1. “Integrated soil fertility management interactions with *Hemileia vastatrix*: combating the coffee leaf rust crisis”

The American Phytopathological Society. (2016, May). Coffee rust.

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Executive Summary

4. Problem

"Coffee rust (*Hemileia vastatrix*) has evolved quickly in Brazil and Colombia (Avelino et al. 2015). Very complex races possessing virulence genes able to break down the resistance genes proceeding from *Coffea canephora*, which have been used in *C. arabica* breeding, have appeared in about 30 and 20 years, in Brazil and Colombia respectively. This period of time is not so long considering that coffee is a perennial crop. A similar evolution is likely to happen in Central America with an increasing presence of resistant cultivars in the landscape, which will exert a high selection pressure on the pathogen. As a consequence, resistant cultivars alone cannot be considered as a durable tactic to fight coffee rust anymore. To improve coffee rust control, resistant materials need to be accompanied with other cropping practices which will impact the disease through different and complementary pathways. This strategy will (i) help to reduce the pressure of the disease when resistant materials will lose their resistance (ii) also help to reduce the pressure of the disease in susceptible materials (iii) possibly help to reduce the possibilities of evolution of the pathogen by preventing intense epidemics.

Heterogeneous spatial distribution of coffee rust attack intensities was observed in Guatemala, within small areas, indicating local effects, probably in relation with coffee management (Avelino et al. 2015). A survey conducted in Nicaragua in 2014 by CIRAD-CATIE, in a coffee area strongly impacted by coffee rust in 2012, showed that farmers following a strict and systematic management program, including properly applied fertilizers and fungicides, had no serious trouble with the disease during this epidemic (Avelino et al. 2015).

Fertilizer applications seem to be critical, but the effects (both direct and indirect) of plant nutrition status on both the severity of rust infection and the capacity of the coffee plant to recover from rust damage, are not well understood. In theory, well fertilized plants grow better, allowing them to renew leaves lost to rust (Avelino et al. 2006), and thus death of the branches is avoided, preventing most of the primary and secondary losses. Well fertilized plants may also better face rust attacks due to improved physiological resistance" (Avelino, 2016).

5. Objectives, Approach, and Evaluation

"The objective of this research is to understand the effects of coffee nutrition and soil health on coffee rust as a basis for developing Best Management Practices and new training programs for technicians and producers" (Avelino, 2016).

An M&E plan for my involvement in the project as a RIFA fellow is outlined in a following section.

6. Audience

Those who will use and benefit from the project findings include the scientific community studying CLR, and Central American coffee producers.

C. Justification

7. Problem

Hemileia vastatrix is a parasitic fungus that causes coffee rust, a disease that is having widespread detrimental effects on coffee producers globally. Coffee rust has high economic significance for producers in the developing world as coffee is one of the most highly traded agricultural commodities and the majority of producers are smallholders (Vandermeer et al. 2014). Since 2012, the disease has had sweeping impacts on production in Central America where producers' yields and incomes have been significantly reduced (Vandermeer et al. 2014). Although the prevalence of coffee rust has greatly increased in Central America in the last decade, limited studies have been conducted surrounding production processes to combat the disease. The majority of the literature discusses the use of foliar copper fungicide applications; and shade cover gradients on the incidence of rust. Based on a review of the existing literature surrounding management strategies for mitigating coffee rust, and on conversations with leading researchers in the field, it is noted that little research has been conducted on the relationships between soil fertility management, coffee plant nutrition, and physiological resistance to rust.

8. Impact

As a recipient of the USAID supported Research and Innovation Fellowship for Agriculture (RIFA), I will be conducting research that measures interactions between soil nutrient availability, plant health and rust disease incidence in coffee plants in farms in Honduras, Guatemala, and Mexico. This research will be hosted by Catholic Relief Services' Blue Harvest (BH); and Agriculture, Soils, Water (ASA) programs in joint collaboration with Dr. Jacques Avelino of Cirad/CATIE (Tropical Agricultural Research and Higher Education Center in Costa Rica), a leading global researcher on coffee rust. In 2013, Avelino and colleagues from the Inter-American Institute for Cooperation on Agriculture conducted a literature review on coffee rust and found that in regards to existing information on rust, soil fertilization, and nutrition, very little information exists. The proposed research seeks to observe a range of soil management practices and provide recommendations that are effective, economically feasible, and environmentally sustainable in context of smallholder coffee farmers.

