Building Resilience in the Face of La Roya

FARMER TO FARMER

Prepared by

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Presented to

The Frank Batten School of Leadership and Public Policy

All uncredited photos courtesy of Farmer to Farmer

"Sí, se puede"

-*César Chávez*

Land Acknowledgement

I am acknowledging that the land on which I've researched, written, and edited this applied policy project was stolen. The Monacan People are the traditional stewards of this land, and have endured a painful history of trauma perpetrated by the University of Virginia. The Monacan people were forcibly removed from this land, and enslaved laborers built up the area that I have called home for the past six years. I want to honor and express gratitude to the Monacan people for their continued stewardship of this land.

Acknowledgements

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To my family and friends (especially Ben), I would not have made it through this higher education journey without you; I'm looking forward to having you all by my side at graduation. My parents' (and grandma's) unequivocal support is the reason that I have made it this far. Lastly, I would like to thank my Batten peers for their input on my project and late nights in the Deloitte Lounge. We've done it!

I never thought that my first trip to Honduras in 2015 would lead me here...

Disclaimer

The author conducted this study as part of the program of professional education at the Frank Batten School of Leadership and Public Policy, University of Virginia. This paper is submitted in partial fulfillment of the course requirements for the Master of Public Policy degree. The judgements and conclusions are solely those of the author, and are not necessarily endorsed by the Batten School, by the University of Virginia, or by any other agency.

Honor Pledge

On my Honor as a student I have neither given nor received unauthorized aid on this assignment

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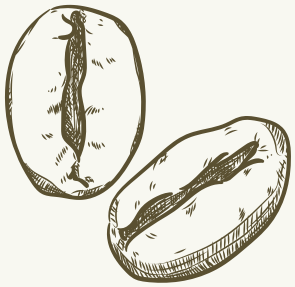

Glossary

Adaptive Capacity: The ability or properties of a person or system that enable it to change in the face of adversity or challenges (Jakku and Lynam, 2012).

Banana Republic: A banana republic is a country that relies on one primary crop for a significant portion of its income, or in other words, is controlled by foreign enterprises (The Economist, 2013). Although Honduras relies on more than one crop, this general idea applies as the country heavily relies on agricultural exports.

Coffee Rust: Coffee Rust, a fungus caused by the Hemieleia vastatrix pathogen, is currently found in all coffee-growing regions of the world (Arneson, 2000). The hosts of this disease include arabica and robusta coffee, two of the most important commercial species.

Fungicide: An organic or chemical agent that destroys fungus.

Hectare: A unit of measurement common in the coffee industry; roughly 10,000 square meters.

Remittances: In this context, remittances refer to individuals in the United States sending money back to their friends and/or relatives in Honduras.

The Northern Triangle: The Northern Triangle is a region of Central America consisting of Guatemala, Honduras, and El Salvador. See Appendix One for a Map.

Executive Summary

This report was prepared for Farmer to Farmer, a Wisconsin-based nonprofit organization that supports grassroots agricultural movements. One of this organization's projects involves working with coffee farmers in Comayagua, Honduras to build sustainable income in the face of climate change.

Climate change heavily impacts the coffee industry, specifically for Honduran coffee farmers. A significant portion of the population in Comayagua, Honduras relies on coffee production for their income (Instituto Hondureño del Café, 2019). One way that climate change negatively impacts the industry is through an increase in coffee rust. This disease affects a coffee plant's photosynthetic capacity, which reduces yield through weakening or killing trees (Arneson, 200). Increased temperatures and erratic rainfall in Central America have sped up the lifecycle of coffee rust, allowing it to reach more plants (McKenna, 2020). *With a limited ability to diversify income and the continued threat posed by coffee rust, low-income farmers will struggle to rely on coffee farming for their livelihood.*

Based on a thorough review of the literature on potential solutions, the following list of potential mitigation strategies was developed:

- Strategy One: Improving Soil Nutrition
- Strategy Two: Increasing Access to Fungicide Spray
- Strategy Three: Introducing Resistant Varieties
- Strategy Four: Pruning Shade Trees
- Strategy Five: Implementing a Disease Monitoring System

These potential strategies were then evaluated against the following criteria: feasibility, effectiveness, equity, sustainability, and cost to reach a final recommendation involving a combination of strategies one, improving soil nutrition, and five, implementing a disease monitoring system. A guide to implementation is provided.

