Sustainable Mitigation Techniques for Coffee Leaf Rust in Loma Linda, Guatemala

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1) Introduction

Agriculture provides employment for an estimated 40% of the current global population and 80% of food consumed in a majority of the developing world (UN, 2014). While the economic and social benefits of agriculture are great, sustainable principles should be utilized to meet the needs of both present and future generations. The term “sustainable development” emerged during the mid-1980s to connect the environmental impact of an increasing global population with the creation of appropriate social policies (Mebratu, 1998). During a World Summit on Sustainable Development, principles and objectives were developed to promote sustainable economies; one such economy is the sustainable coffee sector. The high global demand of coffee is exceptionally important for the economies of countries such as Guatemala, which are largely dependent upon coffee for export earnings and goals of development (International Coffee Organization, 2014). A sustainable coffee economy is strongly desirable because coffee is an evergreen shrub that promotes bio-diversity, prevents soil erosion, and performs carbon sequestration, and by providing a fair wage to employees of the coffee production industry they will have reasonable living standards and ensure maintenance of quality (International Coffee Organization, 2014). As a group of students from WPI completing a degree requirement called the Interactive Qualifying Project, we selected a project of sustainable development in the community of Loma Linda, Guatemala with project sponsor Seven Hills Global Outreach (SHGO).

According to Assistant Director of SHGO, Jesse Mattleman, the community of Loma Linda formed in 1976 and relies on coffee production as its main source of income. Their location in a cloud forest of the Western Highlands of Guatemala has a surrounding environment that provides ideal conditions for the cultivation of coffee plants, and conserving the available

natural resources is essential for the community's sustainable development. However, a recent outbreak of *Hemileia vastatrix*, a fungus that causes the plant disease called coffee leaf rust (CLR) infected a majority of the community's coffee plants and is expected to continue spreading. Approximately 30 years ago, the community faced a similar outbreak and their main source of income was crippled for about eight years. Without knowledge or resources to control the CLR epidemic, the community had to let the contamination run its course and eventually it subsided on its own. By forming Asociación Sostenible Para El Desarrollo Integral y Turistico De Loma Linda (ASODILL), a community organization driven to enhance the community's economic sustainability, the community structured their efforts and was able to connect and form a partnership with our project sponsor Seven Hills Global Outreach (SHGO), who gather resources to solve local problems.

We discovered information regarding the life cycle of a coffee plant and of *H. vastatrix*, the plantation conditions in Loma Linda, and compared to past case studies *H. vastatrix* and CLR in similar conditions. Multiple researchers evaluated different coffee plant and plantation characteristics to see which promoted or inhibited the growth of CLR. It was found that certain agricultural practices could reduce both the propagation of CLR as well as the plant's physiological stress thereby granting more strength to recover from infection. Other scientists found that certain genetic traits of coffee plants made them more resilient to CLR or fully resistant and continue to study selective cross-breeding in hopes of creating the ideal coffee plant that is both resistant to CLR and also of high quality (Mishra & Slater, 2012). The application of various organic or inorganic fungicides to is also effective to prevent the spread of *H. vastatrix*, but only with proper timing and coverage of the plant. In addition, coffee producers noticed that CLR does not completely destroy plantations, and scientists hypothesized that there are natural

antagonists to *H. vastatrix* and CLR. Further examination led to the discovery of an ant-insect mutualism that results parasitism of *H. vastatrix* by the white halo fungus *Lecanicillium lecanii*. While there was a statistically significant effect of *L. lecanii* subsiding *H. vastatrix*, the complexity of the ecosystem has yet to be fully understood.

We compiled information about effective CLR mitigation techniques to assist affected communities. The goal of this project was to develop a sustainable strategy guide that would help coffee plot managers select an appropriate solution(s) to subdue CLR epidemic and prevent the likelihood of future outbreaks. To achieve this goal we sought to learn about the cause and effects of CLR, the results of CLR case studies, and the production conditions of Loma Linda's coffee cooperative and their previous attempts of CLR mitigation. Our CLR Strategy Guide utilizes well-documented and confirmed methods of CLR mitigation and contains information about their characteristics and feasibility. We included our CLR Strategy Guide along with a manual and directions for its different components and respective recommendations. We hope that our investigations will inform Loma Linda about alternative solutions to the CLR epidemic to allow them to agree upon an environmentally conscious, economically viable, and thus sustainable strategy. We also hope to provide insight to future groups seeking a cumulative guide to mitigating CLR and that the guide can be scaled and replicated in other communities.

2) Background

Developing a tool to aid decision makers required understanding their perspectives and the implications of various interventions. This section begins familiarizing the reader with sustainable development and the context of its practice in Guatemala, a country with a diverse culture of unique traditions and social behavior. Next, we focus on our project location Loma Linda, Guatemala by providing information that would determine whether our project was culturally appropriate, equitable, and sustainable. The decision aiding tool was influenced by two organizations that emphasize economic, environmental, and social sustainability: the community's organization Asociación Sostenible Para El Desarrollo Integral y Turistico De Loma Linda (ASODILL), and our project sponsor Seven Hills Global Outreach (SHGO). SHGO is a foundation with employees from across the globe that dedicates time and energy to facilitating the access of basic resources. SHGO partnered with ASODILL to increase Loma Linda's economic growth sustainably by leveraging the natural surrounding environment. A more detailed explanation of the non-profit organizations ASODILL and SHGO are discussed in sections 2.4 and 2.5, respectively. Loma Linda's main source of income is generated by an organic coffee cooperative, however the emergence of *Hemileia vastatrix*, a fungus that causes the plant disease coffee leaf rust (CLR), blighted a majority of the community's plants. We provide a description of the life cycle of a coffee plant, section 2.6, as well as that of *H. vastatrix* in section 2.7. We follow with preventative measures and mitigation techniques of CLR including agricultural practices in section 2.8, planting rust-resistant cultivars in section 2.9, the use of fungicides in section 2.10, and lastly, the naturally occurring indirect biological control of *H. vastatrix*, section 2.11. The forms of CLR mitigation have varying levels of effectiveness as well as different implications that are detailed in the following background.

2.1) Sustainable Development

The main motive of this project was to assist the community of Loma Linda while following a “sustainable development” model. Technological advances led to the Malthusian theory of “environmental limits” that stated that as populations grow, the availability of natural resources would deplete (Mebratu, 1998). Through means such as deforestation and chemical control in agriculture, environmental occupation in both developing and developed countries consequently depletes natural resources, degrades natural ecosystems, and causes pollution. It is difficult to predict the overall effect of these consequences and form a strategy of intervention because they take time to accumulate and pose no immediate threat. However, cognizant of the consequences, corporate, national, and international institutions have implemented sustainable policies that attempt to preserve and conserve economic, environmental, or socio-political resources of the planet for the use of future generations. Along with the concept of a sustainable society (Brown, 1981), the concept of sustainable development emerged in the early and mid-1980s (Clark & Munn, 1986; Brundtland Commission, 1987) in order to connect the ecological consequences of human activities with environmental concerns, as well as socio-political strategies related to human development issues (Mebratu, 1998). The term “sustainable development” was first defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1987, p. 43), what has been described as the main global debate of ecological unease (Dryzek, 1997). The conceptual definition of the Brundtland Commission emphasizes both the needs of the public and the limitations of social policy to meet the needs of both present and future generations (Mebratu, 1998). Our project sponsor SHGO and their partner ASODILL focus on this principle of living in order to conserve the natural surrounding environment while

promoting the development of Loma Linda. However, the vagueness of the definition alongside the increasing importance of its practice in corporate, national, and international policies, has led to varying interpretation, resulting in competitive policy implementation to determine the future of said establishments (Mebratu, 1998).

Although social policy converges on the desirability of sustainable development, the Brundtland Commission's definition is too vague to be used as a guide for making desired changes (Daly, 1996). It sounds great and fits nicely into political campaigns compared with its predecessor "eco-development" and is something to which everyone can agree (Pearce et al., 1989; Mebratu, 1998, p. 502). The concept has been associated with a repeated pattern of trepidation alongside polarized perceptions (Mebratu, 1998). "Sustainable development" has been described as difficult to grasp (Goldin & Winters, 1995), an oxymoron (Tryzna, 1995), and cliché (Holmberg, 1994). Some have been said to dramatize the issue of environmental constraints by predicting impending doom (Bhaskar & Glyn, 1995), and others remain optimistic by arguing that limited resources can be worked with at relatively little cost as long as appropriate, usually market-oriented, policies are implemented (Mebratu, 1998). Despite varying interpretations, the scientific consensus on ecological imbalances caused by human intervention has gradually focused, arriving at the conclusion that the damage inflicted by human activities on the natural environment render those activities unsustainable (Erkins & Jacobs, 1995; Mebratu, 1998, p. 503). The need to unify within a stable principle of sustainable development has resulted in two major positions of the matter: a preservationist position, and a conservationist position (Robinson, 2004).

A preservationist position is expressed in romantic or spiritual terms with intellectual roots in American transcendentalism, European romanticism, religious, or traditional values

(Robinson, 2004; Mebratu, 1998). Alternatively, while a conservationist position favors protection of natural areas as well, the purpose is to consciously conserve land and resources for later use, such as resource extraction and eco-tourism (Robinson, 2004). The conservationist position has often been explicitly founded by a utilitarian and social philosophy with goals that benefit the majority and promote access to the wonders of nature (Nash, 1982). One can perceive the community of Loma Linda's desire to pursue the eco-tourism initiative as a conservationist position, to utilize the environment for the benefit of the community and that of the future as well. However, maintaining environments through conservation does not account for restoring depleted resources and environments, and one must consider the three major components of sustainability where achieving a balance is desirable: the economy, the environment, and socio-politics.

Balance however, is difficult to achieve as conflict emerges between the different objectives of each component. Economic sustainability focuses on financial growth instead of development (Blowers et al., 2012). Sustainable economic development suggests ideas such as quality of life and well-being; ideas that are difficult to define or realize. More importantly, during times of economic hardship, social policy tends to focus strictly on growth. As a result, quality of life and well-being become distant luxuries and hopes rather than realities. A political theme that perceives the environment as an impediment to growth consistently emerges among planners who reiterate that planning must operate to encourage growth (Dept. of Communities and Local Government, 2011). While policies claim to incorporate environmentally sustainable practices, there is usually a lack thereof as a result of focus on growth rather than development. During decision making, there is a tendency to prioritize present economic gain over future environmental loss because ideas are experienced in the present, rather than envisioned as in the

future (Blowers et al., 2012). Furthermore, the social process involving collective choices at a variety of local to global levels gives rise to another problem: the behavioral change of an entire community (Blowers et al., 2012). “It is totally unrealistic to expect many individuals or communities to act unilaterally when others are not doing so. Nor is it realistic to expect sufficient success in the wake of businesses ‘going it alone’ in adopting green practices – any more than it is from individuals doing so” (Hillman, 2011). While ASODILL desires balancing the three components of sustainable development, some of their current challenges are a lack of the community’s understanding, support, and participation (Mattleman, unpublished raw data). Decision making depends on the motives, biases, and political resources of the interested parties (Geva-May & Wildavsky, 1997), therefore understanding the foundational context of their needs and desires is necessary, described in the following sections.

2.2) Guatemala

Guatemala is a country in Central America between the Pacific Ocean and Caribbean Sea, south-east of Mexico, and bordered by Belize, Honduras, and El Salvador. The country has a tropical climate. A chain of mountains and volcanoes divides the country into three regions, the Pacific Coast, the cooler Highlands, and the humid Petén lowlands. In 2012, more than half the citizens of Guatemala are under the age of 19 years old, giving Guatemala the youngest population in Latin America (CIA, 2014). It has a literacy rate of 75.9%, education expenditure accounting for 3% of the GDP, and a school life expectancy of 11 years (CIA, 2014). Nearly 60% of Guatemalans speak Spanish, while the remainder speak Ladino or native languages, such as Q’eqchi, the prominent native language in the region we evaluated (CIA, 2014). Guatemalan traditions originate from Mayan heritage, however less than 5% practice traditional Mayan religion, and Christian faiths including Roman Catholicism and Protestantism are predominant

(CIA, 2014). Despite the unity within Guatemala's regional demographics, the country remains divided among its classes.

The end of 36 years of civil war came with the signing of the 1996 Guatemalan Peace Accords in the Mam Maya village of Todos Santos. However, the resulting dichotomy between the wealthy class and those in poverty created lasting divisions between inhabitants. While Guatemala has the largest economy in Central America, it remains one of the poorest nations. There exists a high level of inequality, with over half the population below the national poverty line, 13% in extreme poverty, and approximately 20% upper class citizens (CIA, 2014) who account for approximately 50% of Guatemala's overall consumption (The World Bank, 2014). During the signing of the Guatemalan Peace Accords, an observer claimed, "as long as we're still poor, peace hasn't arrived" (Burrell, 2012). The civil war caused setbacks for foreign investment due to business insecurity with a lack of infrastructure and skilled workers (The World Bank, 2014). Following the signing of the 1996 Peace Accords, the World Bank designed a Country Partnership Strategy that gave Guatemala objectives of building stable institutions, creating international trade agreements, and promoting inclusive and sustainable growth with hopes of providing equal opportunities to all citizens.

Guatemala has worked to achieve macroeconomic and democratic stability mainly through agriculture (The World Bank, 2014). The agricultural sector accounts for 13.5% of GDP and 38% of the labor force (The World Bank, 2014). Guatemala's major export, coffee, accounts for one-third of all revenue generated by agricultural exports and plays a significant role in the lives of Guatemalans (International Fund for Agricultural Development, 2013). However, the most recent CLR epidemic completely devastated 5% of Guatemala's coffee plantations, equivalent to 125 million coffee plants (World Coffee Research, 2013). Considering that the

yearly capacity for coffee plant production is 1.5 million coffee plants, the significant need for replacing lost plants provides potential for new sectors in coffee plant production (World Coffee Research, 2013).

While coffee dominates Guatemala's exports, alternative income generating solutions are available through crop diversification and eco-tourism. Aside from coffee, key agricultural exports include sugar, bananas, and vegetables. While large companies produce a majority of the crops, small-scale farms cultivate fruits and vegetables for subsistence, but could sell to the large companies and increase the country's net exports. On the other hand, Guatemala's affordable costs of food and housing alongside surrounding lush rainforests and diverse wildlife provide an ideal environment for tourists. Eco-tourism results from a conservationist attitude of protecting the environment while creating a safe and structured setting for backpackers, hikers, and birdwatchers through trails with signage and knowledgeable tour guides who can provide unique encounters in nature (Hempstead, 2011). However, between the majority of Guatemalans living in poverty and a CLR epidemic diminishing available funding to pursue alternative sources of income, strategic planning and partnerships must be made to overcome adversity and achieve macroeconomic stability. "Economic development and stable social structures are critical first steps required in this largely agrarian society" (SHGO, 2014).

2.3) Loma Linda

Loma Linda is a tightly woven community where members rely on one another and work as a team to accomplish objectives. As a cooperative community supported by organic agriculture and coffee-production, the community relies on sustainable principles to meet their current needs and maintain or develop opportunities for future generations. Loma Linda is situated within the Guatemalan chain of volcanoes in the Highlands region. According to the

Assistant Director of Seven Hills Global Outreach, Jesse Mattleman, the community was formed in September, 1976 by a Catholic Cooperative. To live in Loma Linda, newcomers must agree with conditions mandated by the Catholic Cooperative (Mattleman, Unpublished Raw Data). Following approval, accepted peoples are given equal plots of land with communally-built houses that are organized using a spiraling formation, originating on a single lateral road. An approximate population of 1,200 families range in size from five to twelve people who utilize organic agriculture to farm crops such as corn, beans, bananas, bok choy, and more fruits and vegetables, for subsistence (SHGO, 2012). Loma Linda values organic agriculture because it promotes environmental sustainability and earns a marketplace advantage (Mattleman, Unpublished Raw Data). A major component of the community's agriculture and their primary source of revenue comes from a coffee cooperative formed by 120 families. The cultivation, harvest, and processing of coffee is Loma Linda's main form of sustainable development. Like many communities in Central America, the ambient conditions that led to the circumstances of Loma Linda today cause the coffee cooperative to dominate local employment.

Loma Linda has ideal growing conditions for coffee plantations for many reasons. A high elevation produces Hard Bean (HB) and Strictly Hard Bean (SHB) rated coffee beans, the highest quality of coffee beans (Hempstead, 2011). The nearby volcano Santiaguito expels ash into the air that later falls to the ground and makes the soil extremely fertile, soil classified as Andisol (Hempstead, 2011). A variety of nitrogen-fixing trees of the genus *Inga*, such as chalum (*I. micheliana*), caspirol (*I. fagifolia*), and cushin (*I. laurina*), provide nitrogen, an essential nutrient for plant proteins, nucleic acids, and other cellular constituents. Because the *Inga* grow large leaves that later fall and provide long lasting mulch and branch in a crown pattern resulting in shade for nearby plants, the growth of nearby plants such as coffee is slowed, allowing them to

mature over a longer period of time, thus resulting in richer tasting coffee (Inga Foundation, 2014). Shade trees also promote bio-diversity by simultaneously providing habitats to many bird and insect species (Inga Foundation, 2014). Lastly, a long rainy season between May and September promotes natural growth of coffee plants, and a dry season between November and April synchronizes flower bud differentiation (Van Der Vossen, 2009). Loma Linda faces economic hardship if anything interrupts the functionality of the coffee cooperative (Mattleman, Unpublished Raw Data).

The community, aware of a fluctuating global coffee market, the potential blight of coffee plants, and the lack of employment opportunities, has multiple groups that seek to create microbusinesses with local projects to diversify the community's forms of sustainable development. The needs and desires of each group play a role in social dynamic and decision making. In order to fully predict the implications of intervening, one must understand that the social dynamic of the community is a factor. The community values set by the Catholic Cooperative alongside the motives, biases, and political resources of interested parties influenced our project. Other groups beside the coffee cooperative include: ASODILL, a formalized organization for the development of the community; Grupo Organico, an organic farming group within the cooperative; Mundo Verde, a women's coffee collective; and COCODE, a regional government-liaison board for community development. Although our connection to Loma Linda was facilitated by the partnership between our project sponsor SHGO and the community organization ASODILL, many members of the community are unaware of ASODILL's purpose, and therefore do not support it (Mattleman, Unpublished Raw Data). ASODILL's situation reminds us that as a new influence in the society, our CLR Strategy Guide needed to be sensitive to their lifestyle and challenges.

2.4) Asociación Sostenible Para El Desarrollo Integral y Turistico De Loma Linda

Pascual Rafael Escobar of Loma Linda founded the Asociación Sostenible Para El Desarrollo Integral y Turistico De Loma Linda (ASODILL) on October 15, 2006. Translated to English, this means the association for integral development in Loma Linda. ASODILL is a non-profit organization legally authorized by the Guatemalan government with a board of directors that includes a president, vice president, secretary, treasurer, fiscal advisor, and the general coordinator Señor Escobar. Originally formed by 12 politically ambitious members of Loma Linda, ASODILL presented a proposal to the Catholic Cooperative in a general assembly that welcomed the entire community of Loma Linda to join (ASODILL, 2012). Today ASODILL is comprised of 25 active volunteers who dedicate their time and energy to develop local projects and facilitate democratic community participation for sustainable development (SHGO, 2014).

Through community education, campaigns, and training, ASODILL emphasizes and teaches a deep appreciation for the outdoors, aiding the community with collaboration to authorize the surrounding environment as a national protected area (SHGO, 2014). ASODILL also advances an initiative for eco-tourism and responsible environmental practices (SHGO, 2014). The organization supports the needs of local families through education, recreation, and development of food security systems that utilize organic farming. Please refer to table 2.4.1 below to see the principles of ASODILL, including their purpose, mission, and vision.

ASODILL: Asociación Sostenible Para El Desarrollo Integral y Turistico De Loma Linda	
Purpose	"To promote conservation of the natural surrounding habitat while emphasizing environmental education, local knowledge and capacity, ecotourism, organic farming, and sustainable coffee production" (ASODILL, 2012).
Mission	"To be a means of formation, training, and educative growth on the personal as well as collective level, to support learning and transportation through sustainable livelihoods, and to promote the advancement of education in the Guatemalan community" (ASODILL, 2012).
Vision	"To transform monocultural productive practices into crop diversification, to set an example of new forms of livelihoods working towards economic improvement and growth for both the members of ASODILL as well as the community, to establish and create micro-businesses, especially those that are youth-oriented so that the youth of Loma Linda can have a new vision of the future, and to be a model of work and production through agriculture, tourism, and animal raising" (ASODILL, 2012).

Table 2.4.1: ASODILL's Principles (ASODILL, 2012.)

ASODILL, a formalized group with a visible history of activity proved its legitimacy and earned recognition from an international development group, SHGO. SHGO established a partnership with ASODILL and provides support through scholarship funding and donations of basic supplies (ASODILL, 2012). Under the coordination of Señor Escobar, SHGO's partnership with ASODILL is currently focused on a five-year plan to develop and implement an infrastructure for ecotourism in the community to boost economic sustainability by leveraging the incredible natural surroundings of Loma Linda. A series of tour routes were developed and presented to many visitor groups. In 2011, SHGO visited Loma Linda to help clear and construct trails and features and finished most of the work by spring of 2013 (Mattleman, Unpublished Raw Data). A tourist hotel was built, largely with donated labor, and a donated computer forms

the basis of the ASODILL office (ASODILL, 2012).

The ecotourism effort is coupled with a comprehensive plan for local community participation and ownership, environmental education, indigenous capacity-building, and international volunteerism. However, the CLR epidemic resulted in setbacks for social and economic development. Between the initial lack of funding and the predicted loss of coffee plants, members of the community needed to reorganize their objectives and strategize a future plan that, if feasible, would acquire grants for funding. After our project sponsor SHGO informed us of recent developments with the CLR crisis, we shifted objectives to help ASODILL develop a course of action.

2.5) Seven Hills Global Outreach

Our sponsor SHGO was essential to connecting us with the community Loma Linda to gather enough information and make educated decisions with our project. Directed by Ashley Gilbert, SHGO is a non-profit organization based in Massachusetts, “working throughout the world to address basic needs in low resource communities in developing countries” (SHGO, 2014). SHGO prioritizes assisting communities whose greatest challenge is the lack of access to basic resources. Through humanitarian efforts of partnering, SHGO addresses health, education, and human service organizations in developing nations and home communities of Seven Hills’ staff (SHGO, 2014). SHGO places emphasis on environmental, social, and economic sustainability, and addresses the critical need for potable water, food, clothing, education and healthcare in developing countries to enable local solutions to these challenges (SHGO, 2014).

Comprised of a diverse staff from over 45 different countries, SHGO leverages a partnership-based approach with international partners to take a comprehensive approach to international development. SHGO commits to partnerships because they want communities to

develop by using their own means through local knowledge, capacity, and core competencies (Mattleman, Unpublished Raw Data). Partnerships and self-development resonate with sustainability because it ensures that once SHGO finishes a project and leaves the community, that the community will continue to function autonomously. In Guatemala, for those in poverty, environmental challenges like deforestation of the Petén rain forest, soil erosion, and water pollution are distant priorities (SHGO, 2014). In January 2011, a division of SHGO led by Assistant Director Jesse Mattleman visited the rural highlands of central Guatemala to solidify a partnership with ASODILL. The partnership was designed to help the coffee cooperative community of Loma Linda preserve the environment through an eco-tourism social business (SHGO, 2014). ASODILL works to promote conservation while emphasizing economic development through eco-tourism, organic farming, and sustainable coffee production. SHGO provided a series of local knowledge and capacity workshops to teach inhabitants different techniques of self-organization (Trowbridge, 2012). With a shared set of intentions, ASODILL and SHGO are partnered to encourage sustainable, holistic, community-driven development in Guatemala and other parts of the world (SHGO, 2014).

2.6) Coffee Plants

On average, the total amount of coffee consumed a day worldwide is estimated to be 1.6 billion cups (International Coffee Organization, 2010). In monetary value, coffee is the most important agricultural product in international trade (Arneson, 2011), thus it is important to know the species of coffee, the plant's life cycle, and process of cultivation. There are four species of coffee plants as a result of natural and selective cross-breeding, however, we will only focus on *Coffea arabica* and *Coffea canephora* in this project. *C. arabica* (commonly referred to as Arabica), is the most largely cultivated species in the world, farmed mainly in Central and South

America (Mangal, 2007). It has an ideal farming altitude of 1000 meters above sea level and yields coffee beans of the best quality that sell at premium prices (Mangal, 2007). Farmers experience more difficulty cultivating Arabica than other species because it is the most susceptible to CLR and other pests (Mangal, 2007). *C. canephora* (also referred to as Robusta) is the second most cultivated species, produced mainly in Africa. Compared to Arabica, Robusta is a lower quality coffee and prices are typically 30 to 40% less (Mangal, 2007). Robusta is used mainly in instant coffee and for blending with Arabicas to adjust flavor (Mangal, 2007). It can be cultivated at lower altitudes and as its common name "Robusta" implies, it is widely used for robust resistance to CLR and other pests (Mangal, 2007).

The species Arabica and Robusta have many different varieties and range in size from 0.5 to 3 meters tall. Coffee plants have a ternary structure with primary branches, and possibly secondary, as well as tertiary branches. Primary branches originate from the stem of the plant, while secondary grow from the primary, and tertiary from the secondary. Occasionally, additional thick branches called suckers that do not bear fruit will grow on the stem in a vertical direction (Mangal, 2007). Coffee plants reach maturity at the age of five and their fruit is commercially viable at the age of six (Mangal, 2007); after seven years, coffee plants reach maximum production (Charlip, 2003). Until that time, berries from young plants are pruned to reduce physiological stress on the plant (Mangal, 2007). If transplanted from another grove, coffee plants begin producing berries after two years and a crop is available at the end of three years. Though most productive between the ages of five and fifteen, coffee plants produce berries for forty or more years, and fifty-year-old plants are common (Charlip, 2003). Robusta coffee plants for example, can have a lifespan of up to one hundred years (Mangal, 2007). However, to allow natural restoration of degraded landscape, the average plantation lifespan is

thirty years, meaning that coffee plants are economically viable up until that time (Mangal, 2007). The process of bearing fruit begins with flowering, a very sensitive process that cannot be induced artificially (Mangal, 2007). Flowering requires environmental stimuli including the daily light cycle and “blossom showers,” the watering necessary to induce blossoming (Mangal, 2007). In countries such as Guatemala that have a dry and rainy season, a single hard and dependable rain during the dry season induces flowering (Hempstead, 2011). For self-pollinating Arabica plants, pollination of female plants takes place five to seven hours after flowering (Mangal, 2007). Other coffee plants such as Robusta require cross-pollination provided by wind or the presence of pollinators such as honeybees or butterflies (Coffee Research Institute, 2006). Plants are fertilized within 48 hours of pollination, and berries grow in the place of flowers eight months later (Mangal, 2007). Within four months, the green berries typically reach a size of 10 to 15 mm in diameter, and become red during the seventh or eighth month of development (Illy & Viani, 2005).

Coffee plants need a specific environment and the use of proper cultivation techniques in order to survive and thrive. The environmental factors that will ultimately determine the quality of the coffee include elevation, temperature, precipitation, and soil, as well as agricultural practices including pruning, plant spacing, and shade coverage (Mangal, 2007). Higher altitudes provide a cooler environment that causes ripening to delay, allowing beans to mature more slowly, and resulting in higher quality coffee (Mangal, 2007). Optimum daily temperatures range from 20 to 24 ºC, but temperatures higher than 30 ºC or lower than 15 ºC will limit plant growth by inducing plant stress and reducing photosynthesis (Mangal, 2007). Coffee plants need subsoil water at all times, and at least 1,000 mm of annual rainfall or they will require irrigation (Charlip, 2003). The ideal range of precipitation is 1,600 mm to 1,800 mm of annual rainfall

(CBS&A, 2012). The ideal growth medium is red volcanic soil (called Andisol) because it is extremely fertile (Hempstead, 2011). In the first three years of life, the plant requires a good supply of nitrogen, phosphorus, calcium, magnesium, and sulfur to ensure the proper development of roots (Mangal, 2007). The nutrition of the tree is dependent on the surrounding humidity. Low humidity will prevent nutrient absorption because the plant will close its pores to prevent dehydration while high humidity will prevent nutrient absorption because the plant will not eliminate water (CBS&A, 2012). The optimum soil pH ranges from five to six because low pH will overload plants with nutrients while high pH will inhibit plants from absorbing nutrients (Mangal, 2007). The use of nearby shade-trees will prevent soil erosion and protect coffee plants from excess wind and sunlight (Mangal, 2007). Maintaining at least 2.0 meters between rows and 1.5 meters between plants within rows will prevent nutrient competition (Mangal, 2007). Farmers choose to cut-off the top of coffee plants to keep them from growing too tall and make harvesting easier by keeping the fruits within reach (Waller et al, 2007).