9. Long-Term Solutions

My initial work on this project as a RIFA fellow will be part of a larger study between CRS and CATIE, funded by CRS until 2019. The magnitude and scope of the project would make it the largest and therefore potentially most significant study on soil-CLF interactions that we know of at this time.

10. Related Research

What is already known about soil fertility management for coffee plants is that many soils where coffee is grown are acid soils where pH is low enough to cause aluminum toxicity and deficiencies of critical nutrients for production, such as phosphorus, calcium and magnesium (Avelino et al., 2006). It's necessary to control acidity to manage levels of soluble aluminum and to enhance the absorption of essential nutrients, especially of phosphorus which is critical to root development.

Good nutritional status of the host plant is not known to necessarily guarantee physiological resistance, however, and what reports exist on the effects of plant nutrition on disease incidence are conflicting, as effects are dependent on multiple factors (Dordas et al., 2008; Walters et al., 2007). The interactions between biotrophic pathogens like rust which depend on living host cells for their own development and plant nutritional status are not yet clear (Avelino and Rivas, 2013).

In Honduras, it was observed that the incidence of coffee rust was lower in some fertilized plots versus unfertilized plots (Avelino et al., 2006). It was suggested that this had to do with corresponding reduced growth and recovery of underfertilized plants (Ferrandino, 2008). In Brazil also, differences in the incidences of rust were found in plots using different amounts of fertilizers, particularly calcium (Santos et al., 2008). Martinati et al. 2008 tested the effect of silicon on disease defense reactions in coffee plants and found reduced incidence of the disease in plants treated with silicon. Although nutritional factors affecting the plant appear to be associated with the attack of leaf rust, current research does not demonstrate how to improve coffee plant nutrition to improve physiological resistance (Avelino and Rivas, 2013).

It is anticipated that pH management and nutrient availability will correlate with incidence of fungi and other diseases such as coffee leaf rust.

11. Contribution to Knowledge Base

Very little research exists about the relationships between soil fertility management, coffee plant nutrition, and physiological resistance to rust. As mentioned, the magnitude and scope of the project would make it the largest study on soil-CLF interactions that we know of at this time.

Objectives

12. Objectives

The study will be organized as part of the larger CRS coordinated program, Blue Harvest. The goal of Blue Harvest is to restore and protect degraded and critical lands and riparian areas within watersheds in Central America's coffee lands. In Honduras, it focuses on management and restoration of two critical watersheds that are the source of drinking water supply for Honduran communities located downstream. Blue Harvest arose in response to the intensive water resources used in the coffee production and processing operations and the ways in which they affect local communities' drinking water. Blue Harvest promotes sustainable agriculture and land-use in the coffee lands to improve water quality recharge for these communities (CRS Blue Harvest, 2016).

Through the connection to the regional watersheds that coffee production in these areas depends on, the coffee production chain is linked. This research specifically on soil-plant-disease interactions will promote soil fertility management for sustainable land-use practices to benefit production and thereby producer livelihoods.

"The objective of this research is to understand the effects of coffee nutrition and soil health on coffee rust as a basis for developing Best Management Practices and new training programs for technicians and producers" (Avelino, 2016).

Expected deliverables for the study include:

- Data bases with data on rust incidence and/or severity coming from field surveys and laboratory trials

- At least two scientific publications on the relationships between nutrition and coffee rust and one technical publication on best practices based on nutrition for managing coffee rust in each country involved. The objective is to share the results of the study with the scientific and technical community.

Work Plans and Methods

13. Work Plan

Overall project work plan

Timeline	2016	2017	2018	2019	2020	2021
Survey Guatemala, Mexico and Honduras	Field Work	Field Work and analysis, preliminary report on the first year of the survey	Field Work (only Honduras) and analysis, second preliminary report	Analysis and final report		
Field trials Honduras			Field assessments	Field assessments and analysis, first preliminary report	Field assessments and analysis, second preliminary report	Analysis and final report
Laboratory trial in Costa Rica	Nursery establishment	Trial, analysis, and final report				
Laboratory trial in Honduras		Nursery establishment	Trial, analysis, and final report			

RIFA fellowship project work plan

Objective: The objective of this research is to understand the effects of coffee nutrition on coffee rust as a basis for developing Best Management Practices and new training programs for technicians and producers.

