governments of the countries assigned resources to carry out these practices as a measure to avoid a new epidemic (Anacafé 2013, Icafé 2013, Ihcafé 2013, Magfor 2013, MIDA 2013).

8.1.2 Fertilization

Coffee is a perennial crop and usually it remains planted in the same area for long periods of time. As previously mentioned, there are coffee plants that are 20 years or older, thus the plant always takes the same soil elements but in different proportions. It is therefore necessary to in some way replace the elements extracted by the plant, so fertilization is important.

Plant nutritional management plays a fundamental role on the behavior of the crop's productive cycle. Good nutrition provides the minerals required by the plant to perform its metabolic and physiological functions. Therefore, it is fundamentally important to apply fertilizer (chemical or organic, or both) to the coffee plant at different times depending on the results obtained from soil and/or foliar analyses. Fertilization improves the plant's vigor, strengthens its defense mechanisms against coffee leaf rust, and maintains productive capacity (Barquero Miranda 2013) management of the shade trees in association with the coffee plants since these trees contribute to the fertilization of the farm by supplying complementary additional nutrients to the soil. Low tree densities and/or the absence or poor management of leguminous trees (*Erythrina* spp., *Inga* spp., *Gliricidia sepium*) do not provide significant complementary nutrients to the coffee plants. A dense shade arrangement with an excess of timber and fruit trees, could compete with coffee plants for nutrients.

Another important process that takes place in the coffee plantation is soil acidification, which can limit the plant's nutrient uptake. As the soil acidifies, some elements are fixed to the clay substrate (for example phosphorus), or there is a process of element substitution, such as the release of iron and aluminum ions, which can harm the plants. This is why soil improvements are recommended, such as the application of dolomite lime, calcium carbonate or others to reduce soil acidity (Icafé 2011). The use of organic amendments is also very important to reduce soil acidity, regardless of whether the farm is conventional or organic. However, the inclusion of organic fertilizers in the fertilization program is highly recommended. In addition to adding nutrients, organic fertilizers are soil biology potentiators which improve soil structure for a healthier and more productive plantation.

In trying to identify the possible causes of the coffee leaf rust epidemic in 2012, Avelino et al. (2015) found that apart from climate variations that contributed to the development of the disease, crop management was also reduceddue to a decrease in coffee prices (2011-2013). Farmers obtained lower income and as a result, they reduced management practices and fertilizer applications. As a result, the plants were undernourished and more susceptible to the disease.

The coffee institutions of Central America insist that farmers must provide good nutrition to the crop. Many of these institutions have laboratories where farmers can analyze soil and foliar samples. Icafé (2011) recommends that in cases where soil analysis results are not available, the farmer could check the general soil characteristics of the region where the plantation is located and based on this information, apply the proper fertilizer formula and amount.

During the years of the leaf rust epidemic, the coffee institutes, along with the national governments and agricultural ministries, supported coffee farmers with fertilizers in order to achieve faster coffee plantation recovery and reduce potential impacts on the next harvesting season (Anacafé 2013, Icafé, 2013, Ihcafe 2013, Procafé 2013).

8.1.3 Shade

Incorporating shade in coffee farms is a common practice in Central America, where it is estimated that more than 90% of the coffee plantations are associated with trees. Many countries in the region highlight in their reports the importance of adequate shade management to manage coffee leaf rust (MIDA 2013; Procafé 2013; Ihcafé 2013; Icafé 2013; Anacafé 2013).

Trees associated with coffee plants generate great benefits to the coffee farm. Trees help regulate the microclimate of the coffee plantation (coffee plants are sensitive to temperature fluctuations), reduce solar radiation and improve water balance. Trees also increase relative humidity within the coffee plantation, improve soil fertility by providing organic matter to the soil, and leguminous species can also improve soil fertility since they provide nitrogen to the soil. Moreover trees reduce soil erosion by covering the ground with leaf litter and branches (Icafé 2011).