2.7) *Hemileia vastatrix* and Coffee Leaf Rust

The global worth of coffee production from 2009-2010 was estimated to be 15.4 billion USD (International Coffee Organization, 2010). However, a recent outbreak of a coffee fungus called *Hemileia vastatrix* that causes the coffee plant disease CLR resulted in a diminution of global coffee production. The epidemic affected many coffee growing plantations and farmlands in Central America, including communities such as Loma Linda who depend on coffee for employment and a main source of income. CLR is thought to have naturally developed in coffee's country of origin, Ethiopia, Africa (Waller et al., 2007). After transporting coffee plants to Ceylon (now called Sri Lanka) for mass production, the "coffee leaf disease" was first reported by the English explorer Reverend H. J. Berkeley and his assistant, Mr. Broom (Waller

et al., 2007). In the 1869 edition of *Gardeners Chronicle*, they gave the name *Hemileia vastatrix* to describe a fungus they found on some dried coffee leaves associated with the disease (Arneson, 2011). Since the discovery of *H. vastatrix* in Ceylon in 1869, there has been extensive research dedicated to combating this disease.

H. vastatrix directly affects the leaves of the coffee plant by causing premature defoliation that weakens the branches and reduces plant yield (Schieber, 1972). Symptoms of CLR are exhibited by powdery yellow or orange spots about five to eight centimeters in diameter, first appearing on the underside of an infected leaf (Figure 2.7.1). After maturing and causing plant nutrient deficiency, a corresponding yellowing spot occurs on the topside of the leaf that can grow several centimeters in diameter throughout its life cycle (Waller et al., 2007).

Figure 2.7.1: Coffee leaf rust lesion (World Coffee Press, 2014). © 2014 World Coffee Press

Furthermore, it is important to know that this fungus not only causes defoliation, but reduces future foliation and berry production by approximately 50% and 70%, respectively (Suresh et al., 2012). This percentage is positively correlated with the reduction of photosynthesis caused by *H. vastatrix*. The reduction of photosynthesis limits the physiology of the coffee plant such as root growth, flowering, and cherry yield (Brown et al., 1995). Aside from the fungus-leaf interactions, in order to understand the initiation of CLR and its effects on

coffee plants, one must first evaluate the life cycle of *H. vastatrix*. Thorough understanding of both the *H. vastatrix* lifecycle and the initiation of CLR will lead to different avenues of research and development of coffee plants with genes that are resistant to CLR.

The life cycle of *H. vastatrix* begins with the growth of the urediniospore within spores. Development of the urediniospore requires the presence of free water, usually derived from rain or heavy dew, and a temperature within the range of 21 to 25 ºC (Avelino et al., 2004). Furthermore, urediniospores can often produce two to three germ tubes that are used for germ pores. A germ pore is a thin area in the outer wall of a spore through which the germ tube makes its exit on germination (Merriam-Webster Dictionary, 2014). After the development of urediniospore through germ pores in the spore, the germ tube will produce an appressoria, a specialized fungal cell used to infect a host plant, on the stomata of the plant. In turn, this appressoria will produce a vesicle through which infecting hypha enter the substomatal cavity. Hypha are each of the branching filaments that make up the mycelium of a fungus, commonly referred to as an infection peg. This infection will subdivide into the intercellular substomatal cavity and then penetrates the leaf tissue by means of haustoria (Carvalho et al., 2011). The outward displacement of this process is the presence of a lesion on the leaf surface (Arneson, 2011).

However, without a 24 to 48 hour period of continuous moisture, the process of infection of CLR will terminate (Arneson, 2011). Usually occurring during the rainy season but also potentially during the dry season, it takes three to six weeks for infection to develop into lesions. A lesion can produce four to six spore crops over a three to five month period; each spore crop releases approximately 75,000 spores, thus a single lesion can release hundreds of thousands of spores (Waller et al., 2007). Another major factor of the life cycle of CLR, sporulation, occurs

ten to fourteen days after infection, developing new uredinia and urediniospores. Major influences of sporulation are temperature, moisture, and host resistance (Arneson, 2011). A picture of the life cycle of CLR can be seen in Figure 2.7.1 below.

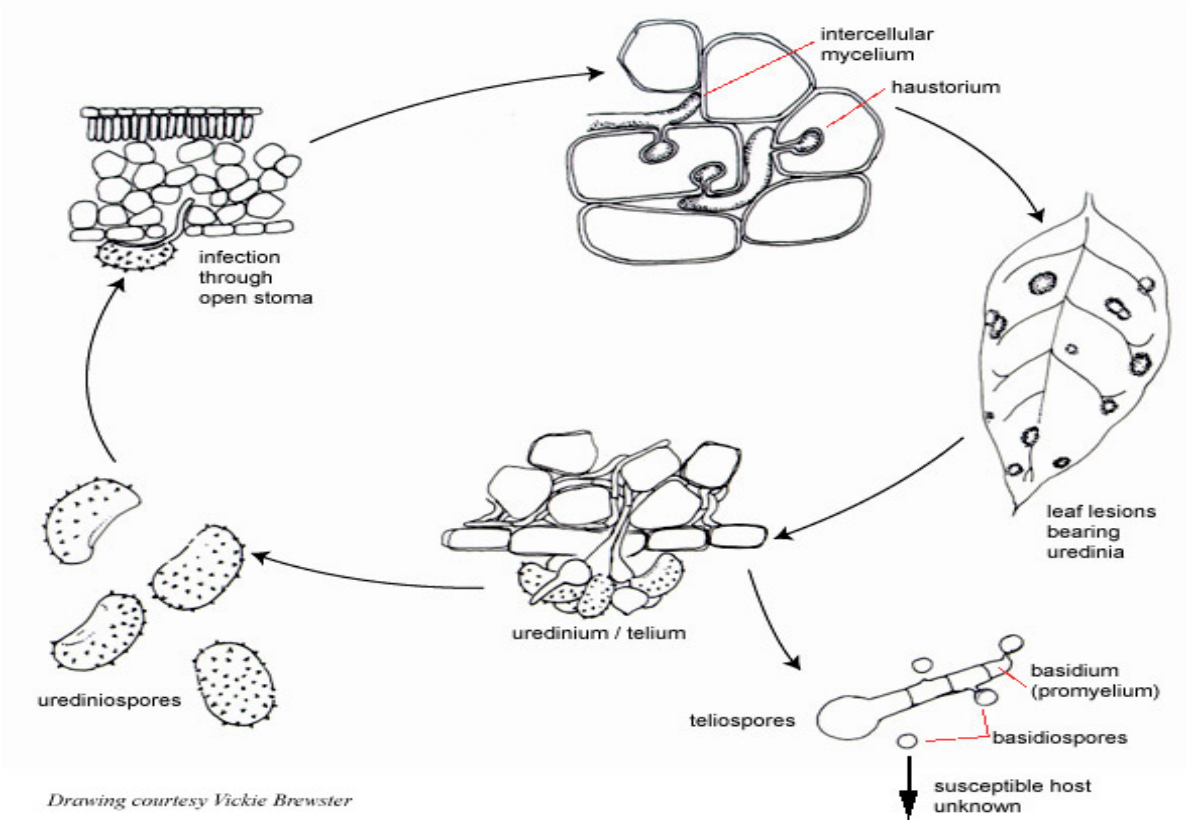

Figure 2.7.1: The life cycle of H. vastatrix is simple. Urediniospores start infections that eventually become lesions that reproduce additional urediniospores (Arneson, 2011).

The life cycle and degree of infection of CLR is mainly determined by the local climate. It is most severe in warm and humid weather, but it also appears in higher altitudes with cooler temperatures. After infection, CLR can spread by wind, rain, infected seeds, insects, and human intervention. Although full-sun style plantations are more susceptible to CLR due to spore dispersal caused by turbulent gusts, coffee plant leaves under full sunlight or high-intensity light will experience slower fungal growth due to a decrease in wetness caused by a greater amount of aeration (Avelino & Savary, 2004). Whether a plantation is covered by shade or under full-sun,

farmers must consider the species and variety of the coffee plants that they are growing and their resistant to rust. It affects two of the world's most commercial coffee species, Arabica and Robusta, however CLR is more aggressive in the former (Schieber, 1972). The reason is because the genes of Arabica are more susceptible to CLR compared to those of Robusta that are more resistant.

2.8) Agricultural Practices

Developing and implementing strategic certain agricultural practices is crucial to every coffee grower when combating CLR. However, it is difficult to determine which are most useful because some may help prevent CLR, while others may actually promote future growth (López-Bravoa & Avelino, 2012). This report focuses on four agricultural practices known to reduce CLR when performed correctly. All are described in detail throughout this section, including coffee plant pruning, adjusting the amount of surrounding shade, spacing plants appropriately, and maintaining soil nutrition. For this information, we relied only on consistent experiments where farmers test effects on CLR under strict control variables to see the conditions that are responsible for the spread of CLR.

A common technique used by farmers to combat CLR is coffee plant pruning. By selecting an appropriate time during a season, pruning can be used to stimulate or inhibit plant growth. Pruning is required to supply good healthy wood for next season's crop, to maintain the correct balance between leaf area and crop, to prevent overbearing and dieback, and to maintain good tree shape. By pruning old, unproductive, and unwanted branches, farmers eliminate branch competition (Mangal, 2007). The plant's physiological stress will be reduced and it can distribute more of the soil nutrients to areas of growth (Mangal, 2007). However, pruned areas will recover and the leaf area will increase thereby increasing plant physiological stress, therefore farmers

should maintain plant shape by active pruning (Avelino & Savary, 2004). Coffee plant farmers thoroughly prune after harvest, during the dry season, to keep plants healthy by cutting off old, nonproductive, or unwanted branches.

Additionally, a regular rejuvenation pruning is normally needed at six to seven years of age depending on tree health and yield pattern (Mangal, 2007). Two methods of rejuvenation, side pruning and full stumping, will eliminate nonproductive parts of the plant and stimulate future growth. Side pruning involves pruning the east side of the tree after harvest two years prior to stumping, ensuring that only 50% of the crop is lost (Mangal, 2007). The farmer must encourage the growth of a new sucker situated 30 to 45 centimeters above ground, and after two years of sucker growth, the original older stem is stumped at a 45 degree angle above the stem of the sucker. Full stumping involves cutting the tree to half a meter at a 45 degree angle to develop a new step from the stump; this is not recommended because the entire crop will be lost for one and most often two years (Mangal, 2007).

Pruning and rejuvenation will increase coffee plant fruit yield and maintain healthy plants that can defend themselves against diseases. However, coffee farmers should prune fruit nodes because increased fruit yield is positively correlated with plant physiological stress that will increase susceptibility to diseases. For coffee plants infected by CLR, the immediate result of pruning is the reduction of foliage that provide host sites for *H. vastatrix*, and the increase of light penetration that is detrimental to urediniospore germination (Arneson, 2011). CLR spots can become visible a few weeks after infection, therefore farmers should attentively cut off any contaminated leaves right away. Clipping parts of the plant displaying lesions effectively eliminates a large amount inoculum thereby reducing infection (Avelino & Savary, 2004).

Fruit yield can also be controlled by adjusting the amount of shade cover. In general, the canopy of shade trees acts like an umbrella that prevents over-exposure from the sun while also protecting coffee plants from wind and physical injury that would enable the penetration of pathogens (López-Bravoa & Avelino, 2012). However, while the canopy of shade-trees protects plants, it benefits fungi such as *H. vastatrix* by diminishing aeration and promoting a humid environment (López-Bravoa & Avelino, 2012). Humidity alone is not enough for the development of *H. vastatrix*. While heavy dew is enough to stimulate urediniospore germination, infection usually occurs during the rainy season because of heavy rainfall (Arneson, 2011). To determine the influence of shade-trees on *H. vastatrix*, a series of experiments were conducted, each with different results.

In an experiment completed in Tarrialba, Costa Rica, it was observed that during months of heavy rainfall, shade trees prevented wind and sunlight from drying the soil and plants, promoted a humid environment, and created a desirable environment for the growth of CLR (López-Bravoa & Avelino, 2012). The researchers concluded that the spread of CLR caused by shade coverage outweighed the protection provided to coffee plants (López-Bravoa & Avelino, 2012). However, the researchers of the study in Costa Rica claim that shade coverage is an unpredictable and controversial variable because it affects the growth of CLR in different ways, and further experimentation was conducted to measure the effects of shade and plant yield on the spread of CLR (López-Bravoa & Avelino, 2012). Two sections of coffee plants were cultivated on the same plot of land in order to maintain consistent conditions of cultivation (López-Bravoa & Avelino, 2012). One side of the plot contained shade trees, while the other plot was fully exposed to the sun (López-Bravoa & Avelino, 2012).

To determine whether shade or fruit yield promoted CLR incidence, each coffee plot contained plants with different amounts of fruit nodes: none, 150, 250, and 500. After two years of measuring the temperatures, wetness, and relative humidity of leaves, results confirmed that excessive coffee plant yield promoted the growth of CLR more than shade coverage (López-Bravoa & Avelino, 2012). Researchers hypothesized that this was because high coffee plant yield induced greater plant physiological stress thereby reducing the plant's ability to fight an infection (López-Bravoa & Avelino, 2012). Although shade coverage minimizes fruit yield, when comparing plants with the same yield from both plots, it was evident that shade also somewhat increased CLR (López-Bravoa & Avelino, 2012).

A study conducted in Honduras concluded that there was a positive correlation between increased percentage of shade and incidence of CLR (Avelino et al., 2006). The study in Honduras concluded that the highest rust incidents occurred between shade percentages of 56 to 83 (Avelino et al., 2006). To define general ranges of shade coverage, our team considered less than 35% to be low, between 35% and 50% to be moderate, and more than 50% to be high. Because utilizing shade coverage results in lower plant yield, farmers often cultivate more coffee plants in the same area, resulting in high population density. This practice affects health of individual plants because high population density leads to interplant soil nutrient competition because soil contains a limited amount of nutrients.

To increase soil nutrition, farmers can choose to add chemical and natural fertilizers or a combination of the two. Chemical fertilizers can be expensive, are made of non-renewable resources such as fossil fuels, and cause environmental pollution due to watershed. Intense rain can wash the nutrients and fertilizers away to nearby rivers and wildlife, contaminating nearby areas. Apart from polluting the earth, high levels of fertilizer can favor CLR because fertilized

plants will grow more, resulting in larger leaf area that favors urediniospore interception. Fertilizers encourage higher plant yields that increase leaf susceptibility and reduce the duration of the CLR latency period (Avelino & Savary, 2004). Too much fertilizer can also lead to increased soil acidity, therefore farmers should take caution. The optimum soil pH ranges between of 5 or 6 because extreme acidic soil will overload the plant and cause it to languise, while alkaline soil will lack the necessary nutrients (Avelino & Savary, 2004). Chemicals such as limestone or dolomite can be used to neutralize the acidity of soil, but can also be harmful to the environment and surrounding ecosystems (Avelino & Savary, 2004). An organic alternative to chemical fertilizers is the use of vermicompost, banana tree leaves, and dried weeds for mulch. Despite the manual labor required, this practice has many benefits. Vermicomposting is an effective means of disposing of coffee pulpa, the shell of coffee cherries removed during extraction of beans. Using banana leaves and mulch reduces soil temperature in hot environments, prevents water loss through evaporation, reduces the growth of weeds near crops, and replaces nutrients lost by the harvest (Mangal, 2007). Mulch is usually applied at the end of the rainy season and should cover the ground with a depth of 10 centimeters, leaving a gap around the plant stem (Waller et al, 2007).

2.9) Hybrid Coffee Plants

A hybrid coffee plant is a crossbreed between parent plants of two different species or varieties of coffee, which can be natural or selective, occurring within nature or a laboratory, respectively (Hybrid Plant, 2012). A hybrid plant is either classified as intraspecific, a crossbreed from parent plants of the same species, or interspecific, a crossbreed from parent plants of different species (Robinson, 2009). There are 134 coffee plant species recognized in the world today (Anthony et al., 2011), and each species and their respective varieties vary in terms of fruit

yield and flavor, but it is well known that Robusta is resistant to CLR and Arabica is susceptible. A variety is a coffee plant within a species that is distinguished by the environment and region in which it is grown. Some attributes that distinguish one region's coffee variety from another are flavor, body, taste, and amount of caffeine, which relate to the cupping quality of the coffee plant's beans (Illy & Vivani, 2005). Cupping quality is a process of smelling, tasting, and describing the flavor of a cup of coffee to define the market value of a plant's coffee beans, and ranges from poor, to good, and lastly excellent (Illy & Vivani, 2005). The genetics of coffee plants have been studied for decades, and various numbers of chromosomes carry different genetic traits. Arabica has 44 chromosomes and Robusta has 22, and certain chromosomes can be matched to create a coffee plant with desirable traits including high fruit yield, excellent cupping quality, and resistance to CLR (Mishra & Slater, 2012). Evidence from various case studies explain that knowing about a coffee plant's genetic pool will provide insight on the identification and development of more coffee plants that are tolerant to CLR (Diola et al., 2011; Gladys et al., 2010; Carvalho et al., 2011). This can also be beneficial to coffee producers such as Loma Linda, who need to maintain coffee production for their economic sustainability.

Arabica has two major varieties that are a product of natural crossbreeding, *C. arabica var. typica* (typica) and *C. arabica var. bourbón* (bourbon). Typica has a tapered stem and secondary branches that produce low seasonal fruit yield, but beans with excellent cupping quality. On the other hand, bourbon has small and clustered secondary branches that yield 20 to 30% more fruit than typica and has beans of excellent cupping quality (Coffee Research Institute, 2006). Loma Linda grows three varieties of Arabica, bourbon, caturra, and catuai. Caturra is a direct descendent of bourbon that can adapt to almost any environment, producing a high yield with good cupping quality (Coffee Research Institute, 2006). Catuai is a cross-breed

of *C. arabica var. Mundo Novo* and caturra, which produces a high yield of beans with good cupping quality (Coffee Research Institute, 2006). Because these plants have high yield with excellent cupping quality, they are ideal for coffee production. However, because Arabica has genetic susceptibility to CLR, 70% of Loma Linda's coffee plants were affected by a recent CLR outbreak therefore hindering the community's coffee production (Mattleman, Unpublished Raw Data). The following sections explains various hybrid coffee plants available in Central America that are specifically crossbred to be resistant to CLR. The S that precedes the names of certain hybrid plants mean selection. Selection is picking a plant with the best quality characteristic from a population with a variety of genetic constitutions (Arterburn et al, (N/A); Kurian et al., 2007). Although it is recommended to maintain a minimum space of 1.5 meters between plants in rows and 2.0 meters between rows in coffee plots, some of these plants may require more or less based on their size and nutritional intake.

2.9.1) S288

S288 grows in a tall upright position and grows dense with secondary and tertiary branches. Fruit nodes bear six to eight pea berries composing up to 40 % of the plant and the recommended spacing is 1.8 meters by 2.0 meters. Because S288 originated from India, its genotype is closely related to *C. arabica* (Kushalappa & Eskes, 1989; Kurian et al., 2007). S288 is resistant to CLR and it is a direct descendant of the S26, a natural hybrid cross-breed of *C. arabica* and *C. liberica*.

2.9.2) S795

S795 was originally discovered in India and is a cross-breed between S288 and *C. arabica var. kent* (Kent) (Kushalappa & Eskes, 1989). It has high yield, good cupping quality, and is resistant to CLR (Clifford et al., 1985). S795 grows in a tall upright position dense with

secondary branches and can produce a high yield of large beans. On average it produces 14 to 16 medium-sized bold fruits per node and the recommended spacing is 1.8 meters by 2.0 meters (Kushalappa & Eskes, 1989).

2.9.3) Agaro x Cioccie x S795

Agaro is a variety of *C. arabica* that originated from Ethiopia (Mishra et al., 2010); Cioccie x S795 is a tall plant with copious secondary and tertiary branches. It yields 12 to 14 oblong, bold fruit per node, and produces large beans with excellent cupping quality. This plant matures faster than most coffee plants, and the recommended spacing is 1.8 meters by 2.1 meters apart (Kushalappa et al., 1989; Mishra et al., 2010).

2.9.4) Devamachy x S881

Devamachy (a cross-breed between *C. canephora* and *C. arabica*) crossed with S881 (a variety of *C. arabica* that originated from Rume, Sudan) is a tall and robust plant with light bronze leaves and dense secondary and tertiary branches (Kurian et al., 2007). It grows eight to ten fruits per node, and yields medium sized beans and the recommended spacing is 1.8 meters by 2.1 meters apart (Kushalappa & Eskes, 1989; Kurian et al., 2007).

2.9.5) S274 x Kent

S274 (*C. canephora*) x Kent (*C. arabica*) is a sturdy tall coffee plant with broad dark-green leaves with wavy margins, and has dense secondary and tertiary branches. It produces 18 to 20 bold, medium-sized, roundish fruit per node and the recommended spacing 1.8 meters by 2.0 meters apart (Kushalappa & Eskes, 1989; Kurian et al., 2007).

2.9.6) Tafarikela

Tafarikela is a variety of *C. arabica* that originated from Ethiopia, Africa but is prominently grown in India (Ramesh et al., 2007). It grows in a tall upright position with dark

bronze colored leaves and few secondary branches. It yields eight to twelve small and oblong fruit per node (Kushalappa & Eskes, 1989).

2.9.7) San Ramon Hybrid

San Ramon Hybrid is a multiple-cross hybrid coffee plant between San Ramon (a variety of *C. arabica*), S795, Agraro, and Hibrido de Timor. It is a dwarf coffee plant with dark green and bronze leaves. It has close fruit clusters that yield 16 to 18 bold, round fruit per node and the recommended spacing is 1.5 meters by 2.0 meters (Kushalappa & Eskes, 1989; Kurian et al., 2007).

2.9.8) Hibrido de Timor

Hibrido de Timor is a cross-breed between *C. arabica* and *C. canephora* originally found in East Timor. It is tall with light to dark bronze leaves and few secondary and tertiary branches. Composing up to 60% of the plant, it yields 12 to 14 large, oblong, and round fruit per node. The recommended spacing for planting this crop is 1.8 meters 2.0 meters apart. Hibrido de Timor has the most resistance to CLR and it genotype has been used in collaboration with other plants to produce more hybrids plant, however it has poor cupping quality (Kushalappa & Eskes, 1989).

2.9.9) Tafarikela x Hibrido de Timor

Tafarikela x Hibrido de Timor are tall and robust plants with light green to bronze leaves and profuse secondary and tertiaries branches. This plant produces 12 to 15 bold, medium-sized fruits per node and the recommended spacing is 1.5 meters by 2.0 meters apart (Kushalappa & Eskes, 1989).

2.9.10) Icatu

Icatu originated from Brazil and has a high resistant to CLR and is a multiple-cross hybrid plant between *C. canephora*, *C. Arabica*, and backcrossed with *C. arabica var Mundo*

Novo (Mundo Novo) and *C. arabica var Caturra*. It yields a high amount of beans with a good cupping quality (Coffee Research Institute, 2006).

2.9.11) Catimor

C. arabica var. catimor commonly known as Catimor is a cross-breed between *Hibrido de Timor* and *C. arabica var. Caturra* (Caturra). This plant matures very early and produces a high yield. Catimor is a plant that when grown at high altitude it has excellent cupping quality, however still produces a good cupping quality at low altitude. Furthermore, Catimor has three main varieties, Catimor T-5175, 5269 and 8667 (Coffee Research Institute, 2006).

2.9.12) Colombia

Colombia, as its name implies, originated from Colombia, and is a tall plant with a selective variety composed of a number of plants from the *Catimor* line that produces large beans with a good cupping quality (Illy & Vivani, 2005).

2.9.13) Sarchimor

Sarchimor is a disease-resistant cross-breed between *C. arabica var. Villa Sarchi* (Villa Sarchi) and Hibrido de Timor. It is similar to Catimor in compact growth and resistance to CLR; Tupi, Obata, and IAPAR59 (Brazil) are Sarchimor-like cultivars (Illy & Vivani, 2005).

2.10) Fungicides

Fungi are the primary cause of crop loss worldwide, however harvest loss can be prevented by applying chemical fungicides, which will reduce fungal infections (McGrath, 2004). Although costly, fungicides are considered a long-term investment that affects current and future seasons and the benefit of maintaining harvest yield may outweigh the price of applying fungicides (Arneson, 2011). Fungicides are chemicals with various levels of toxicity, and must be handled accordingly. Environmental implications must be considered and fungicides should

be mixed with proper amounts of water and only applied when necessary to prevent pollution. Handlers of fungicides must wear protective clothing such as chemically resistant coveralls, shoes, socks, gloves, and eye-wear (EPA, 2003). If the skin or eyes of the handler make contact with fungicides, the handler must thoroughly wash the affected area, and medication may be necessary (EPA, 2003).

There are many different forms of fungicides and methods of application. The most commonly used forms of fungicides are either liquid or gas, and are typically applied to the seeds, roots, leaves, or soil, although in rare cases the fungicide can be injected into plant (McGrath, 2004). Fungicides are most effective both in enclosed areas and with complete coverage of area, and can be applied by hand-held devices (Figure 2.10.1), tractors, or aircraft (McGrath, 2004). Hand-held devices are utilized when in small areas or where precise application is necessary, however the process usually takes longer because infected areas must be treated on a case by case basis. Alternatively, tractors or aircraft are ideal for quick large-scale applications, though neither ensures proper and consistent coverage of specific areas. In any case, selecting the proper fungicide and method of application is crucial to effectively manage any type of fungi (Nameth & Chatfield, (N/A)). For coffee plants infected by CLR, handheld devices are preferable and precise application should begin at the bottom of the plant and proceed to the top (Damicone & Smith, (N/A)). The period of application (e.g., every week or biweekly) varies depending on the type of fungicide used. Rainfall and ventilation decrease the effectiveness of the fungicide, thus reapplication will be necessary (Nameth & Chatfield, (N/A)). Most fungicides must be applied to the plant before fungal infection occurs or at first appearance (McGrath, 2004). If inoculum levels are kept low towards the end of a harvest season, then infection and harvest loss will be reduced in the following season (Arneson, 2011). However,

fungi can develop a tolerance to fungicides, otherwise known as fungicide resistance, thus the selected fungicide must be alternated with other types of fungicides to reduce this risk (Damicone & Smith, (N/A)).

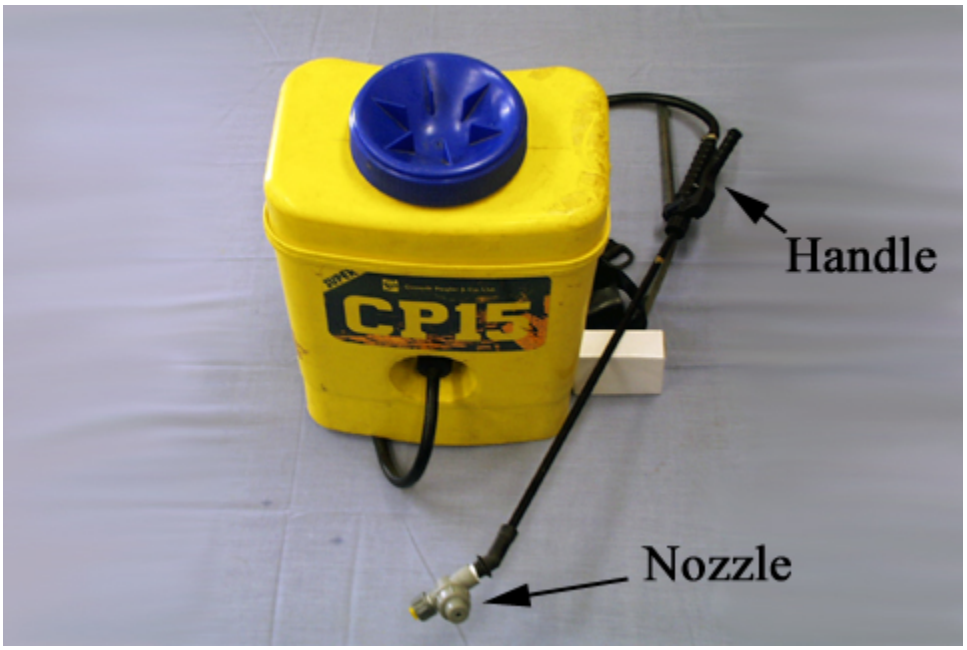

Figure 2.10.1: Handheld Device for Application of Fungicides (McGrath, 2004)

2.10.1) Fungicide Resistance

Before applying any fungicide to a plant, the farmer must understand the concept of fungicide resistance. Fungicide resistance was first reported in the 1970s due to an increase in high-volume crop production requiring chemical control (Hanrahan, 2002). Resistance occurs when a fungus builds a tolerance to a fungicide, leading to ineffective control and crop loss (Wong, 2003). Depending on the frequency of reproduction, a fungus can mutate, develop immunity to a fungicide, and pass the mutation onto offspring; the more frequent the life cycle repeats, the greater the likelihood of the development of fungicide resistance (Hanrahan, 2002). When the same fungicide is used, the surviving organism becomes the dominant strain and over time “the resistant strain replaces all other strains and the disease becomes increasingly difficult

to control" (Hanrahan, 2002). A fungus will develop fungicide resistance much more quickly when the same fungicide is overused. However, there are ways to prevent this from occurring.