Task 1: Design measurement protocols for characterization study
Timeline: June, July 2016

Task 2: Coordinate data collection plan
Timeline: August, September 2016

Task 3: Construct iForm data collection tool
Timeline: August, September 2016

Task 4: Train field teams to collect data using iForm
Timeline: August, September 2016

Task 5: Collect data from 175 farms in Honduras, 175 farms in Guatemala, and 50 farms in Mexico
Timeline: Reference *"Data collection schedule for characterization study"* chart below

Task 6: Analyze data
Timeline: Starting January 2017

Data collection schedule for characterization study

No	Measurement	Month									
		2016					2017				
		(ago)	(sep)	(oct)	(nov)	(dec)	(jan)	(feb)	(mar)	(apr)	(may)
1	Rust incidence	Before harvest			Peak of harvest				After harvest		
2	Rust severity	Before harvest			Peak of harvest				After harvest		
3	Coffee branch growth	Before harvest			Peak of harvest				After harvest		
4	Coffee plant defoliation	Before harvest			Peak of harvest				After harvest		
5	Shade cover	Before harvest							After harvest		
6	Shade type	Before harvest									
7	Shade type	Before harvest									
8	Coffee planting density	Before harvest									
9	Cropping practices applied	Before harvest			Peak of harvest				After harvest		
10	Fruit load	Before harvest									
11	Coffee plant age	Before harvest									

14. Methods

To date, Dr. Avelino/CATIE have received baseline survey data that CRS has already been collected for BH and ASA. CATIE has reviewed what data are currently being monitored by CRS from the farms and has suggested a study design.

The CRS/CATIE research will be carried out over a period of several years to monitor the incidence of multiple disease cycles in farm sites in Honduras, Guatemala, and Mexico. My research will span the first 6 months of the project.

Overall project plan methodology:

"In a first stage (2016-2019), two experimental and complementary approaches will be used, (i) a characterization study, very descriptive, where relationships between management, soil and coffee rust can be highlighted, but with no guarantee that these relationships are cause-effect relationships (ii) laboratory trials where the effects of nutritional elements on the physiological resistance of coffee leaves on rust can be inferred. Increased physiological resistance is one of the mechanisms that could be involved in a better behavior of well fertilized plants to face coffee rust compared with plants with sub-optimal fertilization.

In a second stage (2018-2021), field trials in controlled conditions established by IHCAFE (Instituto Hondureño del Café) in 2016-2017 could be used to study the effects of nutrition on the epidemic growth of coffee rust. Here, an additional mechanism, named "dilution effect" could be studied. This dilution effect is due to the introduction of new healthy leaves or leaf area over time, which reduces the apparent infection rate. Well fertilized plants which have a better growth than plants with sub-optimal fertilization might better cope with coffee rust attacks for that reason. Kushalappa and Ludwig (1982) already observed that negative values of the apparent infection rate could be found during periods when coffee growth, expressed as new leaves or new area, was faster than the increase in diseased leaves or diseased area, resulting in a dilution of coffee rust proportions.

The first stage is proposed for CRS funding within the first CRS-PROMECAFE collaboration (2016-2019). The second stage will be conducted with IHCAFE through PROMECAFE only if new funding is found. The field trials to be conducted in this second stage are described below for information only" (Avelino, 2016).

My RIFA fellowship will involve the following phase of the research, until December 2016:

"(i) A characterization study to collect field data on (i) rust incidence (ii) crop management, particularly fertilization and soil management practices (iii) in a range of soil conditions: the relationships between these variables will be studied to highlight the links between soil chemical composition, fertilizer and amendment applications, other soil management practices and coffee rust incidence.

For that purpose, we will use a subset of 400 coffee farms among the farms studied within the CRS project on soil management: 175 in Guatemala, 175 in Honduras and 50 in Mexico. In each farm, both the plot managed according to CRS advices and the control plot managed by the producer as usual will be considered. As a result, we will have 800 coffee plots under observation.

In addition to the variables measured by CRS within its soil management study, we propose to characterize the following variables: shade type, coffee variety, coffee planting density, slope inclination, slope aspect, cropping practices applied during the studied year, shade cover (twice a year), fruit load (before harvest), coffee plant age, and coffee plant height. Most of these variables need to be considered because of their potential effects on coffee rust incidence. Coffee rust incidence as well as coffee branch growth and coffee plant defoliation will be assessed twice a year: at the peak of the harvest, and just after the harvest.