Nevertheless, the benefits from having shade trees that help regulate the microclimate can also stimulate the development of the coffee leaf rust fungus. However, shade conditions can be favorable to its natural enemies and, for this reason, shade management in coffee growing can play a fundamental role in creating unfavorable conditions for the development of the disease.

The technical recommendations for shade management, in addition to the organic matter contribution, are intended to allow sunlight to reach the coffee plants to drive photosynthesis, but without complete exposure to full sun. Shade needs to be managed according to the type and function of the shade species; therefore, the intensity of pruning of shade trees needs to take the following factors into consideration:

- The amount of solar radiation of the place or region where the coffee plantation is located.
- Terrain slope.
- Precipitation regime of the region.
- Wind direction and frequency.
- Shade species present in the production system.
- Structure of shade tree crowns.
- Height of tree crowns (distance between coffee plant crowns and shade tree crowns).
- Labor and resource availability on the farm.

Icafé of Costa Rica recommends that one or two shade arrangements be made per year (Barquero Miranda 2012). In general terms, shade pruning can be done at the beginning of summer, after the coffee harvesting season, and another at the beginning of the rainy season. During the dry season, the coffee plantation requires more shade, so it is not advisable to prune heavily during that time of year. On the other hand, at the beginning of the rainy season, there is greater cloud cover and a greater light input is required for the plantation. In each coffee plantation, it is important to find the right balance between the number or types of tree associations and the appropriate shade level. An 'adequate shade' level is when the shade is evenly distributed and maintains a coverage of 30% to 55%. In cloudier and/or rainy sites, less dense shade is necessary. In places with longer dry periods, more shade is required; however, more trees are not necessarily needed. By keeping the quantity of trees to a minimum, the risks of competition for water and extreme water shortages are minimized. In general, it is very important use pruning and suitable design to avoid overlapping shade and/or intersecting branches that would reduce the penetration of light to the coffee plants.

Another determining factor is the composition of the shade. It is convenient to have service trees (*Erythrina* spp., *Inga* spp., *Gliricidia sepium*), and timber and fruit trees. Service trees provide great benefits to coffee plants; therefore, it is recommended that the largest number of trees be of this type. CATIE's research has determined that maintaining a density of service trees from 150 to 250 trees per hectare is adequate. Timber trees older than ten years must not exceed 100 trees per hectare, and 40 to 60 woody fruit trees per hectare are recommended. These densities are reference indicators. The final decision on what and how many trees to select depends on climate conditions, soil, species, tree designs and their management as well as the coffee farmer's interests and needs.

Example of managed pruning of *Erythrina* (poró) in association with timber trees in a coffee plantation
Photo: Shaline Fernandes

8.2 Genetic control of coffee crops

Coffee production in Central American countries is based on varieties and selections that were derived from the old coffee varieties: Typica and Bourbon. Among the most representative are Caturra, Catuaí (resulting from the crossing of Caturra and Mundo Novo varieties) and Villa Sarchí (Bertrand et al. 1999). These coffee varieties have high production capacity and bear mostly on lower branches, which facilitates the fruit harvest. However, they are very susceptible to coffee leaf rust.

During a series of national workshops held in 2013, the Central American countries reported the varieties they currently use for coffee production (Table 1).

The CIFC introduced three Timor hybrids (832, 2252 and 1343) which have been the basis for the establishment of coffee breeding programs and the development of new varieties with resistance to coffee leaf rust. The offspring of the Timor hybrid have been widely used in breeding programs in countries of the American continent (Brazil, Colombia and Central America), Asia (India) and Africa.

