COMMUNITY-BASED INTEGRATED PEST MANAGEMENT FOR COFFEE LEAF RUST:

A CASE STUDY OF COLOMBIAN COFFEE SMALLHOLDERS

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Jenny Yoori Lee
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ABSTRACT

Coffee leaf rust (CLR) is a devastating fungal disease specific to coffee (primarily *C. arabica*). From 2008-2013, an unprecedented epidemic of CLR swept through most Latin American coffee-producing countries, endangering the main livelihood source of millions of smallholder farmers. With more incidences of extreme precipitation and rising temperatures that enable higher pest outbreaks, coffee leaf rust is likely to occur with more frequency and potency. Current prevention and treatment strategies employ one or a combination of the following: use of resistant varieties, fungicides, and cultural practices. These strategies mostly focus on the individual farm level, and do not ensure that smallholder farmers properly understand and address underlying causes of the disease in their specific agro-ecological contexts. This paper explores the following: 1) the differential effects of cropping practices and coffee farming systems on CLR incidence and severity, and 2) what strategies tend to be most effective at different scales, from individual farms, to the wider community and landscape. Based on fieldwork done in Cauca, Colombia and a review of best practices in the literature, this study examines community-based Integrated Pest Management (C-IPM) as a holistic and context-appropriate strategy for smallholder farmers managing coffee leaf rust.

BIOGRAPHICAL SKETCH

Jenny Lee has dedicated her studies and professional experiences towards social justice and poverty alleviation efforts. She completed her undergraduate degree in 2012 in Urban Studies and Planning, with a minor in International Studies at the University of California, San Diego. There, she developed her interests in global development, Latin America, urban agriculture, and food systems intersecting with racial and income disparities. Jenny worked in regional planning for the San Diego Association of Governments after graduation, primarily on implementing programs with tribal nations and low-income communities of color.

Jenny then served as a Peace Corps Volunteer in El Salvador from 2014-2016, working in the Community Economic Development sector. She lived in a small village of less than 200 people, and among other projects, catalyzed the establishment of a rural women's association to empower local women to carry out community and rural livelihoods projects. Jenny regularly saw farmers in her site and other villages using toxic pesticides with no protective equipment, and the loss of their harvests from irregular weather during her time there. She was also exposed to coffee farming, as it was one of the crops cultivated in her site. Due to increasing levels of civil unrest and violence in the country, the Peace Corps evacuated all its volunteers from El Salvador in early 2016.

Informed by her experiences in El Salvador and her continuing interest in food and agriculture, Jenny went on to pursue a master's degree in International Agriculture and Rural Development at Cornell University, within the prestigious College of Agriculture and Life Sciences (CALS). At Cornell, Jenny was involved in various projects ranging from consulting projects with the local county government, to coffee farming research in Colombia, to food policy writing and research in India. She is currently a Research Support Specialist at the Tata-Cornell Institute for Agriculture and Nutrition in the Dyson School of Applied Economics and Management.

For my uncle, Don Park, who is valiantly battling Parkinson’s Disease. Thank you for encouraging me to be curious, to travel widely, to explore, and to set my career sights globally.

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LIST OF ABBREVIATIONS

CIALS…Comités de Investigación Agricolas Locales

CLR…Coffee Leaf Rust

C-IPM…Community-based Integrated Pest Management

FCC…Federación Campesina del Cauca

FFS…Farmer Field Schools

FNC…Federación Nacional Cafetera

IPM…Integrated Pest Management

CHAPTER 1. INTRODUCTION

The northern countries[1] of Latin America are the world's leading producers and exporters of Arabica coffee. This is an important source of revenue and foreign exchange for these countries (Perfecto et al., 2005). Colombia is the region's leading producer of high quality, single-origin Arabica. A majority of Latin American coffee producers are smallholders who rely on coffee as their primary livelihood source (Avelino et al. 2015). But smallholder coffee growers are faced with daunting challenges on multiple fronts: volatile coffee prices[2], increased competition from Vietnam and Brazil, higher costs of labor, and climate change affecting viable cultivation areas for Arabica (Eakin et al., 2014; Jaramillo et al., 2011; Ponte, 2002).

A significant loss of harvest due to pests exacerbates the challenges smallholders face. Coffee leaf rust is a fungal disease caused by *Hemileia vastatrix,* one of the most economically damaging threats to coffee production

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[1] Peru, Colombia, Nicaragua, Costa Rica, El Salvador, Guatemala, Honduras, and México. Brazil is the largest producer and exporter of coffee in the world, but exports more Robusta than Arabica. Brazil specializes in low-elevation coffee production, compared to the aforementioned countries, which tend to have more mountainous, higher-elevation topographies producing higher quality Arabica coffee and thus, higher priced coffee beans.

[2] Before 1990, coffee prices used to be regulated by the International Coffee Agreement between producer/exporter countries and consumer countries. This was comparable to how oil is a regulated commodity under OPEC. There were export quotas in favor of producer countries. After the Agreement broke down, deregulation and an oversupply of coffee on the market caused prices to plummet drastically, subject to stock market fluctuations. There have been several 'coffee crises' in the following decades, most notably in the early 2000s, with coffee prices at historic lows. Many smallholders were forced to abandon production altogether and shift to other crops or off-farm production. See Ponte (2002) and Eakin et al. (2006) for detailed discussion of coffee deregulation, structural changes, and price volatility in the global market and impacts on smallholder coffee growers.

worldwide. From 2008-2013, northern Latin American coffee production suffered a crippling epidemic of coffee leaf rust (CLR) as it spread through Peru and Colombia in 2008-2011, and traveled north to Central America in 2012-2013. The rust epidemic caused an estimated loss of USD$616 million revenue in Central America, and reduced coffee production by 31% in Colombia (McCook and Vandermeer, 2015). In some of the hardest hit countries, outbreaks of the disease continue to affect production into the present day. Thus, the rust epidemic has had a direct impact on the food security of smallholder farmers and their households (Bacon et al., 2014; Avelino et al., 2015).

Current approaches for dealing with CLR emphasize immediate control measures at the farm-level using genetics and chemicals. Farmer-centered methodologies and traditional understanding of the disease are also important considerations for CLR management. Holistic approaches that integrate disease management strategies must consider community cultural and political structures, as well as the socio-economic context in which the approaches are situated. This is crucial for farmer adoption of technologies and skills relevant to managing this plant disease.

Additionally, smallholder farmers require different approaches than medium and large farmers. Poor smallholders face different challenges and different contexts, and they use diverse, complex livelihood strategies that should be considered (Chambers, 1995). With the limited number of public agricultural extension agents, there are inevitable problems in farmer access to information and resources from extension. Traditionally, smallholders have experienced problems of elite capture as advisory services tend to visit farmers with more resources, or those who are more easily accessible on the main roads, instead of the poorer farmers in harder-to-reach areas of the same community.

1.1. Rationale

Coffee farming is an integral way of life in the communities where coffee is produced. Families often pass down coffee cultivation from generation to generation. As such, coffee farming drives social development and rural quality of life improvements. Epidemics of coffee leaf rust pose a major threat to the livelihoods of small coffee farmers. This research contributes to the literature about coffee pest management and aims to address the gaps existing in the current studies about this disease.

1.2. Goal

The goal of this study is to examine the ways that disease management of coffee leaf rust can be improved using holistic, community-driven approaches that are appropriate for Colombian smallholder coffee farmers and their context-specific agroecological conditions at both the farm level and the community level.

1.3. Research Objectives

The objectives of this study were two-fold:

1) Evaluate the literature on coffee leaf rust, and the current prevention and treatment approaches.
2) Compare these approaches from the literature with information gathered in the field, and examine holistic strategies for CLR prevention and treatment.

1.4. ***Problem Statement and Research Questions***

1.4.1. Problem Statement

Current CLR strategies mainly focus on the individual farm level as the unit of analysis and prioritize the use of control tactics to address symptoms, rather than systemic disease management approaches. These control measures do not ensure that farmers have a proper understanding of disease life cycles and vectors of transmission to help address underlying factors that contribute to CLR's spread. The disease travels across farms and landscapes, making farmer-to-farmer communication and containment measures of critical importance. There is also inadequate knowledge in the literature about community-based approaches to manage CLR.

1.4.2. Research Questions

1. What are the trade-offs between coffee cultivation practices and CLR incidence and severity?
    - 1.1. What are the trade-offs between CLR management approaches and coffee quality and yield?
    - 1.2. How do these trade-offs influence farm management decisions of smallholder coffee farmers?
2. Which CLR management/treatment approaches are optimal at the farm level, the community level, and the regional level?
3. What are smallholders' perceptions and understandings about CLR, and how can these inform a more systematic plant disease management of CLR using community-based Integrated Pest Management (C-IPM)?

3.1. How can existing organizational structures (the local coffee cooperatives), farmer-to-farmer communication, and social networks be leveraged for community-based IPM for CLR?

CHAPTER 2. BACKGROUND

Coffee leaf rust is one of the most threatening diseases of global importance for coffee production. This chapter outlines the origins and spread of coffee leaf rust as well as the factors that influence its potency during outbreaks.

2.1. Origins and movement along trade routes

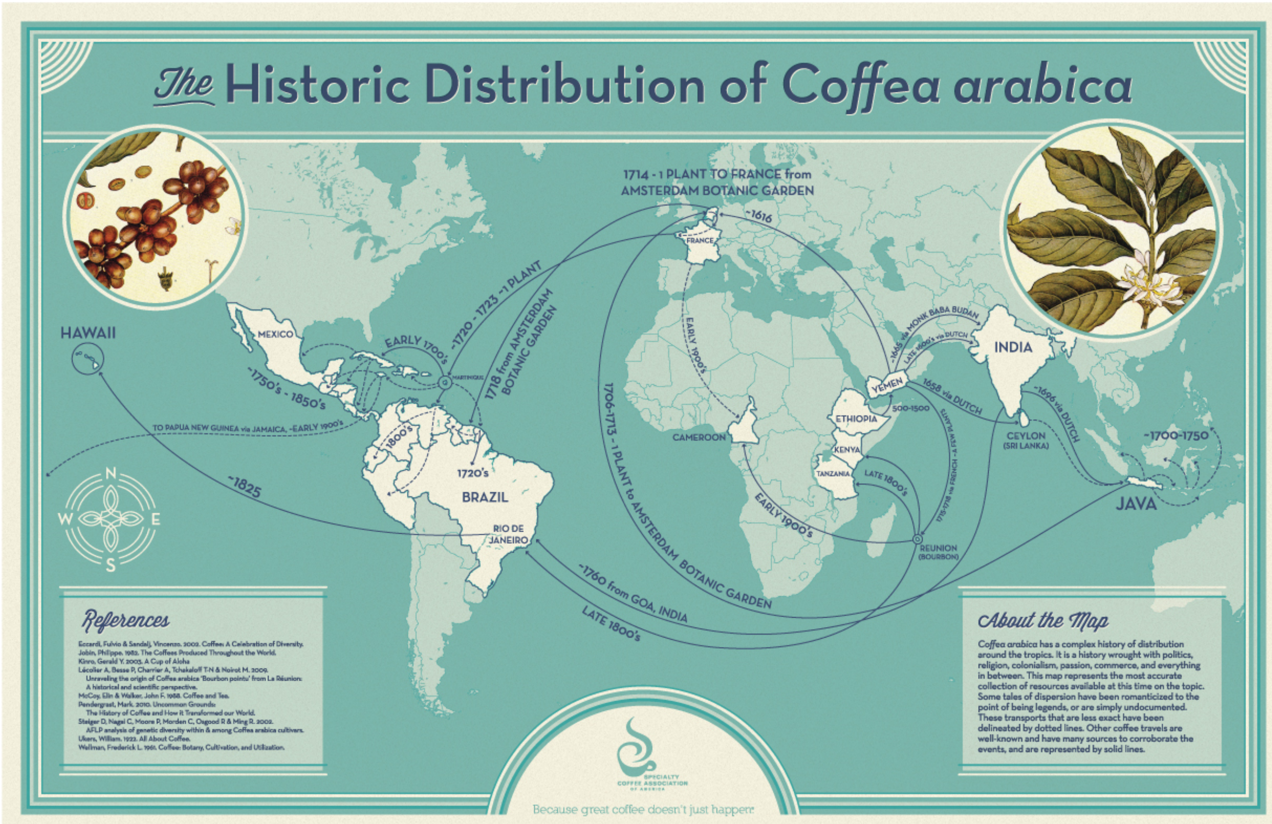
Coffee leaf rust (*Hemileia vastatrix*) is an obligate fungal disease that evolved specifically on the genus Coffea. While there are other species of coffee leaf rust in the wild, *H. vastatrix* affects the two commercially sold varieties of coffee, Robusta (*C. canephora*) and Arabica (*C. arabica*). Of those two, Arabica is the more susceptible variety, and is of higher commercial value than Robusta because it is considered to be of higher quality.

Coffee leaf rust has had a long and interesting history with coffee around the world, related to the commodification of coffee as a cash crop and the trade routes established by European colonial powers. Wild species of coffee originated in Ethiopia, where CLR was endemic, but never severe, as coffee was harvested in the wild in the Ethiopian highlands instead of being intensively cultivated. In the wild, there were a diversity of other plants and natural enemies to keep the disease in check, as well as many species of wild coffee, some of which were resistant to the disease (McCook, 2006). High altitude and cooler temperatures would also have kept the disease at low levels. CLR took hold as a major threat to coffee once it was cultivated as a cash crop in tropical countries.

Pre-colonial trade routes between Africa and the Middle East took coffee to other parts of the world. The oldest record of commercial coffee cultivation traces back to the highlands of Yemen (Waller et al., 2008) and then it spread to Egypt over 1,000 years ago (Gaitán et al., 2015). CLR, which requires water for germination, was not able to survive in the arid climate of the Middle East. This rust-free coffee germplasm was then transported from the Middle East to western India through Arab traders in the 16th century (Waller et al., 2008). From Java, the Dutch took a coffee plant back to the Amsterdam Botanic Gardens in 1706, where it reproduced and became the first 'Typica' variety of Arabica which was eventually propagated throughout the Americas. The growth of coffee's commercial production and trade coincided with Dutch and British colonial expansion.

McCook (2006) discusses how colonial trade and travel routes helped spread CLR from Africa to parts of the British empire in South India and Ceylon (present day Sri Lanka). British soldiers transported the rust spores on contaminated cargo carrying precious goods like ivory. During that time, South India and Ceylon were major coffee producers for Britain, where Arabica coffee consumption had become popular starting in the 17th century (Gaitán et al. 2015). Figure 1 gives a visual depiction of how Arabica coffee spread from Ethiopia to the major countries and regions where it has historically been cultivated as a cash crop.

Figure 1. The global historical distribution of Arabica coffee. Source: NPR (2013)



The history of CLR shows that the pathogen is a versatile organism, adept at evolving according to changes in its environment over time. McCook (2006) describes how British cultivation practices favored intensification through monocropping Arabica, which required taking out non-coffee shade trees that could serve as barriers against windborne spores. Intense monsoon seasons and hot temperatures in Ceylon and South India also favored the spread of CLR. While coffee producers in Ceylon initially left infected farms and relocated to disease-free areas on the island, it inevitably spread to those places soon after. The disease gradually infected and wiped out 90% of Ceylon's coffee production during the epidemic period. This led British and local producers to abandon coffee cultivation and shift to tea production, for which Sri Lanka and South India are now renowned (McCook, 2006). From there, it was only a matter of time before the disease spread along trade routes to the Western Hemisphere where coffee plantations had been established in Latin America and the Caribbean.

2.2. Coffee production in the Americas

Coffee was first introduced to the Americas by the Dutch, with rootstock sent to the Dutch colony of Suriname, off the Atlantic coast of South America, in the early 1700s (Waller et al., 2008). The French then introduced coffee plants to their colony, French Guyana. From there, coffee plants made their way to the Portuguese in Brazil about 20 years after the first introduction of coffee to the New World (Waller et al., 2008).

2.2.1. Economic significance of coffee in Latin America

Coffee is the most valuable tropical agricultural commodity in the world, with an industry worth over $90 billion USD (Jaramillo et al., 2011; O'Connell, 2003). The countries of the Latin American Cordillera comprise one of the world's most prolific producing and exporting regions of high quality coffee, specializing in Arabica coffee grown in high elevation areas, referred to as "milds" (O'Connell, 2003; McCook, 2017). Brazil and Colombia dominate as two of the largest coffee producers globally (Waller et al., 2008; McCook, 2017), but Brazil produces more commodity-grade (i.e. not specialty) Arabicas and Robustas at lower elevations. Coffee production is of great economic value to northern Latin American countries, providing an important source of foreign exchange revenue and serving as a main cash income source for millions of smallholder farmers (O'Connell, 2003; Perfecto et al., 2005).

With the disbanding of the International Coffee Agreement in 1989 (see footnote no. 2, p. 1), the relatively egalitarian market relations between coffee producer and consumer nations shifted drastically in favor of operators based in consumer countries from the 1990s onward (Ponte, 2002; Bacon, 2010). Lee et al. (2012) support Ponte's conclusion that this transference led to more volatility in world coffee prices, with consuming countries retaining a higher percentage of the profits while producer countries experienced declines.