The field work will start in 2016 and will finish at the beginning of 2018 in Guatemala and Mexico (2 years). It will be continued one additional year in Honduras with the help of a consultant to be recruited. The final report of this study will be delivered in the first semester of 2019" (Avelino, 2016).

The following describes methods to be employed, data to be gathered, parameters to be measured, sampling scheme, and experimental design. These data will be compared against standard chemical soil sample results for all of the sampled plots:

0. Plot selection and set-up

In the center of each of the CRS plots, we will create a smaller subplot of 15 plants X 8 furrows. We will mark the four corners of the subplot with surveyor's tape. We will select 5 trees within each subplot. Important: only plots with a majority of varieties susceptible to rust should be included in the study and the 5 trees have to be of a susceptible variety. In each of these 5 trees, we will mark 3 living primary branches (selected from 3 different stories on 3 different sides of the plant) for a total of 15 branches per subplot. These 3 branches don't need to have fruits necessarily. The marked branches need to be identifiable (plants numbered 1-5; branches marked as lower, middle, or upper branch). All of the data taken should indicate which plant and which branch they correspond to. In each farm, data will be taken from two subplots, a subplot being managed under ASA treatments, and subplot without ASA treatments.

1. Rust incidence

Rust incidence is the percentage diseased leaves. On the marked branches, we will count the total number of young leaves, both healthy and diseased (showing *any* level of infection from rust). The criterion used to define leaf age is a very short internode that arises during the dry season. Old leaves are defined as being located between the base of the branch and the short internode. Young leaves, from the current year, are defined as being located between the short internode and the tip of the stem. In the case of two short internodes, if the branch is very old, growth is reduced and effectively the short internode can be very close to the tip of the branch. For example, there may be a pair of new nodes only. If the branch is young, there should be more nodes from the year. So, we will determine where the area with fruit is to decide which is the new zone. To calculate rust incidence, we will divide the number of young diseased leaves by the total number of young leaves on the branch to determine percentage of diseased leaves.

2. Rust severity

Rust severity is an indicator of epidemic severity based on the percent of leaf area size infected. Using the same 15 marked branches used for calculating rust incidence, we will evaluate each of the young leaves (defined as being located between the short internode and the tip of the stem) for rust severity. To do this we will refer to the "Escala Roya" and assign each young leaf a rating of 0 (healthy) - 5 (highest level of severity).

3. Coffee branch growth

We will determine the growth of the 15 marked branches by counting the number of nodes after the short internode.

4. Coffee plant defoliation

Because coffee plants usually have opposite leaves (two leaves at the node), we can assess defoliation by counting missing leaves on the nodes. For the 15 branches, we will count the number of missing leaves on each node starting after the short internode.

5. Shade cover

Using a densitometer, we will calculate the percentage of shade cover at each of the 5 marked plants by calculating shade cover from 4 different stances around the plant and taking their average.

6. Shade type

We will document the number of occurrence of each type of shade tree (a shade tree is considered to be any plant that provides shade to the coffee plant, or approximately 3 meters).

7. Coffee variety

We will document variety type. If more than one variety exists, we will document dominant variety and non-dominant varieties, but no % breakdowns needed. Note: only farms with a majority of susceptible variety plants should be included in the study and the 5 plants must all be from this susceptible variety.

8. Coffee planting density

Density is the number of trees/ha. calculated from the distance between coffee trees in the row and from the distances between rows. To determine coffee planting density, we will measure the distance from the trees in the subplot to their neighboring trees. The reported number should be in the form of distance between rows by distance between plants.

9. Cropping practices applied during the studied year, particularly fertilization and soil management practices (only for within the plot)

Specifically, we will obtain current year's data on:

- Pruning system
- No. chemical weedings
- No. mechanical weedings
- No. chemical fertilizer applications
- No. non-chemical fertilizer applications
- No. liming fertilizer applications
- No. chemical foliar fertilizer applications
- No. chemical soil fertilizer applications
- [For all fertilizer applications obtain amount, brand, and time of application]

10. Fruit load

We will count the number of fruiting nodes on the entire plant for each of the 5 marked plants. We will count by vertical axis. So if the plant has 3 axes, there will be three pieces of information to sum at the end. Note that after the short internode, there cannot be fruit. The short internode separates the old leaves (from last year) from the young leaves (from the current year). The fruits are born on the nodes of the previous year, where there are old leaves. Therefore, to count fruit load we must count the nodes with fruits on the whole branch, and these nodes will be located before the short internode.