Introduction

Client Overview

Farmer to Farmer is a Wisconsin-based organization that aims to build mutual friendship and cultural understanding among rural people so that they can better understand and accompany one another in their common struggles (Farmer to Farmer, n.d.). They support grassroots agricultural movements, including the coffee farmers in Comayagua, Honduras that this report was conducted for. Farmer to Farmer is working towards a sustainable and respectful future for agriculture that belongs to the people who live and work the land; they prioritize equity and accountability in their work and actively advocate for and support local community leadership (Farmer to Farmer, n.d.). This analysis prioritizes the values held by Farmer to Farmer and considers similarly-minded values including local empowerment and job security.

Problem Statement

Roughly one fifth of the population, or almost 30,000 people, in Comayagua, Honduras rely on coffee production for their income (Instituto Hondureño del Café, 2019). Climate change has significantly impacted coffee production and crop yield, specifically through an increase in coffee rust. This disease affects a coffee plant's photosynthetic capacity, which reduces yield through weakening or killing trees (Arneson, 2000). Increased temperatures and erratic rainfall in Central America have sped up the lifecycle of coffee rust, allowing it to reach more plants (McKenna, 2020).

Already vulnerable coffee farmers, specifically those living under the poverty line ($3.10 a day), that do not own the farms that they work on, are at further risk. In Honduras, roughly a third of coffee farmers live under the poverty line, with just over half of them earning less than $1.90 per day. With a limited ability to diversify income and the continued threat posed by coffee rust, these low-income farmers will struggle to rely on coffee farming for their livelihood.

The Coffee Industry—How Does Honduras Fit In?

Coffee is enjoyed daily by billions of people around the world, and the coffee industry is one that primarily relies on labor in developing countries. Honduras is the 5th largest coffee producing country in the world, with production spanning across 15 of the 18 departments (Instituto Hondureño del Café, 2019). See in Figure one below. Coffee represents roughly 30% of the Honduran agricultural GDP, and 4% of the country's overall GDP (Sustainable Coffee Challenge, n.d.). A majority of Honduran coffee is grown on small, family owned farms in rural, mountainous areas.

Figure 1: Honduran Coffee Growing Departments. Data courtesy: The Database of Global Administrative Areas

Despite the global popularity of coffee, the return on investment is continuously declining for farmers, which has led some people to find other crops to grow, or migrate to a different city or country looking for work (Angel et al., 2021). According to the executive secretary of PROMECAFE, a research network formed by Central American national coffee institutes, there are typically large waves of migrants from the Northern Triangle when coffee is not growing well (Angel et al., 2021). Migration north is a last resort. However, according to a PROMECAFE survey, out of 990 farmers, just over five percent shared that at least one family member had left for the border during the summer of 2019 (Angel et al., 2021).

With agriculture as the primary source of income, poverty is particularly dense and widespread in hillside areas of the country with 80% of the rural poor population living there; these households have limited assets to rely on for their livelihood (Inter-American Development Bank, 2019). With more than a third of Honduran coffee farmers living under the poverty line ($3.10 per day) and having limited access to education, the cycle of poverty is inevitable for coffee families (Rushton, 2019). Based on the time that I have spent in Honduras, I have seen firsthand the lack of government assistance available for people living in mountainous regions, specifically a lack of public schools with rigorous curriculums and well-resourced teachers.

Although Honduran coffee farmers' struggles can seem distant, Honduras imported roughly $240,000,000 worth of the crop to the United States in 2020 (Statista, 2021). Since the United States in-part relies on Honduras for its coffee, the effects of climate change, labor patterns, and even politics as they relate to the coffee industry could begin to further pervade global media.

Honduras: A Banana Republic

After manufactured T-Shirts, coffee is the top export of Honduras (The Observatory of Economic Complexity, n.d.). The agricultural industry has long-stimulated the Honduran economy and currently employs roughly thirty percent of the labor force (Statista, 2022).