2.2.2. Ecological significance

Latin America is a hub of biodiversity. Traditional agroforestry practices such as shade grown coffee cultivation have typically helped preserve and maintain biodiversity at high levels (Soto-Pinto et al., 2000). Yet, Latin America also has seven out of ten of the world's most deforested countries (Rice & Ward, 1997). In countries where there has been severe deforestation, coffee farming has preserved fragments of original forest (O'Connell, 2003; Perfecto & Vandermeer, 2009). Coffee farms with higher levels of biodiversity are likely to have increased abundance and richness of pests and natural enemies (Allinne et al., 2016; Borkhataria et al., 2012; Perfecto et al., 2003), which may aid in regulating pest outbreaks.

2.3. Coffee leaf rust in the Americas: la roya

CLR is known by its Spanish name, *la roya*, in Latin America. The first recorded case of *la roya* in the Americas emerged in Puerto Rico in the early

1900s. It is the only case that appeared in the hemisphere before 1970. It was contained by an American agricultural scientist stationed at an agricultural experiment station who recognized the symptoms and acted immediately to destroy the infected plants (McCook, 2006). This shows the importance of quick responses in dealing with CLR.

Furthermore, the spread of CLR was more rapid but not epizootic in Latin America relative to other continents, attributed to the distributional pattern of rainfall spreading spores over short distances (Waller, 1982)[3]. In 1970, CLR made a significant breakthrough on the continent, but it did not turn into an epidemic at the time, as feared by most growers and governments dependent on coffee export revenue (Vandermeer et al. 2014). Instead, CLR became more of an annual nuisance, a constant presence on coffee trees at low levels, with occasional epidemics (Perfecto et al., 2014). Heavy use of fungicides such as Bordeaux mixture played a significant role in limiting the spread of the disease (Waller, 1982).

Alternatively, Vandermeer et al. (2010, 2014) have hypothesized that the low levels of CLR upon first emergence could be attributed to the ecological complexity found in the traditional coffee growing environment of Latin America. This biodiverse setting plausibly facilitated the autoendogenous control of CLR

[3] According to Waller (1982), rust spread more slowly over a period of 50-100 years in Africa and Southeast Asia; while the exact reasons are unclear, it may have to do with rainfall patterns and topography (providing physical barriers or lack thereof to rust spores) of each region.

through complex trophic interactions, mainly involving ant species (*Azteca sericeasur*) found only in Latin America, and antagonistic fungi like the hyperparasitic *Lecanicillium lecanii* (Perfecto et al., 2014) that has been known to attack *H. vastatrix,* among other fungi. There are, however, no known CLR-specific natural enemies, only generalist species (see above) that have shown some potential for biological control of CLR (Perfecto et al., 2014).

2.3.1. Latin America's CLR epidemic, 2008-2013

The most recent epidemic in Latin America from 2008 to approximately 2013 was extremely severe and affected all the coffee growing countries of the Cordillera in Latin America. The 2008-2013 CLR epidemic is partially attributed to prolonged and historically low coffee prices in the early 2000s, which disincentivized optimal practices (Avelino et al., 2015). Coffee farmers, particularly smallholders, had to economize and cut costs for agricultural inputs that contribute to optimal coffee production (Waller et al., 2008). Because on-farm investments in resources and good practices for crop protection are usually neglected during times of economic hardship, it makes more urgent the need to find creative and sustainable solutions for coffee pest management (Waller et al., 2008; Bacon, 2010). These cut-backs plus a combination of excessive rain and heat created conditions conducive to an epidemic in 2008-2013 (Avelino et al., 2015).

Epidemics occurred in Costa Rica in 1989 and Nicaragua in 1995, but these were contained within those respective countries (Waller, 1982). From the mid-1990s, CLR was largely brought under control through improvements of management practices, mainly fungicide applications (Cressey, 2013). However, the 2008-2013 epidemic was different from previous ones in that it spread throughout the entire Cordillera and caused more primary losses than secondary losses (Avelino et al. 2015). Primary losses occur during the current season, affecting the coffee tree's photosynthetic capacity through defoliation and causing leaf senescence and eventually the death of productive branches. Usually, CLR causes secondary losses, where harvests are reduced in the next season following an outbreak of CLR. Severe, irregular weather patterns and drastic temperature fluctuations associated with climate change also likely contributed to the severity of the 2008-2013 epidemic.

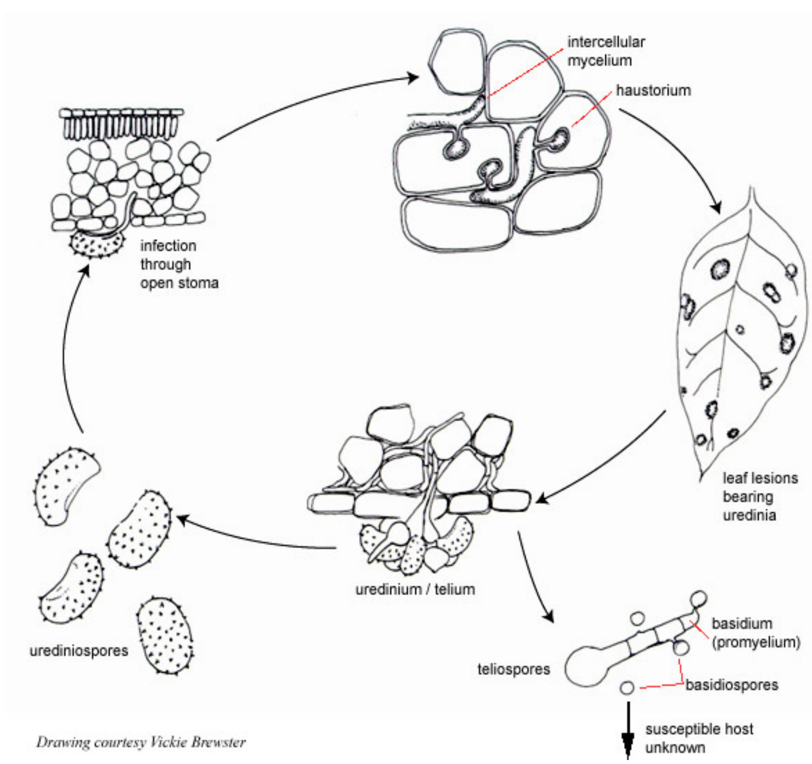
2.4. The Pathology of Coffee Leaf Rust

The most recognizable symptoms of CLR are the distinct yellow-orange lesions that develop on the underside of the coffee leaf. The pathogen attacks the leaves of the coffee plant and thus reduces its ability to photosynthesize, causes the loss of leaves, and consequently, the dieback of branches when especially severe. It is a disease that affects the normal development of the coffee tree over time through successive infections, gradually wearing down the defenses of the plant and draining its nutrient processing by defoliating the tree (Avelino et al., 2004; Waller, 1982). The debilitating effects on an infected coffee plant last into following crop production cycles after the plant has recovered, by reducing young branch emergence and the berry load of the plants (Muller et al., 2008). Repeated attacks on the coffee tree then negatively impacts coffee quality and yield, which both lower the prices and income that the coffee farmers can receive for their beans.

2.4.1. Life cycle of Hemeilia vastatrix

The fungus begins by producing thousands of urediniospores (Fig. 2). After the spores land on or near a coffee leaf, they can remain viable until optimal conditions allow the spores to enter from the underside of the leaf through the stomata, the porous openings that allow gas exchange in the plant (Muller et al., 2008). The entire process from infection to germination, happens rapidly within a few hours (Waller, 1982). Once the urediniospores have penetrated a stoma, they form hyphae that begin to affect the cellular structure of the leaves (Muller et al. 2008), as depicted in Figure 2. The networks of hyphae form mycelia (Figure 2) that colonize the foliar tissues and spread, appearing externally on the

Figure 2. CLR life cycle. Source: American Phytopathological Society (2018)



underside of the leaves. The mycelia reproduce and generate the characteristic coppery powdered spores. Mycelia can contain around 100,000 spores that spread and begin the cycle again (McCook, 2006).

2.4.2. Enabling factors

Important enabling factors include temperature, rain, wind, and worker activities that can spread rust both within the individual canopy and across plots and farms (Gaitán et al., 2015). Other conditions that enable development of CLR include: Older leaves on the ground, high soil moisture content, humid air, and low levels of light (Catholic Relief Services, 2015). Additionally, the length of latent period is important for disease progress – the factors that shorten the latent period are conducive to higher sporulation (Waller, 1982). These include a continuously wet climate and drastic temperature fluctuations (Waller, 1982).

A. Transmission by Humans and Animals

Insect pollinators and larger animals such as birds can spread the CLR spores as they go about their activities (Gaitán et al., 2015). Agricultural workers may spread the uredinospores from their clothes to other coffee plants as they go from tree to tree to harvest the coffee berries. Waller (1982) cites the case of Nicaragua and how new outbreaks peaked just after harvest due to the presence of workers traveling between plants as they collected the ripe coffee cherries.

B. Rain/Water

Water is a prerequisite for spore germination, in addition to being a disease vector (Waller, 1982; Avelino et al., 2004). Rain water droplets that fall from the upper canopy onto the lower canopy of coffee trees can be especially effective in spreading the disease. The kinetic energy of water droplets from the upper canopy trees acts as a major dispersal agent of spores due to the splash effect of water droplets carrying spores down to the coffee trees in the lower canopy (Avelino et al., 2004; Boudrot et al., 2016). On the other hand, an upper canopy of shade trees above the coffee plants can also block transmission of spores from rain and wind.

C. Wind

While there is some debate about whether water or wind transmission of spores is more important, wind is the most important factor in spore dispersal overall (Waller et al., 2007). Particularly with regards to CLR epidemics, wind transports urediniospores across landscapes that offer little wind resistance, such as pastures, until another coffee plot is reached (Avelino et al., 2012). Wind can transport spores both within specific plots and across farms.

D. Temperature

Temperature is another major environmental factor that influences the spread of the disease. Optimal temperatures for *H. vasatrix* spore germination range between 20° and 25° Celsius, with highest activity at 22°C (Muller et al. 2008). Colder temperatures generally tend to impede germination, which is why rust was until recently, less prevalent at higher altitudes. Arabica coffee is typically cultivated at higher elevations, and thus was mostly safe from rust and other pest outbreaks compared to coffee cultivated at lower elevations, where temperatures tend to be higher. With warmer temperatures attributed to climate change, rust has been occurring at higher elevations than before (Jaramillo et al., 2011).

Another temperature consideration that enables CLR is the diurnal fluctuation of temperatures, i.e., the minimum and maximum daily temperatures. Avelino et al. (2004) found that a smaller diurnal temperature range, with higher minimum temperatures and a lower maximum temperature, is the best range for CLR to develop and germinate. This has implications for coffee producers, who can use cultural practices to manipulate the microclimate and temperatures within coffee growing areas of their farms.

2.5. Agroecosystems of coffee and influences on CLR

2.5.1. Shade and sun cultivation of coffee

There exists a controversy in the literature about the effects of shade- and sun-grown coffee production on CLR incidence. There are a number of trade-offs between the two types of coffee cultivation systems (Table 1), and varying degrees of shade. One production environment may be preferable to the other depending on the specific agroecological factors and context of each farm and growing region, as well as the priorities and socio-economic and natural resources (yield, quality, input costs, etc.) available to the farmers. The complexity and multitude of variables that influence CLR outbreaks make it difficult to attribute specific outcomes solely to shade or sun (Avelino et al., 2006), but it is important to consider how these types of cropping systems provide the setting for enabling and disabling factors of coffee leaf rust.

In Latin America, coffee was traditionally grown under the shade of a multi-strata canopy (Perfecto et al., 2005). In Colombia, Central America, and other countries of the Cordillera, coffee was produced mostly by smallholders with small family farm operations rather than large estates (McCook, 2017). These small farms were ecologically diverse, with coffee grown under shade and polycropped with other cash crops like sugarcane, and staple foods, such as maize, beans, and manioc, known locally as *yucca* (McCook, 2017).

Sun-grown or conventional coffee production refers to the method of intensively cultivating coffee under full sun exposure, usually with more tightly spaced, dense rows of trees for maximized yields (McCook, 2017). Due to the intensive nature of the cropping system and high nitrogen (N) requirements, chemical fertilizers tend to be used, more so than in traditional polycrop coffee systems.

Sun-grown coffee was popularized in Latin America in the 1970s, inspired by the global dissemination of Green Revolution technologies and methods (Vandermeer et al., 2010) and partly driven after rust and other pest control campaigns (McCook, 2017). The innovation and widespread dissemination of high-yielding, hybrid cultivars, such as Caturra[4], allowed for denser spacing between coffee trees and grew better in sun than traditional non-hybrid varieties. Because of constant exposure to sun, the yields in this form of coffee cultivation

[4] A popular variety in Colombia, and one of the varieties noted during my fieldwork, described in Chapter 4 of this paper.

are very high. The higher yields were generally expected to make up for the higher costs of production, such as increased inputs of fertilizer and pesticides. But for many farmers, the renovations created more vulnerability to shocks such as drops in coffee prices, increased costs in labor or chemical inputs, or a combination thereof (McCook, 2017). One of the main motivators driving renovation of coffee farms toward sun-grown cultivation was the belief that shade was more conducive to rust due to humidity and darkness of the growing environment (Vandermeer et al. 2010). Sun-grown coffee and resistant varieties were thought to effectively control and prevent the disease (McCook & Vandermeer, 2015). While increased exposure to sunlight was effective in preventing germination of rust spores, sun-grown coffee cropping systems were not as effective in blocking spores transmitted from other areas. The lack of windbreaks from shade trees and the density of coffee trees planted together in monocrop led to faster and more severe oubreaks of *la roya* on 'technified' farms, similar to what happened in colonial Ceylon with the British (McCook & Vandermeer, 2015). Additionally, high fruit load from increased sun exposure is associated with higher susceptibility to CLR, conducive especially to epidemics (Avelino et al. 2004), although the mechanisms behind this are still unclear (Avelino et al. 2015).

Another trade-off to consider for sun-grown coffee is that it does not produce as high a quality cup of coffee as shade-grown coffee (Table 1), due to the quick maturation of the coffee cherry under the sun (Waller et al., 2006). This could potentially lessen the profit margin for farmers. However, coffee quality is determined not just by amount of sun exposure, but also by the overall care and management in the cultivation, processing, and storage of the coffee beans.

Table 1. Shade- and sun-grown coffee cultivation trade-offs (broadly)

	Shade	**Sun**
Inputs - chemical	Can be minimal (depends on size of farm and density of shade cover)	Fertilizer, pesticides, herbicides
Inputs – labor	High cost – more weed cover, maintenance of shade trees and coffee trees; usually cannot use machines for harvest	Lower cost for mechanized harvest
Yields	Lower to intermediate	High
Coffee quality	High – complex flavor profile	Low – fast bean maturation, less flavor/aromas

Shade-grown coffee cultivation also has many economic and ecological trade-offs (Table 1). There are also trade-offs that either inhibit or encourage the spread of CLR, for instance: The reduced intensity and exposure to sunlight lessens the leaf area of the coffee plant, makes it less likely to intercept spores (Soto-Pinto et al., 2002), but the dark and humid environment also favors germination.

The agronomic benefits to shade-grown production include climatic buffering, especially for high altitude areas: 1) wind and storm protection, 2) reduced light intensity leads the coffee plant to flower more slowly, so there is a better physiological balance between cropping level and plant nutrition (Waller et al., 2007), and 3) temperature protection, especially where diurnal high and low temperatures can be drastic. This third condition - the decrease in maximum highs and the increase in the temperature minimum- is also highly conducive to CLR germination (see Section 2.4.2.D on temperature as an enabling factor).

Other benefits include soil and water retention, especially important for coffee farms on steep hillsides. The shade helps with suppression of weeds through reduced light penetration in the canopy, and leaf litter acts as mulch for soil cover and provides nutrients. If leguminous trees are planted, their leaf litter – once decomposed - can provide plant-available forms of N or other macro- and micro-nutrients. For farmers, it also provides a diversified source of income and food, while also reducing agrochemical use and input costs (Bacon et al., 2005; Waller et al., 2006).

While shade-grown coffee may fetch a higher premium either for quality or for specially certified production standards, there are many trade-offs. Farmers must balance between the optimal level of shade and the associated higher costs of labor, lower yields, and possible nutrient competition between the coffee tree and surrounding vegetation (Atallah et al., 2018).

2.5.2. Shade and sun influences on CLR: the controversy

The existing literature points to a lack of consensus about the role of shade cover and its antagonism or conduciveness to rust. Some, like Soto-Pinto et al. (2002) and Haijan et al. (2016), argued that rust incidence was low in their field trials of shade-grown systems due to a diversity of natural enemies found in those agroecosystems that were antagonistic to rust. Other studies (Staver et al., 2001; Lopez-Bravo et al., 2012) claim that while shade overall is antagonistic to CLR because of lower fruit loads, their test plots exhibited higher rust incidence and severity in shade when compared to sun-grown coffee. Their plots were also located at relatively low elevations (600m) in Costa Rica. The diversity of the environments and the different frameworks and approaches of the authors are likely to bias some of the conclusions as well.