Proper maintenance and sanitation of infected areas will promote the health of plants, reduce initial pathogen populations, and lower the rate of disease incidence, thus weakening the fungi and reducing the chances of fungicide resistance (Damicone & Smith, (N/A)). Examples of proper maintenance and sanitation include pruning, maintaining soil nutrients, intercropping, and crop rotation. Plant pruning and maintaining soil nutrients will strengthen the plant and preserve soil nutrients. Intercropping is the practice of growing a plant with a "smother" crop in the same area to efficiently use land space, fully utilize soil nutrients or add them, and eliminate plant competition by weeds (Liebman & Dyck, 1993). Crop rotation is the process of using the same land to systematically grow different crops on a recurring cycle to manage organic matter in the soil and improve its productivity (Liebman & Dyck, 1993). Implementing the aforementioned practices will result in healthy plants that rely less on fungicides and reduce the risk of resistance (Hanrahan, 2002).

When fungicide resistance occurs, all similar cross-resistance groups are affected (Hanrahan, 2002). Cross-resistance is a tolerance to a class of fungicides due to exposure of a related substance and not necessarily direct exposure. When a fungus develops cross-resistance, a fungicide of different chemical composition must be used (Wong, 2003). By knowing the chemical composition of the fungicide and its cross-resistance class, farmers can predict the risk of resistance when alternating fungicides. Regardless of the type of fungicide or whether the fungus has developed cross-resistance it is important that the same fungicide is not reintroduced into the same area (Damicone & Smith (N/A)).Fungicide manufacturers provide information regarding of the fungicide's chemical class, frequency of application, and safety procedure.

Selecting a proper fungicide can be difficult for a farmer, especially if they practice organic agriculture. Whether a fungicide is considered organic or inorganic depends on the type of chemical used (McGrath, 2004). Organic molecules contain carbon atoms in their structure and inorganic molecules do not (McGrath, 2004). Examples of organic fungicides effective against CLR are copper-compounds, sulfur-based, and neem oil fungicides, but an inorganic fungicide, for example is dithiocarbamate; these fungicides are described in the following sections.

2.10.2) Copper-compound

Copper-compound fungicides eliminate fungi and bacteria effectively (Ferreira et al., 1991). Copper fungicides should be applied 14-21 day intervals depending on the rainfall and thorough coverage is required (EPA, 2012). The minimum interval of application is 14 days and the maximum recommended interval is 21 days (EPA, 2012). A copper fungicide should be applied before it rains and at 21 day intervals in the presence of continuous and heavy rainfall to prevent fungicide washaway (EPA, 2012). The risk of fungicide resistance associated with copper-compounds is very low because it is a strong chemical and is very effective against CLR (Arneson, 2011). If the resistance occurs, it must be alternated with another fungicide to maintain effectiveness. When used improperly, such as repeated and frequent applications, they can reach high levels of toxicity that will harm both the plant and the environment (Arneson, 2011). In order to reduce the level of toxicity, copper could be used with other types of fungicides and in addition, the effectiveness of the fungicides will increase (Arneson, 2011). Copper based fungicides are toxic to ingest or inhale, and will irritate the skin and eyes (EPA, 2012), and to prevent plant damage, some care must be taken (Beckerman, 2008). For example, young foliage is sensitive to copper-compound and farmers must use a weaker dose for these types of leaves (Beckerman, 2008). Copper fungicides should not be used if temperature exceeds 30 ºC (EPA,

2012). These practices will avoid damaging the coffee plant's foliage (EPA, 2012). Although copper is highly effective against CLR, the price is high and varies from different places and should be used before the infection of CLR occurs as well.

2.10.3) Sulfur and Lime-Sulfur

As the oldest recognized fungicide, sulfur has been around for over 2000-years and has proven to be very effective against fungi (Beckerman, 2008). Sulfur prevents fungal spores from developing and can be applied through dust, wettable powder, or liquid (Beckerman, 2008). To avoid high levels of toxicity and killing plants, one must not use Sulfur and Neem Oil fungicides in the same area within one month (Beckerman, 2008). While sulfur has a low level of toxicity, physical contact with skin, eyes, nose, or throat will cause irritation (EPA, 2003) Lime-sulfur, is the combination of calcium hydroxide and sulfur mixed together, but it is rarely used because of the strong odor (Beckerman, 2008). Lime-sulfur can be used in temperatures greater than 30 ºC, thus making it suitable for areas in Central America (Beckerman, 2008).

2.10.4) Neem-Oil

Neem-Oil is organic and has a very low level of toxicity but can still irritate the skin, eyes, and nose if physical contact is made (EPA, 2003). Neem oil is produced from fruit and seeds of the neem tree, *Azadirachta indica* (Beckerman, 2008). The neem oil eliminates both powdery fungal spores and insect eggs, which benefits the farmer because insects could potentially spread fungal spores to other plants. Monitoring the amount of infection will determine whether the neem oil will be the most appropriate fungicide (Beckerman, 2008). Again, when rotating fungicides to reduce the chance of fungicide resistance, the neem oil cannot be used on areas where sulfur has been used in the previous month because the combination of the two within a short period of time is toxic and could harm the plant (Beckerman, 2008).

2.10.5) Dithiocarbamate

Dithiocarbamate is a non-toxic and inorganic fungicide. Although dithiocarbamate is effective against fungi, it is not as effective as copper-compound (Arneson, 2011). When dithiocarbamate and copper fungicides are combined, their effectiveness against CLR is improved (Arneson, 2011). However, any combination of dithiocarbamate and copper fungicides will be inorganic (Ferreira et al., 1991). Dithiocarbamate fungicides should be sprayed on the surface of the plant to prevent the spread of infection. A disadvantage of dithiocarbamate is the necessity for frequent application due to its short residual life and unreliability in high temperatures and humidity (Arneson, 2011).

2.11) Indirect Biological Control

Mitigating CLR through the use of good agricultural practices such as reducing dense shade cover, planting resistant cultivars, and applying fungicides seem to have worked to some degree (Fulton, 1984), but even in farms with dense shade cover and without rust-resistant cultivars, CLR epidemics were not as destructive as feared (McCook, 2006). It is possible that the reduced effect of the disease is partly caused by natural antagonists or enemies, and is hypothesized that if farmers encourage ecosystems of natural enemies of *H. vastatrix* and simultaneously practice CLR-inhibiting agricultural practices, plant rust-resistant cultivars, or apply fungicides, the odds of subsiding CLR can potentially increase (Avelino, 2004). In a 2009 study, there was a statistically significant effect, approximately three to five percent, of CLR reduction linked to an indirect effect of an ant-insect mutualism (Vandermeer et al., 2009). After multi-year surveys of this indirect effect, a one-year time lag between initiation and the suppression of CLR was observed (Jackson et al., 2012). The results suggest that effective biological control of *H. vastatrix* will be enhanced by understanding the way that these complex

intertwining ecosystems spread across a landscape, which relates directly to the scale insect *Coccus viridis* (Figure 2.11.1).

Figure 2.11.1: The green coffee scale, Coccus viridis. Adults with crawlers (small white individuals) and nymphs; photograph: John Vandermeer (Vandermeer et al., 2010).

Commonly referred to as the green coffee scale insect, *C. viridis* is a major pest within coffee crops across the globe. A natural enemy of both the scale insect *C. viridis* and the CLR causing fungus *H. vastatrix* is the fungus *Lecanicillium lecanii*, commonly referred to as white halo fungus. *L. lecanii* has been observed to attack *H. vastatrix* both in laboratory and field settings, but only after becoming epizootic, or in other words, prevalent among an animal population such as the scale insects (Jackson et al., 2012). Under normal conditions, scale insects do not reach high population density due to predators such as wasps or the lady beetle, *Azya orbigera* (Figure 2.11.2a). However, the highly aggressive ants *Azteca instabilis* (Figure 2.11.1) tend the scale insects for their honeydew, scare wasps away, and kill mature lady beetles (Figure

2.11.2c). On the other hand, lady beetle larvae, which are normally preyed upon by wasps, remain and feed on the scale insects (Figure 2.11.2b). This is because the larvae secrete a waxy filament that disables the ant's mandible, preventing the ability of the *Azteca* ant to kill (Figure 2.11.2c). Additionally, because mature lady beetles and their eggs are attacked and eradicated within minutes, there remains question about how females manage to lay eggs among the ants. It is believed that female lady beetles strategically oviposit with relation to parasites of the *Azteca* ant, which will be discussed later in this section. Aside from the complex ant-insect interactions, because scale insect populations are tended by the *Azteca* ants, the spatial distribution of *Azteca* ant nests have been studied (Vandermeer et al., 2010).

Figure 2.11.1: Azteca instabilis; photograph: Alex Wild (Vandermeer et al., 2010).

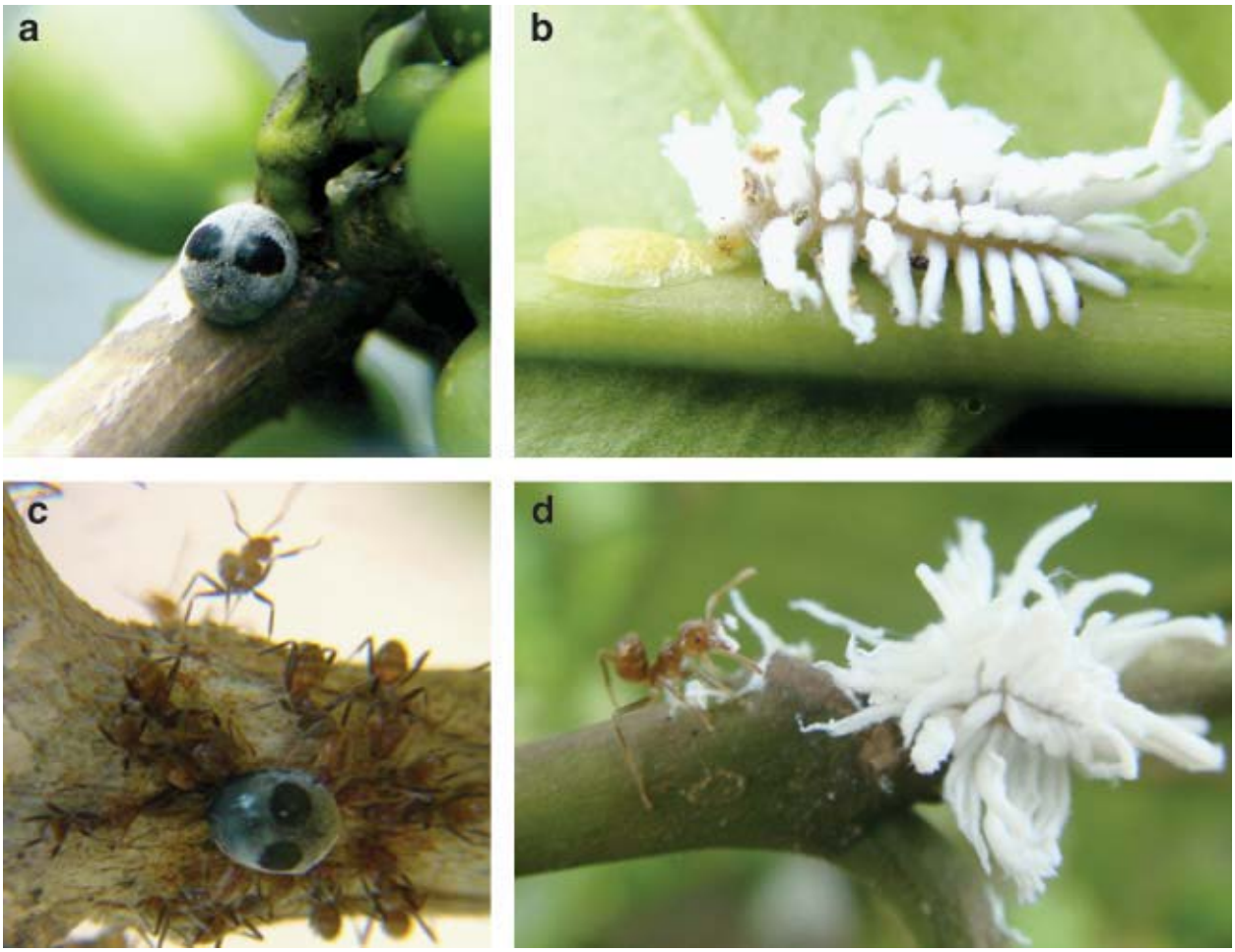

Figure 2.11.2: Azya orbigera (a) adult, (b) larvae eating a scale insect, (c) adult being attacked by Azteca ants, (d) Azteca ant with mandibles filled with waxy filaments of a beetle larva; photographs: Shinsuke Uno (a and c), Ivette Perfecto (b and d) (Vandermeer et al., 2010).

In order for the *A. instabilis* to form a nest, they need a tree and a steady source of food. Shade-trees on coffee plantations provide an ideal nest because the close proximity to coffee bushes typically have significant populations of green scale insects that excrete honeydew. Among many other insects such as the aforementioned parasitic wasps, the *A. instabilis* feed on the honeydew, thus the *Inga* shade-trees provide a home and nearby sustenance. However, without the green scale insects, the *A. instabilis* will not form nests. Although other ants in the ecosystem can tend scale insects, they do not do so as effectively as the *A. instabilis*. For example, in a 2010 study, approximately 3,000 scale insects were found in coffee bushes tended

by *A. instabilis*, while those tended by other ants only had about 50 to 100 scale insects (Vandermeer et al., 2010). Such ants include the *Pheidole ctp,* whose presence can protect a small amount of scale insects and thus initiate colonization by *A. instabilis*. The *P. ctp* can forage in the ground and in trees and are at an advantage when competing with arboreal foragers. However, the *P. ctp* cannot compete their natural enemy, another ground nesting ant called *Pheidole protensa. P. protensa* are incapable of providing the local scale insect concentration required by the *A. instabilis* and it is unknown which conditions are favorable for *P. ctp* or *P. protensa,* however this component of the system remains under study (Vandermeer et al., 2010). In addition to pressure associated with competition between ground and arboreal foraging ants, the nests are not random, but are formed in satellite clusters that follow some other type of unidentified pressure (Vandermeer et al., 2010).

It is hypothesized that the spatial distribution of nests is influenced by predation of the ants by a parasitic fly in the family *Phoridae* within the genus *Pseudacteon,* referred to as phorid flies (Vandermeer et al., 2010). Intensive surveys have established that phorid flies only attack *A. instabilis* in high density populations (Vandermeer et al., 2008; Philpott et al., 2009), and that this "parasitoid uses chemical cues to locate its ant host" (Mathis et al., 2010). A high concentration of *Azteca* ant alarm pheromones, used to signal other ants to tend the scale insects, will signal phorid flies (Vandermeer et al., 2010). Additionally, while under attack by phorid flies, *A. instabilis* release another communicative pheromone to warn other ants and it has also been hypothesized that the "phorid pheromone" also signals nearby lady beetles of an opportunity to lay eggs, which hatch into larvae that feed on the scale insects (Figure 2.11.3) (Vandermeer et al., 2010). "High-density clusters of nests are preferentially attacked by phorid flies and consequently disappear—the ants either die or move on to other trees" (Vandermeer et

al., 2010). Ant-insect populations and concentrations are constantly shifting, while nests are not formed evenly across a landscape, there is a determining factor that has yet to be determined.

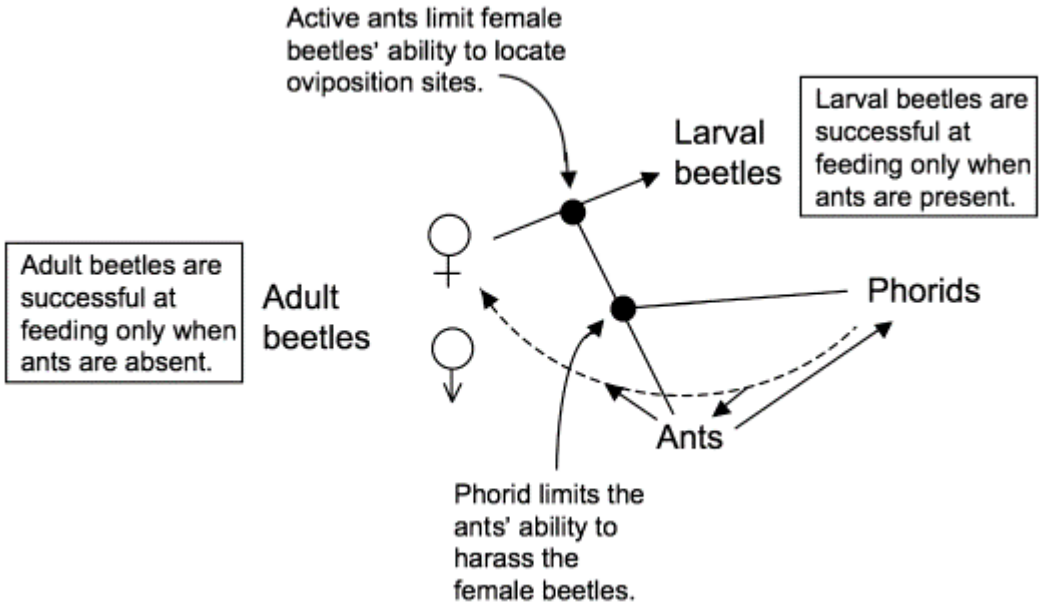

Figure 2.11.3: ant-insect relationships (Vandermeer et al., 2010)

The ant-insect interactions are complex, creating the necessary conditions can be difficult, and it takes time for observable reduction in CLR. Therefore, in order to effectively utilize indirect biological control, it is important to create a high population of the white halo fungus *L. lecanii* in the early arrival of *H. vastatrix* and onset of CLR (Jackson et al., 2012). The abundance of white halo fungus occurs during advanced stages of infection among high density populations of the scale insect *C. viridis* that is only possible under the presence of the arboreal nesting ant and mutualistic partner *A. instabilis* (Figure 2.11.4) (Jackson et al., 2012). *Azteca* ant nests require a location and sustenance, provided by a local concentration of scale insects that may be tended by other ants such as *P. ctp,* however the pattern of formation is affected by an unidentified pressure. Additionally, there has been observed reduction of the tending of scale insects by *A. instabilis* after epizootics of *L. lecanii,* a phenomena that has yet to be explained (Jackson et al., 2012). The distribution of *Azteca* colonies across a landscape results in the spread

white halo fungus and while active epizootics could attack *H. vastatrix* within the same season, the soil serves as an environmental reservoir of white halo fungus propagules (Meyling & Eilenberg, 2006). It is possible that the accumulation of white halo fungus propagules during a season will attack CLR when emerging from dormancy in the following wet season (Waller, 1982) resulting in a one-year lag time effect in the effective suppression of *H. vastatrix* (Jackson et al., 2012). Studies thus far accumulated evidence that indirect biological control with white halo fungus can have a statistically significant and controlling effect on *H. vastatrix* (Avelino et al., 2004; Jackson et al., 2012), yet the complexity suggests further examination should new information come to light.

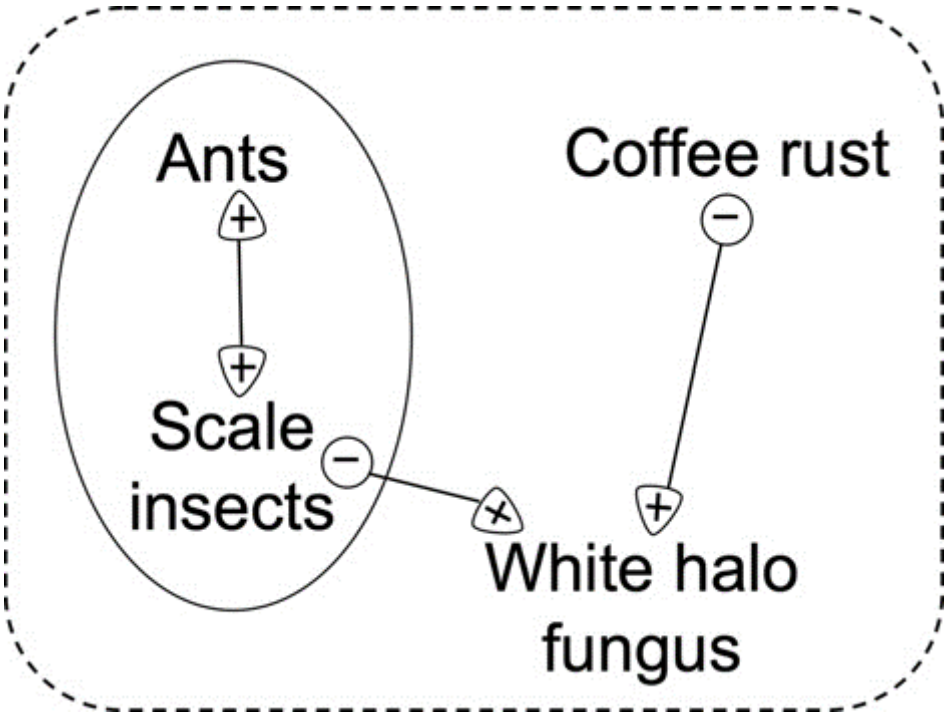

Figure 2.11.4: "The ants (A. instabilis) mutualism with the scale insects (C. viridis) is indicated by positive arrows. The white halo fungus (L. lecanii) has a negative effect on the scale insects, indicated by a negative circle, as well as a negative effect on the coffee rust (H. vastatrix). The ants and scale insects occur in spatially restricted pockets on the farm, indicated by the oval containing them. The farm as a whole, indicated by the dashed rounded rectangle, contains the white halo fungus and the coffee rust" (Vandermeer et al., 2010).

3) Methods

The goal of this project was to develop a sustainable decision making tool that would help coffee plot managers select an appropriate solution(s) to end the current CLR epidemic and prevent future outbreaks. To achieve this goal we followed these objectives:

1. Learn about CLR: its cause and effects
2. Examine CLR epidemic case studies to learn about conditions affecting its propagation and compile potential solutions
3. Learn about Loma Linda's plantation conditions and previous attempts of CLR mitigation
4. Develop a CLR Strategy Guide to aid decision makers in Loma Linda with evaluation of the characteristics and feasibility of mitigation techniques and taking sustainable action

Across the globe and especially for countries whose export earnings are mainly acquired through coffee production, CLR is a significant issue among coffee producers and connoisseurs. Our strategy guide could help the communities of Loma Linda compare the implications of various mitigation techniques and strategize sustainable implementation. In this way, our guide would resonate with ASODILL's principles (see table 2.4.1) and SHGO's partnership based approach by sharing our knowledge rather than providing strict directives. Our project could impact the community by subsiding the CLR epidemic and preserving their major source of income. As a means of accomplishing our objectives, we used rational planning throughout our project, "a process for determining appropriate future action by utilizing scarce resources in such a way as to maximize the expected attainment of a set of given ends" (Morris, 2014). To gather information and develop the CLR Strategy Guide, we performed in-depth interviews and reviewed the relevant literature and case studies using both WPI Summon and Google Scholar.

3.1) Interview Methods

We chose to use in-depth interviewing techniques to learn about the needs and the community and the CLR epidemic they faced. In-depth interviewing allowed us to gather information and clarify our questions to maximize the information we received (Gubrium & Holstein, 2002). “The goal here is one of subjecting yourself and your social situation, to the set of contingencies that play upon a set of individuals, so that you can physically and ecologically penetrate their circle or response to their social situation, their work situation, or their ethnic situation” (Goffman, 1989). Erving Goffman emphasizes that in-depth interviews are utilized to gain knowledge of the informant to understand the circumstances they face and immerse oneself within their perspective. Our project could ultimately affect a community composed of different personal values thus we wanted to enter the mindset of an active member of the community. We desired an informant involved with the community so that they could share first-hand experience of multiple perspectives of the meaning of daily life in Loma Linda, as well as the spread of CLR and the public’s response to it.

We chose to interview Assistant Director Jesse Mattleman and used face-to-face interaction to cultivate a relationship. We wanted to earn her trust so that she would be more likely to share detailed rather than superficial information, her reflection of the natural experience (Gubrium & Holstein, 2002). Her perspective as a partner of ASODILL provided insight that allowed us to make an educated guess of how the community would respond to our project. Furthermore, with a B. A. in International Development and Social Change, Jesse Mattleman focuses on sustainable project development and could provide guidance for our project. Ms. Mattleman visited the community several times before, and personally exchanged ideas with ASODILL’s General Coordinator Pascual Rafael Escobar. Señor Escobar, a

politically ambitious member of the community familiar with its daily proceedings and local capacity; he provided information regarding the nuances of community participation to Ms. Mattleman.

In order to familiarize ourselves with the region, our first goal was to learn about the current demographics, cultural traditions and values, and economics of Guatemala. After completion, we gained a general understanding of Guatemala's agricultural sectors, the capacity of the country's municipality and population, and their cultural values. With a sense of the country's status and objectives, we developed questions geared to learn about Loma Linda without traveling there ourselves. Due to the complexity of our questions, we emailed them to Ms. Mattleman prior to interview sessions so that she could prepare answers for discussion, and later had face-to-face in-depth interviews. We kept audio recordings of our interviews as a reference that we could return to. Although we paid careful attention and took notes, having a recording would allow us to review our understandings and reevaluate different statements, to repeatedly listen to the exact words of our informant and "grasp the native's point of view, his relation to life, to realize his visions of the world" (Malinowski, 1922). Our conversations provided useful information that in turn helped us identify an appropriate project design.

In our interviews, we asked about Loma Linda's culture, capacity for tourists, assets, current projects, and the coffee cooperative. We wanted to understand the local culture as well as the community's objectives and capacity to achieve them. We asked about the challenges they faced to evaluate their needs and desires and develop a project that would foster support. Ms. Mattleman discussed past and present projects to give us an idea of what the community was looking for, and we were able to narrow down to those that were most developed. During a later interview, Ms. Mattleman asked for our progress with developing ideas for potential projects,

explaining that the town lacked funding and that their primary source of income was threatened by a CLR epidemic. We deviated from our prepared questions and decided to listen and learn about the community's perspective and provide technical details describing physiology of the plant disease. Loma Linda lacked the expertise to deal with CLR, thus we found an opportunity to utilize the resources of our school library and the internet to search for past case studies of CLR epidemics and compile successful mitigation techniques.

3.2) Background Research

We searched for historical information about Guatemala, SHGO and ASODILL, coffee production, the CLR causing fungus *Hemileia vastatrix*, and CLR mitigation techniques. To develop our general findings, our project advisors coordinated a meeting with a research consultant at our school library, Rebecca Ziino. Ms. Ziino showed us how to effectively utilize WPI Summon, an online multi-database search utility by using key worlds and filters. By using key terms such as "coffee plants," "coffee leaf rust," and "*Hemileia vastatrix*," and narrowing our results using filters such as publication year, content type, and library location we found academic books, scholarly articles, and peer-reviewed journals to solidify our project.

We found academic books related to coffee planting, production, and processing, which helped us understand the functionality of the coffee cooperative in Loma Linda, and wanted to relate the information to CLR. When searching for CLR and *H. vastatrix*, the recurring databases we encountered were Science Direct and Springer Link, which had variety of journals related to ecology and plant pathology. We uncovered scholarly articles and peer reviewed journals of CLR case studies and experiments, which contained vital information such as coffee production conditions, agricultural practices, and mitigation techniques. We chose the most frequently recurring mitigation techniques and evaluated them according to the coffee production

conditions within the case study. By selecting the most common methods of mitigation, we compared the results in terms of the benefits and consequences and developed the standards we utilize in our guide. After formulating standards for mitigation techniques, we envisioned sustainable strategies and interviewed Ms. Mattleman to review them and see which would be appropriate in Loma Linda. In the interview, we asked about the landscape context and agricultural practices of Loma Linda so that we could compare the information from our case studies and tailor a recommendation, but we ultimately decided that creating a decision-making aid would be the most effective approach to help the community develop a strategy of their own.