By the end of the nineteenth century, businessmen in the United States realized the lucrativeness of growing and exporting their fruit from Central American countries, like Honduras (T.W., 2013). Companies like United Fruit (now Chiquita) seized the opportunity and exchanged infrastructure for land (Eschner, 2017). Prior to being bought by United Fruit, a smaller banana company, Cuyamel, supplied weapons for the 1911 Honduran coup that shifted leadership to a friend of the company (Eschner, 2017). This coup marks the beginning of what would become more than a century of U.S. influence on Honduran political and economic trends.

Although Honduras does not solely rely on coffee in the way that it relied on bananas in the late eighteenth and nineteenth centuries, their labor continues to be exploited for largely unsustainable exports. The American Dream has persisted—but at what cost?

Background

The Impact of Climate Change

Climate change has significantly altered the agricultural landscape, with coffee being no exception. Coffee is a delicate crop requiring very specific elements for effective growth. For example, altitude and shade play a relatively large role in the taste, sustainability, and survival rate of coffee plants. All of these specificities directly impact the income potential for farmers. The effects of climate change on the Honduran coffee industry will only continue to worsen over time, with land area suitable for coffee growth shrinking by up to 50% by 2050 (Inter-American Development Bank, n.d.). The figure below depicts this trend.

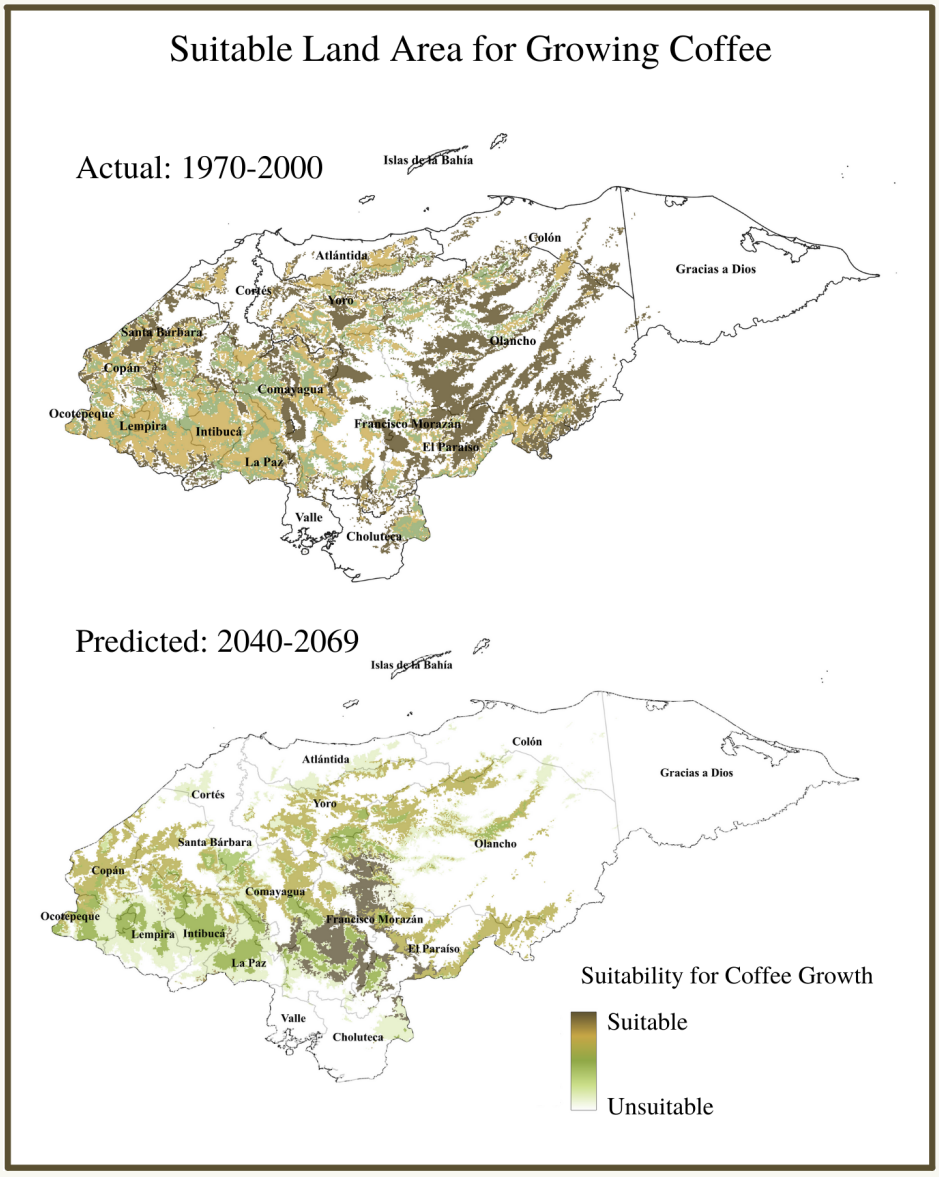

Figure 2: Suitable Land Area for Growing Coffee. Data courtesy: (Bunn et al., 2018)

Altitude is an important aspect of coffee growing because at higher altitudes, cooler temperatures slow down the growth cycle (Fleisher, 2017). This process allows for deeper and more complex flavors to emerge, which is important for consumers. In response to the increased temperatures, unpredictable precipitation patterns, increased disease, and more severe natural disasters that come with climate change, farmers will be forced to move to hire altitude regions to continue growing coffee. These specific effects of climate change are detrimental to the industry primarily due to the sensitivity of the coffee plant and its growth requirements. Currently, roughly sixty one percent of coffee farms in Honduras are located between 1,200 and 1,500 meters above sea level, which is considered a relatively high altitude for coffee growing already (Gomez, 2020).