Table 1. Varieties of coffee used in Central American countries and percentage of cultivated land for coffee production

Guatemala	El Salvador	Honduras*	Nicaragua*	Costa Rica	Panama
Bourbon (19%)	Bourbon (42%)	Typica	Caturra	Caturra and Catuaí (90%)	Arábigo (82%)
Caturra (38%)	Pacas (18%)	Bourbon	Catuaí red and yellow	Other varieties (10%)	Robusta (18%)
Catuaí (22%)	Bourbon/Pacas (26,3%)	Caturra	Bourbon		
Catimor (12%)	Pacas/Bourbon (5,9%)	Pacas	Pacas		
Pache (3%)	Resistant varieties (5,7%)	Villa Sarchí	Catimor		
Típica (0,3%)	Less frequent (2,1%)	Catuaí	Catrenic		
Pacamara (0,1%)		Lempira	Maracaturra		
Other (5%)		Ihcafé 90	Typica		
Robusta (1%)		Parainema	Maragogype		
		Icatú	Pacamara		

*There is no information on cultivated land area
Source: Anacafé 2013, Procafé 2013, Ihcafé 2013, MAGFOR 2013, Icafé 2013, MIDA 2013.

With the arrival of coffee leaf rust (race II) in Central America at the end of the 1970s, and with the knowledge that certain coffee varieties are susceptible to the disease, CATIE and Promecafé established an initiative to search for varieties that are less susceptible to the disease. As of 1978, dozens of trials were established, first at CATIE and then in Promecafé´s member countries (Echeverri and Fernández 1989). As a starting point, descendant lines of the Timor hybrids were introduced in generations F3 or F4. Between 1983 and 1986, several descendants of the Timor hybrid were introduced from Brazil and Portugal and were backcrossed to give rise to the generations F4 to F6 that were crossed with commercial varieties: Catimor, Cavimor (Catuaí x Catimor), Sarchimor or Cachimor (Catuaí x Cavimor) (Figure 1). After 12-years of research, "IHCAFE 90" was released in Honduras as the first Catimor variety with high resistance to coffee leaf rust. In 1995, Costa Rica released another Catimor named "Costa Rica 95 (CR95)" and then in 1996, Panama's MIDA released the "Mida 96" variety. Honduras eventually also released the "Lempira 98" variety which is almost identical to the CR95 variety (Bertrand et al. 1999).

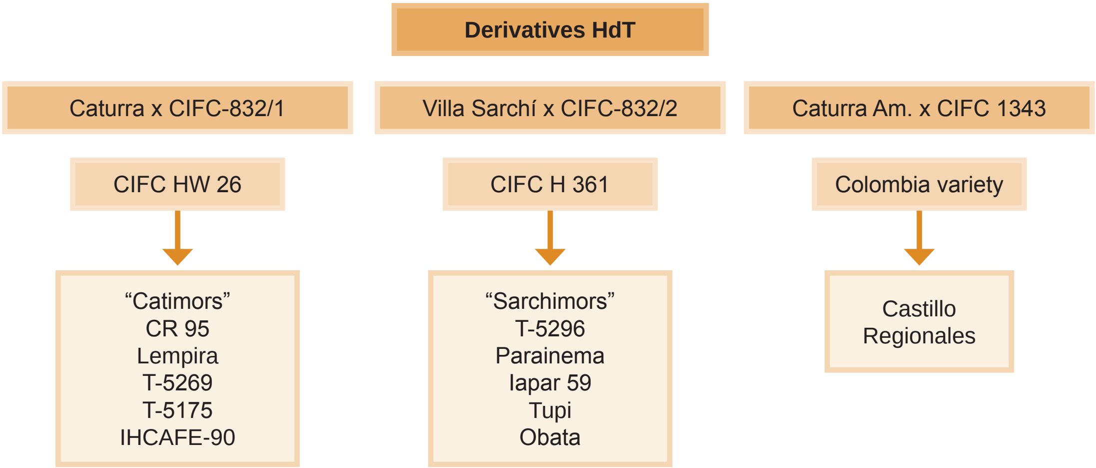


Figure 1. Diagram showing the genetic improvement program developed by CIFC of Portugal and the University of Viçosa in Brazil to develop varieties resistant to coffee leaf rust that are descendents of the Timor hybrid Source: Bertrand et al. (1999).

As a result of the research carried out during the 1980s and 1990s, varieties resistant to leaf rust were released and are now available to Central American coffee farmers.