Soto-Pinto et al. (2002) and Vandermeer et al. (2010) argue that CLR can control itself autonomously when the agroecosystem is biodiverse enough, and therefore encourage more shaded, biodiverse farms rather than use of chemicals or other management practices. Others such as Avelino et al. (2004, 2015), and Staver et al. (2001) emphasize the importance of the type of management and manipulation of agroecosystems. While the debates go on, it remains clear that CLR can spread through both types of agroecosystems, given optimal conditions and the complexity of interactions between factors.

2.6. Current recommendations for prevention and treatment

Coffee leaf rust is a constant presence at low levels in any given coffee growing region of the world. Thus, the main objective for producers should be to minimize disease severity and to prevent the potential for epidemic development, which can be rapid under favorable temperature and wetness conditions (Waller et al., 2007). The most commonly used preventative measures for CLR are fungicides, resistant germplasm, cultural practices, and biological control.

2.6.1. Resistant varieties

Resistant varieties have been developed by crossing Robusta species with susceptible Arabica species. In Colombia, the most commonly grown resistant varieties are the Castillo and Colombia Supremo (Gaitán et al., 2015). While resistant varieties have largely proven to be effective as part of a rust management program (Waller et al., 1982), they are also time limited, temporary fixes, even if they can last many years. As Chapter 2 of this paper has highlighted, *H. vastatrix* is highly adaptable. There are hundreds of races of *H. vastatrix*, some of which are still undiscovered (Vossen, 2009). Disease resistant cultivars have created selection pressure[5] for pathogens that can overcome resistance and high capacity for fungal change have caused the breakdown of resistance in most of the commercially cultivated resistant varieties (Gaitán et al., 2015, p. 34). This was also observed in my field work conducted in Colombia, discussed in Chapter 4 of this paper. Finally, considering the extensive breeding experiments, field trials, and other time and cost considerations to develop a resistant variety, it may take years, or even decades, for improved resistant varieties to reach the market and then farmers.

The coffee community debates contentiously about the quality of resistant and susceptible varieties. Resistant hybrids are perceived as being lower in

[5] That is, if the same resistant coffee varieties are planted in a plot, the pathogen strain that can overcome that specific variety's resistance is selected with no other competition. Thus, breeding for quantitative resistance is recommended as the plant carries a variety of minor resistance genes, and creates durable resistance, which breeds for complex resistance (personal communication, Nelson, Nov. 2017).

organoleptic and aromatic qualities than the traditional, rust-susceptible Arabica varieties. Some countries like Costa Rica have completely banned the cultivation of resistant varieties to preserve quality (Vossen, 2009). Others, like Colombia, have developed national breeding programs and sponsored comprehensive renovations of coffee farms with resistant varieties. Independent taste trials organized by the Specialty Coffee Association of America have shown no major differences in cupping scores between the two (Sheridan, 2015).

As of the time of this writing, it is still unknown how much of a role genetics plays in determining coffee cup quality. A multitude of other factors along the value chain can affect quality: Cultivation practices, processing (de-shelling, drying, roasting), and proper storage can each impact the level of quality and thus the prices based on the cupping score.

Anectodal evidence gathered has shown that farmers received higher quality points for Caturra than they were currently receiving for their resistant varieties (discussed further in Chapter 4). Farmers must decide whether they can maintain a sufficient yield with susceptible varieties and get a higher premium for quality, or supplement the difference in quality with higher yield. This would have economic implications for farmers, who risk a lower price if coffee beans from their resistant cultivars cannot be sold in the specialty market where Fair Trade and other certification bodies have certain quality standards in place. Like wine, coffee has become a specialty commodity valued on terroir, growing practices, and associated organoleptic properties.

2.6.2. Fungicides

Waller (1982), Waller et al. (2007), and Gaitán et al. (2015) discuss the various preventative and treatment fungicide options available for CLR. Protective fungicides, such as copper-based products, will inhibit germination, and systemic fungicides have curative effects to stop infections from spreading throughout the plant. Copper fungicides (Table 2) are the most effective and the least costly, capable of guarding against a range of fungal pathogens and boosting plant productivity (Waller et al., 1982). As a natural element found in soils that bond to the ions, copper fungicides are unlikely to leach into groundwater unless they are applied very frequently at extremely excessive amounts (personal communication, Lauren, Ithaca, Nov. 2017). Bordeaux mixture (copper sulfate and calcium oxide mixed in water) stays on coffee leaves during the rainy season more consistently than other fungicides (Waller et al., 1982). Rainfall redistributes the fungicide throughout the canopy to other coffee plants. Tables 2 and 3 outline the different chemical treatments that can be used, the application rates for a typical manual sprayer often used by smallholders, and commentary related to trade-offs and impacts of each fungicide.

Table 2. Advantages and disadvantages of fixed copper sprays and bordeaux mixture. Source: University of California IPM (2010)

Characteristic	**Fixed coppers**	**Bordeaux mixture**
Ease of storage	Store dry	Store in stock solutions or dry
Effectiveness	Less effective, less persistent	Highly effective and long lasting
Environmental impact	Less active for less time, seldom stains	Longer lasting, more active, stains surfaces
Phytotoxicity	Safe for most plants and tender growth	High pH, leaves a salty deposit, more phytotoxic
Compatibility	Compatible with many pesticides	Not compatible with most pesticides
Ease of preparation	Easily prepared, less safety equipment	Takes longer, more knowledge to prepare, safety equipment required
Corrosiveness	Less corrosive spray mixture	Corrosive spray mixture

Table 3. Fungicides commonly recommended for CLR control. Source: adapted from Waller et al., 2007

Common name	Components	Application rate kg/ha
Contact fungicides		
Cuprous oxide	50-75% wettable powder Cu	2.4 - 3.8
Cupric hydroxide	50% Cu, wettable powder	3.8
Copper oxychloride	50% Cu, wettable powder	3.8
Fentin hydroxide	47.5%, wettable powder	2.75
Systemic fungicides	92.6% triadimefon	0.071 – 0.567
Bordeaux Mixture	50% Copper sulfate ($CuSO4$) + 50% slaked lime ($Ca(OH)_2$) diluted in 100L water	0.5 – 1L in 20L spray pump

2.6.3. Trade-offs and Considerations

Farm size and topography largely determine the efficacy of spraying chemicals. For instance, large coffee farms or plantations would likely be able to make the most efficient use of fungicides, as they are more likely to be located on flatter terrain than smaller, resource-poor farms, allowing for mechanized spraying. Additionally, Waller et al. (1982), Avelino et al. (2006), Bacon et al. (2010, 2014) cite how the increasing costs of agrochemicals relative to the usually low and volatile coffee prices has made it less economical for smallholders to sustainably use fungicides as a primary long-term strategy for CLR treatment (Waller et al., 2007).

Use of fungicides also requires sufficient knowledge and training to apply the fungicide most effectively. Spray frequency and the selection of appropriate fungicides are dependent on the variety of coffee planted (that is, whether it is resistant, partially resistant, or susceptible). Furthermore, the chemicals' interactions with elevation and weather must also be factored in to spray schedules and selection. For instance, coffee farms at lower elevations might need higher spray dosages at more frequent intervals than farms at higher elevations, given that lower elevation farms experience higher disease pressure (personal communication, Nelson, Ithaca, Nov. 2017). Thus, low levels of fungicide applied at a low altitude would be less effective at crop protection.

Another consideration is the safe use of fungicides and farmers' education levels and access to resources. Pesticides (including fungicides) are sold with labels that contain detailed instructions for proper use and safe handling.

Fungicides normally require large amounts of water to dilute for spraying. In developing countries with poor regulations and low literacy levels, farmers are unlikely to be able to follow written instructions, nor to have proper storage facilities and protective gear readily available for spraying (Ekström and Ekbom, 2011). Furthermore, poor farmers may interpret the toxicity level of a pesticide as being more effective than a lesser toxic chemical, as Segura et al. (2004) found in their interviews with Ugandan coffee farmers. There are serious health consequences from improper handling and exposure to these chemicals: Fentin hydroxide, for instance (Table 3), is an organotin compound that can cause central nervous system toxicity, photophobia and mental disturbances, epigastric pains, and a slew of other health problems after exposure (Kegley et al., 2016). Spraying should be rationalized for best economic and health outcomes.

Finally, climate change will also play an increasingly important factor in the effectiveness of fungicides, although currently, the specific mechanisms of change are unclear or still being explored. Associated changes in precipitation and temperature, and higher carbon dioxide in the atmosphere, can all affect the way fungicides interact with the plants, soil, and pathogenic organisms, leading to possible changes in application calendars and methods (Ghini et al., 2011).

2.6.4. Cultural Practices

Many of the variables that influence rust incidence and severity are out of farmers' control, such as altitude of the farm, temperature, precipitation patterns. Other environmental factors are within reach of the farmer. For instance, planting a variety of shade trees is a common cultural practice and can be beneficial for coffee plant growth and coffee bean quality (see Section 2.5 for the discussion on shade-grown coffee).

Farmers can use cultural practices as a preventative measure against CLR, mainly by ensuring the robustness of a coffee tree to maintain its self-defense against pests. Cultural practices can manipulate the growing environment to help protect coffee plants from rust, while also maximizing nutrient uptake, enhancing tree growth, suppressing weeds, and promoting beneficial species or natural enemies. CLR can cause considerable yield reductions in coffee if appropriate management strategies are not used. Some examples of cultural practices that can protect coffee plants against CLR include, but are not limited to, intercropping and/or polycropping; pruning and burning diseased plants; changing the density of coffee trees; planting cover crops and creating windbreaks.

If leguminous trees are planted with coffee plants in a polycrop, nutrient uptake can be enhanced with the leguminous tree leaf litter adding N or K to the soil upon leaf litter decomposition. Cultivating complementary crops also suppresses weed competition, and provides complementary use of sunlight, water, and nutrients by utilizing different root depth and plant heights. They can also attract natural enemies or beneficial insects, and potentially deter pests (Perfecto et al., 2005). For instance, banana trees provide shade, their leaf litter provides K, and their fruit attracts birds that serve as general natural enemies to protect the coffee crop from arthropod pests.

Removing and burning diseased parts of the coffee plant is a reliable prophylactic measure that was traditionally used before more sophisticated control methods were known (Muller et al., 2008). This can be done inter-seasonally between production cycles as a preventative measure to limit the replication of the pathogen. Alternatively, it can also be done during the cycle to prevent disease outbreak from developing into an epidemic (Muller et al., 2008). However, it may be more difficult to burn the diseased plant parts during the rainy seasons in coffee-growing regions.

In general, a healthy plant can defend itself better against attacks from pests. The availability of essential nutrients for the coffee tree are some of the main determinants of its robustness and health. Thus, a good nutrient balance can influence the coffee tree's self-defense or resistance against CLR (Gaitán et al., 2015). In Colombia, we saw plants with phosphorus (P) deficiency (Figure 3), an observation consistent with the volcanic soils found in that country, which have very little available P for plants (personal communication, Lauren, Ithaca, Nov. 2017). Plants require P in the form of phosphate for root growth, flower bud and fruit development (Van der Vossen, 2005; Gaitán et al., 2015). Avelino et al. (2006) found a positive association between rust incidence (R2, R3) and soils low in P but high in acidity, aluminum (Al) and iron (Fe) content on test plots (S1, S2, S4, S6) in Honduras over a three-year study (Figure 4). R1 indicates low rust incidence in their plots (S3) with moderately high acid soils, high magnesium (Mg), Zinc (Zn), manganese (Mn), and P.

Figure 3. Coffee plant with P deficiency. Source: Lee (2017)

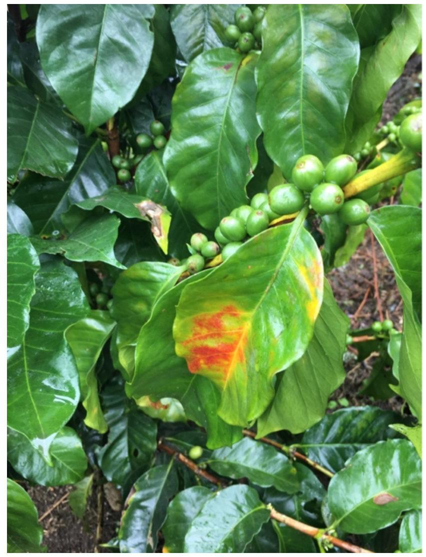
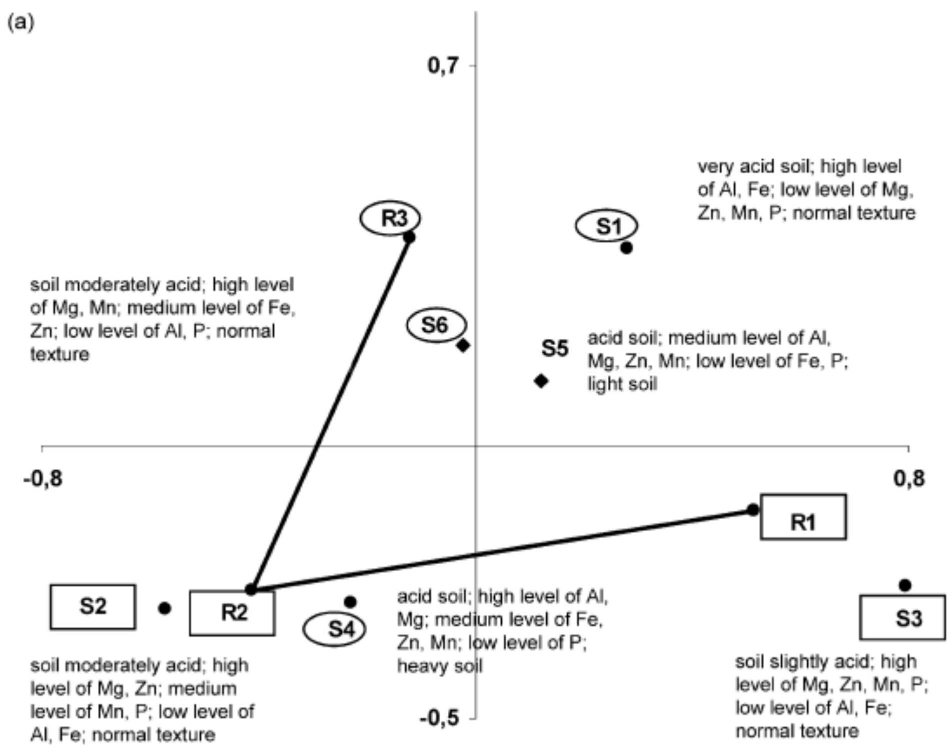


Figure 4. Rust incidence (R1, R2, R3, R4) and soil and altitude relation. Source: Avelino et al. (2006)



2.6.5. Impacts related to shading

There is a positive association between coffee tree fruit load, shading levels, and their effect on CLR incidence and severity, but causal factors are still unknown (Avelino et al. 2006). Additionally, low-productivity trees with a high number of leaves at the beginning of rainy season are also more susceptible to CLR as there are more leaves that can be infected by spores (Avelino et al. 2006). Pruning of coffee trees stimulates new growth, which stabilizes coffee berry production and extends the life of the tree (Catholic Relief Services, 2015). Pruning decreases the foliar surface area, thereby reducing the probability of the rust spores from landing on the coffee tree's leaves (Avelino et al., 2006). In a shade grown system, pruning of overhead shade trees will allow more sunlight to reach the coffee tree, which can hinder CLR development by providing a drier environment (Muller et al., 2008). Pruning should be regularly done in growing environments that are experiencing excessive humidity or darkness from shade (Muller et al., 2008). However, the increased productivity creates increased fruit bearing load on the coffee tree, which has been shown to increase the scope of incidence of CLR (Avelino et al., 2014; Muller et al., 2008).

2.6.6. Farmer capacity and knowledge gaps

Avelino et al. (2006, 2015) attribute much of the last CLR epidemic in Latin America to a combination of sub-optimal practices and optimal environmental conditions for CLR sporulation. Crop protection, while important, may not be a farmer's top priority in comparison to soil fertility, water availability, and other basic and important factors for growing a good crop (Segura et al., 2004), as well as family and social constraints. Plant disease management is particularly difficult for smallholder farmers (called campesinos in Latin America). For example, pathogens are not visible to the naked eye and require knowledge about the pathogenic life cycle to properly address a disease's spread (Nelson et al., 2001). Traditional campesino knowledge may not be strong in this area. Campesinos often call different pests (and sometimes beneficial insects) using the same colloquial terms, and therefore fail to differentiate between pests and their natural enemies (Bentley et al., 1994). Language may be a limitation if the local lexicon does not provide vocabulary to describe and differentiate pests that farmers observe. Disease management strategies must include behavior change campaigns that take into account social, geographic, and educational conditions and confines.