Because Honduras has relatively low mountain ranges in comparison to other coffee-growing countries, such as Ecuador and Columbia, this allows for limited space to adjust. Furthermore, cloud forests, which are typically located above 1,500 meters above sea level, are crucial to the agricultural sector in Honduras (Wilson et al., 2004). With unique foliage and high precipitation, cloud forests are a vital water source for rivers which provide water for agricultural activities across the country. If coffee farmers were to begin growing above 1,500 meters, which is a likely response to temperature increases, they would significantly impact the water sources located at these high altitudes. Furthermore, deforestation and subsistence farming in cloud forests is illegal, as they are often designated as national reserves (Wilson et al., 2004). Despite the danger that growing at higher altitudes poses on water sources, regions suitable for coffee growth are extremely limited, offering farmers no clear solutions.

Case Study: Hurricanes Eta and Iota

Over the past four decades, Atlantic hurricanes have become stronger, wetter, and slower-moving (Shultz et al., 2021). The influence of climate change on the production of tropical storms can be partially explained by abnormally warm water and air temperatures late into the season (Shultz et al., 2021). In November 2020, Hurricanes Eta and Iota devastated Honduras and surrounding countries only two weeks apart. Both storms presented notably high wind speeds, massive flooding, and rapid intensification. In addition to the high death toll and infrastructural damage that these hurricanes caused, they left a mark on Central America that will likely span decades.

Image courtesy: The New York Times

As it relates to the coffee industry, The National Coffee Council of Honduras estimated that Hurricanes Eta and Iota affected fourteen of the fifteen coffee growing departments (International Coffee Organization, 2020). More specifically, total production lost due to the direct impact of the storms was estimated at approximately three percent of exportable coffee in the 2020/2021 season. With less coffee to export, small farms will struggle to make up the difference. The decrease in income, specifically in heavily impacted departments like Comayagua, will reduce the capacity for farmers to build resilience in seasons to come (International Red Cross and Red Crescent Societies, 2021).

As explicitly mentioned above, climate change disproportionately affects smaller coffee farms that have fewer financial resources to adapt and become resilient. Unlike consumers, when there are natural disasters or other climate-related challenges such as flooding and droughts, farmers are unable to move locations or alter their growing strategy on a whim (Worland, 2018). The Senior Sustainability Manager at Keurig noted that this is also important for her company (and others in the industry) as farmers are part of their long-term growth strategy (Worland, 2018).