In the mid-1990s, Promecafé, CATIE and CIRAD, together with the national coffee institutes, initiated the genetic improvement project to produce F1 hybrids. Crosses were made between "wild accessions" collected by the FAO in Ethiopia in the 1960s, which are conserved in CATIE's coffee germplasm collection along with the commercial varieties (mainly Caturra and Catimores and Sarchimores). As a result of this work, 20 F1 hybrids were selected which showed high production (≥50%) in comparison with the control treatment (Caturra variety) and resistance to coffee leaf rust. These genetic materials were established in a network of trials in Costa Rica and other Central America countries (Bertrand et al. 1999). The results of the regional trials allowed the selection of two F1 hybrids from the crossing of a wild variety (Rume Sudan) with a Sarchimor variety (T05296). These hybrids presented outstanding characteristics in different environments: high production, resistance to coffee leaf rust and good coffee cup quality. Through a regional level inquiry, Promecafé named the two F1 hybrids "**Centroamericano**" and "**Millennium**".

Both hybrids have been evaluated since 2000 in two agroforestry systems using *Erythrina poeppigiana* (poró) as shade trees. These trials were established at the CATIE headquarters in Turrialba, Costa Rica, at 600 masl with an average annual temperature of 22.4° C and average annual rainfall of 2400 mm. Coffee trials were implemented with different intensities of shade such as 'poró conventional moderate' and 'poró low organic'. The results of a ten-year evaluation show that the two F1 hybrids display higher production than the Caturra and CR95 varieties (Table 2).

CATIE's long-term trials on coffee agroforestry systems show that F1 hybrids (Centroamericano, Millennium, L2A11, L3A17, L13A12, L3A15) have maintained a certain level of coffee leaf rust resistance/tolerance. In a study carried out between January and April 2010, Montenegro (2010) compared the incidence of pests and diseases in conventional organic and moderate management (Table 3) coffee systems with Caturra, Costa Rica 95 and F1 hybrids. The CR95 and F1 hybrid varieties had the lowest percentages of coffee leaf rust incidence but showed the highest percentages of American leaf spot disease, also known as ojo de gallo.

Furthermore, each national coffee institution has different varieties available for farmers to deal with coffee leaf rust.

Table 2. Mean coffee productivity (fan/ha=qq/ha) based on different coffee varieties under two agroforestry systems at CATIE, Costa Rica

Poró moderate conventional Site 2											
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Mean**
Caturra	19.61	30.97	3.46	25.67	9.08	33.74	27.43	19.93	37.64	5.69	21.32
CR95	51.06	45.63	17.64	14.44	9.21	8.08	20.32	10.72	33.43	39.65	25.02
Centroamericano	91.04	75.17	35.58	27.54	46.04	23.54	47.88	41.75	51.67	24.76	46.50
Poró low organic Site 2											
Caturra	33.63	19.15	37.51	42.75	9.72	29.82	38.36	20.29	25.82	2.99	26.00
CR95	73.50	48.70	34.21	32.06	15.90	15.14	21.39	11.78	17.38	16.89	28.70
Centroamericano	76.21	78.63	43.63	33.83	35.38	17.63	42.08	10.63	17.50	15.42	37.09
Poró moderate conventional Site 3											
Caturra	16.79	31.75	2.75	34.86	22.76	30.54	31.22	30.35	34.06	10.79	24.59
CR95	62.17	70.84	15.75	51.68	45.96	28.60	42.01	34.07	51.50	28.96	43.15
Milenio	45.19	55.51	3.10	16.99	38.75	27.96	21.34	12.81	16.17	12.79	25.06
Poró low organic Site 3											
Caturra	18.09	33.51	13.33	42.47	11.83	22.94	21.56	21.47	19.71	2.61	20.75
CR95	34.71	75.57	17.67	70.64	34.21	27.95	42.64	23.79	35.62	24.79	38.76
Milenio	107.30	109.76	34.88	55.04	71.87	43.57	64.44	46.47	65.20	29.72	62.82