As such, "there is a need for novel coffee rust management systems which fully integrate crop management patterns in order to manage the disease in a sustainable way" (Avelino et al., 2004). It is necessary to incorporate farmers' perceptions, knowledge and practices into pest management extension and research of perennial crops. This has been lacking for tropical fruit crops and coffee in comparison to other types of crops, mainly annuals (Segura et al., 2004).

2.7. Integrated Pest Management and Farmer Field Schools

Integrated Pest Management (IPM) is an agricultural technology that first gained traction in the late 1960s and 1970s. It is derived from Integrated Pest Control, which first emerged at the University of California to combine chemical and biological control methods (Bajwa & Kogan, 1997). This was expanded upon at a symposium in 1966 by the United Nations (UN) Food and Agricultural Organization (FAO), where the concept was re-defined to become what is today known as IPM (Bajwa & Kogan, 1997).

There have been many definitions of IPM over the years. One of the most encompassing versions defines IPM as “a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society, and the environment” (Kogan, 1998 cited in Bajwa & Kogan, 2002). Thus, IPM is a sustainable agricultural approach using a combination of good cultural practices such as plant resistance, biological control, and chemical control, to manage weeds, insects, rodents, and diseases (Palis, 2005).

IPM empowers producers to make decisions based upon economic and environmentally sustainable thresholds for action, and so usually resorts to the use of low-toxicity pesticides as a last resort. IPM views the agroecosystem and the pest’s relation to it as interrelated, and aims to keep an equilibrium of the agroecosystem’s ecological checks and balances (Orr, 2003). Farmer decision-making based on their observations and understanding of various field parameters is key for successful implementation (Van den Berg & Jiggins, 2007).

2.7.1. IPM and coffee cultivation in Latin America

Historically, Latin America has not had a strong institutional culture of IPM implementation for several reasons. The region has typically had an underfunded research and development sector, spending less than 0.5% GDP on R&D as compared to 2.2% in developed countries (Rodriguez & Niemeyer, 2005). This has led to a lack of technical knowledge, and a shortage of IPM researchers. Furthermore, the Latin American public sector experienced severe debt crises and strict structural adjustment programs implemented in the 1980s that further undercut public sector programs (Rodriguez & Niemeyer, 2005). There is precedence for IPM in coffee cultivation, one of the biggest economic engines in Latin American countries. IPM has been effective in reducing damage to coffee trees and yields (Rodriguez & Niemeyer, 2005). The IPM for coffee cultivation in Latin America has mostly been applied to coffee berry borer and other arthropods, rather than CLR. Thus, I am exploring IPM's application for CLR.

At the local level, some practices encouraged by IPM packages have already been commonly done by farmers, such as intercropping and crop rotation (Rodriguez & Niemeyer, 2005). Chaves and Riley's (2001) study looked at the rate of adoption of four IPM recommendations for managing the coffee berry borer (CBB) in Colombia through extension services. They found links between education level, economic status, and choice of recommendation, with resource-poor farmers choosing recommendations that required lower technical skills and financial investment. Among all strata of farmers studied, the cultural practice of constantly harvesting mature berries of coffee and leaving only green berries on the tree was the most used IPM recommendation. In this case, it was easy to understand and provided control at all stages of CBB infestation and was cost effective. Success of the recommendations was not only dependent on the farmers, but also on their feasibility based on socio-economic resources.

Furthermore, Beer et al. (1997) found that shade tree selection and management are important tools for IPM. Shade, as discussed in section 2.5.1, has differential effects. This is particularly the case with CBB and CLR, two of the most economically important coffee pests. Decreasing shade in a high humidity environment can be beneficial for deterring CLR, but may increase CBB infestations (Atallah et al., 2017). IPM's use of critical decision-making and cost-benefit analysis can help farmers adapt to these types of situations where there are various trade-offs dependent on local conditions.

2.7.2. Farmer Field Schools

IPM saw widespread dissemination and adoption among rice farmers in Asia after the initial wave of the Green Revolution (Orr, 2003; Palis, 2005). The main educational approach used to disseminate IPM was the Farmer Field School (FFS), a hands-on, participatory and intensive educational program pioneered by the FAO's Inter-Country Program on Rice IPM in South and Southeast Asia (Nelson et al., 2001). This method was first implemented among rice farmers in Indonesia in 1989-1990 and has successfully trained millions of Asian rice farmers since its inception (UN FAO, 2016).

The FFS approach to learning "gives small farmers practical experience in ecology and agro-ecosystem analysis, providing the tools they need to practice IPM in their own fields" (Pontius et al., 2002). It emphasizes experiential learning through field discovery exercises (Nelson et al., 2001). Farmers are encouraged to make evidence-based crop management decisions according to their values and local conditions (Van den Berg & Jiggins, 2007).

The typical FFS process involves about 20-25 farmers in the same community or surrounding cluster of communities, attending half-day weekly sessions during the entire length of a cropping season, with training taking place in the field with a trained facilitator (Nelson et al., 2001; UN FAO 2016). Facilitators are generally local farmers who are nominated by peers to receive training as a 'lead farmer' of the FFS. Through self-discovery exercises, group work, experimentation, and facilitated discussion, farmers observe and analyze their agroecosystem and compare IPM practices with conventional practices in another field.

Some criticisms of FFS include feasibility of scaling up, cost-effectiveness of programs, and selection bias towards farmers who are more motivated to participate or towards locations with more favorable growing conditions (Berg & Jiggins, 2007). Impact of the programs have been debated but there is no consensus on a conceptual framework for FFS impact assessments, and the range of study parameters does not make it easy to assess (Godtland et al., 2004; Tripp et al., 2005). There are usually post-FFS initiatives resulting from follow-up donor-related activities, but it is unclear how many community initiatives have resulted directly from skills learned in FFS (Tripp et al., 2005). Furthermore, the up-front costs of implementing FFS must be considered in conjunction with short- and long-term impacts of FFS (Table 4), but these impacts are not easily quantified for measuring causal effects.

Table 4. Intermediate and developmental (i.e., long-term) impacts of IPM FFS by domain. Source: Van den Berg & Jiggins (2007)

Domain	Immediate impact	Developmental impact
Technical	Knowledge about ecology	More sustainable production
	Experimentation skills	Improved livelihoods
	Improved crop management	Ability to deal with risks, opportunities
	Pesticide reduction	Innovation
	Yield increase	More cost-effective production
	Profit increase	Reduced public health risks
	Risk reduction	Improved biodiversity
	Reduced water contamination	Improved marketability of produce
	Reduced pesticide poisoning	Poverty reduction
Social	Group building	Collaboration between farmers
	Communication skills	Farmer associations
	Problem solving skills	Community agenda setting
		Farmer study groups
		Formation of networks
		Farmer-to-farmer extension
		Area-wide action
Political	Farmer-extension linkage	Stronger access to service providers
	Negotiating skills	Improved leverage position
	Educational skills	Awareness campaigns
		Protests
		Policy change

2.7.3. Community-based IPM

There are various definitions and conceptualizations of community-based IPM in the literature. Some definitions refer to the 'community' portion of IPM as the principles and concepts of IPM broadened to pest management in non-agricultural settings, such as schools or neighborhoods (Cornell Cooperative Extension, 1999). This definition is more common in the Global North and in urban settings. Another use of the terminology is in the context of the Global South, to describe participatory processes of IPM dissemination at the village level (Dreves, 1996). And still others, such as the FAO (2002, 2016), use "community IPM" to refer to the creation of community organizations as a result of IPM Farmer Field Schools. This examination of community IPM for CLR falls more in line with the latter two uses, in the context of working with smallholder coffee farmers in Colombia.

Community IPM (C-IPM) can develop from IPM FFS as a continuation of the action framework used in FFS. C-IPM institutionalizes IPM at the local level, as FFS alumni continue with follow-up activities to build skills, to organize groups, and to plan and implement their own IPM programs (FAO, 2002). Additionally, the critical analysis and group collaboration skills developed during FFS can have broader impacts on community issues concerning public health, poverty alleviation, and sustainable livelihoods improvement (Van den Berg & Jiggins, 2007).

Immediate post-FFS activities may be dependent on external funding, but over time, FFS alumni may form self-sufficient FFS to continue training other community members (FAO, 2002). In Tripp et al.'s (2005) case study in Sri Lanka, seven out of eight FFS ceased to function after the end of the FFS program, except one that had support from an extension program for seed production.

Tripp et al. (2005) suggest, however, that there may be more potential for FFS follow-up actions, such as community IPM, if there are already-established farmer or community groups to host FFS activities on a consistent basis. They also point to the success of Local Agricultural Research Committees (CIALs from the Spanish *Comités de Investigación Agricolas Locales*) in Latin America. CIALs are complementary to FFS, as CIALs develop small, farmer-based research groups for on-farm experimentation programs based on their research priorities, in collaboration with extension agents and researchers. The CIAL experience has shown that farmer experimentation and adoption of recommended practices can take several seasons (whereas FFS typically only lasts for one season, and therefore may not be long enough in scope to cover certain practices). Ultimately, however, the success of community IPM will be highly dependent on each community's dynamics, and on the local and regional resources available to farmers (Temmer, 2010).

2.7.4. Historical context to consider for C-IPM in Colombia

Historically throughout Latin America, smallholder farmers have experienced oppression due to class and ethnic discrimination. The indigenous population in Central America and the Andes countries of South America, and those of indigenous and African descent in Colombia and Brazil, were dispossessed of their traditionally farmed lands and have been subject to genocide by home country governments. This oppression reached high levels during the Cold War, when right-wing governments tended to associate campesinos as sympathetic with leftist guerrillas. They often used the countryside to hide from military forces, but were not necessarily aided by the campesinos. The original Campesino-a-Campesino (farmer-to-farmer extension) group in Guatemala consisted of indigenous farmers who were violently repressed by government and paramilitary forces supporting large plantation owners whose economic interests were threatened by the campesinos (Holt-Gimenez, 2006). In my research site of Cauca, indigenous and Afro-Colombians experienced similar repression and displacement during the internal conflict that lasted from the 1950s to 2016. This very recent history is an important consideration for any rural program in Latin America, but especially for programs working with campesinos, who may be reasonably wary of community outsiders. Thus, it is necessary to initiate C-IPM endogenously from within a community, with limited outside involvement.

CHAPTER 3. METHODS

3.1. Site Background: Colombia

Colombia's natural topography and location near the equator makes it ideal for Arabica coffee cultivation, the country's most important agricultural commodity (Chaves and Riley, 2001; Gilbert and Gomez, 2016). The Andes mountain range runs along the western half of the country (see Figure 5), creating a cool climate and highlands favorable for coffee production. With such favorable cultivation conditions, coffee has integrated itself into the Colombian countryside as a driver of the rural economy. More than 500,000 families rely on coffee farming as their primary livelihood, with approximately 869,000ha devoted to Arabica cultivation (Chaves and Riley, 2001).

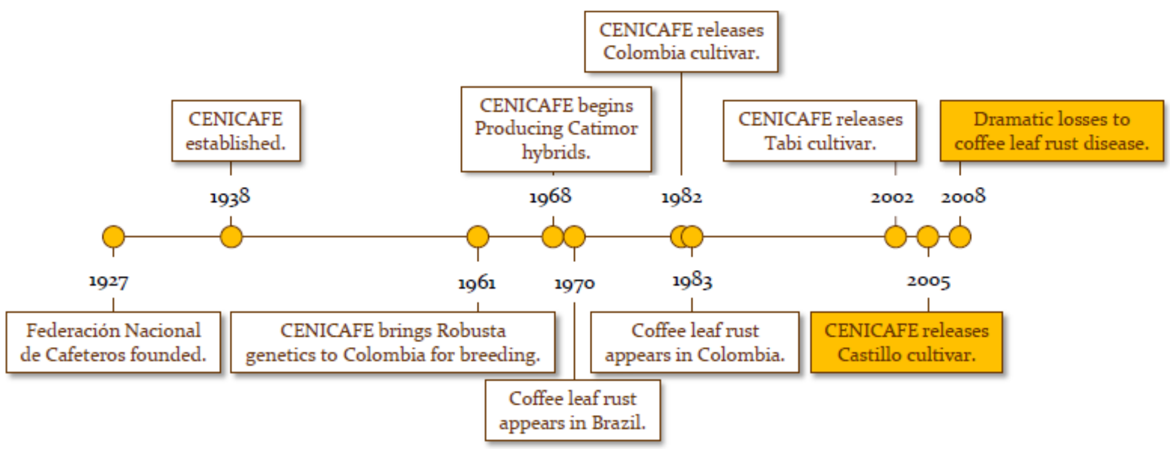
Colombia's population is comprised of three main ethnic groups: mestizo (mixed indigenous and European heritage), indigenous peoples, and Afro-Colombians. The latter two groups have been disproportionately affected by the internal conflict between government forces, paramilitary groups, and guerrilla fighters, with high levels of internal displacement (CIA World Factbook, 2017). From 1985 to 2017, there have been approximately 7.6 million Colombians who were internally displaced due to the conflict, even after the peace treaty between the government and the Revolutionary Armed Forces of Colombia (FARC), as other rebel groups have continued fighting (CIA World Factbook, 2017).

Figure 5. Topographic map of Colombia. Source: De Pinto et al. (2016)

In examining the different scales at which CLR management occurs, Colombia involves both high level institutions and smallholder farmers. The National Federation of Coffee Growers of Colombia (FNC) is a powerful lobby and represents millions of coffee growers, most of whom are smallholders. It guarantees a minimum price to farmers, regulates domestic prices, and quality control for commodity-grade coffee exports (Gilbert & Gomez, 2016).

FNC enacted a national replanting program in reaction to the CLR epidemic. FNC offered low interest loans exclusively for replanting farms with the Castillo resistant variety, which left less flexibility for growers to plant other varieties (Gilbert & Gomez, 2016). The Colombian government also provided financial aid for farmers through its Rural Funding Incentive program which provides low-interest loans to farmers of any agricultural commodity (Gilbert & Gomez, 2016). Thus, at the national scale, the government, FNC and its national research branch CENICAFE, have promoted research and development of rust resistant cultivars as the primary approach to addressing CLR outbreaks in Colombia (Figure 6). Castillo was released in 2005, but the renovation program was instituted during or after the 2008 epidemic, by which time, most farmers had lost their harvests. Thus, this timeline implies that Castillo was not widely available before 2008.

Figure 6. Timeline of CENICAFE resistant cultivars and CLR outbreaks. Source: Coffeelands Program Blog, Catholic Relief Services (2013).



3.2. Department of Cauca

The department of Cauca is in the southwest of Colombia in the Andes region (Figure 5) and covers an area of almost 30,000 km^2, most of which is mountainous (Colombia-SA, 2017). The department's population is mainly indigenous and Afro-Colombian (Federacíon Campesina del Cauca, 2017). Cauca has been hard hit by the five decades-long internal conflict between anti-government, government, and paramilitary forces in Colombia, causing high levels of internal displacement in the department (Martinez, 2015).

Cauca's capital city is Popayán. The FCC headquarters are located in Popayán, which served as the base site during this project while visiting communities in the surrounding municipalities of Piendamó, Rosas, Morales, and Cajibío.

Cauca has a subtropical highland climate with significant rainfall during most parts of the year and a dry season from June to August (Instituto de Hidrologia, Meteorologia y Estudios Ambientales, 1999). The soils in the region are mainly composed of Andisols, which contain high levels of organic matter, but are low in phosphorus, and are volcanic in origin (Bosco et al., 2017). The region is mountainous with a high level of precipitation, therefore making the soils prone to water erosion (Instituto de Hidrologia, Meteorologia y Estudios Ambientales, 1999).

3.3. Federación Campesina del Cauca (FCC)

The Federación Campesina del Cauca (FCC) is an association of coffee growers operating as a private agricultural business. The FCC was founded in 1971 by community organizers who sought to improve land rights and livelihoods for the region's smallholders (campesinos). The FCC has increasingly focused on value addition and product differentiation for their coffee exports. They have been Fair Trade certified and partnered with

Sustainable Harvest since 2004 to reach specialty coffee markets in the United States and Europe. The FCC is currently focusing more on the promotion of organic coffee production amongst its famers and moving into the organic niche market. The FCC supports farmers by producing and selling affordable agricultural inputs including compost-based fertilizers and organic pesticides, conducting chromatography-based soil organic matter tests, taste-testing and quality scoring of coffee, roasting and bagging coffee for export, and providing technical guidance. The FCC provides members access to the specialty coffee market by supporting the costs of Fairtrade (FLO) certification and organic certification.

There are over 700 FCC members spread out across six municipalities within Cauca. Each of these municipalities has a local association of coffee growers that serve as affiliate member organizations under the FCC umbrella. FCC executive board membership consists of a representative from each local coffee association and FCC leaders.

The FCC receives premiums for organic production and Fair Trade. At least 25% of the Fairtrade premiums are transferred back directly to the farmer for quality, which is based on a coffee cupping score of 85 or above. The FCC utilizes the rest of the premiums to pay for microcredit loans to members, technical trainings, inputs such as fertilizer, and services like funerals and healthcare, categorized as indirect revenues or benefits for the farmers. A study by Cerna et al. (2016) quantified some of the indirect revenues: FCC members received an average of 232,450 Colombian pesos (COP) ($77.41 USD) per person in organic fertilizers from the cooperative, and 231,120 COP ($76.96 USD) in training/extension services per person over the period of a 9-year business timeline, from tree establishment to productive (fruit-bearing) years.