In addition to the direct affects that climate change poses on the coffee industry like increases in temperature and unpredictable weather patterns, there is also a significant byproduct: migration. According to a 2018 report by the World Bank Group, Latin America could see nearly eleven million internal climate migrants by 2050 (World Bank Group, 2018). This estimate does not include the expected migrants leaving the region. However, a decrease in rainfall has been associated with a considerable increase in family unit apprehensions at the United States-Mexico Border (Bermeo and Leblang, 2021). According to Jane Jacobs, “if people in all poor, stagnant regions were to have ample access to city work, no matter how distant, we may be reasonably sure that virtually all poor, stagnant regions in the world today would be losing populations at a great rate” (Jacobs, 1984). The idea of migration for better opportunity in the wake of a rightfully-perceived cap on economic growth is not new. The effects of climate change on coffee growing is a harsh example of the reality for many agricultural workers around the world.

What is Coffee Rust?

In addition to the impacts described above, climate change has also worsened diseases that impact coffee production, namely coffee rust in the Honduran context. More specifically, temperature increases and erratic rainfall have allowed coffee rust to thrive in the altitudes that coffee is grown at. For the scope of this project and based on the needs of Farmer to Farmer, the analysis section of this report will focus on ways to mitigate coffee rust.

Coffee rust, a fungal disease caused by the *Hemileia vastatrix* pathogen, is currently found in nearly all coffee growing regions around the world and is known to affect both the arabica and robusta coffee varieties (Arneson, 2000).[1]

[1] Arabica and robusta are the two most commercially important varieties in the coffee industry (Arneson, 2000).

This disease affects the leaves of the plant, becoming detectable with pale, yellow spots. Although these lesions can appear anywhere on the leaf, they tend to develop where water collects (Arneson, 2000). The disease typically begins by affecting the bottom leaves on a tree first, moving further into the tree throughout the season, with infected leaves dropping prematurely. This exposes the tree to further danger, and limits its photosynthetic capacity.

Figure 3: Coffee Leaf Rust. Photo Courtesy: Andrew Gaertner.

Coffee rust spreads predominantly by wind and rain, and less frequently through insect dispersal (Arneson, 2000). Once infected, a plant will begin developing the spores described above after an incubation period of roughly twelve days. If a plant is lucky enough to survive the infection, it later might face a secondary infection and will further limit the tree's ability to produce coffee effectively (Arneson, 2000). Figure four depicts the disease cycle.