Cuadro 3. Incidencia de enfermedades y plagas (promedio y desv. estándar) en Caturra, Costa Rica 95 e híbridos F1 en ensayo de sistemas agroforestales en CATIE, Costa Rica (enero a abril de 2010)

Enfermedades/plaga	Variedades		
	Caturra	Híbridos F1	CR95
Roya	(8,8 ± 8,5) % (c)	(4,9 ± 7,2)% (b)	(3,5 ± 5,9) % (a)
Mancha de hierro	(14,7 ± 9,9)% (a)	(15,6 ± 10,5) % (a)	(14,8 ± 8,5)% (a)
Ojo de gallo	(6,7 ± 10,5)% (a)	(14,7 ± 17,1)% (b)	(14,0 ± 14,3% (c)
Antracnosis	(0,5 ± 1,0)% (a)	(0,5 ± 1,1) % (a)	(0,6 ± 1,0)% (a)
Minador	(0,3 ± 0,5)% (a)	(0,3 ± 0,6) % (a)	(0,3 ± 0,7)% (a)

Letras distintas indican diferencias significativas (α= 0,05)
Fuente: Montenegro (2010).

Anacafé, Guatemala: The Association centers its efforts on the Anacafé-14 variety, which was selected on the farm of a producer. It is a catimor that was selected for its resistance to coffee leaf rust and its high coffee yields. Several agronomic parameters have been used to evaluate its resistance and it has been shown to be superior to the varieties currently in use (Promecafé 2013). Anacafé recommends using this new coffee variety with seeds produced under technical guidance from the coffee institute.

Procafé, El Salvador: The Association recommends the use of the Cuscatleco and Catisic varieties. The institute offers seeds and nursery plants to farmers. It also offers Centroamericano and Millennium F1 hybrids as promising materials for coffee leaf rust resistance (Procafé 2013).

Ihcafé, Honduras: The use of catimores varieties with resistance to coffee leaf rust has been increasing since 1990. The varieties used include Lempira, Ihcafé 90, Parainema and Icatú. It also offers F1 hybrids produced by the Promecafé-CATIE-CIRAD project, and a Catuaí variety that is more susceptible to coffee leaf rust (Ihcafé 2013).

Magfor, Nicaragua: In 2013, Nicaragua’s Ministry of Agriculture reported the coffee varieties that are in use in Nicaragua but no mention was made of which ones are resistant to coffee leaf rust (Magfor 2013).

MIDA, Panama: In its report, MIDA refers to the use of the Caturra and Catuaí varieties for coffee production in Panama, however, it does not mention whether it has other coffee leaf rust resistant materials that are currently being evaluated or recommended for incorporation into production systems. The Mida96 variety has been a valuable option.

Icafé, Costa Rica: Caturí and Catuaí varieties are used in 90% of the coffee areas (Icafé 2013). Icafé's genetic improvement program is evaluating 17 varieties (sarchimores, cavimores and catimores) from the Agronomic Institute of Campinas, the Federal University of Viçosa (Brazil) and the Agropecuária Research Company of Minas Gerais (Echeverría Beirute 2013). These varieties were all subjected to evaluation trials to determine their agronomic and productive behavior (Table 4).

Table 5 presents the results of the evaluation for the 2010-2011 and 2012-2013 production cycles of the 17 varieties. The three varieties with the highest production or coffee yields are IAC-1669-20 (Obata), IAC 1669-13 (Tupí RN) and IAC Obata RC. According to Echeverría Beirute (2013), the evaluation is still underway as only two production cycles are available; the next phase corresponds to testing in different coffee producing regions in the country, to determine climate change adaptation in selected materials.