Cornell University faculty and students have partnered with the FCC since 2015 on consultation projects every winter. Cornell University's Student Multidisciplinary Applied Research Team (SMART) program in the Cornell International Institute for Food, Agriculture, and Development (CIIFAD)[6] was the main research and consultation vehicle of partnership. The past research teams in 2015 and 2016 provided pro-bono short-term consultations to the FCC on organizational analysis, chemical and physical soil analysis, and cost-benefit analysis for a benchmark smallholder producer in the region. The 2017 team, of which I was a member, developed a soil health testing kit using soil pH and Active Carbon levels as the main parameters, and conducted interviews with farmers on the factors influencing their decisions regarding production in organic or conventional farming.

3.4. Local coffee grower associations within FCC

At the local level, the local grower associations play a large part in dissemination of information and advice from the FCC. They promote sustainable agriculture practices such as composting of coffee cherry pulp, waste management, and planting of shade trees, especially banana and Inga

[6] This was part of the International Programs office in the College of Agriculture and Life Sciences, but has been dissolved since this research project took place. The SMART program is now housed in the Emerging Markets section in the Dyson School.

trees[7]. These were spread throughout the communities through workshops and field visits from FCC technical advisors with leaders of the local coffee associations helping with implementation.

The following associations were selected for site visits in communities within the municipalities of Morales, Rosas, Piendamo, and Popayán. Table 5 shows the average biophysical characteristics and average cupping scores for each municipality and association.

Table 2. Biophysical characteristics and average cupping scores. Source: FCC (2017)

Municipality	Altitude (elevation above sea level in meters)	Mean Temp °C	Mean Annual Precipitation (mml)	Mean cup score (out of 100 points)
Morales	1635	25.5	2150	84.5
Rosas	1758	18.0	1900	87.0
Popayán	1520	22.0	1950	84.5
Piendamo	1685	18.0	1990	87.0

3.5. Data collection

This study used a combination of primary and secondary data. Primary sources were gathered during exploratory fieldwork in Colombia, detailed in the next section. Secondary sources of data were gathered using Cornell University databases to assess studies on current existing practices and knowledge of CLR, coffee farming, Integrated Pest Management, and related topics.

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[7] Leaf litter from banana and Inga trees can provide potassium and nitrogen, respectively, increasing plant-available nutrients upon decomposition for coffee trees and other crops.

3.5.1. Semi-structured interviews and coffee leaf rust questionnaire

The fieldwork component of this study was conducted in January 2017 for two weeks in Cauca, in conjunction with the SMART research team comparing farm management practices and soil health on organic versus conventional farms. The Federación Campesina del Cauca provided a demonstration of their cupping and scoring process in their laboratory and arranged guided visits to 16 coffee farms in the surrounding area, from which 14 interviews about coffee leaf rust were conducted with coffee farmers. Two of the farmers' answers were not usable for the rust sample, thus there were 14 instead of 16 farmers in the rust study group.

There were 20 interview questions and an interview guide with semi-structured questions. Questions were both quantitative - about input prices, yields, and other variables - as well as qualitative, open-ended questions about conditions that led up to their biggest rust outbreak and current conditions. All interviews took place in Spanish.

The farms in the sample were less than two hectares, and one was 6.6 hectares. All farmers interviewed were members of their local coffee producer associations. Some of the respondents were on the executive board of their local associations.

Farm visits began with a board member of the local association showing us their farm, where interviews also took place. Then the first farmer would take us to visit other households in their community for interviews. Additionally, I conducted unstructured informal interviews with the FCC's quality cupper and compost facility manager who accompanied the research team on farm visits. FCC technical advisers were on field visits to other sites and were unavailable for interviews during the time of the data collection. All respondents were informed of the types of questions that would be asked and were given the option of not participating at any point.

Of those interviewed about coffee leaf rust, there were six organic farms, three transitioning from conventional to organic, and five conventional farms. These farms were selected to help represent the different types of production in the area, but were more so for the SMART research into organic versus conventional coffee cultivation. For the research on CLR, the production type (organic/conventional) does not seem to be as pertinent of a factor as the density of shading used in production, based on studies evaluated during the literature review. Therefore, organic and conventional production were not analyzed for this study. Nevertheless, differences related to those production types, and factors that could correlate to rust incidence or severity are considered generally throughout.

3.5.2. Direct Observation

The following biophysical parameters at the farm level were observed and assessed: Amount of shade, intensity of slope, CLR incidence per farm plot, and severity of outbreak (termed as localized severity). Scores were assigned based on my observations, and thus, subjectively determined. Systematic sampling and assessment of these indicators would have been more appropriate, but was not carried out due to lack of time in the field.

For shade density, a score of 1 represented a full sun situation and a score of 5 represented a completely closed canopy, scores of 2, 3, and 4 represented farms with some, moderate, and heavy shade, respectively. For slope, a 1- 4 scale was used to show slopes from mild to steep. Score of 1 represents a flat surface; score of 2 was assigned to a medium-grade slope (20°-40°); score of 3 was for high slopes (40°-60°), and score of 4 was for a 'very high' slope (greater than 60°). Finally, localized CLR severity was observed and given a score on each farm. A score ranging from 1-1.9 was categorized as 'low severity' with only one branch of a coffee tree showing symptoms of coffee leaf rust; scores of 2-2.9 were 'medium severity' with about 50% of a tree being visibly infected; a score range of 3-3.9 was 'high severity' with the tree being nearly or completely defoliated, or rust spores being highly visible on most of the tree.

3.5.3. Biophysical Samples

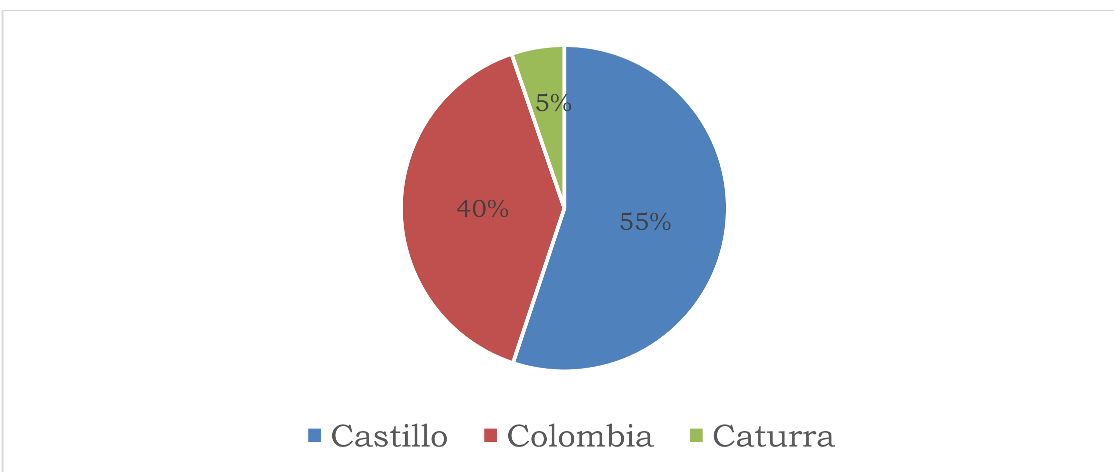
Tropical soils generally tend to be acidic, and the level of acidity in soils affects the nutrient availability and uptake for plants. Thus, soil pH was measured using a Low Range (4.0-6.2) Cornell pH Test Kit. Soil samples were collected from the top, middle, and bottom parts of each farm. On-farm pH samples were tested in the presence of the farmer so they could see the results immediately and directly. The pH tests were later replicated on air dried samples at the FCC laboratory. All farms, regardless of production type, fell within the recommended pH range for coffee production (Wellman, 1961).

CHAPTER 4. RESULTS AND DISCUSSION

4.1. Coffee varieties at time of field visits

All farms visited in early 2017 had either fully or partially replaced Caturra susceptible varieties with rust resistant varieties (Castillo, Colombia Supremo). The majority of varieties planted were Castillo, followed by Colombia and a small fraction of Caturra (Figure 7; Table 6). All farmers surveyed planted some fraction of Castillo, but 93% of respondents expressed dissatisfaction with Castillo's cupping quality and general robustness against CLR. On the other hand, 79% of respondents planted the Colombia variety (Table 6), and all respondents had favorable opinions about the cupping quality (Table 5) and ease of cultivation with the Colombia variety.

Figure 7. Coffee varieties planted across all sampled farms



Forty-three percent of respondents still had Caturra on their farms. Some Caturra varieties were too negligible to be counted, usually left over from the farm renovations to resistant varieties. Other farms continued cultivation of Caturra, such as Farm 2, which had the largest amount (20%). All respondents, even those who had fully replaced Caturra, communicated their perceptions that Caturra was the better coffee cultivar to grow in terms of cupping quality (and thus, receiving quality premiums).

Table 6. Coffee trees – total number of coffee trees and distribution by variety per farm. R = resistant variety; S = susceptible variety

	Total # coffee trees	Avg # trees per ha	# Castillo-R	% Castillo-R	# Colombia-R	% Colombia-R	# Caturra-S	% Caturra-S
Farm 1	4,000	2,000	2,000	50.0	2,000	50.0	0	0
Farm 2	7,700	3,850	2,100	27.2	3,500	45.0	2,100	27.0
Farm 3	11,000	4,400	11,000	100.0	0	0	0	0
Farm 4	6,000	3,000	3,000	50.0	3,000	50.0	0	0
Farm 5	4,000	4,000	2,000	50.0	2,000	50.0	0	0
Farm 6	4,000	2,667	0	0	4,000	100	negligible	--
Farm 7	2,300	2,300	2,000	87.0	300	13.0	negligible	--
Farm 8	5,000	5,000	4,000	80.0	0	0	1,000	20.0
Farm 9	12,000	4,000	6,000	50.0	6,000	50.0	0	0
Farm 10	2,800	1,400	800	28.6	2,000	71.4	0	0
Farm 11	4,650	1,550	850	18.3	2,950	63.4	850	18.0
Farm 12	2,300	1,725	500	21.7	1,800	78.2	0	0
Farm 13	5,020	2,500	2,500	49.8	2,500	49.8	20	0.004
Farm 14	5,000	5,000	5,000	100	0	0	0	0

The respondents spoke about Caturra almost nostalgically. This indicated a sense of attachment that went beyond economic calculations of cost-benefits. It also means that a farmer's decision to grow a specific cultivar is based on personal preference, cultural or family ties to a certain variety or growing practices, such as organic methods. These factors may present possible barriers to adoption of resistant varieties, and tell us that such factors must be considered for community-based Integrated Pest Management programs for CLR to work and influence adoption of certain CLR preventative technologies and practices.

Due to the large-scale renovations across all the farms, the coffee trees during the time of the field visits were relatively young, with an average age of 11 years (Table 7). Most of the rust-resistant, high-yielding varieties have a shorter productive lifespan of about 10 years, while traditional varieties like Caturra have been known to have 20-30 years of production (McCook 2017). Rust (*roya*) usually impacts mature coffee trees that are in the production stage of their life cycle. In the epidemic period of this study, however, roya hit trees of all ages (Table 7), from nursery seedlings to very mature trees. The wide distribution of infection across all ages of trees is indicative of the enabling environmental and management conditions that exacerbated an outbreak into an epidemic, regardless of tree age.

Table 7. Ages of coffee trees: current and during epidemic years

Age of coffee trees in years		
	Current (All)	Epidemic years (Caturra)
mean	11	12
median	4.5	10
max	12	25
min	<1	5

4.2. Agro-ecological context of the study area: Biophysical characteristics of farms (Soil pH and farm slope)

The soil pH on all farms in the sample showed little variation for pH levels (Table 8). The soil samples confirmed standard pH levels for tropical soils and fell within the pH range for coffee, which is between 4.5 and 7 (Wellman, 1961). Average pH was 5.6 (Table 8). About 36% of respondents indicated during interviews that they applied lime to their soils to manage acidity. With pH falling in the normal range, it does not appear to be one of the limiting factors to nutrient absorption nor one of the enabling factors of CLR susceptibility.

Table 8. Soil pH by position on farm slope

Farm	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Mean**
Top	5.4	5.6	5.4	5.2	5.8	6.2	5.9	5.2	5.8	6.0	5.4	5.8	6	5.4	**5.7**
Middle	5.4	5.0	6.0	5.4	6.2	5.4	5.8	5.6	5.8	5.8	5.2	5.8	5.9	5.6	**5.6**
Bottom	5.0	5.6	5.2	5.8	5.4	5.6	6.0	5.8	5.4	5.9	5.8	5.8	5.6	5.8	**5.6**
Mean	**5.3**	**5.4**	**5.5**	**5.5**	**5.8**	**5.7**	**5.9**	**5.5**	**5.7**	**5.9**	**5.5**	**5.8**	**5.8**	**5.6**	**5.6**
Std dev	**0.23**	**0.35**	**0.42**	**0.31**	**0.40**	**0.42**	**0.10**	**0.31**	**0.23**	**0.10**	**0.31**	**0.00**	**0.21**	**0.20**	**0.01**

Approximately 44% of farms in the sample were on medium-grade slopes (Table 9), classified as a score of 2 (20°-40° slope). The steepness of a farm's slope can affect various factors related to production costs and microclimate such as labor, inputs, air flow, water flow and humidity levels – all of which influence CLR incidence and severity. The farms on medium and low slopes tended to be organic farms, while the farms on high and very steep slopes fell into the conventional production category. It was easier for the farms on the low and medium grade slopes to transition to organic production (which tends to be more labor intensive) because there were lower labor costs and fewer resources required than on farms with steep slopes. This has implications for other kinds of technology adoption, such as community-based IPM for coffee leaf rust. A community-based approach would need to consider the different production factors and limitations that could influence farmer adoption of rust prevention technologies and practices.

Table 9. Percent of farms categorized by slope steepness gradient.

Slope	% farms
Low (1 = 0°-20°)	21%
Medium (2 = 20°-40°)	44%
High (3 = 40°-60°)	21%
Very high (4 = 60°-80°)	14%

4.3. The role of shade and CLR

Shade is one of the most influential and controversial considerations for coffee leaf rust management (see Ch. 2, section 6.5). Each farm was assigned a score based on density of shading (Table 10). There were 36% of farms in the sample with a score of 4, which was the second highest density score (Table 10). The majority of farms (86%) had shade scores of 3 or higher (Table 10), representing moderate to very dense levels of shading in the upper canopy.

Shade grown coffee was actively promoted and encouraged by the FCC, which corresponds with the high percentage of farms practicing dense shading.

The most commonly planted shade trees were banana trees, and Inga, a leguminous tree species. Farmers also planted maize and other food crops at middle and lower levels of the canopy. Another commonly observed method of shading was the practice of dense spacing between each coffee tree. This resulted in coffee trees being self-shaded because sunlight could not easily penetrate through the dense layers of branches.

Table 10. Shade density scores and scoring system key for the farms.

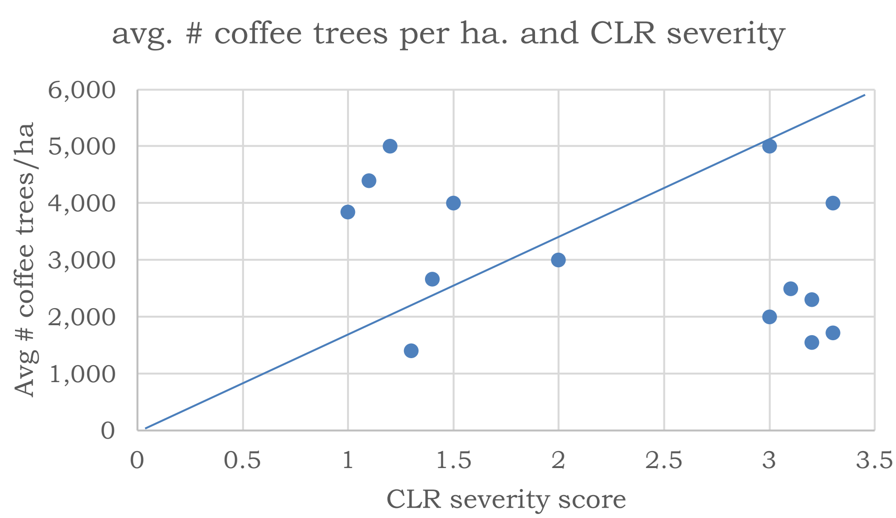
Shade density scores		
Score	**# farms**	**%**
1	1	7
2	1	7
3	4	29
4	5	36
5	3	21
Total	14	100

Scores- 0 = plots in full sun; 1 = low amount of shade from upper canopy, and low density of self-shading from coffee; 2 = low medium shade, two to three shade species, dense shade patches; 3 = moderate shade, four species, dense coffee plantings providing self-shading, and patches of sun; 4 = high shade, five species, some sunlight but high density of cover canopy in most plots; 5 = very dense shade, five or more species, little to no sunlight penetration in most plots

This dense plant spacing and shading practice could be more conducive to a larger, more severe outbreak (perhaps even epidemic) of CLR than just a localized outbreak. Dense spacing retains more moisture on leaves, which is conducive to spore germination (Pereira, 1995). Infected trees are also likely to touch and contaminate other coffee trees in a densely spaced row, with no other non-coffee trees in between serving to block rust spores.