3.3) CLR Strategy Guide

We reviewed the field of decision-making to understand how individuals and groups choose between alternatives and searched through predefined, systematic, and recognized methods to choose an appropriate method and adapt it to fit our objectives. We chose to use the decision matrix approach because we wanted to rank and compare alternatives among a given set of criteria (Tague, 2004). We created a small but sensitive range of ranks from one to seven where one is a low scoring rank and seven is a high scoring rank, and included an additional rank UNK for information that is unknown. Each criterion has its own defined ranking system that explains how each rank should be evaluated. The ranks we designed are a combination of interpreting quantitative data from case studies and understanding qualitative information about the needs and desires of Loma Linda. For some criteria, we omitted ranks from ranking systems to scale the ranking system because such criteria did not require seven ranks. We chose to have users calculate an average rank for each alternative so that an alternative with unknown information would not score significantly lower than an alternative with more information. After reviewing the descriptions of alternatives, criteria, and ranking systems, the user ranks each

criterion for each alternative, calculates the total of each alternative, and then calculates the average rank of each alternative to compare them to one another.

Additionally, we chose the decision matrix approach because it followed the principles of sustainable development emphasized by SHGO and ASODILL, as well as SHGO's partnership-based approach. The three major mitigation techniques we discovered have economic, environmental, and social implications. Although we understood the implications from our perspective, providing a single detailed recommendation to the community would be unsustainable because different people could respond differently depending on their perspective, which would produce mixed results and make the recommendation less effective. We solved the possibility of different responses by choosing an equitable system that could produce a sustainable recommendation in any set of production conditions. The decision matrix approach yields different results based on the interests of the user, thus by using their personal values, motives, biases, and resources to assess criteria and rank alternatives, all members of the community could actively participate in the decision-making process. Furthermore, we wanted to provide a method of decision making that shares our knowledge of CLR and empowers users to decide what to do. We share our knowledge by pre-filling the ranks of criteria that requires specific information unavailable to Loma Linda and explain why we chose those ranks. The decision makers use their knowledge of local circumstances to rank the remaining criteria. In this way, we work together by sharing our knowledge with one another. Loma Linda is a democratic society and by instead recommending that they distribute the guide to all interested parties, we are encouraging them to come to a collective decision among the economic, environmental, and social factors. We would not be in the community to manage its implementation, but decision makers would not be alone in choosing a sustainable strategy.

The traditional decision matrix includes all the alternatives and a single set of criteria. Agricultural practices, planting rust-resistant cultivars, and application of fungicides, each had multiple alternatives and implications associated with them. We decided that creating a single matrix was too complex to evaluate and modified the initial concept of a single decision matrix into a two-stage process with multiple matrices. The two-stage process was a method of sub-optimization to break a complex issue down into smaller components and then piece the components back together (Geva-May & Wildavsky, 1997). We designed the first stage to contain three matrices, each for a specific form of CLR mitigation that has a particular set of alternatives and criteria to rank them. After calculating the average rank of each alternative for all three mitigation techniques, the user reviews the information they received, compares the alternatives to one another, selects a set of alternatives that they prefer, and proceeds to the second stage. The second stage has a single decision matrix to rank the feasibility of the set of preferred alternatives among criteria that encompasses every mitigation technique. We chose a two stage process so that the decision maker would compare alternatives within each subcategory of CLR mitigation, narrow all the alternatives to those they preferred from all three subcategories, and then compare their feasibility; we wanted Loma Linda to evaluate their options and strategize a sustainable course of action.

4) Findings

Beginning our project, we were aware only of its location, Loma Linda, Guatemala, and the identity of our sponsor, Seven Hills Global Outreach. We learned that Guatemala is a mountainous country with a varying landscape that is divided by two chains of volcanoes, and has a tropical climate with a long rainy season and a short dry season. These factors affect the propagation of CLR in various ways that are described in the background and briefly discussed in the CLR Strategy Guide. We also learned that Guatemala is a country with serious social inequity, recovering from a 36 year civil war that hindered economic growth. Guatemala has a large yet poor economy that is dominated by agricultural exports and needs stable institutions to promote inclusive and sustainable development. We learned of the prevalence of religious and traditional values, and combined this knowledge with information about the country's history and economy to assume the context within Loma Linda. We applied our understanding of the country's social dynamics and focused on understanding the motivations, biases, and political resources of interested parties (Geva-May & Wildavsky, 1997) within Loma Linda to predict the use of our strategy guide and attempt. To verify our assumptions, we chose to interview SHGO Assistant Director Jesse Mattleman. Her expertise regarding Loma Linda as well as regular contact with community leaders such as ASODILL General Coordinator Pascual Rafael Escobar provided a perception we could relate to as outsiders, as well as general information applicable to CLR mitigation. We scheduled an interview to gain knowledge of daily life in Loma Linda including member interactions, local customs, employment, and the community's challenges.

4.1) Interviews and Directing Our Research Effort

In our interviews with Ms. Mattleman, we asked questions about Loma Linda's cultural values, community participation, energy and resource infrastructure, and the impact of the coffee

cooperative to develop different strategies that could potentially enhance the community's economic sustainability. Ms. Mattleman told us of SHGO's goals of holistic, community-driven, sustainable development by using a partnership strategy, the community values and general information, and that any interventions we chose first required cultivating trust with the community. She spoke of strongly supported projects and the local capacity to accomplish them, as well as the challenges such as a lack of investment capital and an economy solely centralized around coffee production. Ms. Mattleman emphasized selecting projects that the community was most interested in, and suggested projects to pursue such as the solidifying both the infrastructure and business operations of the community's eco-tourism initiative. We learned about the prominence of the coffee cooperative and other agricultural exports such as pakalana, and that the community seeks to explore sustainable alternatives to income generation. She planned another trip to Loma Linda to check the community's progress and any new developments, and we planned another meeting after her return.

At our second interview, we prepared to receive current information regarding our previous questions to reevaluate our initial plans, and to share newly developed questions of previously discussed projects. When we asked about the most recent developments in the community, Ms. Mattleman alerted us of an emerging coffee plant blight locally known as roya that affected a majority of the coffee plants in the region. The coffee cooperative of Loma Linda predicted a major harvest loss that would result in less funding for the development of new projects, thus we improvised a new set of questions and ultimately changed our project objectives. We focused on gaining additional information about roya and discovering mitigation techniques to salvage the remaining coffee plants in Loma Linda. The community lacked technical details about roya thereby providing an opportunity for us to search for mitigation

techniques and develop strategic intervention. Ms. Mattleman planned to make another trip to Loma Linda, and we planned a future meeting to discuss our findings.

4.2) Initial Stages of Research

We began by focusing on the cultivation conditions and practices of the coffee production industry to learn about the most important considerations of cultivating coffee. After finding a book called *Greenbook* by the Guatemalan National Coffee Association Asociación Nacional del Café (Anacafé), we learned about regional coffee cultivation in Guatemala and the relative production conditions including average annual rainfall, temperature, relative humidity, altitude, soil, harvest season, drying process, and quality of the coffee beans. We matched Loma Linda's location to the regional coffee production map in Anacafé's book and found that the community is located in the Volcanic San Marcos region, nested at a high altitude within Guatemala's chain of volcanoes, which maintain fertile Andisol. The elevation and soil quality results in ideal coffee production conditions and the better qualifications of coffee beans, hard bean and strictly hard bean. To relate the information to roya, we used a Google to find out more about the plant disease and quickly discovered that the disease's English name is coffee leaf rust (CLR), and is caused by the fungus *Hemileia vastatrix*. The three major mitigation techniques we found associated with CLR were agricultural practices, the implementation of rust-resistant cultivars, and the application of fungicides. Each mitigation technique depended on the regional climate and landscape context of the plantation. In order to find out the results of the mitigation techniques in practice, we proceeded to use our school library's databases to search for past case studies of CLR.

4.3) Compiling Information: CLR and Mitigation Techniques

While we found case studies of experiments pertaining to CLR epidemics across the globe, we narrowed our search to those within Central America to find those with conditions similar to Loma Linda. The conditions we compared included weather patterns, landscape context, soil characteristics, varieties of coffee plants, and quality of coffee beans. The case studies allowed us to understand the emergence and development of CLR and compile mitigation techniques used in similar conditions. We found that cultural practices, such as pruning coffee plants, controlling shade coverage, maintaining a minimum of 1.5 meters by 2.0 meters of space between coffee plants, and maintaining soil nutrition, reduced plant physiological stress and increased the likelihood of plant recovery after infection. Pruning, adjusting shade coverage to or below 50%, and maintaining minimum plant spacing will also improve ventilation and weaken the fungal infection. Pruning also reduces overall plant matter thereby reducing the area for inoculum. In the case of applying fungicides, farmers can also save money by reducing leaf area because the plant will require less coverage. Fungicides are expensive and will also become ineffective if used too frequently because the fungus may develop a tolerance. Preventing fungicide resistance requires rotating different fungicides, which can have different environmental effects and will be more costly in the end. Furthermore, implementing rust-resistant cultivars in between plants in rows lowers inoculum and also prevents future harvest loss. While it will take approximately three years for newly planted rust-resistant cultivars to mature, the long-term benefit of CLR resistance may outweigh harvest loss during the period of replacing plants.

Regular inspection, use of agricultural practices, rust-resistant cultivars, and fungicides may help mitigate a CLR epidemic, yet a natural enemy of *H. vastatrix* also plays a role. The

prevalence of the white halo fungus *L. lecanii* occurring among high density populations of the scale insect *C. viridis* will result in parasitism of *H. vastatrix*. However, in order for such populations of scale insects to form, they must be tended by *Azteca instabilis.* Furthermore, the distribution of *L. lecanii* over a landscape is directly caused by the pattern of *Azteca* nest formation, as well as by the soil that acts as an environmental reservoir of *L. lecanii* propagules. There ant-insect interactions also grow more complex because white halo fungus epizootics initiated by researchers resulted in observable reduction in the tending of scale insects by the *Azteca* ants. It is our hope that future experiments regarding indirect biological control will yield new information that can significantly aid coffee plantations during CLR epidemics.

4.4) Intervention Analysis

To verify our newly acquired information and ask technical questions regarding landscape context and agricultural practices in Loma Linda, we contacted Ms. Mattleman and scheduled a short interview. We shared our thoughts with her in order to work together and analyze their implication in the coffee plantation conditions and operations in Loma Linda. During the interview she described the infrastructure of the coffee plots, the fertile volcanic soil (Andisol), and the practice of cultivation. We found that each family within the coffee cooperative of Loma Linda produces a small amount of coffee that cumulatively provides income for the community and that their coffee production is unregulated compared to larger plantations, thus certain mitigation techniques would be totally unnecessary and ineffective. For example, airplane dispersal of fungicides would be inappropriate because the community is relatively small and examining each coffee plant individually to apply fungicides with hand-held devices would be more suitable.

We found that communicating with Ms. Mattleman was seriously important because we needed to know more about the conditions in Loma Linda to apply our knowledge of mitigation techniques and understand their implications. Examining past CLR epidemics in similar circumstances gave us the necessary information to provide a recommended course of action, but because the mitigation techniques were sensitive to the local climate and landscape context, we interviewed Ms. Mattleman to learn about those of Loma Linda. Unable to answer all of our questions, she forwarded the remainder to Señor Escobar via email. Señor Escobar replied shortly thereafter and explained the varieties of coffee planted in Loma Linda, the genus and species of shade trees, an explanation of previous attempts with fungicides, and the desire to plant the rust-resistant cultivar referred to as Salchimore (Sarchimor); the conversation is translated and included in Appendix D. The email explained that the fungicides were ineffective, and that implementing Salchimore was too expensive and difficult to achieve. At this point, we acquired enough information regarding the cultivation of coffee plants and the information related to CLR to create and troubleshoot the CLR Strategy Guide.

4.5) CLR Strategy Guide

After compiling mitigation techniques used in the past, we designed the CLR Strategy guide to share our knowledge that is unavailable in Loma Linda and allow them to fill in the gaps related to varying local circumstances. This is achieved by providing information about alternatives and criteria for decision makers to review, pre-filling the ranks of certain criteria and explaining our rationale, and having decision makers use their own knowledge and interests to strategize a sustainable course of action. We found that by reading the description of the alternatives and each criterion with a respective ranking system, the decision maker should understand the implications of each intervention and be able to rank their importance. The

decision matrix approach empowers users by allowing them to join decision making process by ranking alternatives according to their values, regardless of cultural background or social status. The decision matrix approach is a systematic and flexible way of reviewing information and coming to a decision. Our strategy guide can be used by anyone and in any type of circumstances to evaluate the sustainability of each mitigation technique. This decision making tool is designed to be user friendly and can be used by any individual or collection of individuals dealing with *H. vastatrix*.

To evaluate various alternatives with different selection standards, we designed the CLR Strategy Guide to contain two stages. The first stage contains a total of three decision matrices, one for each major form of CLR mitigation: agricultural practices, implementation of rust-resistant cultivars, and application of fungicides. Each matrix ranks the alternatives within a major form among criteria based on implementation factors with the strongest effect. After deciding which alternatives among the major forms are preferential, the user utilizes the second stage that has a single decision matrix used to rank the feasibility of implementation. Calculating an average rank for each alternative will maintain consistent results between the alternatives with information and those with unknown information and recommend mitigation techniques.

The effects of different criterion are ranked using a predefined ranking system with a range of one to seven, as well as an additional rank UNK reserved for instances when the information is unknown. The resolution of the range was chosen to provide sensitivity to criteria with accuracy and precision (Geva-May & Wildavsky, 1997). If we had chosen a smaller range the ranks for alternatives would lack enough deviation to produce different results. We created a manual that provides step-by-step instructions directions (located in Appendix A), definitions for both our alternatives and criteria, ranking systems for each criterion, and recommendations for

the matrix results. Additionally, we conveyed our findings of CLR mitigation techniques by filling ranks for each different criterion in order to share information with decision makers. This was done to help the decision maker understand the implications of certain alternatives that could only be determined by extensive review of multiple case studies prior to filling in the remaining ranks. While our group could have recommended certain courses of actions in defined conditions, we could only estimate the possibilities to a reasonable extent. We filled in values for criteria that we knew about based on our research and left circumstantial criteria that only the decision maker would know blank. We knew that the variety of mitigation techniques depended on local circumstances that could not be evaluated from our location and that some of the methods of subsiding CLR may have already been used or could be inapplicable.

Furthermore, in order to prevent confusion of the users, another major consideration was the use of proper terminology. If a user ranked alternatives in two different forms with different terminology, the outcomes would probably change thus we ensured that any repeating criteria had the same ranking systems. For example, if in one scenario the user had to choose between a risk and guaranteed benefit, they would choose the guaranteed benefit. In the exact same scenario if the user had to choose between the same risk and a guaranteed loss, the user would choose the risk in hopes of avoiding the guaranteed loss because people are averse to loss (Patton & Sawicki, 1993). While the alternatives we found had potential to solve the CLR epidemic, they also involved losses through costs of equipment, labor, time, and the predicted harvest loss. As a result, we created criteria for major forms of CLR mitigation and alternatives within based on potential gain and loss they experienced. The decision maker uses the ranking system to first evaluate an intervention's qualitative characteristics and lastly the costs of labor, materials, or equipment. Using the decision matrices, a user could translate their interests and interpretation of

the criteria to rank and alternatives and arrive at a recommendation (Patton & Sawicki, 1993). With limited resources such as funding or labor, the decision maker would want to strategically choose a proper set of alternative mitigation techniques and efficiently execute them. This tool is designed so that the decision maker, who understands the implications behind the choices they make, would be able to rank the related criteria of available alternatives and come to a decision based the resulting average rank; the reasons that the user chose ranks would be put in terms of numbers to simplify their analysis.

4.5.1) CLR Strategy Guide Description

The CLR Strategy Guide is composed of two stages and containing a total of four decision matrices. Alternatives apply to the columns of the matrices, while criteria apply to the rows. Each decision matrix contains a general description, definitions for each alternative and criterion, and a ranking system for each criterion to reference when selecting ranks. The user must review the general descriptions and definitions of each matrix to understand their purpose, as well as their alternatives and the criteria to rank them. Each criterion ranking system has a rank UNK for when information is unknown, and range of one to seven to rank each alternative, where one is the worst rank and seven is the best. For certain criteria, ranks 2, 4, and 6 were omitted to incrementally scale the ranking system because they were not so sensitive as to require seven ranks. The user should refer to the tables provided below as a guide to selecting the appropriate rank values for each cell. After users review the descriptions and ranking systems, they first fill the empty cells in the matrices by ranking the alternatives among as many criteria as they can. Some of the ranks were pre-determined by our knowledge, however if the user knows the information that we ranked UNK, they should change the value as they see fit. After ranking all the criteria, the user adds the ranks in each column to acquire a total, and divides by

the number of numerically ranked criteria to acquire an average rank. For directions to rank criteria among alternatives, please refer to Appendix A.

The user must complete the first stage, composed of three decision matrices for each major mitigation technique. Each matrix is designed to rank and compare the alternatives related to each mitigation technique. After calculating and comparing the average rank of each alternative from all three matrices, the user should understand the alternatives and their implications and be able to select the alternatives they think are most appropriate. After selecting a set of preferred alternatives, the user should proceed to the second stage and rank the feasibility of all the preferred alternatives to determine which preferred alternative can be implemented and which would require additional assistance through grants or other means. The columns of the feasibility matrix can be changed to whichever alternatives a user finds are most suitable, however the criteria are to remain the same. Again, the use must sum the ranks for each alternative and then divide by the number of numerically ranked criteria to acquire an average rank and compare which alternative is the most appropriate and preferential.

4.5.2) CLR Strategy Guide Recommendations

This tool was designed so that decision makers could review the mitigation techniques we found through investigative research of past case studies related to CLR epidemics.

- **The user must complete all three matrices within the first stage of the CLR Strategy Guide prior to utilizing the matrix within second stage. Each matrix within the first stage was uniquely tailored to evaluate the characteristics of different agricultural practices, rust-resistant cultivars, and fungicides, and decision makers should consider their implications.**
- **The user must read the descriptions of each alternative, criterion, and associated ranking systems to effectively rank the alternatives within a particular mitigation technique to understand the complex nuances and implications of implementation. Only after full review of all the potential alternatives within the first stage can the user rank the feasibility of the preferred alternatives. The feasibility matrix is utilized to determine whether alternatives can be implemented and the columns of the feasibility matrix are blank so that the decision maker can select a set of preferred alternatives.**
- **It is recommended that the CLR Strategy Guide is distributed to each person involved in the decision making process because it will yield different results based on the interests of the user. By becoming knowledgeable about the CLR mitigation techniques, the users become active participants in the decision making process and can collaborate as a group to come to a decision.**

- **If the group cannot come to a collective decision, discussion should allow the users to reevaluate their interpretation of the definitions and ranking systems in order to repeat the process of completing the CLR Strategy Guide.**

4.5.3) First Stage: Agricultural Practices Matrix

4.5.3.1) Agricultural Practices Matrix Description

CLR has been spreading throughout all parts of the world so it is important to consider all possibilities that may help Loma Linda overcome the CLR epidemic. It is primarily important for farmers to know agricultural practices of preventing or mitigating CLR as well as how they work. We created the agricultural practices matrix so that the farmer can learn about the alternative techniques that will help reduce CLR if used properly. By examining previous case studies, we compiled simple practices including plant pruning, adjusting shade if necessary, managing appropriate space between plants, and keeping plants healthy by maintaining soil nutrition. The alternatives, criterion, and ranking systems are described below, followed by recommendations for each cultural method. We found that the most important characteristics of the agricultural practices to evaluate were effectiveness against CLR, necessary training, seasonal time commitment, physical demand, and the cost of equipment.

		ALTERNATIVE AGRICULTURAL PRACTICES			
		Pruning Fruit Nodes	**Adjust Amount of Shade**	**Coffee Plant Spacing**	**Maintaining Soil Nutrition**
CRITERIA	***Effectiveness against CLR***	7	5	5	5
	Required Training	3	3	5	1
	Seasonal Time Commitment				
	Physical Demand				
	Cost of Equipment				
	Total:				
	Average:				

4.5.3.2) Descriptions of Agricultural Practices

Pruning Fruit Nodes:	Cutting away excessive fruit nodes and dead branches from trees to maintain plants healthy.
Adjust Amount of Shade:	Altering shade coverage to allow different levels of sunlight to enter into the coffee plots.
Coffee Plant Spacing:	Maintaining distance between coffee trees in plots, to allow plants to absorb proper amounts of nutrition from the soil and promote air circulation between plants.
Maintaining Soil Nutrition:	Using fertilizers to maintain good soil nutrition, and chemicals to keep healthy pH levels in the soil.

4.5.3.3) Agricultural Practices Matrix Criteria and Respective Ranking Systems

The raking systems below describe each prefilled criteria, along with a guide to help the user complete the remaining cells. The prefilled values were chosen based on our research.

Effectiveness on CLR: The effectiveness of each cultural method against CLR. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The Information is unknown.
Rank 1	No effect on CLR
Rank 3	Slightly effective against CLR
Rank 5	Moderately effective against CLR
Rank 7	Most Effective against CLR

Required Training: Amount of training required to properly complete each technique. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	More than two hours of training
Rank 3	One to two hours of training
Rank 5	Half an hour to an hour of training
Rank 7	Less than half an hour of training

Seasonal Time Commitment: The frequency that a farmer will perform the task during the season.	
Rank UNK	The information is unknown.
Rank 1	Frequently, every day
Rank 2	Very often, multiple times per week
Rank 3	Often: two times per week
Rank 4	Weekly
Rank 5	Somewhat often, less than Weekly
Rank 6	Very rarely, monthly
Rank 7	Rarely, less than once a month.

Physical Demand: The manual labor classified by the strength or endurance required to complete the task.	
Rank UNK	The information is unknown.
Rank 1	Workers must be capable of lifting 50 kg.
Rank 2	Workers must be capable of lifting 25 kg.
Rank 3	Workers must be capable enduring up to 10 hours of work.
Rank 4	Workers must be capable enduring between 7 and 10 hours of work.
Rank 5	Workers must be capable enduring between 4 and 7 hours of work.
Rank 6	Workers must be capable enduring between 1 and 4 hours of work.
Rank 7	Workers only have to endure an hour of work or less.

Cost of Equipment: Cost of Implementation (shears, fertilizers, shovels, etc.). Prices vary depending on location of user *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	Expenses exceed user's budget
Rank 3	Expenditures strain the users budget but are manageable
Rank 5	Amount of money required is well within the user's budget
Rank 7	Materials are free or can be easily borrowed

4.5.3.4) Agricultural Practices Recommendations:

Below are some tips on how to implement each cultural method. The user must keep in mind that these are only guidelines so they should use their best judgment on their own land.

Pruning Fruit Nodes:

The farmer can choose to cut off the top of the tree to keep the trees short and make picking the beans a lot easier. Sucker branches and unproductive branches should also be pruned to reduce plant physiological stress. Suckers are branches that grow out and bend vertically but do not bear fruit. They need to be cut straight down as close as possible to the trunk (Figure 4.2.3.1).

After a single season of yield, branches will grow longer and only produce fruit at the ends (Figure 4.2.3.2). Once the branches reach about the age of 3, they will produce an extremely low yield, and must be pruned to stimulate growth. Once a branch is cut off, a new one will grow in its place and produce more berries. It is important to apply fertilizer to pruned plants in order to encourage growth and make the new branches stronger.

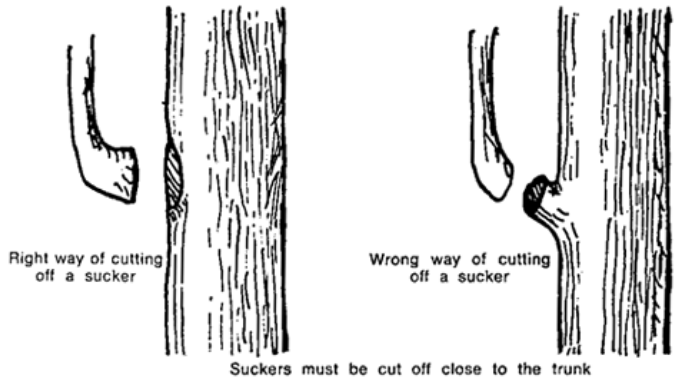

Figure 4.2.3.1- Right Way to Cut a Sucker Branch. (Coffee, 1977)

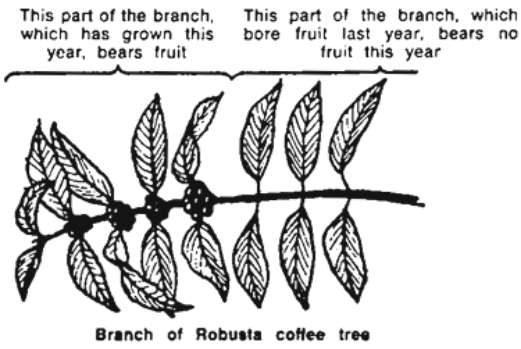

Figure 4.2.3.2- Coffee Branch. (Coffee, 1977)

Adjust Amount of Shade:

Moderate shade has roughly 35 to 50% coverage over coffee plots. This is the recommended percent coverage because it protects coffee trees, prevents soil erosion, and ensures proper ventilation by sunlight and air.

Plant Spacing:

If coffee trees are planted in rows and there is not additional information regarding their specific spacing requirement, they should be 1.5 meters apart within rows and rows should be 2.0 meters apart. This will prevent nutrient competition and malnutrition.

Maintaining Soil Nutrition:

If using chemical fertilizers, the farmer should only apply the minimum amount needed around the tree in the form of a circle with a radius of about 1 meter. The farmer should be careful to keep the fertilizer from touching any part of the tree to prevent it from burning (FAO, 1976).

If using natural fertilizers such as vermicomposting, the farmer must create a suitable environment for the worms. The best are red worms and they need a box filled with waste, preferably kitchen leftover scraps. The worms will eat up to half their waste in a day, so a box of worms would normally produce rich soil in about 3 months.

They should also be careful to use the minimum amount of fertilizer to prevent soil acidity and pollution. If the soil reaches a pH level less than 5, limestone can be added as necessary to raise the level to 5 or 6 (FAO, 1976).

4.5.4) First Stage: Rust-Resistant Coffee Plant Selection Matrix

4.5.4.1) Rust-Resistant Coffee Plant Selection Matrix Description

This matrix was created to select the most beneficial hybrid plant for the town of Loma Linda. From research, we found that resistance, yield, and cupping quality are the most important factors when selecting a cultivar, however each plant also had different space requirements, as well as different availability. Through review of results from past case studies of CLR, we used available information to pre-fill some of the ranks of criteria. We prefilled the ranks of the rust-resistance for all the plants, the cupping quality for all the plants except S274xKent, the yield for all the plants except Colombia, S274xKent, and S795, and the coffee plant space requirement for S274xKent and S795. The decision maker must review the descriptions of every plant we found (or the plants that they wish to rank) as well as the description of each criterion with its respective ranking system.

		ALTERNATIVE COFFEE PLANTS								
		S795	**S274xKent**	**Icatu**	**Catimor**	**Colombia**	**Bourbon**	**Caturra**	**Catuai**	**Sarchimor**
CRITERIA	***Resistance to CLR***	7	7	7	7	7	3	3	3	7
	Cupping Quality	7	UNK	5	3	5	7	5	7	
	Yield	UNK	UNK	5	7	UNK	5	5	7	
	Coffee Plant Space Requirement	7	7	UNK	UNK	UNK	UNK	UNK	UNK	
	Cost of Plant and Seedling Availability									
	Total:									
	Average:									

4.5.4.2) Descriptions of Rust-Resistant Coffee Plants

Hybrid Coffee Plants	**S795:**	A cross-breed between S288 and *C. arabica var. kent* (Kent). It grows in a tall upright position with many secondary branches that produce large, bold beans.
	S274xKent:	A sturdy, tall coffee plant with an abundance of secondary and tertiaries branches that produce medium-sized, bold, round beans with a broad navel. It is characterized by broad dark-green leaves with wavy margins.
	Icatu:	First cross-bred between *C. canephora* and *C. arabica* then cross-bred with *C. arabica var Mundo Novo* (Mundo Novo), it yields a high amount of beans with superior cupping quality.
	Catimor:	A cross-breed between *Hibrido de Timor* and *Caturra.* This plant matures very early and produces a high yield.
	Colombia:	Cross-bred from a line of the *Catimor* variety, this plant grows tall and produces large beans.
Coffee Plants Grown or Available in Loma Linda	**Bourbon:**	A variety of *C. arabica* that produces quickly maturing cherries. Although strong winds will cause them to fall, they yield small beans with an excellent cup quality (Coffee Research Institute, 2006).
	Caturra:	A direct descendent from *C. arabica var bourbon*, it can adapt to almost any environment and produces a high yield with good cupping quality (Coffee Research Institute, 2006).
	Catuai:	A cross-breed of *C. arabica var Mundo Novo and C. arabica var caturra.* This plant produces a high yield with good cupping quality (Coffee Research Institute, 2006).
	Sarchimor:	A rust-resistant relative of Catimor crossed between Villa Sarchi and Hibrido de Timor that is available in Loma Linda (Illy & Vivani, 2005).