Table 4. Evaluation of coffee varieties by Icafé, Costa Rica

Treatment	Introduction	Name of the variety	Type
1	IAC1669-13	Tupí RN	Sarchimor
2	IAC 1669-33	Tupí	Sarchimor
3	IAC 4932	Obatã amarillo	Sarchimor
4	IAC 1669-20	Obatã	Sarchimor
5	IAC Obatã Amarillo	Obatã amarillo RL	Sarchimor
6	IAC Obatã RC	Obatã	Sarchimor
7	H419-3-4-6-14	H419-3-4-6-14	Cavimor
8	H419-10-6-2-5-35	H419-10-6-2-5-35	Cavimor
9	H419-3-3-7-16-4-1-1	H419-3-3-7-16-4-1-1	Cavimor
10	Acuâ MG1332	Acuâ MG1332	Sarchimor
11	Araponga MG1	Araponga MG1	Cavimor
12	Catiguâ MG2	Catiguâ MG2	Cavimor
13	Catiguâ MG3	Catiguâ MG3	Cavimor
14	Oeiras MG 6851	Oeiras MG 6851	Catimor
15	Pau Brasil MG1	Pau Brasil MG1	Cavimor
16	Paraíso MG H419-1	Paraíso MG H419-1	Cavimor
17	Sacramento MG1	Sacramento MG1	Cavimor

Source: Echeverría Beirute (2013).

Table 5. Coffee production based on the evaluation of 17 varieties of coffee, Icafé of Costa Rica

Treatment	2010/2011	2011/2012	Mean	Superiority	
IAC 1669-20	133.74	123.56	129.68	109%	A
IAC 1669-13	139.02	107.89	119.67	93%	A B
IAC Obatã RC	111.64	111.29	112.47	81%	A B C
IAC Obatã amarillo	99.93	109.31	106.11	71%	B C D
Araponga MG1	95.99	106.87	103.59	67%	B C D E
H419-3-3-7-16-4-1-1	97.44	107.58	103.11	66%	B C D E
Catiguâ MG3	96.58	107.93	102.82	66%	B C D E
Catiguâ MG2	87.09	115.8	101.44	63%	C D E F
IAC 4932	91.48	115.32	101.2	63%	C D E F
IAC 1669-33	98.96	105.07	99.32	60%	C D E F
Paraíso MG H419-1	79.46	107.65	93.55	51%	D E F G
Pau Brasil MG1	93.6	91.44	92.52	49%	D E F G
H419-10-6-2-5-35	63.33	111.25	88.96	43%	D E F G H
Oeiras MG 6851	94.04	82.8	87.93	42%	E F G H
Sacramento MG1	70.07	95.88	83.79	35%	F G H
H419-3-4-6-14	70.88	79.95	75.85	22%	G H I
ACUÂ MG1332	59.51	100.5	74.2	20%	H I
Caturra Testigo	71.90	52.27	62.09	0%	I
Catuaí (testigo)	79.22	48.39	58.54	-6%	I

Source: Echeverría Beirute (2013).

Based on the information provided by the coffee institutes and the ministries of agriculture of the countries, work is being done to tackle coffee leaf rust. In Central America there are varieties or hybrids with coffee leaf rust resistance or tolerance which have demonstrated their production capacity with respect to traditional varieties. One important aspect that needs to be evaluated is the coffee cup quality of these varieties, since the cup quality of Timor hybrid varieties are not very good. However, the Catimores and Sachimores do not always present quality problems and at times have surprisingly won competitions and obtained high scores in coffee tastings, compared with varieties recognized for their quality.

The combination of at least two varieties (with resistance and/or tolerance to leaf rust and ojo de gallo/leaf spot separately) in different lots on the farms is a key strategy, since no variety is resistant to all diseases.

8.3 Chemical control in coffee production

Chemical control of coffee leaf rust has been one of the first tools used since the arrival of the disease in Central America. Much research has been done regarding the fungicides that can be used to combat the disease; however, the use of protective fungicides has been the general norm since there have been no frequent or severe attacks and the few that have occurred have been very localized.