Nevertheless, upon examination of planting density of coffee trees per hectare and localized CLR severity, no correlation was found, although clusters do appear in the sample (Figure 8). Farms with CLR severity scores of 3 to 3.5 were clustered in the same community in Piendamo, tended to not practice intercropping at consistent intervals, and were mostly organic farms that did not use copper or other fungicides. The farms in Morales had higher numbers of coffee trees planted per hectare but lower CLR severity scores. These farms intercropped coffee at more consistent intervals with maize and/or banana trees, and were mostly conventional farms. With the small sample size, however, it cannot be determined whether there are significant correlations between planting density of coffee trees and CLR severity.

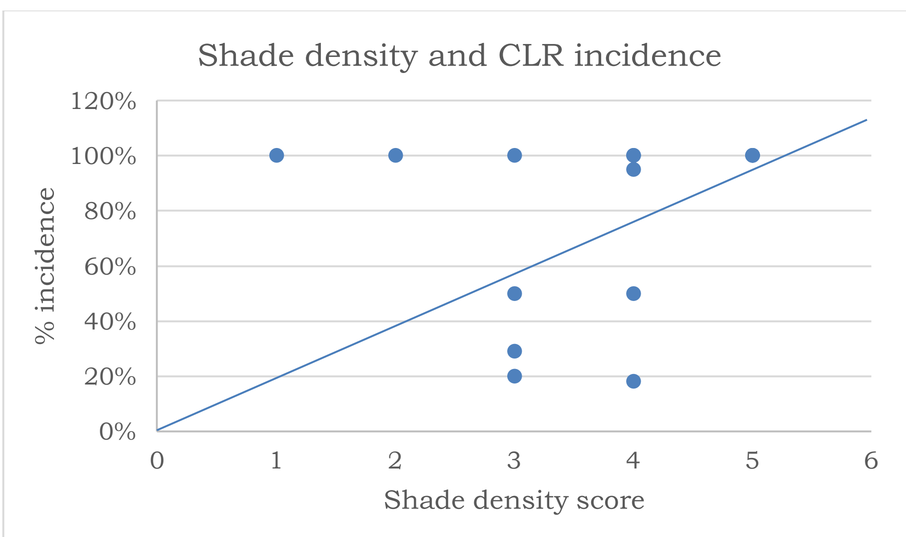
Figure 8. Coffee tree density per hectare and CLR severity



Additionally, there are a multitude of variables (see Sections 2.4 and 2.5) between the communities, and the individual farms, that could have influenced CLR severity, so it cannot be solely attributed to density of coffee trees without further examination.

Was there a correlation between farms having higher shade density scores and the number of plots showing signs of rust? Not necessarily, as Figure 9 indicates. While most of farms in the sample had moderate to high densities of shade canopy cover, there was no correlation between their density scores and the percentage of plots exhibiting rust symptoms. Farm 4 with a low shade density score of one, still had rust present in all plots, while Farm 11 with a higher shade density score of four only had rust present in two out of eleven plots. This indicates that rust cannot be attributed to shade alone given the other variables present, e.g. organic or conventional production, slope gradients, weather.

Figure 9. Shade density scores and CLR incidence. Line represents 1:1 relationship.



4.4. Recollections about the epidemic (Pre-resistant varieties)

All respondents remembered acutely the significant losses in harvest and income incurred by the CLR epidemic. Respondents estimated crop losses ranging from 30% to 100%. Cerna et al.'s survey (2016) reports an average reduction of 69% in their surveys of FCC farmers. To make up for the loss of income, producers resorted to either one or a combination of loans, wage labor, or savings (Cerna et al., 2016). Some of the respondents in this sample indicated this as well: Farmer 10 explained how he had to work on other farms as an agricultural laborer and work off-farm jobs to replace his lost income during the epidemic. The farmers interviewed had established economic coping mechanisms that buffered the lean season caused by the epidemic. Many of the farmers had alternative incomes, either in small non-farm businesses, or in the form of remittances from children living in cities, or from selling other crops in addition to coffee. Due to the coffee price crisis in the early 2000s (See Ch. 1, Footnote 2), farmers may have diversified their income sources more than previously, and thus were less vulnerable.

It was also clear from their responses that most of the farmers interviewed were unprepared for the CLR epidemic when it occurred.

Excerpt from interview with Farmer 9, Rosas association:

> *Respondent: "La roya came on very strong and very quickly that year."*
>
> *Interviewer: "Why do you think the outbreak of la roya was so strong? What methods or practices did you use to control la roya?"*
>
> *Respondent: "I didn't fertilize my plants properly. And the weather was very warm, so the disease took hold faster and more severely."*

> *Interviewer: "Can you explain why you did not fertilize the plants?"*
>
> *Respondent: "I just didn't."*

Excerpt from interview in Piendamo with Farmer 4, who lost an estimated 60% of his coffee harvest to CLR during the epidemic:

> *"I didn't think it [la roya] would do too much damage, so I left it alone. By the time we noticed la roya had spread across the farm, it was too late."*

Farmer 4 said that he used to apply fungicides, but found them to be less effective than proper plant health maintenance and fertilization, his current CLR control method. Furthermore, Farmer 4 had previously used a copper-based fungicide, which is preventative. The perceived or actual lack of effectiveness of the fungicide could be attributed to various factors – water dilution, improper application schedules, weather at time of spraying, and so on. Since it must be applied before CLR symptoms appear, it is usually less effective at curing the disease once lesions manifest. Most likely, this may be why the farmer found fungicides ineffective.

Respondents varied in their understanding about vectors of transmission and enabling factors of CLR. Nearly all the respondents conveyed their perception that hotter temperatures played an important enabling role in rust prevalence and severity, while only one respondent indicated that water was a major factor. There was awareness of human vectors as well. Farmer 4 indicated that rust was spread by workers during harvest going between plants and carrying spores on their clothes. However, in the epidemic, Farmer 4 said he suffered more losses pre-harvest, when there were less workers, indicating a natural spread by wind or rain. Although respondents indicated general awareness that certain conditions (such as high temperatures) were more enabling of a severe CLR outbreak, most did not talk about rain or wind acting as primary vectors. In fact, one farmer said he used to use fungicides but now felt he did not have to because "when it rains heavily, the water washes away the rust." Water, however, is one of the most important vectors for CLR.

Fertilizer applications were used preventatively against rust. Fertilizer application is commonly used by growers in Colombia as a pest management "treatment." It helps maintain resilience against pests and diseases, and protects yields even when an infection is imminent, by aiding plants' nutrient absorption. On the other hand, increased fertilizer applications could exacerbate CLR severity, since coffee plants are more susceptible to the disease after producing a high fruit-load (Avelino et al., 2006; see Chapter 2).

Respondents generally viewed shade as helpful in pest management and as an bringing other benefits like enhancing coffee bean quality. Farmer 4 echoed: "It lowers the temperature, which helps prevent la roya." Furthermore, Farmer 1 claimed: "Roya is worse on the sun-grown farms." Because those farms were not in the sample, this claim could not be corroborated. While it appeared that the trees in neighboring sun-grown farms that we passed through were visibly less healthy and defoliated from rust, other factors such as management and microclimate could not be assessed in their role of tree health.

4.5. Current Situation: Control and preventative practices

Proactive behavior for CLR prevention was lacking among respondents. When asked if and how often they monitored their plots for signs of rust, only

36% of respondents answered in the affirmative and reported monitoring their plots every 15-20 days (Table 11). This was usually performed when the farmers or their laborers went out to do maintenance or harvest coffee cherries. Out of the respondents that monitored their plots, only two actively followed up with phytosanitary burning or other disease control measures for small rust outbreaks. Others (65%) did not actively monitor their plots for rust. Fertilization and stumping (a practice of cutting trees down to a stump and letting it regrow for better growth) were the most common cultural practices (Table 11).

Table 11. Rust control measures used at time of field visits.

Types of control	**Cultural methods**	**Copper fungicides**	**Sulfocalcico (sulfur and lime)**	**Homemade formula**	**Resistant varieties**
Farm 1	Intercropping, Fertilization, hedgerows, pruning			*	*
Farm 2	Fertilization, stumping	*			*
Farm 3	Intercropping, stumping				*
Farm 4	Fertilization, intercrop, prune, stumping		*		*
Farm 5	Limited control			*	*
Farm 6	Monitor	*	*		*
Farm 7	Fertilization, thin spacing, monitor			*	*
Farm 8	Limited control			*	*
Farm 9	Monitor, prune, burn	*			*
Farm 10	Monitor, prune, stumping, burning		*		*
Farm 11	Prune, stumping	*	*		*
Farm 12	Limited control		*		*
Farm 13	Limited control		*		*
Farm 14	Fertilization, burning, monitor	*	*	*	*
Total (n)	10	5	7	4	14
%	71%	36%	50%	29%	100%

(Table 11 continued): Percentages based on total number of respondents (n=14). Total percentages reflect respondents counted for more than one measure. "Limited control" = only using resistant varieties and not employing other methods of concurrent control. Fungicides include copper-based contact fungicides and sulfocalcico. Homemade = remedies including soap and ash-based mixtures.

The FCC had promoted environmentally friendly, natural inputs for pest control. Thus, 50% of the farmers used *sulfocalcico*, or lime and sulfur, an organic product made in bulk by the FCC at their factory, as a general fungicide and pest deterrent. Farmers also made a homemade spray consisting of ashes and soap base. Copper fungicides were only used by 36% of the farmers interviewed and mainly by the conventional farmers (Table 11). Cultural practices were used to maintain general plant health, but not explicitly expressed by farmers as a main prevention/management method, with the exception of fertilizer use and removing and burning diseased parts of coffee trees. All farmers used resistant varieties.

Additionally, most farmers grew a mix of coffee varieties on their farms (see Figure 7 in Section 4.2). Plots were grouped either by tree age and/or by variety. Caturra that had not been uprooted during renovations were still mixed in with the newly planted resistant varieties on 36% of farms in the sample, sometimes planted in very close proximity. On approximately 30% of the farms, the only visible rust symptoms were on the remaining Caturra varieties. Furthermore, during field explorations, infected leaves with live spores were found among the leaf litter on 64% of farms sampled[8]. This would elevate the risk of storing inoculum in the live tissues of the leaves and potentially spreading rust to other coffee trees in the plot and the rest of the farm. Even though the other trees were resistant varieties, it was clear that they also had rust.

Yet the farmers did not express much concern in the interviews. As evidence of inoculum-containing coffee trees and leaf litter on all sampled farms showed, the risk of contamination was high. But, due to the systematic renovation of farms with resistant cultivars, many farmers expressed a sense of complacency or assurance that roya was not much of a threat, indicated by Farmer 3 in Morales:

> *"Because all the coffee trees in production are resistant varieties now, I don't have a roya problem."*

In fact, this farmer's trees did show signs of rust to some extent. Rust was observed on all farms in the sample, with approximately 50% of farms showing rust-infected Castillo and 25% of farms with rust-infected Colombia varieties. Figure 10 shows a Castillo coffee tree that has been severely defoliated from CLR on an organic, shaded farm that the FCC considered to be one of its most successful farms in terms of environmentally sustainable practices and yield. This farmer had replaced all of the Caturra varieties - half of his farm with Castillo and the other half with Colombia. At the time of the field visit, the plot

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[8] But given the small sample size, it is difficult to conclude how widespread this was among all farms in each community. And this was done by observation on walk-throughs of farms, but not systematically measured due to lack of time.

with Castillo had been infected with rust, although localized severity varied from mild to severe throughout the plot.

Although Caturra was a popular variety due to its high cup quality (and associated quality premium), it was very susceptible to pests, which was further exacerbated by suboptimal management practices. This, along with the subsidized campaign to promote high-yielding, resistant cultivars contributed to a large portion of Caturra being removed on most of the farms visited.

Figure 10. Castillo tree defoliated by coffee leaf rust. Source: Lee (2017).

In other countries like Costa Rica and Guatemala, Caturra and other susceptible varieties are still being grown at great risk to the farmers, who are depending on the high premiums of specialty coffee. Farmers must juggle trade-offs between coffee quality, higher prices for higher cupping scores, and the cost of maintenance and labor for susceptible varieties. They must also consider the initial cost of replanting and renovating a farm with resistant varieties, waiting for about five to eight years to reach maturity for berry production. Off-farm or other alternative income is essential during that time.

4.6. What roya problem?

What did farmers learn from the epidemic? Given that they lost so much to roya, it would be expected that the farmers would try to manage and contain an outbreak, no matter how small. There is not only the possibility of losing one's entire harvest in the present season due to roya, but also losing the productive capacity of all the trees in the following seasons, as the disease returns cyclically and weakens the host plant until it dies. Furthermore, because roya is usually present on coffee farms at low levels throughout the year, it is important to clarify that eradication (i.e., control) is not the goal, but management. Thus, disease management should emphasize prevention of the potential for CLR's logarthimic reproduction snowballing into an epidemic. The urgency to contain the disease at the outset of small outbreaks did not manifest among most respondents.

The interview responses suggest both ignorance about coffee leaf rust's dispersal mechanisms and good prevention practices (see Section 4.5). Approximately 14% of respondents said they had a threshold of waiting until 50% of the plants were infected to act, by which point, it would most likely be too late to save the coffee crop. There were a few exceptions in the sample, from two respondents in Rosas and Popayan. Farmers 10 and 11 answered that they would act immediately to remove and destroy infected plants in their plots because "it would spread quickly otherwise." Farmer 10 had adopted resistant varieties about five years earlier than the epidemic start year, and had one of the largest farms, indicating he perhaps had better financial resources, a higher education level, and access to information that gave him an advantage in dealing with the epidemic.

The interviews revealed that suboptimal practices were a major factor leading to the big outbreak of *la roya* in 2008-2014. This is consistent with the hypothesis by Avelino et al. (2015) that lower than usual prices of coffee disincentivized good plant management practices, like regular fertilization applications and pruning, which would require more labor costs and input purchases. When prices are too low, farmers must address lean seasons of food insecurity and find off-farm labor or work as day laborers on larger farms (Bacon et al., 2017).

Observations from each farm showed resistant cultivars had rust and other fungi[9] present. The presence of other diseases indicate that the coffee plant could have been made more susceptible to CLR due to the plant fighting off multiple threats simultaneously. Furthermore, there are over 100 strains of rust, and of those that are applicable to *C. arabica*, there are more sub-strains, which are constantly evolving (Rozo et al., 2012; Talhinhas et al., 2017). Thus, it is only a matter of time before a resistant variety starts to show signs of susceptibility

[9] The most prevalent one was *ojo de gallo* or Cercospora leafspot, which reduces plant vigor and photosynthetic capacity when severe.

to an evolved CLR strain. Some resistant cultivars may last decades, while others, like Castillo, start to show symptoms after a few years in use. This highlights the importance of management practices that heighten overall plant health to reduce susceptibility, in addition to breeding for resistance and spraying fungicides. Improving farmers' capacity in CLR management is dependent on their understanding of the constantly evolving nature of the disease, and to adjust their management strategies with this possibility in mind.

From informal interviews with the FCC staff and comments by farmer respondents, it appeared that most of the technical advice and promotion of good practices had gone towards intercropping, composting, and shade tree planting. These practices are important for disease management as they help reduce abiotic stresses that make plants more susceptible to CLR. However, these practices were not explicitly linked to CLR prevention and mitigation measures. It was clear from interview responses that farmers did not have an understanding of the life cycle or mechanisms of the disease's spread. This points to a knowledge gap that identifies where action may be taken to prevent another outbreak of CLR from reaching epidemic levels once the pathogen inevitably maneuvers around the currently available resistant varieties.

4.7. Justification for Community-based Integrated Pest Management for Coffee Leaf Rust

In this case study, a plethora of interdependent, complex factors influencing CLR outbreaks and farmers' decisions point toward the need for an integrated and participatory approach. Based on evidence from the previous chapters, business as usual is not working. Community-based Integrated Pest Management (C-IPM) is a possible alternative that should be explored (see Section 2.7.3 for detailed background). IPM programs can have varying levels of participation among farmers, scientists, and other stakeholders, ranging from top-down transfer of technology, to participant-generated designs (Norton et al., 2005). The main difference between C-IPM and IPM is in the delivery. C-IPM is a grassroots, bottom-up way of formulating an IPM program where the beneficiaries set the agenda. It is internally driven by community members, rather than external actors.