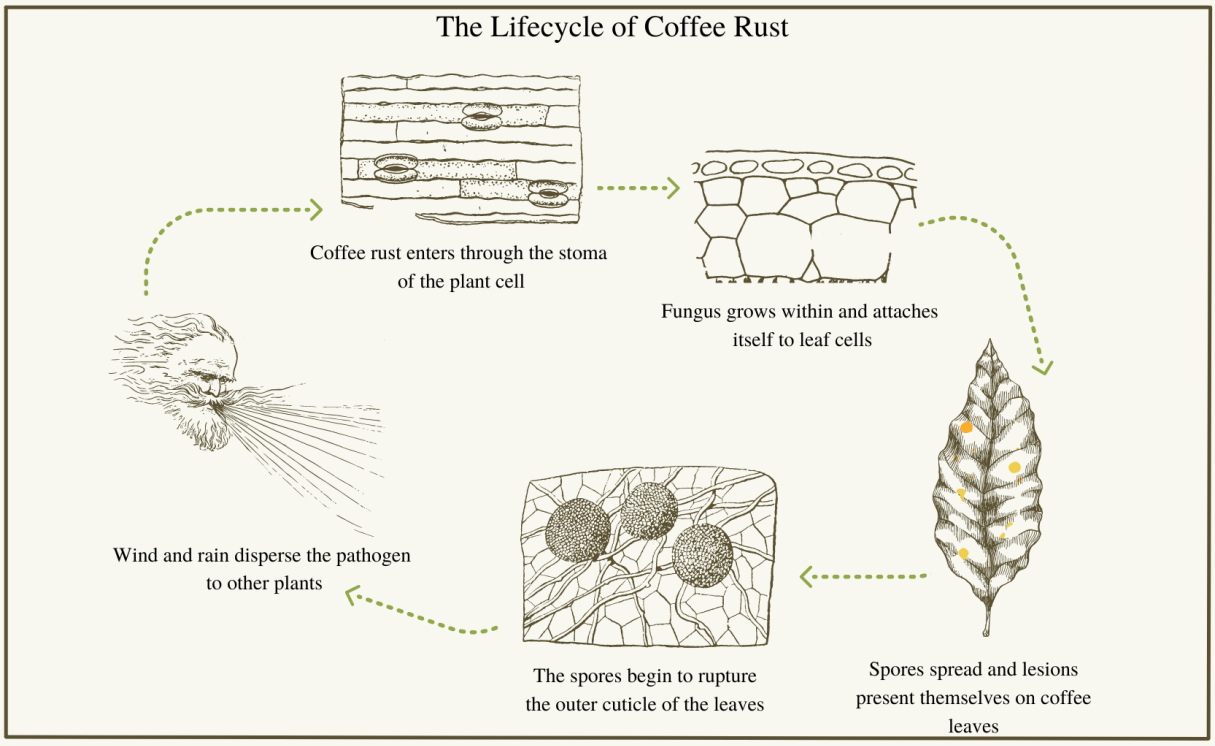

Figure 4: The Disease Cycle of Coffee Rust. Information Courtesy: APS.

The economic impact of coffee rust has been detrimental to the industry. In 2013, coffee rust destroyed roughly thirty percent of Honduran coffee farms (Technoserve, 2021).[2] This disease is only able to survive under certain environmental conditions, and data suggests that a recent rise in temperature has produced ideal ecosystems for the fungus to survive (Drapkin, 2014). Furthermore, as temperatures continue to rise, coffee plants at higher altitudes will begin to be affected by coffee rust which will decrease the area that coffee can thrive in.

As a consequence of damaged plants, this disease alone has caused the loss of 500,000 jobs in the Central American coffee industry (Foote, 2014). The negative impacts of coffee rust on the industry are also contributing to increased immigration out of the Northern Triangle, specifically from Honduras and Guatemala. Despite high demand for Honduran coffee globally, small-scale, family owned farms are often face the most long-term impacts of diseases like coffee rust, as they lack the financial resources to adapt. With limited resources to protect their crops, they are often left to face the unpredictability that the coffee industry has to offer. See Appendix Two for a chart of the outputs and outcomes of coffee rust.

A Brief History of Coffee Rust

Coffee rust was first reported to be affecting wild coffee plants in Lake Victoria, Kenya in 1861 (Hernandez et al., 2014). It then travelled to then Ceylon (now Sri Lanka), likely via dried coffee leaves, and changed the agricultural landscape in a matter of less than thirty years. Coffee production shortly moved to South and Central America, with most people confidently assuming that the rust would be unable to cross the Atlantic (McKenna, 2020). Due to an epidemic starting in Brazil in 1971, coffee rust spread rapidly throughout the coffee-growing region of the Americas (Hernandez, et al., 2014). Today, the disease is the most destructive in the coffee industry and forced nearly two million farmers off their land between 2012 and 2017 (McKenna, 2020). As detailed above, climate change will only continue to exacerbate this problem.

[2] Coffee rust's Spanish translation is "la Roya."

Current Mitigation Practices

As discussed above, coffee rust has negatively impacted the coffee industry for well over a century. In response, the Honduran coffee farmers that Farmer to Farmer works with have implemented and relied on several strategies with varying success. First, many farmers have begun to diversify the crops that they grow (Gaertner, 2022). While they primarily grow coffee due to its lucrativeness as an export, they also grow bananas, oranges, chayote, etc. for consumption and local sales. Furthermore, many of the farms have a diverse array of animals that help to provide income in some cases (Gaertner, 2022). As climate change continues to impact smallholder farmers, diversification will become increasingly necessary to ensure financial sustainability (Bunn et al., 2018). Although this practice does not directly impact coffee rust, it provides farmers with an additional revenue stream for when disease is rampant.

In addition to diversifying crops grown on the farm, farmers are also relying on income sources outside of the agricultural sector. According to Andrew Gaertner, Treasurer of the Farmer to Farmer Board of Directors, another strategy being implemented at the family-level is having one member of the household work abroad and send remittances back (Gaertner 2022). This is an important strategy, specifically in response to coffee rust, as rural households in Latin America that are able to diversify their income outside of the agricultural sector tend to see higher earnings and more stability than those who exclusively rely on agricultural production (Hans et al., 2008). This analysis focuses on changes that can be made to the farm's approach to coffee rust control, however it is vital for Farmer to Farmer to continue encouraging income diversification strategies so that farmers will be better equipped to handle unexpected shocks to the industry.