The rational basis for chemical management of coffee leaf rust must involve the knowledge of plant's phenology, for which it is necessary to understand and identify the periods of greatest susceptibility to the disease (Sagarpa et al. 2013). Coffee leaf rust incidence increases during the fruiting and harvesting season. In March-April there is usually a decrease in severity due to weather conditions that are adverse for the fungus, for example, leaf fall during the harvesting season, dry season winds, and defoliation induced by the disease. Therefore, the most favorable conditions under which it is recommended to start the application of fungicides occur before the beginning of the rainy season (Sagarpa et al. 2013).

The first products used to control coffee leaf rust were the sulfur-based fungicides; however, overall results showed that they were not very satisfactory (Barquero Miranda 2013b). New trials showed that copper-based fungicides offered better results. These fungicides are classified as protective or contact fungicides, which means that they do not enter the plant tissues to which they are applied. Their mode of action is to cover the plant tissue forming a protective barrier. Copper-based fungicides act on fungus spores by blocking respiration processes, protein production and weakening the cell membrane (Barquero Miranda 2013b).

Research has also been done on systemic fungicides, which enter and move within plant tissues as water and nutrients circulate. These are known as curative fungicides because they have the ability to stop fungal infections from the interior of the plant, attacking the infection in the early stages of disease development. The triazoles is a fungicide group that has shown better activity in controlling coffee leaf rust. These fungicides inhibit the formation of ergosterol, an essential substance for the fungus' development (Barquero Miranda 2013b). The following fungicides are found in the triazole group: Tebuconazole, Difenoconazole, Epoxiconazole, Cyproconalzole, Triadimenol, Propiconazole, Tetraconazole, and Flutriafol[2] (Zambolin 2013).

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[2] Se indican los nombres técnicos ya que los nombres comerciales pueden ser varios y variar de país a país o entre regiones de un país.

For organic coffee production, Central American countries have authorized products that are available on the market. Examples include copper sulfate-based products (“Bordeaux mixture”), copper and plant extracts.

For an effective chemical control, producers must monitor the status of the disease in the coffee plantation before deciding what type of control will be applied (protective or curative). Barquero Miranda (2013b) points out that if leaf rust incidence in the coffee plantation is less than 10%, protective fungicides (cupric) should be used, but when the level of infection is higher than 10%, systemic fungicides (curative) should be used instead. Protective fungicides are ineffective in cases of very strong infections.

The national coffee institutes and the ministries of agriculture of the Central American countries emphasize the need to use chemical control in managing coffee leaf rust. In addition, they insist on the use of appropriate and frequent cultural practices (see section 8.1 and Chapters 4 and 5). The technical staff that provides technical assistance has the names of the products and the formulas that must be applied as well as an application calendar. In general terms, the recommendation is that the first application should be made after the first flowering, which normally occurs at the beginning of the rainy season.

The efficiency of the protective fungicides depends on the weather conditions, since rains can wash away the product. It is advisable to use surfactants for better product adherence and coverage on leaf surfaces. Furthermore, several product applications must be made for greater efficiency in controlling the disease. Application frequency will also depend on environmental conditions and disease incidence.

It is recommended that a mixture of fungicides (triazoles and strobilurin) be applied when systemic fungicides are used to control and prevent coffee leaf rust (Zambollin 2013) and prevent the fungus from developing resistance. Table 6 presents the systemic fungicides (technical names) and the recommended application doses. Trade names are omitted because these may vary between countries and regions.

Fungicides containing active ingredients belonging to the triazole and strobilurin group are marketed together, therefore the farmer does not necessarily have to purchase the two products separately in order to make the mixture. Different commercial compositions/combinations can be found for application.

Table 6. Systemic and protective fungicides that are recommended for combating coffee leaf rust.