4.5.4.3) Rust-Resistant Coffee Plant Selection Matrix Criteria and Respective Ranking Systems

These criteria were care chosen carefully and are assigned ranking systems that we developed from information of rust-resistant cultivars and their important considerations. The percentage of resistance to CLR of a coffee plant is not a quantified variable. However, based on all of the plants and their varieties reviewed in this project, it was determined through research that these plants have CLR-resistant genes. In order to rank the resistance of these plants in our matrix we reviewed the following articles: *Resistance to leaf rust in coffee carrying S H3 gene and others S H genes* (Sera et al., 2007), *Marker assisted selection and breeding or leaf rust resistance in coffee* (*Coffea arabica L.*)*-some recent leads* (Prakash et al., 2011), and *Studies on the Chitinase Activity in Coffee* (*Coffea arabica L.*) *Genetic Resources in India* (Dinesh et al., 2010). Following compilation of the information we gathered from these articles, we defined a range of percentage of resistance. Detailed information that defines each criteria and provides a ranking system is listed below.

Resistance to CLR: This criterion ranks the resistivity and susceptibility of CLR. Resistance to CLR characterizes the genetics of a plant that has the ability to resist CLR. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	A plant that possesses genes with 0 to 40% resistant against CLR
Rank 3	A plant that possesses genes with 40 to 60% resistant against CLR
Rank 5	A plant that possesses genes with 60 to 80% resistant against CLR
Rank 7	A plant that possesses genes with 80 to 100% resistant against CLR

***Cupping Quality*:** The process of smelling, tasting, and explaining the flavor and resulting market value of a plant's coffee beans. This criterion ranks important flavor attributes of coffee such as fragrance/aroma, flavor, aftertaste, acidity, body, sweetness, defect and clean cup. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	The cupping quality of the beans produced is of poor flavor, taste, sweetness, aroma, aftertaste, clean cup, low acidity and high bitterness.
Rank 3	The cupping quality of the beans produced is of fair flavor, taste, sweetness, aroma, aftertaste, clean cup, medium acidity and medium bitterness.
Rank 5	The cupping quality of the beans produced is of good flavor, taste, sweetness, aroma, aftertaste, clean cup, average acidity and low bitterness.
Rank 7	The cupping quality of the beans produced is of excellent flavor, taste, sweetness, aroma, aftertaste, clean cup, above average acidity and no bitterness.

***Yield*:** is usually expressed by the amount of productivity of the plant in terms of fruit and berries the coffee plant produces per node. This criterion measures the productivity of the plant in terms of the amount of fruit, bearing node, flowers per node and berries the coffee plant produces per node. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	When a plant has poor productivity in bearing flowers and berries per node.
Rank 3	When a plant has fair productivity in bearing flowers and berries per node.
Rank 5	When a plant has good productivity in bearing flowers and berries per node.
Rank 7	When a plant has excellent productivity in bearing flowers and berries per node.

Coffee Plant Space Requirement: The amount of required spacing unique to each coffee plant (in meters) to flourish efficiently. Spacing is very important because it is related to the plant size, the amount of nutrition competition, and the ability to move between plants during disease management. For the following ranks spacing applies to coffee plants in rows spaced 2.0 m apart. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	2.2m between plants in rows, resulting in the fewest number of plants per plot.
Rank 3	2.0m between plants in rows, resulting in a lesser number of plants per plot.
Rank 5	1.8m between plants in rows, resulting in a greater number of plants per plot.
Rank 7	1.5m between plants in rows, resulting in the greatest number of plants per plot.

Cost of Plant and Availability of Seedling: The cost of a plant within the matrix illustrates how much a plant cost per pound and the availability of seedlings within the region. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	The plant costs within 75 to 100% of the farmer's income and plant seedlings cannot be found in Central America.
Rank 3	The plant costs within 50 to 75% of the farmer's income and plant seedlings can be found in Central America.
Rank 5	The plant costs within 25 to 50% of the farmer's income and plant seedlings can be found in Central America.
Rank 7	The plant costs less than 25% of the farmer's income and plant seedlings can be found in Central America.

4.5.4.4) Rust-Resistant Coffee Plant Recommendations

Every plant needs proper management and maintenance in order to grow and reach its full potential. To help the farmers of Loma Linda achieve a high yield and good or excellent cupping quality, they need to follow the following procedure:

- They should choose a hybrid with a high resistance to CLR and that can produce good cupping quality.
- They should utilize the recommended spacing to eliminate nutrient competition and also control weeds.
- The farmer needs to water their plant about two to three times a week, except during the rainy season.
- Apply the necessary amount of fertilizer.

For detailed information on field management and coffee plant cultivation, farmers should refer to ***Arabica Coffee manual For Lao-PDR*** by Edward Winston et al., 2005.

4.5.5) First Stage: Fungicide Selection Matrix

4.5.5.1) Fungicide Selection Matrix Description

This matrix was developed in order to strategically select the proper fungicide(s) for Loma Linda. By comparing case studies of past CLR incidents, we compiled a set of fungicides that were most successful. Each fungicide has different implications, and we found that the most significant factors to consider were fungicide resistance, effectiveness against rust, and toxicity. In addition, the community would want to compare whether the fungicide is organic, how available it is to them, and how much it costs. This matrix has prefilled data already given based on our research of each component.

		ALTERNATIVE FUNGICIDES				
		Copper Compound	**Sulfur-Based**	**Lime-Sulfur**	**Neem Oil**	**Dithiocarbamate**
CRITERIA	***Fungicide Resistance***	7	7	7	UNK	7
	Effectiveness Against Rust	7	7	7	5	5
	Toxicity	1	5	5	7	3
	Organic	7	7	7	7	1
	Availability of Resources					
	Prices of Resources					
	Total:					
	Average:					

4.5.5.2) Description of Fungicides

Copper-Compound:	Copper-Compound is an organic fungicide that is very effective against fungi and bacteria. It kills spores by disrupting function of enzymes.
Sulfur-Based:	Sulfur-Based fungicides are considered organic and assimilate into plants and soil as a nutrient while preventing the development of fungal spores.
Lime-Sulfur:	Lime-Sulfur, otherwise known as calcium hydroxide, is an organic fungicide that has less risk in damaging coffee's foliage. Lime sulfur has a foul odor that many people dislike, but the smell does not affect the heath of the plant.
Neem Oil:	Neem Oil a type of vegetable oil pressed from fruits and seeds of the neem tree *Azadirachta indica*. This fungicide is organic and reduces the germination of *CLR* urediniospores, and kills adult insects, as well as their eggs and larvae. Neem Oil prevents fungal attack of plant tissue and contact activity to mite pressure on the plant.
Dithiocarbamate:	A dithiocarbamate is a highly toxic inorganic fungicide. It is moderately effective against CLR, but can be stronger when combine with copper.

4.5.5.3) Fungicide Selection Matrix Criteria and Respective Ranking Systems

Fungicide resistance is a major concern because by frequent reproduction, the fungi could develop a mutation that would make it immune to the fungicide and pass the mutation to future generations. Immunity to the fungicide wastes time and money because the fungicide will be ineffective and the fungus will continue spreading. We shared our knowledge of each fungicide's risk of fungicide resistance to help the farmer make an accurate choice. However, we did not consider the fungicide resistance produced by rotating fungicides. We also prefilled the ranks of effectiveness against rust so that the farmer would know how effective each fungicide is against CLR. Toxicity is a criterion because excessive use of a fungicide can affect public health. We

shared this information to notify the community of Loma Linda of the danger associated with the use of each fungicide. We found that Loma Linda's greatest concern is maintaining the organic certification of their agriculture and ranked those that are organic with a seven and those that are inorganic with a one. In addition, the community would evaluate the availability of the fungicide, which is directly related to the price. If the fungicide were unavailable or too expensive for Loma Linda, it would not be economically sustainable. The price of resources includes the fungicides as well as the necessary equipment.

Fungicides Resistance: This criterion measures the risk that CLR will develop resistance to each individual fungicide. The risk of fungicide resistance is based on the individual fungicide and does not consider when they are combined or alternated between applications. Fungicide resistance is when the CLR adapts and become susceptible to the fungicide being used. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	Risk of fungicide resistance is very high
Rank 3	Risk of fungicide resistance is high
Rank 5	Risk of fungicide resistance is moderate
Rank 7	Risk of fungicide resistance is low

Effectiveness Against Rust: This criterion measures how effective the fungicides is against the CLR based on how strong the chemical is. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	Not really effective against CLR
Rank 3	Somewhat effective against CLR
Rank 5	Moderately effective against CLR
Rank 7	Very effective against CLR

Organic: This criterion indicates whether the fungicide is organic and inorganic. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	Inorganic
Rank 7	Organic

Toxicity: This criterion ranks the toxic levels of each fungicide. Toxic can affect both the soil and the farmer's health as well. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	Toxicity level is very high
Rank 3	Toxicity level is high
Rank 5	Toxicity level is low
Rank 7	Toxicity level is very low

Availability of Resources: This criterion determines whether the fungicide and materials are available to Loma Linda. Refer to Recommendations below for description of materials. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	40% of resources for implementation are available
Rank 3	60% of resources for implementation are available
Rank 5	80% of resources for implementation are available
Rank 7	100% of resources for implementation are available

Prices of Resources: This criterion determines the cost of the fungicide and the equipment needed for implementation. Equipment includes but is not limited to: coveralls, chemical resistance glove, protective eyewear, and chemical containers. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	The cost of materials exceeds 40% of the farmer's income.
Rank 3	The cost of materials is within 25% to 40% of the farmer's income.
Rank 5	The cost of materials is within 10% to 24% of farmer's income.
Rank 7	The cost of materials is within 1% to 9% of farmer's income

4.5.5.4) Fungicide Recommendations

All Fungicides:

Controlling the CLR causing fungus *H. vastatrix* is critical because coffee plants infected by CLR yield coffee beans that cannot be consumed. Although, fungicides have a high rate of success to control fungi, they are costly and improper use will yield poor results. Fungicides may be considered inorganic depending on environmental regulations, therefore farmers should verify how the chemical they are using will impact the market-place classification of their product. Furthermore, CLR develops from the bottom of the leaf, therefore the fungicide must be sprayed directly upward to fully cover the infected area, as well as the rest of the plant (Arneson, 2011). Farmers should carefully mix proper ratios of fungicides to water. Do not use fungicides sooner than the recommended intervals because it can result in damaging the coffee plant foliage and increase the risk of resistance. Except for Lime-Sulfur, farmers should not use fungicides in temperatures exceeding 30 ºC. Proper equipment is required during application process such as coveralls, shoes plus socks, chemical resistance gloves, and protective eye wear.

Copper Compound:

Product is to be applied 14-21 day intervals and must completely cover the infected area of CLR. Avoid frequent use of this fungicide because it is highly toxic; if possible, alternate copper-compound with a less toxic fungicide.

Sulfur-Based:

Product is to be applied 7-14 day intervals and must completely cover the infected area of CLR. **Warning:** Do not use Sulfur-Based and Neem Oil fungicides in the same area within a month's period because it is very poisonous.

Lime-Sulfur:

Product is to be applied 7-14 day intervals and must completely cover the infected area of CLR. Farmer can also use this fungicide if temperature exceeds 30 ºC. **Warning:** Do not use Lime-Sulfur and Neem Oil fungicides in the same area within a month's period because it is very poisonous.

Neem Oil:

Product is to applied 7-14 days intervals and thorough coverage is necessary to provide good disease and mite control. Two pints of Neem Oil is used with 5 gallons of water per acre. **Warning:** Do not use Neem Oil and Sulfur-based or Lime-Sulfur fungicides in the same area within a month's period because it is very poisonous.

Dithiocarbamate:

Product is to be applied 7-14 day intervals and proper coverage is required. This fungicide should be sprayed on the surface of the plant because it will protect the spread of infection and is most effective way of applying dithiocarbamate.

4.5.6) Second Stage: Feasibility Matrix

4.5.6.1) Feasibility Matrix Directions

The columns of the above table were decided based on the assumption that a decision maker would evaluate the feasibility of implementing all the agricultural practices as well as the highest ranking rust-resistant coffee plant and fungicide. However, the column subjects can be changed to whichever alternatives the decision maker feels is most appropriate. In order to use the feasibility matrix, a decision maker had to have completed all the first stage matrices to understand the numerous available alternative mitigation techniques and respective implications. After finding the alternative with the highest average rank, the decision maker uses a column for any number of alternatives to evaluate the feasibility of implementation. The definitions of different criterion and their respective ranking systems are provided below for clarification. All decision makers must review and understand the definition of criterion and respective ranking systems to prevent different interpretations. To understand the definitions of each intervention please refer to previous alternative description tables and respective appendices. The ability to implement mitigation techniques will be determined by the criterion and their ranking systems that are explained below. After understanding the defined ranking system for each criterion, the user fills empty cells with values from 0 to 7. After filling in values for each criterion, the user adds values within each column to acquire a total. The total values will show the decision maker which alternatives scored highest in the current circumstances.

		PREFERED ALTERNATIVES					
CRITERIA	***Physical Demand***						
	Seasonal Time Commitment						
	Appropriate Workforce						
	Local Government Capacity						
	Financial Cost						
	Expected Profit						
	Total:						
	Average:						

4.5.6.2) Feasibility Matrix Criteria and Respective Ranking Systems

Physical Demand: The manual labor classified by the strength or endurance required to complete the task.	
Rank UNK	The information is unknown.
Rank 1	Workers must be capable of lifting 50 kg.
Rank 2	Workers must be capable of lifting 25 kg.
Rank 3	Workers must be capable enduring up to 10 hours of work.
Rank 4	Workers must be capable enduring between 7 and 10 hours of work.
Rank 5	Workers must be capable enduring between 4 and 7 hours of work.
Rank 6	Workers must be capable enduring between 1 and 4 hours of work.
Rank 7	Workers only have to endure an hour of work or less.

Seasonal Time Commitment: The frequency that a farmer will perform the task during the season.	
Rank UNK	The information is unknown.
Rank 1	Frequently, every day
Rank 2	Very often, multiple times per week
Rank 3	Often: two times per week
Rank 4	Weekly
Rank 5	Somewhat often, less than Weekly
Rank 6	Very rarely, monthly
Rank 7	Rarely, less than once a month.

***Appropriate Workforce*:** The type of workforce appropriate for performing the task that may be considered too dangerous or risky for women and children. *(*Note: rank 2, 4, and 6 were taken out in order to scale the range to fewer ranks.)*	
Rank UNK	The information is unknown.
Rank 1	Young and capable adults ages 18 to 30
Rank 3	Capable adults ages 18 to 50
Rank 5	Adults ages 18 to 50 and children ages 14 to 18
Rank 7	Anyone can accomplish the task

***Capacity of Local Municipality*:** The ability of the local government to achieve the task if a feasible solution is proposed because it benefits the community as a whole.	
Rank UNK	The information is unknown.
Rank 1	The local government will not provide assistance.
Rank 2	The local government will provide minor assistance but requires aid from outside sources.
Rank 3	The local government will provide minor assistance and does not require aid from outside sources.
Rank 4	The local government will provide assistance but requires aid from outside sources.
Rank 5	The local government will provide assistance and does not require aid from outside sources.
Rank 6	The local government will provide major assistance but requires aid from outside sources.
Rank 7	The local government will provide major assistance and does not require aid from outside sources.

***Financial Cost*:** The money required to buy tools, materials, and implement the task.	
Rank UNK	The information is unknown.
Rank 1	The community cannot afford it and out of reach.
Rank 2	The community cannot afford it but grants are available if a feasible solution is proposed.
Rank 3	The cost is expensive but affordable; grants are available if a feasible solution is proposed.
Rank 4	The cost is mildly expensive but affordable; grants are available if a feasible solution is proposed.
Rank 5	The cost is manageable and grants are available if a feasible solution is proposed.
Rank 6	The cost is low and manageable without grants.
Rank 7	The solution is free of charge.

Expected Profit: The amount of money gained after recovery that could cover the cost of the task as well as produce additional revenue.	
Rank 0	Not applicable
Rank 1	There is no profit.
Rank 2	The profit is much less than the initial cost.
Rank 3	The profit is less than the initial cost.
Rank 4	The profit is equal to the initial cost.
Rank 5	The profit is more than the initial cost.
Rank 6	The profit is much more than the initial cost.
Rank 7	The operation yields complete profit because there was not an initial cost.

4.5.6.3) Feasibility Matrix Recommendations

The decision matrix approach allows decision makers to rank criteria for alternative mitigation techniques based on their personal interests. In order to successfully evaluate their feasibility, decision makers should consult interested parties within the community. In this way, the parties can collectively gather and compare results with one another. An assembly should be held so that each party can voice their opinions and concerns, thus the community as a whole can come to an agreement.

4.6) Tests and Revisions

4.6.1) Overall Tests and Revisions

We first wanted to use a numbering system of negative to positive five in order to rank negative effects with negative ranks and positive effects with positive ranks; the magnitude from least to greatest determined the least impact to the greatest impact, respectively. However, we discarded this method because it did not have a high enough resolution to be able to rate things accurately, and if an intervention had more negatively impacted criterion then it would score lower regardless of whether it was a more appropriate intervention. For example, we knew that all of the agricultural practices were crucial agricultural practices in order to overcome the CLR epidemic however in our tests they ranked the lowest compared to rust-resistant coffee plant implementation and also the use of fungicides, although both implementing rust-resistant cultivars and fungicides were more costly and had worse repercussions. As a result, we defined a new criteria ranking system ranging from one to seven as explained in the CLR Strategy Guide directions where an additional rank UNK indicates the information is unknown, rank one is the least beneficial, and rank seven is the most beneficial. We also explored the possibility of using multiplying factors to give certain criterion or alternatives more weight than others. However, we removed the multiplying factor because it created serious disparity between answers and also correlated with other criterion, thus it was unnecessary.

4.6.2) Agricultural Practices Matrix Tests and Revisions

In order to refine the agricultural practices matrix, we had to continuously edit the criteria and alternatives. We realized that two of the previous alternatives were the same. One was “using chemicals to maintain soil nutrition, while the other was “keeping soil at a pH of 5-6” We realized that using chemicals to raise the pH the soil is a method used by farmers to make sure

that the plant gets enough nutrition from the soil. Both titles were combined to “Maintaining Soil Nutrition (Fertilizers and raising soil pH).”

4.6.3) Rust-Resistant Coffee Plant Selection Matrix: Tests and Revisions

In order to assist the people of Loma Linda evaluate another potential mitigation technique during a CLR epidemic we created a rust-resistant coffee plant selection matrix. To create a more precise matrix we made some alterations such as condensing some criteria. For example, in our first matrix we had several criteria that discussed fruit per node, potential fruit yield, supposed body size and aroma. We took all of these categories and refined it to create one new criterion called yield. We also eliminated some criteria that were irrelevant to our topic. For instance criterion such as “Saving otherwise spent on chemical control” were deleted from the matrix because it did not compare plant characteristics and the implication was reviewed by the cost of plant and seedling availability. Furthermore, criteria that could not have been easily determined like “Predicted harvest loss as a result of replacement” were also removed. The remaining criteria in the final revision of the matrix are relevant considerations to replacing coffee plants with rust-resistant cultivars in the presence of a CLR epidemic.

4.6.4) Fungicide Selection Matrix: Tests and Revisions

While constructing the Fungicide Selection Matrix, we noticed that were many adjustments to be made in order to produce consistent results. Originally the fungicides were in columns but were later shifted to rows to maintain a consistent visual element between matrices. Initially we created a matrix with predetermined values derived from our knowledge, but after testing the matrix we noticed that some criteria outweighed others and implemented multiplying factors that exhibited such weights. The user rates the importance of each criterion using a scale of 1 to 3, where 1 low importance, 2 indicates moderate importance, and 3 indicates serious

importance. We found that setting weights for two criteria would be appropriate because our objective was to allow the user to choose the best fungicide based on the requirements and their effectiveness. Risk of fungicide resistance and Effectiveness against CLR ranked as a 3 because if they selected a fungicide that was susceptible to the fungus building a tolerance, or that was ineffective against CLR, the result would be failure; this matrix aids in pointing the user in the right direction. However, we ultimately eliminated the weight system because it created significant disparity between the results.

To create the final revision of Fungicide Selection Matrix, we first decided to look into the major consideration when selecting a fungicide. Our initial criteria initially included "frequency of application" and the "amount of labor" separate from one another, but we eliminated them because they were similar for all fungicides. This allowed us to avoid unnecessary criteria to negatively impact the matrix. We also initially had four organic fungicides in our matrix because Loma Linda is focused on organic practices. However, we decided to add an inorganic fungicide in the matrix for comparison. Overall, we found that the six criteria that we chose for the Fungicide Matrix were appropriate by testing it; the results in the Appendix B.3 supported our claim.

4.6.5) Feasibility Matrix: Tests and Revisions

When Loma Linda's main source of revenue was diminished by the CLR epidemic they needed to evaluate their resources and make a plan. We understood that the results from each matrix of the first stage of the guide required strategic implementation in order to utilize resources as effectively as possible. The purpose of each prior matrix was to evaluate the characteristics of each intervention, understand the implications, and produce a set of ranked alternatives. However with a mixed set of mitigation techniques with various implications, a

decision maker had to review the options again. Some alternatives require more manual labor, have higher startup costs, or are performed in risky or dangerous environments, so we designed the second stage of our guide accordingly. Using the feasibility matrix, managers consider the general concerns of feasibility before choosing alternatives, such as physical demand, seasonal time commitment, and an appropriate workforce, the capacity of municipality, financial cost, and potential financial gain.

In the final version of this matrix, the decision maker applies the results acquired from the first stage and places them into the columns of the matrix. They evaluate the labor that includes physical demand and type of workforce that can be used, the ability of their local government to implement the intervention, the cost of the intervention, and lastly the investment return should they succeed. In this way, the user evaluates the requirements for each intervention, the capacity of their municipality, and the possible financial outcomes. We chose this because our sponsor informed us that funding would not be our concern, but that the community of Loma Linda could apply for grants if feasible plans were provided.

5) Conclusions

Recapitulations

We developed our project using the guidance and support of Ms. Mattleman. She expressed the importance of Seven Hill Global Outreach's (SHGO) partnership-based approach and emphasis of sustainable development that resonated with ASODILL's objectives. We learned that they take pride in their economy of organic agriculture, and that various groups with slightly different interests could collectively agree through democratic assembly. We understood the exceptional importance of the community's coffee cooperative, and the significant threat posed by the coffee leaf rust (CLR) epidemic to their sustainable economy. By reviewing previous CLR epidemic case studies conducted throughout Central America, we learned of many different approaches including but not limited to agricultural practices, hybrid coffee plant implementation, and the use of fungicides, each with different requirements and implications. CLR is a complex coffee plant disease that has evolved over time to adapt to different environments. While we were able to find mitigation techniques in particular contexts, it was important that whatever information we could convey to Loma Linda would not only be viable, but sustainable as well.

Our review of agricultural practices to mitigate CLR consistently revealed that coffee plant yield, nutrient competition, and poor nutrition induce physiological stress. However, coffee plant yield has the highest effect on the spread of CLR. Plants that are too close together compete for soil nutrients, but also lack sufficient ventilation to pass a CLR infection. Maintaining soil nutrition is the use of fertilizers and pH buffers is equally important to pruning and distancing coffee plants by at least 1.5 by 2.0 meters, however the most effective techniques depend on the context of the farmland. The vast surrounding rainforest and vegetation provide dense shade

coverage to Loma Linda's coffee plots. Although these conditions promote the growth of high quality crops, they may also be conducive to CLR. However, the high altitude, seasonal rainfall, and Andisols provide ideal conditions for the implementation of rust-resistant cultivars.

The research showed that resistance to CLR is caused by rust-resistant genes within the genome of the coffee plant. The selective cross-breeding of rust-resistant cultivars within laboratories has provided new varieties of coffee that can withstand a CLR epidemic. While a majority of Loma Linda's coffee plants are infected by CLR, the benefit from killing the disease-ridden plants and replacing them with resistant breeds of coffee plants could outweigh the use of chemical control through fungicides. However, to effectively evaluate this possibility, they would need to perform a cost benefit analysis to compare the cost of replacement coupled with the recovery period for the new plants to yield beans with the projected loss due to infection. By utilizing hybrid plants, the community could save money otherwise spent on fungicides, however the fungicides may be effective on their own.

There are various fungicides with different levels of effectiveness and toxicity. Users must be aware that fungi can develop a tolerance to the fungicide that will nullify their effectiveness and also recognize that fungicides can have lasting environmental implications. In order to effectively use a fungicide, it must be applied before or during the onset of a fungal infection, as well as rotated with other fungicides to prevent the development of fungal tolerance. Fungicides have a cross-resistance class that determines which fungicides are safe and effective to pair and rotate. Additionally, fungicides may be organic or inorganic, and because communities like Loma Linda value organic agriculture, users must be aware of the fungicide's classification. While fungicides may be the most effective means of CLR control, they are the most expensive and can pollute the environment that may in turn affect local ecosystems.

Lastly, the theory of natural antagonists may explain the reason that more recent CLR epidemics have not been as detrimental as that of Ceylon (now called Sri Lanka) in 1869. There was a statistically significant indirect biological control of the CLR causing fungus *Hemileia vastatrix* related to an ecosystem including ant-insect mutualisms and the white halo fungus *Lecanicillium lecanii*, however the ecosystem remains under study. There needs to be a necessary local concentration of scale insects for *L. lecanii* to become hyperparasitic of *H. vastatrix* yet this only occurs under the protection of *Azteca* ants that have also been observed to cease tending scale insects after epizootics of *H. vastatrix.* However, the observation was made after epizootics were caused by researchers, and not by natural means. Between the time it takes and the conditions necessary for the ecosystem to develop, the researchers have not yet reached a conclusion to strictly regulate nests and parasitism of *H. vastatrix* by *L. lecanii*.

We constructed our CLR Strategy Guide by utilizing information of the community's values and conditions, as well as case studies of previous CLR incidents. It was not our goal to recommend a course of action and we chose to use the decision matrix approach because of its circumstantial flexibility. The people who care for their community and have worked in the coffee production industry for generations would be able to make an educated decision far greater than our own capacity. The community is hopeful that a solution can be found and will find coping methods with or without that solution. The assistant director of our sponsor SHGO, Jesse Mattleman, informed us that should a viable solution arrive, the town could apply for grants and outsource funding; we hope that the information and results that we have provided, will drive the community in the right direction.

Recommendations

In order to fully utilize the potential of our CLR Strategy guide, users should be aware of the following considerations:

1. **The CLR Strategy Guide should be distributed to all interested parties. The decision matrix approach was utilized so that users would be empowered by actively participating in the decision making process. The recommendations produced by the matrices will differ among different users, thus it is important that every person contributing to the decision making process ranks the alternatives according to their values.**
2. **We selected the alternatives within each subcategory of mitigation techniques based on our knowledge of local resources and the possibility or availability of the alternative within the region. If there are other alternative agricultural practices, rust-resistant cultivars, or fungicides that are not listed in the CLR Strategy Guide that the user would like to consider, the user should utilize the appropriate matrix to rank the alternatives among applicable criteria.**
3. **The decision matrix approach was also used so that the decision makers could collaborate with their results and discuss their rationale. After completing the CLR Strategy Guide, the users should collectively discuss their results and concerns to come to a decision by majority. If a decision cannot be made, the discussion among peers may encourage a reevaluation of the descriptions of alternatives, criteria, and associated ranking systems.**

Technology, Society, and Sustainable Development

We found it inspiring to learn that people from developing countries and communities such as Loma Linda, Guatemala are able to create and conserve sustainable lifestyles. Loma Linda is a positive representation of a group of people who founded a remote community under noble principles and wished to preserve their values and minimize their impact on the surrounding natural environment. Although a romantic perspective of sustainable development, one of the fundamental tenets of the concept of sustainability was formulated by many religious groups, who acknowledged the surrounding environment and claimed that humans must live in harmony with nature (Mebratu, 1998). It is no surprise that the religious values of the community translated through their desires to find a sustainable approach of subsiding coffee leaf rust (CLR) and ensuring the survival of their community. We developed the CLR Strategy Guide to help the community review the numerous implications of CLR mitigation with cultural sensitivity and equity. It is our hope that our CLR Strategy Guide will allow the inhabitants of Loma Linda to evaluate the implications behind the alternatives to narrow their focus and decide which option is most feasible. The decision matrix approach can be utilized by any decision maker, therefore our CLR Strategy Guide can be used by any coffee grower, whether the plantation is large and highly regulated, or small and preferentially regulated. We were able to share our learned knowledge of CLR mitigation techniques acquired through technological research with a group of people with limited resources but professional expertise of coffee plant cultivation; together, we utilized the partnership-based approach to provide a recommendation in light of the CLR epidemic. Our project was locally defined, collaborative, participatory, empowering, sustainable, equitable, and replicable, and the experience was incredibly enriching.