Physical environments are diverse, heterogeneous spaces. This makes landscape-level strategies especially important for containment of CLR, as coffee leaf rust spores mainly spread through rain and wind over large areas of land (personal communication, Vandermeer, Mar. 17, 2017). Community-based IPM could address this spatial dimension of non-localized transmission across farms. A typical IPM program might address pest management by involving only the farmers with contaminated fields. C-IPM would go a step further by including other farmers in the vicinity for prevention and containment strategies, leveraging existing forms of community and social capital for maximum efficacy. Effective pest control is dependent on community collaboration to contain and eliminate an outbreak because of the possibility of contamination spreading across fields in one locality. Farmers across Cauca would need to strategize for landscape level containment and C-IPM provides the forum to do so with FCC as a facilitator.

Additionally, management decisions can affect neighbors depending on their proximity to one another and their locations within the community. Based on the varying environmental conditions and heterogeneous ecosystems (e.g., areas protected from CLR by natural barriers; farms at higher elevation versus farms at lower elevation), farmers will have different constraints and advantages in dealing with CLR. Given individual conditions, it is critical for farmers to understand the roles those hetereogeneities play in enabling or disabling the pathogen and its virulence. A community-based approach would allow for this understanding. It would also facilitate continuous monitoring of CLR "hotspots," to track any changes in movement of CLR outbreaks and/or changes in the pathogen's behavior over time. For example, if CLR were to move into previously protected areas, it would indicate a major change in the disease's behavior, necessitating an evolving management strategy.

The first objective of a C-IPM program for CLR in Cauca should be to address the significant gaps in knowledge about the disease. The farmers interviewed in the sample drew some important associations between environmental factors and CLR (Table 12), but responses did not indicate understanding of nuances and complications, especially regarding non-localized transmission between farms. The farmers could easily discuss what made CLR more severe, but less so with the topics of prevention and management. This indicates that they knew more about what makes CLR worse without knowing how to make it better. Responses did not indicate knowledge about the causal pathogen nor evolving strains of rust against resistant varieties. Rain was also a cause of some confusion among farmers regarding its ability to mitigate or worsen rust incidence and severity. The responses from Cauca farmers in my surveys were consistent with findings from previous studies (Bentley et al., 1994; Segura et al., 2004) that have documented how small coffee farmers in Honduras and Mexico were unable to identify causal agents for plant health problems, including CLR and its pathogen *H. vastatrix*.

Table 12. Farmer perceptions about rust enabling and disabling factors

Enables CLR	**Disables CLR**
Hot(ter) temperatures	Shade trees – cool the microclimate, provide wind breaks against spores
Rain	Rain
Mono-cropping coffee	Fertilization
Workers spread spores	

Farmers must identify the gaps in their knowledge of CLR in order to address outbreaks more effectively according to their farms' and communities' specific agroecological conditions. The farmers interviewed displayed partial knowledge about biological control of pests learned through experimentation and experience, mainly dealing with *broca* (coffee berry borer). For example, several of the farmers planted yucca, which they claimed served not only as a staple food source, but also as a deterrent of *broca* by attracting a fungus that acted as a parasitoid. Similar knowledge of biological control with regards to *la roya* (CLR) was not expressed. A C-IPM program would need to start from what the farmers currently know and fill in the gaps. These missing gaps can be filled by extension agents or researchers who can initially teach and train the farmers about rust's life cycle, mechanisms, and the complex spectrum of enabling factors. Farmers can then form their own understandings in relation to their communities and farms as they develop plans to experiment and test potential methods. Community-based farmer research and extension committees, known as CIALS in Latin American countries, have provided precedent for the continuation of experiments and testing for farmers, linking local and academic research (Braun et al., 1999, 2000).

In addition to knowledge gaps, my survey indicated different social groups and characteristics that further justify a C-IPM approach, both in Cauca and at a broader scale. Organic farmers were the minority within the overall FCC membership body. These farmers were also observably more resource-rich than conventional farmers, with better farmable land, which indicates that the organic farmers were self-selecting as innovators and experimenters.

Interview responses displayed some differences in collective mindsets and behavior between organic and conventional farmers. Organic farmer respondents revealed a tendency to think more communally. Interview questions were posed to organic farmers about their thoughts on the current FCC structure of having organic premiums redistributed among co-op members for community development projects. Their responses indicated their views of the community being like family, and their opinion was that it was better to share those premiums than to keep them to oneself. A large motivating factor for the organic farmers to take on the risk of organic certifications was because they saw it as benefitting the larger community. They were, however, a minority group within the larger cooperative, as most farmers were still farming conventionally.

The organic farmers repeatedly used the phrase *la vida organica* during interviews, loosely translated as "organic agriculture as a way of life." It referred to a systems-thinking mindset regarding their crops, surrounding environment, and human health. This established attitude indicates that an integrated approach like IPM may be received well among the organic farmers as it fits with their values and current farming practices. Organic farmers in the sample appeared to be better educated and more resource-rich than the conventional farmers, which also means they could better cushion the risks associated with transitioning to organic methods.

Conventional farmers in the sample did not express the same familial sentiment openly. Furthermore, these farmers appeared more resource-poor than the organic farmers. But it is the conventional group of farmers, especially those who mono-crop coffee, that must see IPM as worth more to their livelihoods than any perceived risk. This will require behavior change, communication, and education, but also more thoughtful catering to farmers' constraints and barriers to adoption, such as steep slopes, that make it harder for conventional farmers to implement certain practices (see Section 4.3, Table 9).

During the initial stages of a C-IPM program, facilitators and participants must address constraints to collaboration, and find productive avenues for cohesion among disparate groups within communities. Different outlooks and an apparent resource gap between the two farmer groups present an initial consideration for action before and during the C-IPM process. While a conventional IPM program might view the differences as constraints alone, community-based IPM would view them as possible opportunities to leverage different strengths while also concurrently addressing existing problems.

The farmers come from two broad cultural groups - mestizos and Afro-Colombians. This brings up the unanswered question: Is there enough cultural cohesiveness to foster collaboration, or would differences hinder communication? A community-based approach to plant disease management would mainstream gender, ethnic, class considerations into the programming and design, thus helping foster more empowerment and inclusivity of marginalized groups and motivate seemingly disparate groups of people to participate to solve community-wide issues. C-IPM would also encourage in-depth communication and reflection before, during, and after projects to help work through any underlying barriers that might be hindering community collaboration, an essential element of CLR management.

4.7.1. Communication – a note of caution

Effectively and sustainably using C-IPM with CLR in Cauca calls for a strong communication component. There were observed challenges in farmer-to-farmer communication between the villages. In Morales, Farmers 1, 2, and 3 did not communicate with each other or their other neighbors about pest problems. These respondents observed that when a pest outbreak occurred on a neighbor's farm, it soon spread to their farms. Yet, there was a lack of communication.

Farmer 1 was also considered the most successful organic farmer in the FCC and was Afro-Colombian, while the other two farmers were of mestizo origin and were conventional farmers. In contrast, Farmers 10 and 11 in Rosas were two organic farmers of mestizo origin, very proactive and communicative even with the conventional farmers in their communities, but the other farmers also appeared to be mestizo. While ethnic relations were not explored for the scope of this case study, more in-depth interviews would need to be conducted for a C-IPM program to determine if any communication constraints can be attributed to ethnic differences.

Furthermore, there were communication constraints between the FCC and the local growers. The communities in this study are located on mountainous terrain where roads are inconsistently paved. This made travel somewhat difficult. Cell phone signal was intermittent during my field visits. A study by Cerna et al. (2016) also indicates that the lack of cell phone signal coverage was a constraint for FCC in communicating with farmers. As FCC's extension staff is highly outnumbered in comparison to the number of members served (six technical advisors for 700 members); this indicates a severe constraint in their physical ability to disseminate information and technology to farmers. Technical advisors go to all the farms but given the high ratio of farmers to advisors, they are only able to visit each farm once a year for comprehensive assessment.

Historically, government extension in Latin America virtually disappeared during the neoliberal structural adjustment programs undertaken by various Latin American governments in the 1980s and 1990s (Holt-Gimenez, 2006).

Small farmers have had to rely on each other, input dealers, and what little extension support was available, for many years now. Coffee farmers may have more resources due to the economic importance of the crop and the national level farmer organization, e.g. in Colombia (FNC). Nevertheless, it appeared that at the local level, extension visits were still rare and often not accurate.[10]

Another area of consideration is farmers' caution of outsiders. This differed by community, but it was most noticeable in the first community of Morales. Farmers 2 and 3 either had difficulty understanding questions, or were obfuscating answers during the interviews. Their general attitudes appeared to be suspicious of outsiders, or extremely reserved. They gradually appeared more comfortable as the interviews progressed. Farmer 1 was generally more at ease with sharing information about his farm and appeared to be better off financially, as he owned a shop and had a better house than the others (see Section 4.8 on organic and conventional farmers' resource gap).

When a researcher, an extension agent, or an NGO worker comes to rural communities – like the ones visited in Cauca – they are further set apart as 'outsiders' by their professional status and their educational level. In Latin America, professionals are usually addressed by the title *licenciado*, which refers to their university education. While the title garners respect, it generally does not incentivize local capacity-building that creates the community ownership

[10] One of the farmers interviewed told me that the government extension agent had told him to lime his soils by an excessive amount compared to what his actual soil pH level required when my research team performed the pH test (see Ch. 4, section 3 for examination of soil pH).

needed for long-term success of rural and agricultural development work. Having predominantly outsider participation to conceptualize, initiate, and implement projects and programs is unsustainable and ineffective, particularly in rural communities in an international context (Bunch, 1982). Nevertheless, outsiders are needed to introduce some necessary elements of external information, connections, and resources. C-IPM allows for integration of outsiders without giving away local ownership of the process.

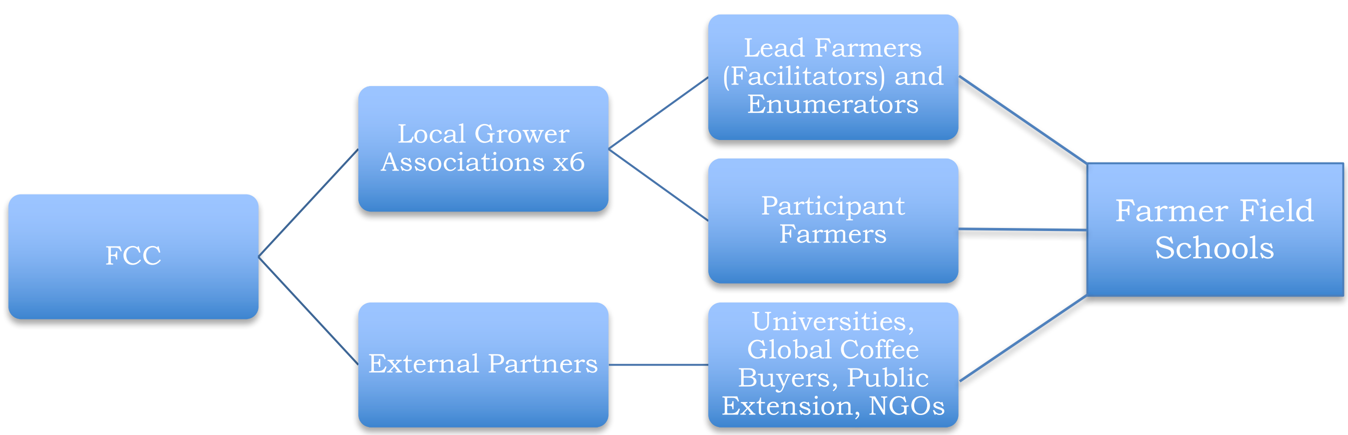
C-IPM creates more opportunities for smallholder farmers with less formal education to participate fully in the creation of solutions through active, experiential learning techniques. Smallholders could feel more empowered to participate, when previously they may have felt insecure about their lack of literacy and other qualities. Older rural women in Latin America are particularly more likely to be reserved about participating in groups because their age and gender demographic has typically received less formal schooling and social norms have confined public expression more than males. Collaboration on daily C-IPM tasks and peer learning in a C-IPM program can empower the less educated and marginalized community members, while also creating more community cohesion among participants.

4.8. C-IPM Design

This section explores some of the critical elements for designing a C-IPM program specific to CLR in Cauca. Given the context of the study, Farmer Field Schools (see Section 2.7.2) and farmer exchanges are some approaches considered here for a C-IPM program due to their participatory curricula and the intensive learning process that would be necessary for CLR management. These are certainly not the only participatory, community based approaches. Coffee-growing regions in other parts of Colombia and Latin America may need different types of C-IPM programs depending on their geographic, biophysical, and socio-political contexts in relation to CLR.

The FCC serves as an umbrella organization, unifying the six local cooperatives throughout the Department of Cauca (Figure 11). Because of FCC's small staff capacity relative its total membership (see section 4.9.1), the local grower associations would need to play an important role in the C-IPM programs at the community level. The FCC could be a convener, using its connections to external partners, and providing financial and material resources. At the local level, there would need to be different tiers of leaders to develop and drive the C-IPM program.

Figure 11. Proposed C-IPM actors and organizational structure for Cauca



4.8.1. Roles and Responsibilities of Different Lead Farmers

The board members of the local coffee-grower associations are leaders of their communities and are experienced coffee farmers. It would be essential to leverage this local leadership capacity for C-IPM. These lead farmers would likely continue in their roles as liaisons between their associations and the FCC and external partners. A lead farmer should be a dynamic and active person within the community who has the capacity to convene groups and is generally well-liked and respected among community members.

Field visits revealed some of the important characteristics needed in lead farmers. For example, Farmer 11, a woman, was the president of the local coffee grower association of a village in the municipality of Popayán. She was an organic farmer with a very charismatic personality. Farmer 11 understood the importance of communication between farmers for effective pest management, and expressed that she and her neighbors communicated regularly about pest problems. At the time of the interview, she was running a demonstration plot that had been set up with the FCC, indicating another characteristic needed for a lead farmer - a willingness to experiment.

Lastly, though lead farmers are often considered successful farmers, being a farmer with high yield does not guarantee that one is also a good facilitator or disseminator of knowledge (Simpson et al., 2015). Facilitation training is essential for lead farmers, including techniques for effective information sharing and dissemination, especially for dealing with a complex challenge like CLR. A C-IPM program would need to keep such characteristics in mind when designing criteria for selection of facilitators and trainings.

Lead farmers should be voted into their roles collectively by all C-IPM participants. It is critical for long-term viability of a program that it is viewed as farmer-developed and farmer-driven. Community-based IPM lends itself to this as farmers' knowledge and judgment of their specific agroecological systems are central to determining action steps and working collaboratively with other farmers.

Different groups of lead farmers with varying responsibilities can aid in the even distribution of workload and can maximize comparative advantage in skillsets. Current community leaders may not have enough time to participate in all aspects of a C-IPM program, particularly the more time-consuming farmer field schools (FFS), in addition to their familial and other responsibilities (Simpson et al., 2015). It is recommended that there be a cadre of leaders for different aspects of the C-IPM program. The lead farmers who already play a significant role in their communities can catalyze action, and receive facilitation and data collection training from outside organizations. They would then co-train other lead farmers to serve as facilitators for FFS. The FFS lead farmers would be working closely with C-IPM participants on a daily basis, and would need certain qualities like being approachable, friendly, and patient. Lead farmers who are already community leaders or who are coffee association board members may be perceived as less approachable by lower-ranking community members. Selection criteria can also be set to require a certain number of women lead farmers, for more gender inclusivity. There have been documented cases where women lead farmers have trained more women farmers than men lead farmers (Simpson et al., 2015), accessing more marginalized members of communities that (majority male) extension agents and leaders do not reach.

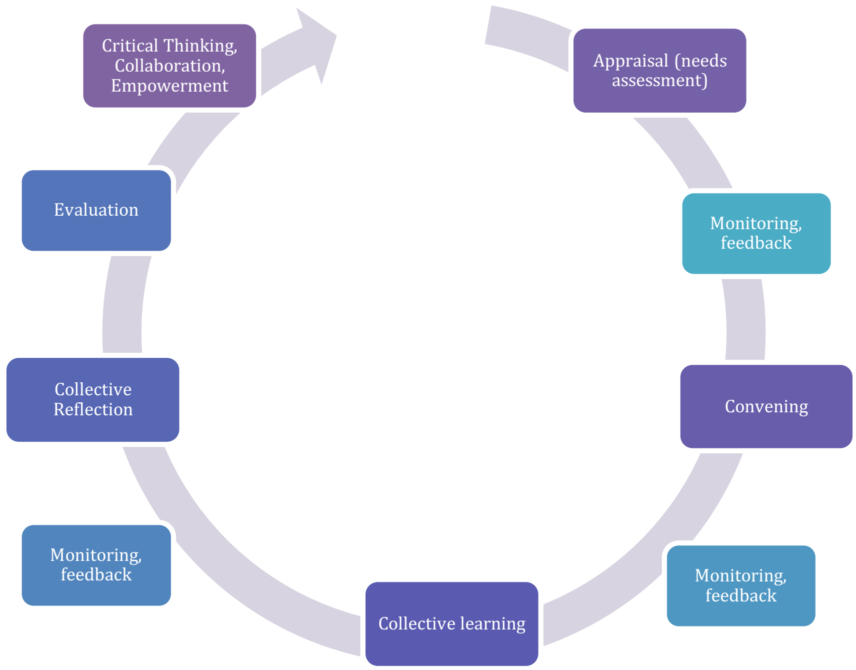
Expanding lead farmers may open more avenues toward empowerment for women or ethnic minorities who are bypassed due to social community norms or politics. With existing communication challenges between FCC staff and farmers spread throughout the region of Cauca (see section 4.9.1), and the lack of smallholder involvement in decision-making processes with cooperative leaders (Hernandez-Aguilera et al., 2018), these lead farmers would also likely facilitate improvements in communication throughout the FCC organizational structure.