11. Coffee plant age

We will document coffee plant age by number of years (months are not necessary). The 5 plants do not necessarily have to be all of the same age; they simply should be representative of the plot.

15. Experimental Site

My involvement with this larger research project will be field work and coordination of data collection in Honduras, Guatemala, and Mexico. Field trials will be established in Honduras with the involvement of IHCAFE beginning in 2018; laboratory trials have been started in Costa Rica (without my involvement) and will be replicated in Honduras in 2017.

Evaluation, and Outreach

16. Evaluation

Monitoring and Evaluation Matrix

Objective: The objective of this research is to understand the effects of coffee nutrition on coffee rust as a basis for developing Best Management Practices and new training programs for technicians and producers.				
Activities	Outcomes	Measures of Success	Documentation of Success	Progress to Date
1) Design measurement protocols for characterization study	1) Clear description of data collection points and how to measure them – to be referenced by field teams across 3 survey countries	1) Data collectors' understanding of measurement protocols	1) Final document translated to Spanish and distributed to field teams	1) Measurement protocols for characterization study in final form
2) Coordinate data collection plan	2) Allocation of labor for data collection in order to meet the large sampling size requirement of 400 farms	2) Sufficient distribution of data collectors to meet sampling requirements within desired timeframe	2) Written plan outlining technical staff, farms sites, and timeframe for data collection	2) Honduras data collection plan coordination in progress; Guatemala data collection plan coordination TBD; Mexico data collection plan coordination TBD
3) Construct iForm data collection tool	3) A tool for inputting data in a field setting and for managing a large	3) Pilot the iForm data collection tool to ensure that the written	3) Verification via monitoring of data collection to ensure that data collectors	3) iForm data collection tool is in draft form

	data set	protocols work in the field	are inputting data consistently in iForm	
4) Train field teams to collect data using iForm	4) An equip field team prepared to aid with data collection using the iForm tool	4) Necessary number of data collectors trained; ability to collect data points demonstrated by data collectors	4) Verification via monitoring of data collection to ensure that data collectors have gathered data consistently and understood training material	4) Honduras field team training scheduled for August 8 and 9; for Guatemala training date TBD; for Mexico training date TBD
5) Collect data from 175 farms in Honduras, 175 farms in Guatemala, and 50 farms in Mexico	5) Data collected will yield information on shade cover, shade type, coffee variety, coffee planting density, cropping practices applied during the studied year, shade cover, fruit load, coffee plant age, coffee rust incidence, coffee branch growth, and coffee plant defoliation	5) Completion of data entry by field teams for all target field sites	5) Complete data set for farms surveyed	5) Data collection in Honduras scheduled to begin in September 2016; in Guatemala start date TBD; in Mexico start date TBD
6) Analyze data	6) Data gathered from the characterization study will be analyzed to highlight the relationships between management, soil and the incidence of coffee rust	6) Relationships between management, soil and coffee rust are explored, but with no guarantee that these relationships are cause-effect relationships	6) Publication of preliminary report on first year of the survey in 2017; publication of final report made available in open access journal and to technicians and producers	6) Preliminary publication to be written in first quarter of 2017; final data analysis and report to be completed in 2019

17. Outreach

Outputs include a better scientific understanding of the effects of nutrition and soil health on coffee rust. Scientific publication will be an outcome of the study at several points throughout the study. Recommendations for farmers will be made about how to improve coffee nutrition and soil management in order to regulate coffee rust.

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Effects of Soil Fertility on the Incidence and Severity of Coffee Leaf Rust (*Hemileia vastatrix*)

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Introduction

Hemileia vastatrix is a parasitic fungus causing coffee leaf rust (CLR), a disease having widespread detrimental effects on coffee producers globally. Since 2012, the disease has had sweeping impacts on production in Central America and México where producers' yields and incomes have been significantly reduced.

Drawing from research in Brazil and Colombia, CLR has evolved relatively quickly, and complex races of the pathogen have been shown to break down the resistance genes proceeding from *C. canephora* used in *C. arabica* breeding (Avelino, 2016). A similar evolution is likely to occur in Central America where an increasing presence of resistant varieties is predicted to have high selection pressure on the pathogen (Avelino, 2016). Taking this into account, resistant varieties cannot be considered as a standalone solution to combat rust; they should be accompanied by management strategies that limit the presence of the disease through complementary mechanisms (Avelino, 2016).