6) Appendices

Appendix A) User's Manual to the CLR Strategy Guide

User's Manual to the CLR Strategy Guide

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Interactive Qualifying Project

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A.1) How to Rank Criteria

This manual provides information on how to fill in the ranks for each criterion within the matrix. Also, it informs the user of relevant details and produces a recommendation that can assist them during a current coffee leaf rust (CLR) epidemic. Furthermore, this manual has descriptions and step-by-step examples that the user can follow.

The decision making tool is composed of three primary decision matrices designed to rank the characteristics of each intervention, and a secondary decision matrix to rank the feasibility of the preferred alternatives. Alternatives form the columns of the matrices, while criteria to rank form the rows of each matrix. A general range of ranking criteria of one to seven was developed, one indicates the lowest rank, and seven indicates the highest rank. UNK stands for unknown and can be written in the corresponding cell if the user does not know the information or it has not yet been discovered.

After users review the descriptions of the alternatives and each criterion with their respective ranking systems, they begin filling the empty cells of the three primary matrices, and then add the ranks within each column to acquire a total, then divide the total by the number of ranked criteria to determine the average; the largest average is the highest recommended alternative. The decision matrices provide visible scores that allow the user strategize their efforts. After the user determines the highest ranking alternatives, he/she chooses whichever they prefer, and assign them to the columns of the feasibility matrix to determine which can be implemented and which would require additional assistance through grants or other means.

Rank UNK: Unknown

Rank 1: Worst

Rank 2: Very poor

Rank 3: Poor

Rank 4: Fair

Rank 5: Good

Rank 6: Very good

Rank 7: Best

		ALTERNATIVE FUNGICIDES				
		Copper Compound	**Sulfur-Based**	**Lime-Sulfur**	**Neem Oil**	**Dithiocarbamate**
CRITERIA	***Fungicide Resistance***	7	7	7	UNK	7
	Effectiveness Against Rust	7	7	7	5	5
	Toxicity	1	5	5	7	3
	Organic	7	7	7	7	1
	Availability of Resources					
	Prices of Resources					
	Total:					
	Average:					

Figure 1) example of the Fungicide Selection Matrix, developed in order to strategically select the proper fungicide for Loma Linda. The user will rank the criteria for each alternative fungicide.

A.2) Understanding the Columns, Rows, and Prefilled Values

A.2.1) Columns

The columns in this example are the different fungicides the team discovered through research. The "**ALTERNATIVES**" are circled in green (Figure 2), and are to be ranked among the "***CRITERIA***", that are circled in blue (Figure 2). In order to understand these alternative fungicides, refer to the "Description of Fungicides" in our IQP report.

A.2.2) Rows

Each row indicates a different criterion based on the fungicide characteristics that are circled in blue (Figure 2). In order to understand these criteria, refer to "Fungicide Selection Matrix Criteria and Respective Ranking Systems" in our IQP report.

Alternatives

		ALTERNATIVE FUNGICIDES				
		Copper Compound	**Sulfur-Based**	**Lime-Sulfur**	**Neem Oil**	**Dithiocarbamate**
CRITERIA	***Fungicide Resistance***	7	7	7	UNK	7
	Effectiveness Against Rust	7	7	7	5	5
	Toxicity	1	5	5	7	3
	Organic	7	7	7	7	1
	Availability of Resources					
	Prices of Resources					
	Total:					
	Average:					

Criteria

Figure 2) alternatives and criteria of the Fungicide Selection Matrix

A.2.3) Prefilled Values

Within the matrix there are values that have been prefilled using our knowledge of the alternatives. The prefilled data were assigned the color **black** and circled (Figure 3).

		FUNGICIDE ALTERNATIVES				
		Copper Compound	**Sulfur-Based**	**Lime-Sulfur**	**Neem Oil**	**Dithiocarbamate**
C R I T E R I A	***Fungicide Resistance***	7	7	7	UNK	7
	Effectiveness Against Rust	7	7	7	5	5
	Toxicity	1	5	5	7	3
	Organic	7	7	7	7	1
	Availability of Resources					
	Prices of Resources					
	Total:					
	Average:					

Prefilled

Figure 3) prefilled values team discovered during research

A.3) Step 1: How to Fill Rows with Numbers

After understanding the alternatives, each criterion and its respective ranking system, and prefilled values, the user can start filling in the blank rows.

*Note: In this example the next row to be filled is "**Availability of Resources**"*

		ALTERNATIVE FUNGICIDES				
		Copper Compound	**Sulfur-Based**	**Lime-Sulfur**	**Neem Oil**	**Dithiocarbamate**
CRITERA	***Fungicide Resistance***	7	7	7	UNK	7
	Effectiveness Against Rust	7	7	7	5	5
	Toxicity	1	5	5	7	3
	Organic	7	7	7	7	1
	Availability of Resources					

Figure 4) values to be filled in by user

Availability of Resources

Note: The farmer will use the ranking system provided for this criterion to rank each alternative.

		ALTERNATIVE FUNGICIDES				
		Copper Compound	**Sulfur-Based**	**Lime-Sulfur**	**Neem Oil**	**Dithiocarbamate**
CRITERIA	***Fungicide Resistance***	7	7	7	UNK	7
	Effectiveness Against Rust	7	7	7	5	5
	Toxicity	1	5	5	7	3
	Organic	7	7	7	7	1
	Availability of Resources	7	7	5	3	3
	Prices of Resources					

Figure 5) example of "***Availability of Resources***" that is filled in

Availability of Resources

Note: Repeat this step for the next criterion.

		ALTERNATIVE FUNGICIDES				
		Copper Compound	**Sulfur-Based**	**Lime-Sulfur**	**Neem Oil**	**Dithiocarbamate**
CRITERIA	***Fungicide Resistance***	7	7	7	UNK	7
	Effectiveness Against Rust	7	7	7	5	5
	Toxicity	1	5	5	7	3
	Organic	7	7	7	7	1
	Availability of Resources	7	7	5	3	3
	Prices of Resources					

Figure 6) values in the "***Prices of Resources***" to be filled in by the user

Prices of Resources

Note: The farmer will use the ranking system provided for this criterion to rank this alternative.

		ALTERNATIVE FUNGICIDES				
		Copper Compound	**Sulfur-Based**	**Lime-Sulfur**	**Neem Oil**	**Dithiocarbamate**
CRITERIA	***Fungicide Resistance***	7	7	7	UNK	7
	Effectiveness Against Rust	7	7	7	5	5
	Toxicity	1	5	5	7	3
	Organic	7	7	7	7	1
	Availability of Resources	7	7	5	3	3
	Prices of Resources	5	5	5	5	1

Prices of Resources

Figure 7) example of filled in "***Availability of Resources***" and "***Prices of Resources***" rows

A.4) Step 2: How to Calculate Column **Total**

After ranking the alternatives, add the numbers within each column. If there is a UNK in the row, ignore it and continue adding the rest of the values.

Note: an example of how to add the "**Copper-Compound**" column being added and the sum is being entered into the "**Total**" row (Figure 8).

		ALTERNATIVE FUNGICIDES
		Copper Compound
CRITERIA	***Fungicide Resistance***	7
	Effectiveness Against Rust	7
	Toxicity	1
	Organic	7
	Availability of Resources	7
	Prices of Resources	5
	Total:	34

7
+
7
+
7
+
1
+
7
+
5
34

Figure 8) calculating **Total** for Copper Compound

Note: Repeat this step for the remaining alternatives

		ALTERNATIVE FUNGICIDES			
		Copper Compound			**Neem Oil**
CRITERIA	***Fungicide Resistance***	7	…..	…..	UNK
	Effectiveness Against Rust	7	…..	…..	5
	Toxicity	1	…..	…..	7
	Organic	7	…..	…..	7
	Availability of Resources	7	…..	…..	3
	Prices of Resources	5	…..	…..	5
	Total:	34			27
	Average:				

UNK + 5 + 7 + 7 + 3 + 5

27

Figure 9) calculating total for Neem Oil

*Note: In the "**Neem Oil**" column, the UNK was ignored during Step 2. The above shows an example of how to add the column with UNK values (Figure 9).*
Note: Values with UNK in them are ignored during addition.
Note: Repeat these steps for the remaining Alternatives.

A.5) Step 3: How to Calculate the **Average:**

To fill in the "**Average**" row, take the number in the "**Total**" row and divided it by the number of rows that were actually added during calculation of the **"Total"** row. Rows that had a UNK are to be ignored during the division.

		ALTERNATIVE FUNGICIDES	
		Copper Compound	
CRITERIA	***Fungicide Resistance***	7	Since all of the rows had a value to be added in the Copper-Compound column, we would use the *# of rows = 6* Since the column was add in Step 2, the Total in this example is "**Total**" = 34 ["**Average**" = "**Total**" / "# of rows"] Example: "**Average"** = 34/6 "**Average"** = 5.66
	Effectiveness Against Rust	7	
	Toxicity	1	
	Organic	7	
	Availability of Resources	7	
	Prices of Resources	5	
	Total:	34	
	Average:	5.66	

Figure10) example of calculating the "**Average**" for the Copper-Compound column
Note: Repeat this step for the remaining Alternative

		ALTERNATIVE FUNGICIDES	
		Neem Oils	
CRITERIA	*Fungicide Resistance*	UNK	Since one of the rows were ranked UNK in the Neem Oil column, we would use *# of rows = 5* Since the column was add in Step 2, the Total in this example is "**Total**" = 27 ["**Average**" = "**Total**" / "# of rows"] Example: "**Average"** = 27/5 "**Average"** = 5.40
	Effectiveness Against Rust	5	
	Toxicity	7	
	Organic	7	
	Availability of Resources	3	
	Prices of Resources	5	
	Total:	27	
	Average:	5.66	

Figure 11) example of how to calculate the "**Average**" for the Neem Oil column

		ALTERNATIVE FUNGICIDES				
		Copper Compound	**Sulfur-Based**	**Lime-Sulfur**	**Neem Oil**	**Dithiocarbamate**
CRITERIA	***Fungicide Resistance***	7	7	7	UNK	7
	Effectiveness Against Rust	7	7	7	5	5
	Toxicity	1	5	5	7	3
	Organic	7	7	7	7	1
	Availability of Resources	7	7	5	3	3
	Prices of Resources	5	5	5	5	1
	Total:	34	38	36	27	20
	Average:	5.66	6.33	6.00	5.40	3.33

Figure 12) example of Matrix after Step 1, Step 2, and Step 3 are complete.

*Hint: For the "**Neem Oil**" column, we ignored the UNK, thus the # of rows was 5.*
Final answer was 27 / 5 = 5.40

A.6) Step 4: How to Locate the Highest "**Average**"

After everything is filled out in the Matrix, locate the highest value in the "**Average".** This value would suggest the recommended Fungicide for the CLR epidemic.

Recommended Fungicide based on simulation of this example

Fungicide Recommendations	
Copper Compound:	Product is to be applied 14-21 day intervals and must completely cover the infected area of CLR.
Sulfur-Based:	Product is to be applied 7-14 day intervals and must completely cover the infected area of CLR. **Warning:** Do not use Sulfur-Based and Neem Oil fungicides in the same area within a month's period because it is very poisonous.
Lime-Sulfur:	Product is to be applied 7-14 day intervals and must completely cover the infected area of CLR. Farmer can also use this fungicide if temperature exceeds 30 ºC. **Warning:** Do not use Lime-Sulfur and Neem Oil fungicides in the same area within a month's period because it is very poisonous.
Neem Oil:	Product is to applied 7-14 days intervals and thorough coverage is necessary to provide good disease and mite control. Two pints of Neem Oil is used with 5 gallons of water per acre. **Warning:** Do not use Neem Oil and Sulfur-based or Lime-Sulfur fungicides in the same area within a month's period because it is very poisonous.
Dithiocarbamate:	Product is to be applied no sooner than 14-21 day intervals.

Figure 13) Fungicide Recommendations Table. Since the highest value in our example was "**Sulfur-Based**" with an "**Average**" of 6.33, the user would focus on the orange circle above that gives helpful recommendation.

A.7) Feasibility Matrix Directions

After the user complete the three matrices using the directions in this manual, they should select the preferred alternatives from each matrix and place it in the "**Columns"** of the matrix below to evaluated and get the best alternative of Loma Linda.

A PREFERRED ALTERNATIVE

		PREFERRED ALTERNATIVE				
C R I T E R I A	***Physical Demand***					
	Seasonal Time Commitment					
	Appropriate Workforce					
	Local Government Capacity					
	Financial Cost					
	Expected Profit					
	Total:					
	Average:					

Figure 14) The Feasibility Matrix

Note: After the user place these alternative in this columns, they should use the ranking system provided and rank each of these alternative following the method described in this manual.

Appendix B) Example of a Completed CLR Strategy Guide

B.1) General Description

The following tables show completed examples with estimated values based on information we gathered throughout the duration of the project. The explanations of the prefilled values are in black and the explanations of the estimated values are in red.

B.2) The First Stage: Example of a Completed Agricultural Practices Matrix

		ALTERNATIVE AGRICULTURAL PRACTICES			
		Pruning Fruit Nodes	**Adjust Amount of Shade**	**Coffee Plant Spacing**	**Maintaining Soil Nutrition**
CRITERIA	***Effectiveness against CLR***	7	5	5	5
	Required Training	3	3	5	1
	Seasonal Time Commitment	3	3	4	3
	Physical Demand	3	1	2	3
	Cost of Equipment	7	6	5	2
	Total:	23	18	21	14
	Average:	4.6	3.6	4.2	2.8

B.2.1) How Alternative Agricultural Practices Were Ranked

Pruning the Fruiting Nodes:	
Effectiveness on CLR:	Ranked 7 because every case study we used concluded that this is the most effective way of fighting CLR.
Required Training:	Ranked 3 because farmers are already familiar with this process.
Seasonal Time Commitment:	This was rated 3 because this task can be time-consuming, depending on the size of the plot.
Physical Demand:	This was rated 3 because even though this can be a time consuming task, it is fairly simple work with minimum danger.
Cost of Equipment:	This was rated 7 because the materials need to complete this task are very cheap and the community most likely already owns them.

Adjusting the Amount of Shade:	
Effectiveness on CLR:	Ranked 5 because this technique requires work before it can be effective against CLR, otherwise it can help CLR grow.
Required Training:	Ranked 3 because this technique requires some safety training.
Seasonal Time Commitment:	Ranked 3 because the process of reaching high tree branches and cutting them may require a lot of time at the beginning of the season.
Physical Demand:	Ranked a 1 because this process may be restricted to male adults, restricting the amount of available workers.
Cost of Equipment:	Ranked 6 because the farmers most likely already own the tools needed to cut down tree branches, especially because of their location.

Plant Spacing:	
Effectiveness on CLR:	Ranked 5 because this technique is found to help decrease CLR in every article we found.
Required Training:	Ranked 5 because most farmers already know how to implement this technique
Seasonal Time Commitment:	Ranked 4 because spacing out coffee trees within plots only needs to be done at the beginning of the season and maybe sometimes throughout the season
Physical Demand:	Ranked 2 because the process of excavating coffee trees and replanting them may require extensive labor
Cost of Equipment:	Ranked 5 because the materials needed to replant crops are the same as the materials needed to replant them at different spaces

Maintaining Soil Nutrition (Fertilizers and raising soil pH):	
Effectiveness on CLR:	Ranked 5 because this technique can help decrease CLR, but too much use of chemicals can increase CLR
Required Training:	Ranked 1 because using different chemicals the right way and amount requires the most training.
Seasonal Time Commitment:	Ranked 3 because raising the pH in soil to 5 or 6 can require training. Also, it may take a small number of applications of fertilizers and chemicals to make sure the coffee plants receive the right amount of nutrition.
Physical Demand:	Ranked 3 because the process of preparing the soil to receive the chemicals can be extensive.
Cost of Equipment:	Ranked 2 because buying the chemicals can be very expensive, especially if a plot requires several applications.

B.2) The First Stage: Example of a Completed Rust-Resistant Coffee Plant Selection Matrix

		ALTERNATIVE COFFEE PLANTS								
		S795	**S274xKent**	**Icatu**	**Catimor**	**Colombia**	**Bourbon**	**Caturra**	**Catuai**	**Sarchimor**
CRITERIA	***Resistance to CLR***	7	7	7	7	7	3	3	3	7
	Cupping Quality	7	5	5	3	5	7	5	7	5
	Yield	3	5	5	7	5	5	5	7	5
	Coffee Plant Space Requirement	7	7	3	7	5	5	3	5	3
	Cost of Plant and Seedling Availability	7	5	5	5	5	7	7	7	1
	Total:	31	29	25	29	27	27	23	29	21
	Average:	6.2	5.8	5	5.8	5.4	5.4	4.6	5.8	4.2

B.2.1) How Alternative Rust-Resistant Coffee Plants Were Ranked

S795: A cross-breed between S288 and *C. arabica var. kent* (Kent). It grows in a tall upright position with many secondary branches that produce large, bold beans.	
Resistance to CLR	Ranked 7 because it possesses genes with 80 to 100% resistant against CLR
Cupping Quality	Ranked 7 because the cupping quality of the beans produced is of excellent flavor, taste, sweetness, aroma, aftertaste, clean cup, above average acidity and no bitterness.
Yield	Rank 3 because it has fair productivity in bearing flowers and berries per node
Coffee Plant Space Requirement	Ranked 7 because it requires 1.5m between plants in rows, resulting in the greatest number of plants per plot.
Cost of Plant and Seedling Availability	Ranked 7 because it costs less than 25% of the farmer's income and plant seedlings can be found in Central America.

S274xKent: A sturdy, tall coffee plant with an abundance of secondary and tertiaries branches that produce medium-sized, bold, round beans with a broad navel. It is characterized by broad dark-green leaves with wavy margins.	
Resistance to CLR	Ranked 7 because it possesses genes with 80 to 100% resistant against CLR
Cupping Quality	Ranked 5 because the cupping quality of the beans produced is of good flavor, taste, sweetness, aroma, aftertaste, clean cup, average acidity and low bitterness.
Yield	Ranked 5 because it has good productivity in bearing flowers and berries per node.
Coffee Plant Space Requirement	Ranked 7 because it requires 1.5m between plants in rows, resulting in the greatest number of plants per plot.
Cost of Plant and Seedling Availability	Ranked 5 because it costs within 25 to 50% of the farmer's income and plant seedlings can be found in Central America.

Icatu: First cross-bred between *C. canephora* and *C. arabica* then cross-bred with *C. arabica var Mundo Novo (*Mundo Novo), it yields a high amount of beans with superior cupping quality.	
Resistance to CLR	Ranked 7 because it possesses genes with 80 to 100% resistant against CLR
Cupping Quality	Ranked 5 because the cupping quality of the beans produced is of good flavor, taste, sweetness, aroma, aftertaste, clean cup, average acidity and low bitterness.
Yield	Ranked 5 because it has fair productivity in bearing flowers and berries per node.
Coffee Plant Space Requirement	Ranked 3 because it requires 2.2m between plants in rows, resulting in the lesser number of plants per plot.
Cost of Plant and Seedling Availability	Ranked 5 because it costs within 25 to 50% of the farmer's income and plant seedlings can be found in Central America.

Catimor: A cross-breed between *Hibrido de Timor* and *Caturra.* This plant matures very early and produces a high yield.	
Resistance to CLR	Ranked 7 because it possesses genes with 80 to 100% resistant against CLR
Cupping Quality	Ranked 3 because the cupping quality of the beans produced is of fair flavor, taste, sweetness, aroma, aftertaste, clean cup, medium acidity and medium bitterness.
Yield	Ranked 7 because it has good productivity in bearing flowers and berries per node.
Coffee Plant Space Requirement	Ranked 7 because it requires 1.5m between plants in rows, resulting in the greatest number of plants per plot.
Cost of Plant and Seedling Availability	Ranked 5 because it costs within 25 to 50% of the farmer's income and plant seedlings can be found in Central America.

Colombia: Cross-bred from a line of the *Catimor* variety, this plant grows tall and produces large beans.	
Resistance to CLR	Ranked 7 because it possesses genes with 80 to 100% resistant against CLR
Cupping Quality	Ranked 5 because the cupping quality of the beans produced is of good flavor, taste, sweetness, aroma, aftertaste, clean cup, average acidity and low bitterness.
Yield	Ranked 5 because it has good productivity in bearing flowers and berries per node.
Coffee Plant Space Requirement	Ranked 5 because it requires 1.8m between plants in rows, resulting in a greater number of plants per plot.
Cost of Plant and Seedling Availability	Ranked 5 because it costs within 25 to 50% of the farmer's income and plant seedlings can be found in Central America.

Bourbon: A variety of *C. arabica* that produces quickly maturing cherries. Although strong winds will cause them to fall, they yield small beans with an excellent cup quality (Coffee Research Institute, 2006).	
Resistance to CLR	Ranked 3 because it possesses genes with 40 to 60% resistant against CLR
Cupping Quality	Ranked 7 because the cupping quality of the beans produced is of excellent flavor, taste, sweetness, aroma, aftertaste, clean cup, above average acidity and no bitterness.
Yield	Ranked 5 because it has good productivity in bearing flowers and berries per node.
Coffee Plant Space Requirement	Ranked 5 because it requires 1.8m between plants in rows, resulting in a greater number of plants per plot.
Cost of Plant and Seedling Availability	Ranked 7 because it costs less than 25% of the farmer's income and plant seedlings can be found in Central America.

Caturra: A direct descendent from *C. arabica var bourbon*, it can adapt to almost any environment and produces a high yield with good cupping quality (Coffee Research Institute, 2006).	
Resistance to CLR	Ranked 3 because it possesses genes with 40 to 60% resistant against CLR
Cupping Quality	Ranked 5 because the cupping quality of the beans produced is of good flavor, taste, sweetness, aroma, aftertaste, clean cup, average acidity and low bitterness.
Yield	Ranked 5 because the plant has good productivity in bearing flowers and berries per node.
Coffee Plant Space Requirement	Ranked 3 because it requires 2.0m between plants in rows, resulting in a lesser number of plants per plot.
Cost of Plant and Seedling Availability	Ranked 7 because it costs less than 25% of the farmer's income and plant seedlings can be found in Central America.

Catuai: A cross-breed of *C. arabica var Mundo Novo and C. arabica var caturra*. This plant produces a high yield with good cupping quality (Coffee Research Institute, 2006).	
Resistance to CLR	Ranked 3 because it possesses genes with 40 to 60% resistant against CLR
Cupping Quality	Ranked 7 because the cupping quality of the beans produced is of excellent flavor, taste, sweetness, aroma, aftertaste, clean cup, above average acidity and no bitterness.
Yield	Ranked 7 because it has excellent productivity in bearing flowers and berries per node.
Coffee Plant Space Requirement	Ranked 5 because it requires 1.8m between plants in rows, resulting in a greater number of plants per plot.
Cost of Plant and Seedling Availability	Ranked 7 because it costs less than 25% of the farmer's income and plant seedlings can be found in Central America.

Sarchimor: A rust-resistant relative of Catimor crossed between Villa Sarchi and Hibrido de Timor that is available in Loma Linda. (Mattleman, Unpublished Raw Data; Illy & Vivani, 2005).	
Resistance to CLR	Ranked 7 because it possesses genes with 80 to 100% resistant against CLR
Cupping Quality	Ranked 5 because the cupping quality of the beans produced is ofgood flavor, taste, sweetness, aroma, aftertaste, clean cup, average acidity and low bitterness.
Yield	Ranked 5 because it has good productivity in bearing flowers and berries per node.
Coffee Plant Space Requirement	Ranked 3 because it requires 2.0m between plants in rows, resulting in a lesser number of plants per plot.
Cost of Plant and Seedling Availability	Ranked 1 because it costs within 75 to 100% of the farmer's income and plant seedlings cannot be found in Central America.

B.3) The First Stage Example of a Completed Fungicide Selection Matrix

		ALTERNATIVE FUNGICIDES				
		Copper Compound	**Sulfur-Based**	**Lime-Sulfur**	**Neem Oil**	**Dithiocarbamate**
CRITERIA	***Fungicide Resistance***	7	7	7	UNK	7
	Effectiveness Against Rust	7	7	7	5	5
	Toxicity	1	5	5	7	3
	Organic	7	7	7	7	1
	Availability of Resources	7	7	5	3	3
	Prices of Resources	5	5	5	5	1
	Total:	34	38	36	27	20
	Average:	5.7	6.3	6.0	5.4	3.3

B.3.1) How Alternative Fungicides Were Ranked

Copper-Compound ranked as shown in the example for the following reasons:	
Fungicide Resistance	Ranked 7 because it has the least amount of risk for CLR to be fungicide resistance. Copper-Compound is a strong chemical and that is why is has a very low risk.
Effectiveness Against Rust	Ranked 7 because Copper-Compound is a strong chemical and is very effective against CLR.
Toxicity	Ranked 1 because it is very toxic. Copper-Compound is very toxic to humans through ingestion and inhalation, irritating to skin and eyes.
Organic	Ranked 7 because it is organic.
Availability of Resources	Ranked 7 because we assume that Copper-Compound and equipment is 100% available to Loma Linda.
Price of Resources	Ranked 5 because fungicide would cost between 10-24% of farmer's income.

Sulfur-Based ranked as shown in the example for the following reasons:	
Fungicide Resistance	Ranked 7 because it has the least amount of risk for CLR to be fungicide resistance. Sulfur-Based is a strong chemical and that is why is has a very low risk.
Effectiveness Against Rust	Ranked 7 because Sulfur-Based is a strong chemical and is very effective against CLR.
Toxicity	Ranked 5 because it has low toxicity level. Sulfur-Based is low toxic to humans, but still irritating to skin, eyes, nose, and throat.
Organic	Ranked 7 because it is organic.
Availability of Resources	Ranked 7 because we assume that Sulfur-Based and equipment is 100% available to Loma Linda.
Price of Resources	Ranked 5 because fungicide would cost between 10-24% of farmer's income.

Lime-Sulfur ranked as shown in the example for the following reasons:	
Fungicide Resistance	Ranked 7 because it has the least amount of risk for CLR to be fungicide resistance. Lime-Sulfur is a strong chemical and that is why is has a very low risk.
Effectiveness Against Rust	Ranked 7 because Lime-Sulfur is a strong chemical and is very effective against CLR.
Toxicity	Ranked 5 because it has low toxicity level. Lime-Sulfur is low toxic to humans, but still irritating to skin, eyes, nose, and throat.
Organic	Ranked 7 because it is organic.
Availability of Resources	Ranked 5 because we assume that some Lime-Sulfur is available and all equipment is available to Loma Linda. Lime-Sulfur is assumed that Loma Linda must order more elsewhere, thus in total, 80% of resources are available.
Price of Resources	Ranked 5 because fungicide would cost between 10-24% of farmer's income.

Neem Oil ranked as shown in the example for the following reasons:	
Fungicide Resistance	Ranked UNK because the information was unknown.
Effectiveness Against Rust	Ranked 5 because Neem Oil although effective, it is not the strongest mitigation technique to CLR. Its chemical is natural and is not as strong as other fungicide chemicals.
Toxicity	Ranked 7 because its toxicity level is very low. Neem-Oil is very low toxic, but still irritating to skin, eyes, and nose
Organic	Ranked 7 because it is organic.
Availability of Resources	Ranked 5 because we assume that some Neem Oil is available and all equipment is available to Loma Linda. Neem Oil is assumed that Loma Linda must order more elsewhere, thus in total, 80% of resources are available.
Price of Resources	Ranked 5 because fungicide would cost between 10-24% of farmer's income.

Dithiocarbamate ranked as shown in the example for the following reasons:	
Fungicide Resistance	Ranked 7 because it has the least amount of risk for CLR to be fungicide resistance. Dithiocarbamate is a strong chemical and that is why is has a very low risk.
Effectiveness Against Rust	Ranked 5 because Dithiocarbamates are strong chemicals and is effective against CLR. Dithiocarbamates mixed with Copper-Compound will make a very effective fungicide.
Toxicity	Ranked 3 because they are highly toxic to humans through ingestion and inhalation, and irritating to skin and eyes.
Organic	Ranked 1 because it is inorganic.
Availability of Resources	Ranked 3 because we assume that the fungicide is not locally available to Loma Linda, but the equipment is available. In total, 60% of resources are available.
Price of Resources	Ranked 1 because fungicide would cost 40% of farmer's income.