Board members of the local associations are typically more accustomed to working with community outsiders than the regular farmer, so they should facilitate outsider involvement from NGOs, research institutions, or extension. Some of these organizations may already have some experience working in these communities. If, however, there were any negative experiences with outsiders in some communities on previous projects, then a new counterpart organization would need to be involved, which would require more time to build trust with community members. NGOs and researchers can train data collectors, lead farmers, and co-host workshops on CLR education and awareness. Global coffee buyers (Figure 11) may also be potential partners to fund or participate in C-IPM programs as rust presents a threat to their purchases of high quality coffee.

The C-IPM program in Cauca also needs to consider compensation for lead farmers. In Simpson et al.'s (2015) survey of farmer-to-farmer extension programs in Africa, they found that most lead farmers were essentially volunteers. Some programs compensated lead farmers for travel and communication expenses, while only a fraction received regular stipends or salaries. Similarly, in Cauca, it is not likely that there would be much funding available to pay lead farmers a regular stipend, but the FCC can explore options in restructuring the distribution of their premium awards, using in-kind payments, or covering travel expenses.

Conceptually, a C-IPM program in Cauca would have a cyclical process with monitoring throughout each step (Figure 12). This provides opportunities at each stage for the farmers to think critically about CLR in relation to their livelihoods, and to adjust and adapt the program as needed during the process according to the idiosyncrasies of each community. This framework is heavily influenced by Participatory Action Research and Research for Development principles (Arévalo & Ljung, 2006; Douthwaite et al., 2015; Gonsalves, 2005). C-IPM develops farmers' research and investigative capacities to create more farmer-centered solutions to problems that they find both on their farms and in their communities.

Figure 12. The C-IPM conceptual framework



4.8.2. Appraisal (Needs Assessment)

Participatory Rural Appraisal (PRA) is recommended for conducting a rapid but comprehensive needs assessment in a community-based approach to IPM for CLR (Figure 12). PRA is a methodology that enables and empowers locals (particularly the marginalized) to critically assess and discuss issues in their community, while also incorporating the active participation of outsiders in the process (Narayanasamy, 2009). It is also flexible and broad enough to adapt to different contexts, so practitioners can use the most context-appropriate tools from the suite used in PRA (Narayanasamy, 2009).

One of the main PRA tools is participatory mapping. It helps community members express their knowledge and serves as an 'equalizer' between the literate and illiterate; between the vocally expressive and the more reserved (Narayanasamy, 2009). The maps can vary, ranging from CLR outbreaks by farm, to natural resources that might help prevent spore dispersal, and maps of any other pertinent aspects of the community. It is also a useful tool for monitoring and evaluation. Other tools that can be used in PRA include semi-structured interviews, participatory calendars, gender disaggregated activity diagrams or calendars (Gonsalves, 2005). Which tools are used depend on the facilitators, the participants, and the context.

Outsiders, such as researchers, extension agents, and NGO workers, would need to train community-selected enumerators and facilitators for PRA (Table 13). These actors need to identify and recruit key counterparts in the community. The FCC and local grower associations would be invaluable facilitators throughout the process, especially for connecting outside partners to local associations (Figure 11). Initial workshops should introduce outsiders, establish a general baseline of community priorities for addressing CLR, and train enumerators to carry out PRA.

The enumerators should be chosen from among youth, women, or other groups that can access various social circles and be further empowered through learning these techniques of critical questioning and analysis. These groups may be more open to using newer technologies, such as mobile applications, that provide access to sources of outside information.

Table 13. Roles of outsiders and insiders in PRA. Source: adapted from Narayanasamy (2009)

OUTSIDERS (researchers, FCC, NGO workers, extension agents, etc.)	**INSIDERS** (locals, cooperatives, FCC board & staff)
Establish trust, rapport; convene	Map, model, diagram
Catalyze action, facilitate inquiry	Score, quantify, rank
Choose and adapt methods as needed	Show, inform, explain

Have the 'insiders' make the decisions	Discuss, analyze, plan
Observe and listen	Act, monitor, evaluate

Additional facilitators should be trained for Farmer Field School component of the C-IPM program, so that lead farmers who have helped facilitate the PRA and initial convening workshops do not become overburdened with work in addition to their usual tasks and responsibilities. Group data collection should be done by enumerators to gather baseline data of farm types and rust levels and severity on farms to help prioritize needs around addressing CLR (Table 13). In addition to baseline data for CLR, the initial assessments should find opportunities and constraints that influence community collaboration (see Sections 4.8-9), and take note of farmer knowledge, practices, and perceptions.

4.8.3. Convene

After the baseline data collection and needs assessment, there should be a convening stage to set a collective agenda (Figure 12). This stage should have community workshops in each of the local grower associations that make up the FCC. Meetings or workshops between different communities should also be part of this stage. These should be facilitated by the FCC and board members of the local grower associations. The workshops are opportunities to introduce outsiders such as extension agents, NGO workers, coffee buyers, or other external stakeholders who will be important partners for CLR management. These meetings could also include broader community visioning beyond CLR to further community investment (Douthewaite et al., 2015). The main purpose of the workshops, however, would be to collectively process the results of the PRA/needs assessment and prioritize action areas concerning CLR. Those action items could then be incorporated into the curriculum for a Farmer Field School for CLR.

Another important objective of these meetings is for all stakeholders to co-design the C-IPM curriculum, and to ensure, as much as possible, that it does not produce additional or unforeseen burdens on a particular group of people. This is important especially for women, whose time is usually the most constrained among the rural poor (Pinstrup-Andersen, 2013). Even something as simple as setting a meeting time and a religiously and politically neutral meeting place that works for both men and women can be an incentive that increases broader community participation for C-IPM. Intentionally doing activities to create more awareness and to address misperceptions about labor distribution between gender and ethnic groups can help reduce any additional burdens on one group.

4.8.4. Collective Learning

Disease management is knowledge intensive and requires farmers to innovatively confront a pathogen that cannot be seen with the naked eye, making it more challenging than insect pest management. Most fundamentally, "without understanding basic issues such as the pathogen as causal agent, sources of inoculum, and the concept of a latent period, farmers are unable to grasp the basis for disease management strategies" (Nelson et al., 2001; pp. 685). For this reason (also explained in Chapter 2 and the Results section of this chapter), Farmer Field Schools (FFS) and intercambios (farmer exchanges) are two recommended approaches to C-IPM for CLR in the context of this case study. FFS and intercambios can leverage community members' social networks for diffusion of information and knowledge, tested and proven by locals themselves (Vasilaky, 2013).

The successes of the Campesino-a-Campesino (CAC) movement in Central America and the Caribbean provide precedent for participatory and empowering forms of adult education for farmers in the region. Lessons were tailored in terms that the campesinos were familiar with, but were not redundant, explaining obvious information (Bentley et al., 1994). Holt-Gimenez (2006) describes how one of CAC's main teaching methods were intercambios, an unstructured socialization method of learning of farmer-to-farmer exchanges, where one group of farmers visits another. Intercambios can last one afternoon, a weekend, or several days. They can be done with or without the facilitation of NGOs or other organizations. More informal sessions led by campesinos tend to focus on the development of social networks and observing the agricultural practices that they find relevant in the other community. Intercambios also serve to socialize farmers who may not be accustomed to working collaboratively to solve problems. In the cases highlighted by Holt-Gimenez (2006), the campesinos shared tools, seeds, information and other resources during these exchanges. Given the existing networks of coffee grower associations connected under the FCC umbrella, intercambios may be quite beneficial and feasible for Cauca's coffee producers.

Some of the intercambios should take place within the same community, not just between different villages. Intercambios would allow coffee growers to experientially understand the specific topographic and resource constraints faced by other farmers in their own community. On average, organic farms were located on less steeply inclined slopes than conventional farms (see Section 4.3). This difference in topography influenced farm management decisions, which in turn, influenced CLR management practices. Intercambios would provide opportunities for resource-rich farmers to better understand the constraints that their resource-poor farmer neighbors may be facing, and vice versa. This would potentially provide the farmers with an improved foundation to work together more effectively on experiments and to develop a community-wide strategy that addresses CLR for various micro-contexts.

Farmer Field Schools (FFS) provide the in-depth training and active learning environment that is essential for learning about CLR and experimenting with management options. Due to the de-centralized, localized nature of FFS programs, participants can adapt to situations as they emerge and evolve in their specific field and community contexts. IPM, as taught in Farmer Field Schools, relies on farmers' observations and experiential learning to determine when and how to act on a pest threat. Literacy is not a requirement for FFS, as curricula are designed for smallholder farmers with little formal educational training. It also provides opportunities for collective experimentation in the field. A well-designed FFS will have frequent feedback loops that allow farmers to try out their innovations and get feedback on outcomes and process from more highly skilled farmers (Arévalo & Ljung, 2006). FFS provides the 'recognizable successes' (Bunch, 1982) of seeing immediate results in a growing season, which is critical for technology uptake and sustained participation.

FFS participants can learn about CLR and its management through activities that illustrate pathogen behavior, resistance, and virulence. Nelson et al. (2001) used various games to help farmers understand plant disease, including a simulation exercise to illustrate infection cycles using beans and poster paper with grids. FFS uses simple but effective tools to teach farmers about complex concepts and to reinforce their existing knowledge, to combine for a comprehensive capacity for disease management.

4.8.5. Collective Reflection

On a monthly or other regular interval, there should be a collective meeting for reflection on the aspects of the program that are working well for participants, and aspects that need improvement or adjustment. The reflection should largely be done by the participants themselves, with as little outside facilitation as possible. The participants can discuss problems together and re-calibrate the C-IPM agenda as they see fit. They may decide on using a certain cultural practice against CLR for instance, instead of using the reflection session to evaluate their group work or looking towards the future. But those are also important activities that can be done in other reflection sessions.

4.8.6. Opportunities for broader community engagement and empowerment

C-IPM for CLR is a long-term commitment, going beyond addressing immediate symptoms. Rust is constantly evolving and it is ever-present throughout the year in Colombia and nearly all coffee growing areas of the world (see Ch. 2). It may take some time to reconcile theoretical, abstract concepts with farmer perceptions, and how to couch those concepts in their vernacular and ways of understanding the surrounding world. Additionally, developing trust and learning together with participants requires taking "social time" (Marquardt, 2006; pp. 316). Even after a principal project may end, the relationships do not. There should always be a level of contact that is maintained in the long-term between community members and the NGO or other practitioners working in those communities (Marquardt, 2006). It is especially critical for any programs working in rural communities to view farming issues as connected to community development issues.[11]

For instance, C-IPM could be a catalyst on gender issues in community participation and leadership. The FCC participates in Fairtrade to sell their coffee. While Fairtrade requires organizations to have women's participation and inclusion in certification process, the intended effect has fallen short in practice (Lyon et al., 2010). As a result, while Fairtrade coffee farm-based organizations (FBOs) tend to be more egalitarian with respect to gender than non-Fairtrade FBOs, there are still inequalities perpetuated by cultural tradition and structural factors. Cultural biases continue to limit women's participation and leadership roles in organizations, as do time constraints due to their socially assigned

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[11] Reducing poverty in the Global South is tied directly to agricultural growth, as farming is the primary livelihood source for the rural poor. See Asfaw et al. (2011) for detailed discussion about the poverty reduction effects of agricultural development programs.

household and reproductive responsibilities. There is a culture of *machismo* in many Latin American countries, including Colombia. In organizations, this tends to translate itself into a strong-man leadership style with an authoritative male figure. Observations indicated that the FCC board and managerial staff members were predominantly male. This was also the case in other Fairtrade-organic coffee FBOs studied by Lyon et al. (2010)[12]. These issues are not explicitly addressed by Fairtrade, but could be incorporated at each step of the C-IPM process as mentioned earlier in the previous stages.

4.8.7. Scaling Up C-IPM

C-IPM for CLR management should leverage community organizations already in place. The FCC and the local coffee grower associations are the foundations from which to facilitate FFS and other participatory IPM programs. As coffee producers are nearly all organized into cooperatives or other farmer-based organizations, this organizational capacity can help implement with scaling up of C-IPM programs from local communities to wider Cauca and perhaps even nationally throughout Colombia. Through these FBOs, farmers also have market linkages and access to outside sources of information.

Because the FCC was originally founded to help with farmers' rights and other social issues, the connections between farm productivity and community development were ingrained in the organizational philosophy at the outset.

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[12] See *Gender equity in fairtrade–organic coffee producer organizations: Cases from Mesoamerica* by Lyon et al. (2010) for detailed discussion on gender in Fairtrade coffee organizations, using organizations in Mexico and Guatemala as case studies.

The FCC leaders were very conscientious about taking a rural livelihoods approach and not solely focusing on productivity issues. C-IPM would further help tie those two together coherently while also aiding with CLR. Local coffee grower associations' leaders represent each member municipality at FCC board meetings, which provides a mechanism for communication and feedback between FCC and its members spread out throughout Cauca. C-IPM should aim to be institutionalized at various scales, from local to regional to national for long-term sustainability and up-to-date information exchange (Norton et al., 2005).

The issue of scaling up depends on the goals of the specific program, technology, and issue in question. As Norton et al. (2005) articulate, scaling up may not be needed if an IPM program's goal is to help farmers in a certain locality solve a pest problem, with a priority to intensify training and knowledge. On the other hand, an international organization may want to diffuse lessons to as many farmers as possible, but at the expense of less intensive learning. Thus, an important outcome of a collective needs assessment (see Section 4.9.2) is to also help develop the appropriate ways of scaling up while respecting the needs and desires of the community.

FFS programs typically devote more resources into training a small number of people due to the knowledge-intensive nature of the programs. In the potato growing region of the Ecuadorian Andes, an IPM FFS and field day program co-funded by the FAO and INIAP[13] cost $50,000USD for 302 participants plus 1700 Field Day participants (Alwang et al., 2005). Such expenses are not sustainable for long-term continuation once donor funding expires. This makes it critical to have community-based IPM that can become self-sustaining programs. By limiting outsider involvement and starting at a grassroots level generated by and for the local farmers, C-IPM programs can be sustainable and address CLR and other complex livelihood and farm constraints. Finally, it can be difficult to generalize the findings from a FFS to a broader population without linkages to upstream market actors or scientists in higher institutions. Farmer-based organizations like the FCC serve as a link to disseminate a two-way stream of knowledge from farmers on the ground to the higher educational and other research institutions.

[13] "Instituto Nacional Autónomo de Investigaciones Agropecuarias (INIAP), a semi-autonomous agency that was formed to make agricultural research in Ecuador more productive by introducing market-based incentives" (Alwang et al., 2005, pp. 72)

CHAPTER 5. CONCLUSION

Coffee leaf rust (*H. vastatrix*) is a versatile disease that has co-evolved with coffee (C. Arabica) for nearly a thousand years. The coffee leaf rust (CLR) epidemic that took place in Colombia and northern Latin American coffee producing countries from 2008-2013, highlighted the lack of comprehensive and integrated approaches to address the disease. Colombia's response to the epidemic was relatively quick, and involved a campaign of farm renovations to replace what remained of surviving susceptible coffee trees with resistant varieties. My field research in Cauca, Colombia among smallholder farmers, however, showed that CLR had started to overcome resistance by some of the promoted resistant varieties. Interviews with the farmers also revealed a fundamental lack of understanding about CLR's main enabling mechanisms and good preventative practices. My field visits further highlighted the heterogeneous terrain and agroecological environment of each farm, as well as socio-economic diversity of farmers within the same community and across different communities.

With these factors in mind, it was clear that business as usual was not working for these smallholder coffee farmers. In this paper, I propose community-based Integrated Pest Management (IPM) as a possible way forward because it emphasizes behavior change and requires intensive understanding of a complex pest. IPM uses an ecologically and contextually derived suite of technologies and practices to address a pest issue. Emphasis on community-based IPM (C-IPM) for coffee leaf rust would ensure that farmer learning and farmer research remain central driving forces to an IPM program for CLR, while also adapting to the idiosyncrasies of each farm(er) and each community.

While this study was more exploratory and qualitative in nature due to time and resource constraints, I recommend that future studies expand the scope to establish baseline data across all associations in the FCC to include systematic CLR sampling and socioeconomic data from community census surveys, focus group interviews, and participatory mapping and agricultural timeline exercises. There are many facets from this study that can be further deeply examined in future studies – gender, farmer social networks, ethnic diversity within communities, technology adoption, and on. The main issue that arises from my analysis of potential opportunities and constraints for C-IPM is communication – between farmers within a community, and between farmers and community outsiders (extension agents, NGO workers, foreigners, etc.). Good pest management is highly dependent on good communication, and should not be overlooked in favor of only using technical packages.

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