Fertilizer applications seem to be critical, but little research has been conducted on the effects of the relationships between soil fertility management, coffee plant nutrition, and physiological resistance to rust (Avelino, 2016).

Objectives

The research objective is to understand the effects of soil health on coffee leaf rust as a basis for developing Best Management Practices and new training programs for technicians and producers.

Timeline	2016	2017			2018		2019
Characterization study in Honduras, Guatemala, and México	Field work **Phase I** (Preharvest)	Field work **Phase II** (Postharvest)	Analysis, preliminary report on the first year of the survey	Field work **Phase I** (Preharvest)	Field work **Phase II** (Postharvest)	Analysis, second preliminary report	Analysis and final report
Laboratory trial in Costa Rica	Nursery establishment	Trial, analysis, and final report					
Laboratory trial in Honduras		Nursery establishment			Trial, analysis, and final report		

Methods

In June 2016, CRS began working with CATIE and regional partners Promecafe, IHCAFE, and GAIA to conduct research that measures interactions between soil nutrient availability and coffee leaf rust disease presence at plots in Honduras, Guatemala, and México.

To study soil-rust interactions in a field setting, we use a subset of ~300 coffee plots among plots involved in CRS's Agricultura, Suelos, Agua (ASA) programming (~175 in Honduras, ~75 in Guatemala and ~50 in México). In each plot, CRS technicians and partner organizations collect data from both a subplot managed with fertilizer treatments and a control subplot managed by the producer as usual. As a result, the research study will have ~600 coffee plots under observation.

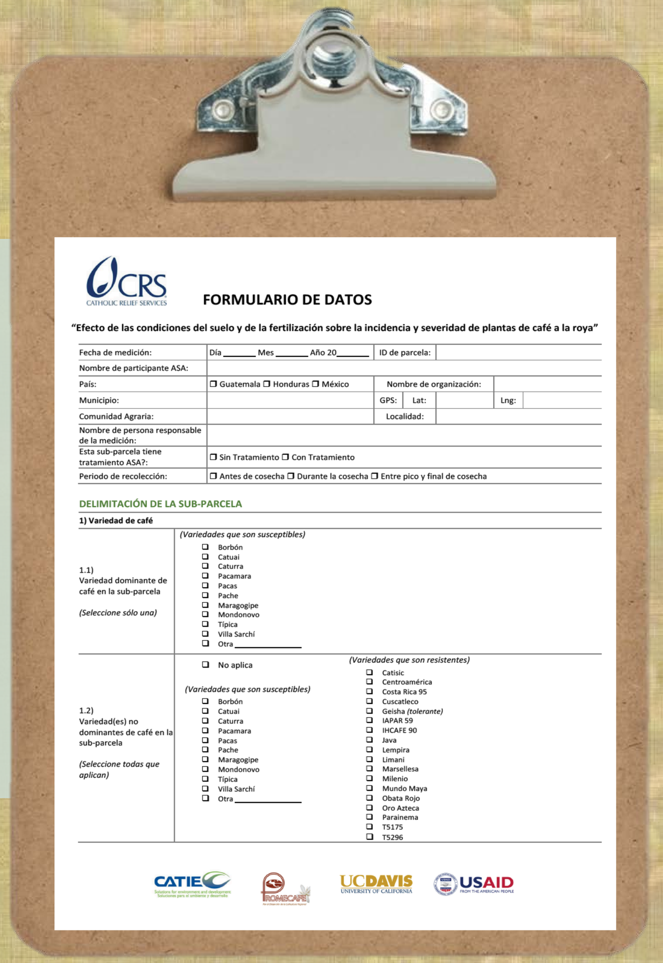
In addition to existing chemical soils baseline data manged by CRS, we trained technicians and smallholder producers in collecting data for the following variables: variety, density, plant age, cropping practices applied during the studied year, branch growth, defoliation, rust incidence, rust severity, fruit load, shade type, and shade cover. Most of these variables need to be considered because of their potential effects on CLR incidence.