B.4) The Second Stage: Example of a Completed Feasibility Matrix

		PREFERED ALTERNATIVES					
		Pruning Fruit Nodes	**Adjust Amount of Shade**	**Plant Spacing**	**Maintaining Soil Nutrition**	**Copper Fungicide**	**Sarchimor**
CRITERIA	***Physical Demand***	6	3	4	7	6	4
	Seasonal Time Commitment	5	7	7	3	5	1
	Appropriate Workforce	7	3	3	7	3	3
	Local Government Capacity	UNK	UNK	UNK	UNK	4	4
	Financial Cost	7	7	7	7	3	3
	Expected Profit	7	7	7	7	4	6
	Total:	32	27	28	31	25	21
	Average:	6.4	5.4	5.6	6.2	4.1	3.5

B.4.1) Description

As mentioned in the feasibility matrix directions, above alternatives were chosen by us under the assumption that the decision maker would want to use all agricultural practices and evaluate the highest scoring fungicide as well as rust-resistant coffee plant. The ranks chosen for the example of the completed feasibility matrix are described in the following tables, followed by the results after the ranking explanations.

B.4.2) How Alternatives Were Ranked

Pruning the fruit nodes ranked as shown in the example for the following reasons:	
Physical Demand	Rank 6: The physical demand does not require strength but endurance.
Seasonal Time Commitment	Rank 5: After the first pruning, the farmer must examine each plant somewhat often.
Appropriate Workforce	Rank 7: Anyone can prune the fruit nodes.
Local Government Capacity	Rank UNK: The role of government intervention in implementation of the preferred alternative is unknown.
Financial Cost	Rank 7: It costs nothing.
Expected Profit	Rank 7: The technique costs nothing and therefore results in total profit.

Pruning Shade-Trees to Adjust Amount of Shade ranked as shown in the example for the following reasons:	
Physical Demand	Rank 3: Workers must be strong to manage branches and endure working through an afternoon.
Seasonal Time Commitment	Rank 7: Once the branches are pruned, it will take a significant amount of time for them to regrow.
Appropriate Workforce	Rank 3: Only capable adults should be using sharp tools and lifting heavy branches.
Local Government Capacity	Rank UNK: The role of government intervention in implementation of the preferred alternative is unknown.
Financial Cost	Rank 7: It costs nothing.
Expected Profit	Rank 7: The technique costs nothing and therefore results in total profit.

Plant Spacing ranked as shown in the example for the following reasons:	
Physical Demand	Rank 4: Workers do not need to be strong, but the task takes a long time to finish.
Seasonal Time Commitment	Rank 7: If the plants are properly spaced to begin with, or even after uprooting and spacing the plants, the task is complete and does not require more time.
Appropriate Workforce	Rank 7: Uprooting and replanting single plants is not a strenuous task and can be achieved by anyone.
Local Government Capacity	Rank UNK: The role of government intervention in implementation of the preferred alternative is unknown.
Financial Cost	Rank 7: It costs nothing.
Expected Profit	Rank 7: The technique costs nothing and therefore results in total profit.

Maintaining Soil Nutrition (Fertilizers and raising soil pH) ranked as shown in the example for the following reasons:	
Physical Demand	Rank 7: The physical demand does not require strength or endurance.
Seasonal Time Commitment	Rank 3: The level of nutrients within the soil must be checked often, about twice a week. If the user feels that nutrition is stable, they can increase this period.
Workforce	Rank 7: Anyone can check the soil nutrition and feed the plants.
Local Government Capacity	Rank UNK: The role of government intervention in implementation of the preferred alternative is unknown.
Financial Cost	Rank 7: It costs nothing.
Expected Profit	Rank 7: The technique costs nothing and therefore results in total profit.

The use of a **copper fungicide** ranked as shown in the example for the following reasons:	
Physical Demand	Rank 6: Workers don't need to be strong but must be able to endure short periods of walking around and applying the fungicide.
Seasonal Time Commitment	Rank 5: Fungicides have to be applied every 7 to 21 days, therefore the time commitment can be less than weekly.
Workforce	Rank 3: Only capable adults should be handling dangerous chemicals.
Local Government Capacity	Rank 4: The local government may be able to afford them but require outside intervention.
Financial Cost	Rank 3: Fungicides are expensive but affordable; grants are available.
Expected Profit	Rank 4: While the fungicides result in long term profit, they are expensive and the money spent on fungicides cannot be used for other things.

Replacing diseased plants with **Sarchimor** ranked as shown in the example for the following reasons:	
Physical Demand	Rank 4: Cultivating new plants is not necessarily physically demanding and the community is surely used to the labor
Seasonal Time Commitment	Rank 1: There is significant time involved with cultivating new coffee plants
Workforce	Rank 3: Only capable adults should be cultivating the plants.
Local Government Capacity	Rank 4: The government may be able to help with some of the costs because it will benefit them in the end, but requires outside aid through grants.
Financial Cost	Rank 3: The financial cost is not as high as fungicides and is manageable
Expected Profit	Rank 6: The potential gain after recovery is high however the start-up costs of the plants deducts from the community's annual budget.

Appendix C) Excerpts from the First Interview with Jesse Mattleman (2013)

Cesar: At this moment we want to collect general information because we were thinking of all the ways that we can help Loma Linda, but we don't know exactly what their needs are. It would be pointless for us to come up with solutions like, "let's throw a bio digester in there" or wind turbines; maybe they don't even need it.

To help us with our questions, we purchased the book by Jennifer sands that described the village or town.

Jesse: I'm not sure about the year but I know it was some time ago, but it was great that she could bring some of those processes to light, and we have been in touch with her so if you want to talk to her let me know. I don't think she's in Massachusetts, I can't think of where she is; I haven't spoken to her for a while. She works for an organization called cooperative for education and what they do is they have this motto, she'll explain it better than I do, where they get textbooks to kids who are attending school in Guatemala who don't have a lot of resources so that's what they would use as their course-books for everything. So without that it's kind of you know, tough to go to school at all and follow along, and this is true for college too because I know books cost so much, is every year new editions come out, and so kids that have previous editions are then excluded, and so they have a sustainable way of getting textbooks to kids, and so they actually have an amazing system where the kids chip in to purchase some of the textbooks so there's participation and so then the kids have a stake in it, and so if they got it with their own you know, money or traded in you know, it's a point system I'm pretty sure, then they're going to protect that book with their life. I would be happy to connect you with her.

Jesse: Yeah you guys are really digging into this stuff and I think from our perspective one of the best things we've done around all the partnerships is just, figure out if we can set up meetings and interviews with anyone and everyone who's done work there, who's done research there, who's written about it. So this is a great path for you I think, knowing that there's still a lot to be determined the more people that you can talk to, I mean that in and of itself is a research process, so I'm sure that that would be accepted by your professor as well.

Kingsley: Another thing we were thinking about is can we get in contact with some of the students from Clark who have been there?

Jesse: Yup, yes definitely; there's one student who actually, she's not a Clark student but she just got back last week so she'll have the best perspective and they had her working hard so she'll give you a sense of what it would be like to travel there too.

Kingsley: Yes.

Jesse: Okay awesome. Who's the best point person for me to work with via email and all that? I know I communicated with you and you (Cesar and Maria). Is it best to just write to one of you and cc the rest of you or is someone in charge of communications?

Cesar: Yes, we have a group Gmail.

Kingsley: Let's just dive into the questions.

What role does the church play in Loma Linda?

Jesse: It's a good question; the church plays an important role in that geographically the way the community is oriented is basically you have one road and it's upwards. So you walk up a hill as you walk up a road and you have the church at the top. So if you're coming into their community for only five minutes you're going to notice the church first and foremost. It's like a bright big yellow building with huge steps and everything sort of leads up to that. I think religion is just

really ingrained in the values that they keep but not necessarily something that dictates the social hierarchy. I think it's more about the ethic and the morals that they live by, and so one of the other questions was what are religious activities like, what might not be acceptable because of religion, and this is true in a lot places in Guatemala, just being very conservative Catholics and conservative in unsocial ways. And so not necessarily being understanding of drinking alcohol, in fact the whole community is dry, and so things that you know, we would never associate with the Catholic Church here in the US or other parts of the world are very much true there.

So I think I just answered the next question; in terms of the church values and interactions with visitors you'll definitely notice that there is a strong moral fiber and so you know a great example of this is that it's a dry community and they'll often times you know. Before a meal or before a meeting say a moment of prayer. It's not evangelical, it's not like when you come in there they're going to try to convince you that this is the best thing, that you should convert or anything like that, in fact they're really open minded because at the core of what they believe, and this falls in step with their community structure and their religion, is service and acceptance and hospitality and all of that but you know, there are some differences that you may imagine. I'm sure you guys can answer the behaviors that visitors should avoid.

Cesar: Is there any etiquette code visitors have to follow?

Jesse: Nothing that comes to mind now let me think about it a little more. I think in general just being very appreciative and you know, their traditional Ladino hospitality, they're going to try to feed you, they're going to try make sure you're comfortable, all of that and so just being sensitive to that. So if someone offers you food, unless you are allergic or really don't think it's good food, just taking it symbolically, because it's really an offering that means something to them maybe more than it means something to you and so things like that. But it's intuitive and they're so

warm and welcoming so I don't think there will be anything culturally where you're like, "God how do you interpret that" because they're going to show you tons of love.

We're really careful about that because obviously if you're a traveler you don't want to eat something that you think is going to make you sick and you have to be conscious of that. But ultimately it's just a sign of hospitality and love and what you probably don't see is that. It's hard for them to get food; they're able to feed their families but you know, it's because of the work that they do with their hands. And so to give you that and serve you first, to give you the biggest plate is really to say you're that honorable you're really that special. So it's a really neat feeling and if you can express your appreciation for that it goes a million miles.

Kingsley: The next one: we know that the community is formed by the church who distributed the land upon conditions and rules...

Cesar: Did we skip the one about participating in religious activities?

Jesse: Oh yeah; you definitely can, like if you're interested in going to church you would be welcome there and even if there's not a service going on the church is open and it's really beautiful on the inside so it's worth looking in and seeing what it's all about. A bunch of different religious holidays like saint days and they celebrate all of those and so I guess those are across all catholic people but they take them quite seriously. And so certain days that I don't anticipate, for example I'm working with Pascual on a project he you know, he’s not calling me back and he'll say, “oh you know we had saint whatever day and all the kids are off school and we did a festival or we had a big dinner” or something like that so there are a lot of these holidays that you might experience when we're there I couldn't even tell you when they are, but they're often so that would be really neat if you were there for that.

Cesar: And the follow-up for that question was whether we would be excluded from certain activities like if they had a ritual or tradition that they perform or rite of passage or something, and they would say "no this is for village members only, you cannot participate in this."

Jesse: Potentially not so much religious, but potentially if they're having a meeting about a very sensitive community issue they wouldn't mind having outsiders there but I think generally you would be fine and they would certainly be prepared for you to be there so they would love to include you. If there's a communion going on or a school graduation or school play or something like that, they would just put you in the front row and be so happy to have you there but if something really sensitive was going on I'm sure they would just politely ask you to you know take an hour, take a break while they do whatever they need to do.

Cesar: I wasn't sure if we you know, show up at the hotel and I don't know someone says, "No I don't feel like going to the church, I just want to stay in my room." Would they feel offended by that or would they be alright?

Jesse: No I don't think that would be it; I think that the best thing to do when you're there is just get in as much as you can. And so whenever I travel you know, it can be exhausting because you're trying to do stuff in another language and you're eating all this new food and you're waking up early and the terrain is up and down so you're hiking a lot and it's easy to just say, "alright I really need to just take a day off" but you're there for such a short amount of time, to pack it all in is always the best thing so when you get home you can breathe a sigh of relief and know that you've seen everything and done everything. But of course if you really were feeling ill or under the weather they would want to check and make sure that you're okay, but they certainly wouldn't be offended if you needed to take a nap or something like that.

I also think, as you would imagine, it's a beautiful place in terms of the surroundings and the natural world and that's something that they would love to share with you; it's something that they're really proud of. In terms of skills: I was actually going to mention this to you when you were talking about the group and sort of understanding the needs before jumping in with your solutions, which I totally agree with but just as you ask about what the skills of Loma Linda has, I think it would be useful for you as a group to sit down and talk about what are the four of your core competencies. And by that I mean the community might want you know, to plant pineapple trees, but if none of you know how to plant pineapple trees then it's not a match made in heaven right? But figuring out what you can offer and juxtaposing that to the needs that are there.

Maria: That totally makes sense but the IQP is supposed to take us out of our comfort zone. It's supposed to be so we can learn and understand things that are completely apart from our majors. So even though most of us are mechanical engineering majors, helping them plant pineapple trees, which would be something we could do.

Jesse: Okay great, so maybe even pairing that down; so obviously you're a little bit flexible on what the project is but what skills intangible or tangible do you bring to the table? So maybe you don't know how to plant pineapple trees but you could learn and that's what you focus on as a group, but for example you have the language skills, maybe someone has the agricultural experience, maybe someone has marketing experience, someone can build a website, all of those things too, are just useful to have down on paper and within that there's going to be an element of teaching yourself how to do good and figuring out how to step out of what you've done before and making it work for this. But just having what is possible in a very broad sense would be really neat to see.

Maria: Okay we'll work on that.

Jesse: Well you guys have read a lot, you tell me what the skills are.

Cesar: We thought it would be something like you know, I read about basket weaving with bamboo or obviously agrarian skills, but we also thought about their traditions and maybe that they had dances at times and obviously they had colorful dresses. We thought that maybe if they knew this and there were skills passed down from older generations that could be passed down to kids, and I know that the ASODILL organizational overview mentioned that they wanted to provide micro-businesses for kids. Sort of like how kids here make a lemonade stand to sell lemonade because then they think "oh I can make money" and they think that they can profit so it would provide a brighter vision of the future for them, the kids. So if they taught their kids how to tailor a dress or something like that or dolls and decided to sell it to tourists who think "oh that's so neat I haven't seen something like that" then it would be like the lemonade stand, they would be selling to people coming by and it would be the micro-business for them. That would be the major skills that I was focused on; do they teach their kids to tailor or basket-weave or is it just planting?

Jesse: Agriculture is the biggest one and I think it's the most ingrained and so you'll take hikes through the forest and they'll be plucking different plants and barks and they'll show you "this is used for that" and you'll think "oh that's nice" but then you see that it actually can be used and they do use it. One of the coolest examples is this tree, they call it a vampire tree, and when you hit it even just to make a tiny little dent, you don't have to cut it down but just a little scratch, it looks like blood is coming out. It's actually like the sap is red and it kind of beads the way a paper-cut would and it has a property to it. You know when you have a cold sore and you put that numbing medication on it, just a little dot on your lip or a canker sore, it has that same effect

and it's completely natural and very sustainable and so that's not something that they're selling, I don't even know what it would take to necessarily bottle that up. But you know, certain parts of plants that are edible that are really high in nutrition that have medicinal properties that can be manipulated to create x y and z; it's ingrained, they're very knowledgeable about it which is very cool.

There is some effort to do different job skills which you mentioned and I think a lot those involve youth. The biggest problem is there's not a market to sell a lot of these things and so it's great to have these skills and they've had a lot of training on different skills but there's not always a great end goal after that. For example they had a really cool workshop because a lot of the ladies there like to cook and you'll stay with host families and taste the food and it's amazing. They had a cake baking workshop where they learned how to do really neat pastries; that's a great skill and maybe they could have some small sales with tourists but there's not a need in the community to have a bakery and there's such a small market that, how would they put that skill to use? If it's for the sake of education I think it's really fun you learn something you try something new you get to just be social and all those things have value but one of their biggest overall needs is very overarching and one of the biggest reasons behind their ecotourism besides their conservation efforts is, "how can we create jobs for the next generation and how can we keep the community of Loma Linda alive and kicking."

If there's no opportunities for youth to actually make money, and so what would be really interesting would be to think about some of the skills they have whether they're agriculture based or artisan based, because there's a little bit of that it's not very prominent but there are a few people that are really skilled and could certainly teach others, how do you get those to a market? Well still attracting people to stay in Loma Linda, so you could for example take a bunch of

baskets and go down to the nearest city and sell them but that doesn't necessarily go back into Loma Linda's economy it just goes into my pocket because I'm selling the baskets and so in what way can that be integrated into the structure of their community where you know, young people are staying and the next generation is coming up the ranks. Families are feeling like they can stay in Loma Linda and they don't have to be going out all the time for work and so on.

Cesar: Is there a management structure that exists like there where it's an honor system, say someone brings the baskets to the city sells them and throws the money in a pool that's like a savings for general project revenue or something like that.

Jesse: Not explicitly but I think it's ingrained, and so for example everyone has to produce a certain amount of coffee but you'll see coffee drying on the side of the road and no one ever worries, "maybe my neighbor is going to take my coffee" it's very moralistic in that way so I'm sure something like that could be arranged. One of the biggest things about Guatemala that is really neat but also has its own level of problems is that there's a lot of really great tourist attractions when it comes to markets and you'll see the woven fabrics that the traditional indigenous Mayans wear and that fabric can also be used for tablecloth and place-mats and t-shirts and all of these things that we love to buy because they're so unique.

Everything from woven baskets and bracelets to bead-work and woodwork and that's just like the coolest, and you'll love to take it home with you and it's really affordable and all of that but if you're one person making a basket and Guatemala is overrun with this market of artisan crafts how do you create a niche. Is it, do you find a particular supplier that wants to work with you because you're a great community and they want to support that. Do you create a certain way of marketing that where people love to buy it because they know that it's going to a great cause

rather than just a warehouse of Guatemalans that make this stuff for the tourists industry, so more layers of complicated stuff, but good food for thought.

Cesar: It'd be like if the government had, I don't know about things in Guatemala we'd have to do a little more research, but here you know they have edible arrangements so you know, if they were making baskets for the company that does edible arrangements and also producing produce, again that's a solution to stuff we don't know about.

Jesse: It's a good thought and I think you're thinking along the right lines in terms of partnership building and so it's unlike that if I see a whole row of baskets that I'm just going to happen to magically pick the one from Loma Linda but if I have a company where I put flowers in pretty baskets to deliver and we have a partnership, well I know you're going to come to me and hopefully you believe in my mission and I want to believe in your mission.

So that's how we work, we only work through partnerships; we can go to Guatemala and say you know "what do you guys need, you want to do ecotourism alright well let us build a couple of trails and couple of huts and you'll be off with ecotourism" that would be easy right? But when you have to partner you take the time to form those relationships and things are maybe slow and a little more complicated but hopefully there's more ownership and more sense of driving the project forward from a local point of view that in the end we believe it's a lot more sustainable.

Cesar: The partnership could also advertise, one of the questions we had was shade-grown certified coffee which is a thing that Smithsonian came up with here in America and there's a lot of regulations, requirements that need to be met, but on the other hand they make more money on the coffee because people buying it know that they're creating an ecofriendly environment for the birds, they're also buying organic, and it's good coffee, so they add those premiums knowing

that they can help something out. So it could be like "help the village of Loma Linda" integrated into the regular Guatemalan economy.

Jesse: It's a good thought and we're not too far apart in age I'm sure, just thinking about our generation and I really think and I don't know if you do, but I would be curious to hear that there's a shift happening in our generation because there's so many cool brands that have a social meaning behind them that if I have a choice to buy a Hershey's chocolate bar or some really cool chocolate bar that came from the rainforest and a portion of the proceeds goes back to them, in our generation it's cool to do that whereas previous generations were more industrial.

Perhaps they're interested in the profit or just a very different climate in terms of business and economics and ethics and I mean from where I sit I'm seeing social entrepreneurship and social marketing as cool, and you have to be critical of that you have to say is this a marketing thing or is this really going to a good cause? But assuming it's legitimate, it's a really interesting solution. Definitely something worth looking into, we've been looking into the example of baskets but just to put an asterisk next to that I'm not sure how many people do baskets versus other types of artisan goods.

Kingsley: Do they do carving into different wooden designs?

Jesse: Yeah so they do this thing, I have no idea what the word is in English maybe you do, it's called pidograbado it's like...

Maria: I don't know what pido means but grabado means engraved.

Jesse: Yeah so basically it's like wood carving. They use flames to color parts of the wood darker, and so if wood is burnt it will get darker brown, almost to a really dark black color, and you know, your regular word you can just see the grains of the wood and so just, it adds a cool element to the wood where you can have color and carvings or gradations of color. They love to

do that, it takes a long time, that's the only problem. The other problem is that even though I think it's really cool, the reception in Guatemala has been that people don't think it's really cool.

Kingsley: The reason I asked this question was because when people travel to Africa, the Kenyans have this cool carving to always bring back, and it's always a memory so I was wondering if that happened because tourists go there and see this cool carving design they may like it and want to bring it back to put it in their houses, someone sees that and is like "where you got it from" "oh I went on a trip to Loma Linda, that's where I got it from" that word of mouth can spread a concept of that.

Jesse: I think it's a matter of what it is that they're carving and so that would be, I'm putting a ton of ideas out there and I'll help you narrow it down as we go along but, that's another big question to say what sells and is popular and what doesn't sell and for whatever reason it isn't popular, and that's really a market feasibility study. To look at what sells and what doesn't, at what cost you know, it could be that they're making spoons and everyone wants forks, you don't really have to change your game that much but you got to realize that you got to start doing forks.

Maria: But you're saying that there's not much chance to do micro-businesses?

Jesse: I think there is an opportunity for micro-businesses, I'm not sure that fellow families would want artisan crafts because those are more novelty goods, but I think there's always a possibility for micro-businesses as long as it's relevant to the people living there. And certainly things like crafts and this cool social marketing that you've brought up is a potential micro-business but it would have to be at a market probably outside of Loma Linda.

And so thinking about how to create a community that has enough opportunities that people want to stay and then in a less tangible sense, thinking about how to create a community sentiment that engages the next generation in this sort of passion that their parents have been able

to live out. And so here are their parents creating these incredible structures that breed you know, social equity; how do we get the next generation to care about that and to want that. It's a big philosophical question as well as an economic one.

Maria: Do you know how the kids feel about this?

Jesse: I think right now a lot of kids leave because they want to pursue higher education which is not available in the community. A lot of kids in the states leave their hometowns to go to college too I think they're a little less concerned about that, but the question is do they come back after that or do they go away, and I think they're just on the cusp of that because the first generation of kids are just hitting that point and right now they're not as interested in coming back because there's not a lot of opportunity for them to work. There are some that have come back or that have just stayed after high school and Pascual is really trying to engage them with students. Well not students, but young adult or volunteer groups where they'll help out with different community projects and sort of find purpose through that.

He also really wants to start offering Spanish lessons because Xela is a huge pass-through city for tourists that want to take Spanish classes and so it's a big language learning center, and I think that his mindset is "well we're close enough to Xela, we offer a really cool and different environment, if we could offer people Spanish lessons the same way they're getting in Xela but on top of that with all this neat ecotourism stuff and the experience of staying in a really authentic and rural community, maybe that would attract people out of Xela and into Loma Linda. And that would be a job really well suited to young people who have more exposure to western culture and maybe more ability to communicate with you know Americans or Europeans primarily, so it's a good question.

Minh: Do you know their like capacity there? I believe 1,200 right now in the community.

Jesse: I don't believe that they're looking to expand more and so they haven't been fully let me into this process because again it's a sensitive thing but they don't just let anyone move into the community and so you roll into town and you're like "I want to get this house and start my family here." You have to be sort of interviewed the same way that if you're like living in an apartment building that's a coop; you'll sit before the coop board before you sign that lease. I think that if there's any movement in, it's very small because I haven't encountered anyone or heard of anything if at all.

Minh: Would you have to be like Catholic or something to move into the community?

Jesse: It's a really interesting question because it's totally different I mean can you believe if you tried to rent an apartment and someone's like "not in our town" but it's not done in a malicious way it's just done to preserve that sense of their community. But perhaps if they are thinking about growth they need to reexamine that policy, so it's a very pertinent question I think. Tourism capacity: ecotourism, birdwatchers, backpackers, sort of off the beaten path travelers; they're not looking to attract people that are wanting a luxury experience.

Guatemala is a big backpacker destination and so often times it's young people or people that are willing to have a really rustic experience because it's cool and you learn a lot and it's totally different and you don't mind sort of being out in nature because a lot of people enjoy that as opposed to luxury clientele, where they would need a hotel room with cleaners and really pristine surroundings and all that. But I think that they have a really big market, just Guatemala being what it is for backpackers, students, language learners, all of that.

Cesar: Our adviser actually did discuss that he went backpacking through Guatemala; he really enjoyed it.

Jesse: Cool; their capacity to host tourists is pretty small for tourists that want to stay in the hostel. And so there's four bedrooms in the hostel, three of them have two double beds and one of them has just one bed I don't know what size it is. They do a lot of home-stays so when we take students down we put them in home-stays because it's a great way to get to know the culture and the language and you eat your meals with families anyways so it's just to give them the full experience.

So there's a lot of capacity for home-stays although no one's ever done a survey to see how many people would be willing to host tourists, but we're going down in January and we have I think 17 people and we're basically taking up the hostel and a number of homes and that's perfectly fine. It's not a huge capacity like the way you know a major hotel would be but you know, as far as Guatemala goes for a pretty small community, they can pretty much handle it.

Maria: Are they looking to expand their hostel?

Jesse: Yes so they would love to rebuild their hostel.

Jesse: Yeah so right now its land that they got from the church, and that land isn't being threatened at all but I think that they have dreams of being more independent and being able to expand more. So we've talked to them over the years about interesting models for different eco huts and eco cabins. If you Google them you can see everything from very rustic examples to really high end eco lodges where you pay hundreds of dollars a night to stay and it's really amazing; almost like tree-houses and stuff like that. They would love to just have the tourist experience be a little bit removed from the community, not because the people don't want it but because they think the tourists would like to be more in the element of the woods and nature and

so I think that's their long term goal, but they're not being pushed off of their land or anything like that now.

Jesse: The other hope for building is to build almost like an eco-park. And so they have like a picnic area and a kids playing area and maybe like a waiting area, a small swimming area; they have some land that's by a river and so that's the thing that they've been talking about and thinking about, hopefully including a zip-line which would be a really neat eco attraction. And so when I say a park it's not like a theme park it's more just like a patio area and a place where you can host events and have things for kids and families and picnics and things like that.

Maria: Do you know how much they're looking to expand?

Jesse: I don't, let me find out more about that. My guess is that they would do it little by little as the funds became available, so they would probably start as small as they needed to just to begin and then build outwards from there.

Minh: How many tourists do they get a month?

Jesse: I have no idea; look into this group called Quetzal trekkers. They are a hiking company or like a trekking company in Xela and they do treks through Loma Linda. They have their calendar online so you'll be able to see how often they pass through Loma Linda so that will tell you how regularly people are passing through; it might be once a week or once every two weeks.

They also have people that just find out about Loma Linda because a friend was there or they saw a flier or something like that and I would guess that that's probably under 20 people a month on a typical month. Obviously if we bring a group and we're 17 that you know throws off the numbers for that months and gets you a lot more tourists that one month but I think that organically it would probably be less than 20, that's my guess.

Cesar: Another question we had about the hostel is that, I don't know where I pulled the idea from, but I felt like in the lobby they might have just like an about-us section like it has you know, glass cases. We talked about artifacts they might put there like saying "this is the shovel our first founder used" I don't know something like that but you know, anything they could tell us about their town's history that they could just tell people that "this is who we are, this is what we stand for, this is what we do" and I don't know.

Jesse: They have a little patio that's attached to the hostel and they have some neat posters out there that talk about the mission and vision of ASODILL. They have some pictures from some of their scenic walks and information about recycling and coffee and things like that so a little bit of that is going on, but it would be interesting to see if they would want to do something more elaborate with like history or art or something like that.

Cesar: Yeah that already sounds really good, I mean that's what I was hoping they would want to share.

Jesse: I don't think we've photographed it in particular but if you look at some of the photographs that we've had meetings out on that little patio and you see the background, you'll see the example of some of those photos.

Cesar: Some PDF I was looking at there's the banner that says ASODILL in the background.

Jesse: Yeah that was probably it.

Cesar: The next question was about the accommodations; we weren't sure about their energy consumption or how they get it, and that's why we were thinking about bio digesters in the first place. I mean, I was talking to a friend of mine who used to live in Brazil his whole life and he was like, I was telling him about the project and he was like "a ton of different rural areas use bio

digesters because it's free natural gas and fertilizer" and it's also a good way to control your waste I guess.

Jesse: I think the question about the bio digesters was that, you guys could probably answer it better than I could, I know they come in all shapes in sizes, they don't have cattle so they wouldn't be able to put cattle waste in it, and they are very deliberate about their food sources so I really don't know how much food waste they produce. I don't know how much is needed to keep a minimal bio digester going versus how much you know a very sustainable community would produce or if there's other you know fodder that you can put in there. I know people always talk about ways which work apparently but communities tend to be resistant to but they just think it's kind of icky and I just never talked to those communities about it. I don't know any of those ratios or amounts or what types of materials would be appropriate versus inappropriate but you know, a good thought. In terms of energy they have electricity which I assume means that they're on the national grid because they don't use generators but I can look into that a little bit.