Technical name	Fungicide group	Grams and/or ml/litro	kg and/or ml/200 in liters
Copper oxide	Protective	2.5-3.5 g	0.5-07 kg*
Copper hydroxide	Protective	2.5-3.5 g	0.5-07 kg*
Copper oxychloride	Protective	4.5-5.0 g	0.9-1.0 kg*
Propiconazol	Triazol (Systemic)	1.25 ml	250 ml
Triadimenol	Triazol (Systemic)	1.25 ml	250 ml
Tebuconazol + Triadimenol	Triazol + Estrobilurina (Systemic)	1.75 ml	350 ml
Cyproconazol + Carbendacin	Triazol + Estrobilurina (Systemic)	1.25 ml	250 ml
Cyproconazol + Pyraclostrobin	Triazol + Estrobilurina (Systemic)	2.50 ml	500 ml
Cyproconazol + Trifoxistrobin	Triazol + Estrobilurina (Systemic)	1.50 ml	300 ml

*Indicated dose to apply to every 0.5 ha of coffee land area.
Source: Prepared from Zambollin (2013) and Barquero Miranda (2013).

Other aspects/qualities related to the control of coffee leaf rust have to do with the application equipment. For both protective and curative fungicides, well-calibrated application equipment should be used with the appropriate application nozzle. The operator must make sure to cover the foliage (particularly under the leaves). This is especially important for the application of protective fungicides, since they do not move through the plant; therefore, the tissue should be well covered, otherwise there is the possibility that foliar areas will be left without disease protection.

The control of coffee leaf rust must be viewed as a joint strategy where cultural practices, medium and long-term genetic control, and chemical control interact. With the application of appropriate cultural practices, farmers contribute to creating adverse conditions for the development of the disease and, consequently, there will be less use of fungicides to control the disease. Obviously, this results in benefits for the environment and human health, as well as the farmer’s pocket.

El control quimico de la roya, sea en agricultura convencional u orgánica, debe ser aplicado siguiendo las recomendaciones técnicas y con los equipos de protección adecuados una vez que todos, en un mayor o menor grado, implican riesgos para la salud humana y el medio ambiente.

Para conocer más detalles sobre métodos de diagnóstico ver el documento "**Compilado sobre Medidas de Control de la Roya del Cafeto**" elaborado por el Proyecto Roya CATIE-CIRAD-PROMECAFE/ NORUEGA (Solicitar a http://bibliotecaorton.catie.ac.cr/).

8.4 How to develop a technical session with the farmers

It is recommended that extension agents and/or facilitators use the content of the previous chapter to organize a technical session with coffee farmers. Propose the following activities for this session:

- Select a plot on a producer's farm that is representative of the region's production system. Consider whether it is possible to select a plot with coffee under shade and another with full sun exposure.
- Prepare a section during the meeting to evaluate the status of the coffee crop. This section should evaluate:
  - The general status of the coffee plants: foliage, plant height, number of branches per plant, penetration and distribution of light, aeration (air circulation); presence of exhausted, diseased and broken branches that require pruning, or if pruning is done using technical criteria.
  - Analyze with the coffee farmer the components/factors that could be improved through cultural practices to help improve the status of the plants and the coffee plantation.
- Analyze the production system. Pay attention to the following components:
  - If the production system is under full sunlight, discuss the advantages and disadvantages and the convenience of using shade. Explain the effects of direct light on the plant's physiology and the conditions for the development of coffee leaf rust.
  - If the production system is under shade, analyze the shade conditions: Is it well regulated? Is the system very exposed (little shade)? Is it necessary to implement some practices to improve light penetration? Is it necessary to provide better shade conditions? Analyze the relationship between the physiological qualities of the coffee plant and the shade, as well as the conditions that favor and/or limit the development of leaf rust.

- With the participant, evaluate coffee leaf rust incidence. It is recommended to use some of the methods presented in Chapter 6; however, due to ease of execution and the number of observations that must be made in the field, it is suggested to use CATIE´s methodological approach (Virginio Filho et al. 2009).
- From the results of the evaluation of coffee leaf rust incidence, and, if available, the determined degree of the attack’s severity, proceed to analyze the results with the coffee farmers and decide the best chemical control method to be applied (protective or curative fungicides) and/or organic control, as well as the complementary management plan.
- With the participants, perform the coffee leaf rust chemical control practices and/or control with organic products. Before the practice, check the status and calibration of the equipment.

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