Obtained from farmer interview:

1) Dominant variety in the subplot
2) Plant density within the subplot
3) Age of majority of coffee plants within the subplot
4) Management practices during the current year

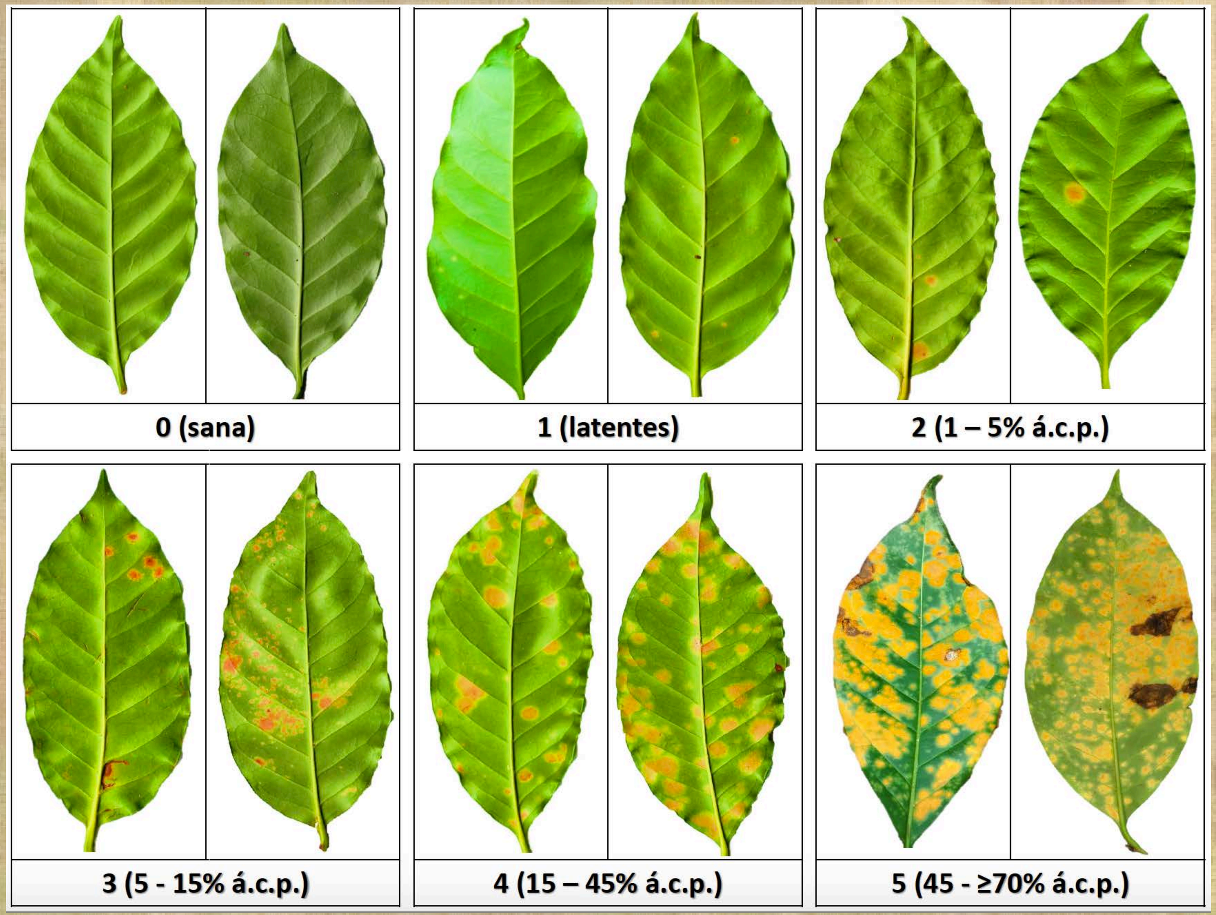
Obtained by technician:

- 5) Branch growth
- 6) Defoliation
- 7) Rust incidence
- 8) Rust severity
- 9) Fruit load
- 10) Shade type
- 11) Shade cover



Expected Outputs

- A better understanding of the effects of soil health on CLR to the scientific and technical community;
- Value to producer livelihoods in being conducted by Catholic Relief Services, whose objective is that the results of the study are significant and useful to smallholders.



Upcoming Work

- Phase II (2017) of field work;
- Data bases on rust incidence and severity coming from field surveys and laboratory trials;
- At least two scientific open-access publications on the relationships between soil health and coffee rust;
- One technical publication on best practices for managing coffee rust in each country involved.

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