Cesar: Yes, the interest is to generate income, but I know it's not free to build a wind turbine. What about water?

Jesse: Well the good thing about water is that because of their elevation and because their water comes from above, they have gravity in their favor and they have water that comes down the mountain that they literally can funnel into a holding tank and then the community below receives it. And so they have an incredible water system and they have to worry a lot less about water purity and water safety than many other communities that are low resource because their elevation is high and their water source is even higher which is really cool. They do have a big holding tank and a pump that they've had operational for a really long time and some people

have holding tanks on their roofs as well, which are just sort of like smaller barrels probably one or two times the size of those trash barrels that we put outside that hold water for that particular house; not all houses have them, but that's really neat.

And then for cooking and for heat people have stoves that are wood burning, and so they may have small ways to do things after dark or circuits to have certain appliances going but it's not as though the entire city or the entire village is lit up at night; it's sort of a personal level. But for all their cooking and eating they have these stoves that they pretty much tend to all day long because if they're not cooking a meal, they're making tortillas.

Maria: How do they purify their water?

Jesse: The community people as far as I know don't have to do anything to it. I'm not sure if they have like a chlorine system in the holding tank, I could look into that. I imagine that they have something and you guys probably know a lot about water stuff too, more than I do.

Minh: I thought I read that they boil their water.

Jesse: When tourists come...

Cesar: Well usually the mountain sediment will filter it enough that it's pretty pure, plus with the elevation it's not like it's got acid rain.

Jesse: Guatemalans don't drink a lot of water, I mean for us it's like everyone carries a water bottle around.

Maria: What do they do then?

Jesse: They just, I mean obviously they drink water sometimes when they have to but it's not ingrained in society the way it is for us like, "always get a bottle of water or a fountain" all that stuff, there's just not as much of an emphasis on that. I think for us too when we travel the terrain is really tough and so we're always wanting to stay hydrated when we're at a higher elevation and

they are just more adjusted to it. They drink a lot of coffee as you would imagine but not the good stuff because that all goes elsewhere and so a lot of their coffee is pretty weak and they sweeten it with sugar and it's almost like, it looks like iced tea, but it's coffee and they love the taste of that. They'll have it hot sometimes too and they do a lot of fruit juices because they have such amazing juice. If you're into smoothies or juices they'll make lemon ginger juice or mango orange juice and really great stuff like that.

Cesar: Have they ever complained, using the stoves, that it generates a lot of smoke and stuff like that?

Jesse: It's a big effort in Guatemala; right now some have within Loma Linda been part of an initiative to get more efficient cook stoves and some have not. I haven't talked to those households that have gone through the change to see if it's better. All of them have these cook-stoves that are cinder-blocks so they almost look just like a brick platform that's maybe like this big. And you put the wood in a little sort of cubby underneath so it's not as though they have a campfire in their home, although way back when and still in a lot of rural communities that is the case and for that reason a lot kids in Guatemala have asthma and older people have respiratory problems because you have this smoke basically in your household a lot of the time which can be dangerous. I assume that the cinder-block stoves they have with the cubbies still emit some smoke that's probably not great for your health but you're certainly not walking into a cloud of smoke or having an unchecked fire when you walk into the homes but that would be cool to see how people feel about the more efficient stoves.

And then there's a lot of efforts in Xela, particularly with the group I connected you with, are trying to re-imagine the stoves to be really efficient, to cut down on the amount of wood that you have to put in them and then to be really safe you know so the outside doesn't necessarily get

super-hot if you're cooking in it. So if you have kids running around and things like that, so it's something that people are always thinking about and designing and sometimes we think it's overdone because everyone talks about it but it would be really interesting to look at everything that's out there in terms of cook-stove efficiency and decide who's jumping on this because it's trendy, and who has a really unique effective and different design.

Cesar: That’s where we were coming from with the bio digester, my friend from Brazil was telling me, all these people decided to use the bio digesters because of the natural gas produced. You can power lights or build efficient cook-stoves; I know they were vermicomposting the coffee grounds because they found out that it was bad to just throw it out there, bad for the soil, some pH thing. But the bio digesters produce pH free fertilizer. It's like dirty dishwater, it's not just food scraps but it's like dishwater or coffee grounds or anything like that, so it just turns out to be like this water that's pH free and they pour it on plants and you can just see how much healthier the plants turn out, but that's why we were looking for more information about.. Well we'll get there because again it's a solution to something that might not be a problem.

Jesse: Yeah it's a good thing to think about though, I mean you obviously want to drop your biases as much as possible but if you're excited about something that makes for the best project because you'll really want to see it through and be engaged with it which is important to us and to them too.

Cesar: Another question we had which was relative to the water types of sanitation, septic system is prevalent. Do they have outhouses or do they have like a tank that it all goes to?

Jesse: I don't necessarily know all the engineering behind it but I know that they are off of a gravity system for the most part, although I'm sure that they have access to pumps because obviously it has to stay functional if it gets overloaded or blocked up for some reason, but I know

that there is a septic tank at the bottom of the hill. So you have the water tank at the top way up and you have the septic tank way down at the bottom; I don't know exactly how everything feeds into it. Some houses they have, and the hostel, they have two toilets that you can flush, it's not like that have a really strong flush that we're used to here but there are toilets like you or I would have in our homes too. And then they have some toilets that are like a lot more rustic that are just like an outhouse seat in a shack that's close to a house but not inside the house. It seems like most people have some form of toilet that's personal to their family as well as shower or bath but let me look into the septic question because I know a little about it but not the engineering behind it.

Jesse: Do you want to pick and choose a couple more questions that are priorities now that you know more?

Cesar: Yeah, we already covered the first one, subsistence I believe. So we were kind of thinking of what other employment they had aside from the coffee cooperative like if they also exported fruits or vegetables of if they just ate it for themselves.

Jesse: They grow this other plant called pakalana. I don't know what it's called in English or in the states; it's like ornamental so if you buy a bouquet of flowers and you'll see there are green leaves that are sort of filler flowers. They cultivate that in a farm setting so that's something that's really valuable because people want flowers at all times of the year but they're not always growing indigenously in the US, at this time in the year for example, so they can export that. I don't know exactly how they do it but it's through a similar cooperative structure and then I think they can do it in small ways like fruits and vegetables but a lot of that is for subsistence.

Maria: Can you tell us a little more about the trails? I read that most of them were unfinished.

Jesse: There's a couple of them that are finished and have been, and there's a couple that you know, they're hike-able and walkable but they would like to do more just to maintain them. Let me send you, there's a guy who was doing GIS mapping of the trails so I can send that to you, so that you'll be able to see more or less. So all the trails are maintained by ASODILL and some of the more finished ones have signs along the way to let you know what the route is called, they have like benches so you can take a break or lookout points where there's almost like a little gazebo that overlooks a scenic area where you can stop and take a picture or just take in the scenery. Those are the finished trails that they love to take people on; some of the less finished ones are just paths through the woods that they try to maintain but aren't always able to do it perfectly. You could still hike them and walk on them but I think they would like to be a little more professional about it.

Maria: Based on your knowledge of Loma Linda, what do you recommend to work on more or to look more into? I mean we have so many things in front of us and we want to get working but we just really don't have a sense of what are their pressing issues and things like that they really want us to work on.

Jesse: Yeah let me get back to you on that because that's I think the key question on everyone's mind. What's your question?

Kingsley: That was one, the second one was what type of resources the government of Guatemala offers Loma Linda?

Jesse: If there's an emergency, they'll have some discretionary funding. And so for example there was some extreme weather last year and the government was able to help repair the road. They weren't able to fund the entire project but they were cognizant of the fact that they need to take care of this community and it can't be cut off in this particular way. I know they have also

gotten funding from government affiliated sources like USAID but that's not the Guatemalan government that's our government and so government funding in Guatemala, ask your boyfriend he'll roll his eyes, is you know, something that is wonderful and needs to happen more but isn't always reliable and may come with strings attached. I haven't heard about too much government funding affecting their community but I imagine some of their structure was brought to them by government agents just given the grid and the roads and whatnot.

Cesar: One major question we had was: what does the community believe their major assets are? What do they value most I guess? Do they have livestock or do they care about the coffee or do they have, I don't know how to word it, what matters the most to them?

Jesse: Yeah I think that for them its two things that, you probably think I'm a broken record, but the agriculture and the environment hand-in-hand. What's cultivated and also what they can preserve, and then also economic opportunity, and so being able to preserve their own community by providing for the families that live in it. I think it would be interesting to look into, and I can connect you to someone with this, basic environmental ethics, because I'm not too well versed in it but it helps conceptualize monetary value for assets such as a really rare bird or a really amazing rainforest that we know is worth a lot but we're not exactly sure how that feeds into our economic system which is based on currency, as opposed to trees or hiking trails or this really amazing volcano that everyone wants to preserve but can't necessarily quantify, and so that might be an interesting tool for you to leverage. Okay the big burning question, I know this is getting long and I won’t keep you here much longer, but would you guys mind if I just observe for five minutes your own thoughts on how to answer that question and I'll interject when goods points come up or sinking points.

Maria: We talked about a lot of things, the bio digester, I think that's one of the things that we really like and we would like to contribute, and then the stove, I think that's one thing to work on. Other things we talked about was basically just trying to have the coffee bean shade certified. I don't know if they want something like that too.

Minh: Because it costs money to get certified.

Cesar: It's like 400 a day and the process can take up to four days, but if they're doing multiple plots of land that they would charge just one rate for multiple people because I guess it's really just for the person to go out there and inspect the area, so they can do multiple people at once. So it could be up to 1,200 dollars but with the exchange rate, I forget what it was but the families only make about three dollars a month or something, so if everyone contributed their entire salary for a month then yeah they could cover it but every three years they have to renew the certification. And there's other things like they have to have the tree diversity that allows birds to come in, it has to have a certain canopy height... I don't remember all the specifics but it was stuff like that you know, just with the exchange rate was my major concern.

Jesse: That's a good point; what else has sort of been kicking around?

Kingsley: We were thinking about the crops and agriculture diversifying from not just coffee alone, incorporating all other types of fruit even like cash crops that can help with the town too, so that was another thing we were looking at.

Minh: Plants that could be possibly planted there but they haven't thought of yet, that would be you know profitable as well.

Jesse: Anything else I mean anything and everything let's just put it out there and get it on paper.

Cesar: Education, I mean my parents wanted me to go to school in this town because I grew up in a city called new haven it's a pretty like, you know there were a lot of robberies etc. etc. so we moved to Madison because we knew it was separate from all that and that it had a good education system, we knew that the kids were sheltered if you will but it was safe and we got good morals like Christian morals and stuff down there. So Loma Linda is isolated enough that it's not really, obviously it doesn't have a high crime rate and you know, they do have good morals and judgment and they are all about family and stuff like that, so is there a way for them to improve their education system.

Kingsley: Another thing we were thinking about, even though we have said it so many times during our meeting was ecotourism. We were thinking of ecotourism; in which way the hiking trail, how can we advertise the town to other people that we can invite more visitors in, and in that sense that we can get more, the town can have more revenue coming in and incorporate that. So some of the ideas that we're looking at are to open up a website you know just to have a site, you know if you look at other destinations it would have a very nice website to go to showing the town of Loma Linda so we were thinking of something like that too.

Cesar: They were trying to think of ways to improve the participation of the community members. Somewhere it said that only some of them, well the members of the community would only attend the workshops that were beneficial to them, like if it taught them a skill that they could use, internet or word.

Maria: It is a cycle and then Professor Rosbach told us that we needed to kind of step back because we can't find solutions like you said without knowing what the problem is so he said we have to step back a lot.

Maria: We were talking about possibly wind turbines. They are on a hill and I think it would be perfect.

Minh: Do they have greenhouses? I read an article that they were trying to build greenhouses but the wind kept blowing it away because they were made from bamboo.

Jesse: They don't.

Minh: So those projects that they tried?

Jesse: They may have tried it before; I know they have a community garden that they use for food security so that has a lot of different crops in it because it is what they would eat or give to families who need things to eat, I would imagine that they have thought of that but I can't tell you why it hasn't been done or maybe it has been done but didn't work. But especially for those types of crops it would be really beneficial I think to have a greenhouse, it might be a structural issue like the wind blowing or.

Maria: We should find out if they want one..?

Minh: It was on one of the PDFs I read from 2010 or something; maybe it's changed.

Cesar: I know it's redundant but I didn't see ecotourism on the list, but we were thinking of ways to improve the trails.

Jesse: Yeah so there's ecotourism in terms of the business operations of it but we'll also add ecotourism, sort of like the infrastructure of the environment. So those would be the huts, the trails, the lookouts. This is awesome but here's what I would suggest that you: first of all I think you have to keep asking a lot of questions and you're going to feel like you're in a vortex of, you have your questions and then you get them answered and then you think “we're good to go let's run with it” and then 50 more questions pop up and more questions and more questions, so get comfortable here because this is the nature of working with people in communities.

There are times when you have to make educated assumptions, especially for the purpose of you guys knowing that you have a limited amount of time. So feel free to take those liberties when you have to, but do ask those questions and even if you can't ask those questions to me or find your own answer to them, make a section of your paper of your poster whatever it turns out to be to say, "these are the complications we found" because first of all I know Geoff and Derren really well, and they're going to be really interested in knowing that you are aware of all the different layers so just acknowledging that is going to get you far in terms of showing that you have a well-rounded understanding of it and then it leaves room for groups that come after you to pull one of those questions out and follow up on it, which is also I think really important for the IQP structure.

With all of this stuff there's going to be a lot of research that you're going to have to do to understand what's been done in the past, what works well, what doesn't work, if something does work is it appropriate for Loma Linda, is it appropriate for this environment? And so you have your starting point let's say you decide to look at stoves okay what's the history of it, okay where are some cases that use, what case studies worked often, what case studies did not work, how can we avoid these mistakes, how do we ensure that we're as successful too? Well it's going to take some adaptation right? And then that's when you really start thinking about Loma Linda. There's a whole process that comes before any of these things just get plopped on the ground in Loma Linda, and this is intuitive you'll get through all of this naturally as you begin researching it, but just keep it in mind, I think right now you're focused really deep onto Loma Linda and that's a great approach, but if that's becoming really intense maybe to zoom out and say let's look at one aspect of community development and see how it may or may not be appropriate for Loma Linda.

The cool thing about this project is although you want to make a difference in Loma Linda and I think there are some practical ways of doing it you might do a whole lot of research on shade certified grown coffee and your ultimate conclusion despite having traveled to Loma Linda, researching this for a really long time, might be “this is not right for Loma Linda therefore let's pack up and get out of here, this isn't going to be something that's going to be beneficial for Loma Linda.” It might seem counter-intuitive but understanding that, and I'm just using that as an example I have no idea, but understanding that that isn't a good fit is just as important as understanding that it is a good fit because the next person that walks into the community and says "let's do this shade certified stuff" they're going to say "no way Jose we know that it doesn't work and here are all the reasons why." So don't be afraid to pick something and then realize that this doesn't work, because you'll see maybe there's an application elsewhere; that's an important conclusion. Maybe there's no application in Loma Linda in which case you've brought to light something really important because so often in international development work, and in Liberia the good example is that you see people come in and say "oh my god you have a hospital but you don't have an x-ray machine, we're just going to plop down an x-ray machine." There's no power, no one knows how to read the x-rays, all that stuff, so it's important to dig into all of these things which is what I think you guys will spend a lot of your time doing.

Some of these are a little more immediate than others, which isn't to say choose one or the other but just so you're aware, ecotourism: that's alive and well in the community and so in addition to research you could do a lot with practical applications of that. Greenhouses: they're not alive and well in the community and so you'll want to talk to people in the community about that and you'll want to understand the conditions that are needed, but you'll want to look more at other communities and other examples and dive into the research aspects of that more. Same

with wind turbines you know, you'll have to do a little more on the books which might be great because you only have a limited amount of time in Guatemala but just to be able to be aware of that you know the shade certified coffee, that's going to be a little more research intensive here as opposed to on the ground there; bio digester: same thing. Still there's a little bit of everything because you have some stoves in the community some stoves floating around in rural communities, different designs that have come to light that you might want to compare and contrast.

If you choose something as large as agriculture, education, community participation, I would recommend that you pick a really small aspect of that because you're not going to be able to overhaul the education system, but perhaps you can find one change to the curriculum, or one course that they could offer, or one type of classroom management methodology that seems really appropriate and then flush out your whole argument around that, because if you look at education in Guatemala as a whole, you are going to be really overwhelmed with the short amount of time that you have. I think some of their most pressing needs, and this is from my experience with them, is economic development, ecotourism, both sides of ecotourism, and I think that they would be interested in any one of these other things but maybe aren’t aware that this is an option to even say that this is a need that we have, so that's where you're going to have to use your good judgment to say I really think that this is a fit or I at least believe that it deserves more research attention to understand whether that's something that you bring to the table that they're not aware of.

What else can I tell you? Does all this make sense so far? The ecotourism infrastructure, you can do a lot of that with your hands. If you want to go an work really hard I'm sure they'll give you the experience of doing that, but also having some sort of a final proposal and so not

just going to Guatemala and cleaning up trails, but maybe offering some ideas or innovative ways to keep their infrastructure alive whether it's through you know, these huts, or these cabins, or different types of things that come along in the ecotourism programs and trails. Maybe you look at other ecotourism programs and see what amenities they have that makes them cool and successful and that would be really neat and draw a lot of people to that community. The thing for this branch of ecotourism, although this is maybe a little bit more about marketing, and so do they have a process for checking people into the hotels, do they have a process for building, do they have a process for when someone calls them up and says, “hey I want to visit your community, well what now.” Assuming this is just going to become more and more popular they're going to have to have these types of pathways really well designed, and so looking at other businesses seeing how it's been done well. You know, figuring out how they can create efficiency with inconsistencies would be really cool and interesting, and then you almost have a portfolio at the end of this project to say "here are our suggestions, here are our recommendations; let's adapt it together to make it work for you" and I think that that applies to a number of these.

Really big questions going on with ecotourism is volunteerism and how can volunteerism be profitable for the community, because when I go to Guatemala and I pick up a couple of sticks of bamboo on the trail, I'm not really helping them all that much. It probably costs them a lot more to feed me and house me than it does you know, the benefit that they get from my two hands on their trails and so I know there's a ton of volunteering programs that take young people oversees; there are probably a lot through WPI. How can you monetize that and create economic opportunities through volunteerism because we know that students and people seeking experience will pay, not a ton of money, but a little bit of money to have these experiences to

have it on their resume to get to go somewhere really awesome. That would be a really interesting question because the community is so nice and so welcoming; if they say, “hey you're coming to help us we don't need anything in return your help is enough” but in reality it doesn't always even out. So that I think is a really critical question for economic development and then you have these much more concrete things like a bio-digester and cook-stove. And so everyone knows what that is and it might be a little easier to round your brain around it in the beginning, but some neat comparisons and case studies that could be made.

Kingsley: This was really helpful because at this point the group moves in a better direction with a better sense of where to go from here.

Jesse: Alright so let me go through these other questions and anything that seems interesting that we didn't talk about. I'll get you a response to and I'll make a couple of those connections that I think were on that paper. Let me write them again, Jennifer sands the Clark students and don't forget the volunteers. If you don't hear back from me or I'm not giving you what you need, call me and just say “hey” tap me on the shoulder, “we need this” because I don't want to forget about anything but it's a really busy time and I'm gone for the beginning of January probably getting back right when you guys start up again to... when do you come back from break?

Kingsley: The 16th, yup that's when.

Jesse: If you guys are planning on doing work over break I recommend that you do not. So if you absolutely have to, just saying that I'm going to be gone from the New Year until you're back to WPI, so we can pick it back up again.

Maria: Okay that sounds good.

Kingsley: Thank you.

Jesse: Let me know what you need even if it's just like “we're having a disagreement” or “this topic versus this topic what are your thoughts?”

Maria: We were thinking of sending over a survey depending on what we talk about after this meeting, would that be cool with you?

Jesse: Yes, definitely, and I know we didn't get into travel but I'm assuming you guys are on board. So can one of you send me your travel dates? And I can begin to just confirm with Pascual that that's cool. A couple things that I would mention to you about travel just that it's coming up sooner than you realize: if you're home over break just make sure that your passport is still valid and you have to have at least six months on it from your return back to the US. So if you go in March you’d have to have March plus six months which is just a funky little rule, but you're probably fine because passports last what like ten years or something like that, but just double check that. And if you go on CDC the center for disease control they have travel information for Guatemala and so you're probably up to date on all your vaccinations from being a student but just to double check that you don't need boosters on anything because you'll need to do that before Guatemala like take malaria medication which, have you ever done that?

Kingsley: Thank you.

Jesse: Sure and if you're confused later on give me a call and we can work through some of the questions. For you guys, just mentally to get you to relax a little bit, you're going to have to know your topic and I think that you can start moving in a more productive direction. I think everyone feels a little better in a million ways but it'll get there and this is an important part of the process.

Appendix D) Pasucal's Information Regarding Landscape Context in Loma Linda

1. Would the community of Loma Linda introduce hybrid coffee plants that resist rust? (Must pass replacement slowly in stages, not all changes at once.)

Indeed coffee farmers in Loma Linda want to change the varieties they are using. At this time, now that the Roya attacks the varieties of Arabica in Loma Linda called Bourbon and Caturra, and now that we know that the most resistant variety is a hybrid called Salchimor. However, it is not easy to find and sells a little expensive to buy pylons. Furthermore, due to the height of Loma Linda, it is not easy to create a nursery for small plants. Yes it's possible to work with, but it has to be planted in a high altitude; in that way we have the desired results.

2. What types of pesticides are used in their coffee? (Organic and / inorgamic)

I can not specify the names of the pesticides used but I will investigate and will reply with a new email because we already sprayed twice but the results are useless because the rust is very sturdy.

3. What type / breed / specific name of Arabica coffee is grown:

Bourbon, Caturra, and Catuaí, varieties of Arabica.

4. How would you rate the ground that coffee is grown in? (For example - volcanic, dry, etc.)

I do not understand the question.

5. At what temperature level is the best coffee grown?

The altitude that Loma Linda has is very good to produce the best coffee. The harvested product so far has been classified as Hard and Strictly Hard, which are the best rankings, although I will also send new information.

6. Is there a specific type of shade tree that is planted to help the cultivation of coffee? What are the trees specifically called?

The best shade for a good coffee trees are the INGAS: Chalum, Caspirol, Cushin, Guagua, like, the tree called Pito and others.

---------- Forwarded message ----------

From: **Mattleman, Jesse** <jmattleman@sevenhills.org>

Date: 2014-03-23 18:28 GMT-04:00

Subject: RE: Preguntas Sobre la Roya

To: María Cantos <iqp2014@gmail.com>

Cc: "Emerson Gilbert, Ashley" <aemersongilbert@sevenhills.org>, "Ankermann, Dayna" <DAnkermann@clarku.edu>

Dear Maria and Team,

Sounds wonderful - thank you!

FYI - I am headed to Guatemala from March 26 to April 3rd and will not have internet access during that time. When is your final due date, and what do you expect your group's needs may be as you approach the homestretch? It would be helpful to have a better picture of what lies ahead as your project progresses and your term comes to a close. This also includes any final presentations you may have as we would like to plan to attend if possible. Keep us posted and good luck!

Best,

Jesse and The SHGO Team

Jesse Mattleman

Assistant Director

Seven Hills Global Outreach

81 Hope Avenue Worcester, MA 01603

Phone: 508.755.2340 x 2929

Direct: 508.983.2929

Fax: 508.849.3888

jmattleman@sevenhills.org

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From: María Cantos [mailto:iqp2014@gmail.com]

Sent: Saturday, March 22, 2014 10:40 AM

To: Mattleman, Jesse

Subject: Re: Preguntas Sobre la Roya

Hello Jesse,

Pascual's answers are very helpful. We can see that he is very knowledgable about his land. I'll email you if we have any questions.

Thank you for your time,

Maria Cantos

Sent from my iPhone

On Mar 18, 2014, at 1:55 PM, "Mattleman, Jesse" <jmattleman@sevenhills.org> wrote:

Dear Maria and Team,

Please see below for Pascual's responses to the questions you posed. Let me know if you need any help or support with translation, follow up, etc. Please correspond through me rather than directly to Pascual at this point. Thank you and great work!

FYI - It appears he did not understand question #4. I am not sure if I asked it properly in terms of gathering the technical information that you need (?) or perhaps this is simply a gap in

Pascual's own knowledge about coffee growing. Please let me know how I can clarify this for him, and if you can phrase the question in Spanish that would also be helpful as a guide for me to inquire and explain better.

Thanks and keep me posted!

Best, Jesse

Jesse Mattleman

Assistant Director

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From: Pascual Rafael [mailto:pascualrfl@gmail.com]

Sent: Tuesday, March 18, 2014 1:53 PM

To: Mattleman, Jesse

Subject: Re: Preguntas Sobre la Roya

Hola **Jesse:**

Respuestas a las preguntas de los Estudiantes Ingenieros:

1. ¿Estaría la comunidad de Loma Linda introducir las planta hibridas de café que se resisten la roya? (Debe pasar la sustitucion en fases poco a poco, no todos los cambios al mismo tiempo.) Efectivamente los agricultores de cafe en Loma Linda, si quieren hacer cambios de las variedades que están utilizando, en este momento, ya que la ROYA ataca mas a la variedad llamada borbón, caturra, arábigo, variedades que hay en Loma Linda, y en este momento se sabe que la variedad mas resistente es una híbrida llamada Salchimor, pero no es fácil conseguirla ya que sale un poco caro comprar los pilones y debido a la altura de Loma Linda no es fácil crear un vivero para plantas pequeñas si es posible trabajar con ella pero ya tiene que tener una altura un poco grande y sembrarse y así tener los resultados esperados.

2. ¿Qué tipos de pesticidas se utilizan en sus plantas de café? (orgánicos y / oinorgánicos) no puedo precisar los nombres de los pesticidas utilizados pero los investigaré y se los enviaré en nuevo correo porque sí ya se fumigó dos veces pero los resultados son inútiles ya que la roya es muy resistente.

3. ¿Qué tipo / raza / nombre específico del café Arábica se cultiva: -borbón, caturra, catuaí, arábigo.

4. ¿Cómo clasificaría el café se cultiva en el suelo? (Por ejemplo - volcánico, seco, etcétera...) no entiendo la pregunta.

5. ¿En cuál nivel de temperatura se cultiva el café mejor? la altura que tiene Loma Linda es muy buena para producir el mejor cafe, ya que el producto cosechado hasta el momento se ha clasificado como Duro y Estrictamente Duro, que son las mejores clasificaciones, aunque también enviaré una nueva información al respecto.

6. ¿Hay un tipo específico de árbol de sombra que se planta para ayudar a los cultivos de café? Como se llama los arboles especificas? la mejor sombra para un buen café son los árboles de las INGAS: Chalum, Caspirol, Cushin, Guagua, otros similares, el árbol llamado Pito y otros.

Es un gusto colaborar en cualquier información que requieran mis amigos.

Pascual

El 18 de marzo de 2014, 8:27, Mattleman, Jesse <jmattleman@sevenhills.org> escribió:

Hola Pascual,

Hay un grupo de estudiantes aquí en Worcester quien están estudiando como parte de una universidad que se llama WPI, es una universidad técnica de ciencias y ingeniero en Massachusetts. Ellos están estudiando la roya en Guatemala y tienen unas preguntas para ti y ASODILL. Me puedes mandar sus ideas y respuestas antes del viernes de esta semana? Gracias por su tiempo y ojala el trabajo de ellos puedan ayudar con más información sobre la crisis del café en Loma Linda y Guatemala. Si no sabes la respuesta a una(s) pregunta(s), no hay problema - la información es muy técnica y ellos solo necesitan saber lo que saben Uds. en Loma Linda.

1. ¿Estaría la comunidad de Loma Linda introducir las planta hibridas de café que se resisten la roya? (Debe pasar la sustitucion en fases poco a poco, no todos los cambios al mismo tiempo.)

2. ¿Qué tipos de pesticidas se utilizan en sus plantas de café? (orgánicos y / o inorgánicos)

3. ¿Qué tipo / raza / nombre específico del café Arábica se cultiva

4. ¿Cómo clasificaría el café se cultiva en el suelo? (Por ejemplo - volcánico, seco, etcétera...)

5. ¿En cuál nivel de temperatura se cultiva el café mejor?

6. ¿Hay un tipo específico de árbol de sombra que se planta para ayudar a los cultivos de café? Como se llama los arboles especificas?

Muchas gracias por todo su apoyo! Siempre aprendimos mucho de ti y sus colegas en Loma Linda :)

Saludos,

Jesse y Los Equipos de SHGO y WPI en Worcester

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www.sevenhills.org

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