A third strategy that farmers rely on to limit coffee rust is the presence of shade trees on their farms (Gaertner, 2022). Currently, only twenty percent of Honduran coffee is grown in full-sun conditions (Bunn et al., 2018). Although this is not a practice chosen to directly combat coffee rust in many cases, some believe that it decreases disease (Arneson, 2000). This decrease likely stems from the lower-yielding trees that grow in shaded conditions. However, others believe that the trees providing shade limit dew collection on leaves; according to the American Phytopathological Society, this likely does not contribute significantly to a decrease in disease. It is important to note that other studies have found that shaded coffee plants actually experience more sporulation than trees in full-sun, but the lower yields sometimes falsely imply that there is less disease present (Avelino et al., 2020). This research likely will not impact current practices, as shade contributes to the coffee microclimate in other key ways in Honduras.

Farmers rely on more than just the strategies above to combat coffee rust, however crop diversification, multiple income sources, and shade trees all contribute significantly. The analysis portion of this project does not aim to alter current practices, but rather suggests methods that can be implemented to bolster them.

A Review of Potential Solutions

There is limited literature on potential solutions to combat coffee rust specifically in a Honduran context. However, literature in other contexts and strategies combatting similar agricultural diseases can provide an understanding of possible solutions for coffee farmers in Comayagua. Underpinning the review of these sources are the primary goals of any implemented intervention:

1. Limit the ability of the fungus to survive and affect plants on the farm
2. Build adaptive capacity at the farm level to combat coffee rust directly
3. Implement long-lasting strategies that prioritize farmer needs and opinions

In prioritizing these three goals in the review of potential solutions, Farmer to Farmer will be able to implement a strategy that will support farmers in generating more sustainable income. Most of the solutions discussed involve technical agricultural interventions: improving soil nutrition, increasing access to fungicides, introducing resistant varieties, and pruning shade trees. One of the strategies is a cultural shift at the farm level: implementing a formal disease management system. Climate change will continue to intensify the coffee rust epidemic in Honduras, however the hope is that farmers will be better able to prevent its effects.

I. Improving Soil Nutrition

A coffee plant's nutrition and general health are vital in combatting disease and soil plays a significant role in providing necessary nutrients to the tree. Coffee trees are typically grown in acidic soil, however extreme acidity can lead to a decrease in the available nutrients that the plant to thrive (Avelino et al., 2006). Moreover, extreme soil acidity inhibits the plant's ability to uptake nutrients by diminishing the root permeability. Therefore, soil conditions need to be just right for a plant to receive all of the nutrients that it needs.

Although there is not extensive research directly linking specific aspects of soil health to the occurrence of coffee rust, coffee rust thrives when soil pH is favorable for growing coffee, and when the soil itself contains less than three percent of organic matter content (Lamouroux, 1993). This research suggests that increasing the amount of organic content in soil, which will in turn improve soil nutrition, might positively affect a plant's ability to combat this disease. However, it is also important to note that the slow nutrient release of organic fertilizers can create an initial nutritional imbalance that actually promotes favorable rust conditions (Resende et al., 2021). The presence of essential nutrients in the soil is still important in disease reduction despite the sensitivity of coffee plants. At the very least, the improved nutritional content in the soil can reduce the presence and severity of coffee rust to a level that allows farmers to effectively control the disease through other mechanisms (Dordas, 2008).

Micronutrients can reduce the effects of disease presence in plants directly, or through improving resistance (Datnoff, 2007). According to a study conducted in Brazil, an increased presence of boron, zinc, and manganese reduced the severity of coffee rust, and increased the presence of two compounds associated with resistance to the fungus (Pérez, 2020). Although there is limited research on this strategy as it relates to coffee rust, there is significant research that generally explores and highlights the relationship between nutrient-rich soil and a plant's capacity to combat disease (Datnoff, 2007; Elmer, 2015; Dordas, 2008).

II. Increasing Access to Fungicide Spray

Another way of preventing coffee rust is through directly killing or preventing the disease from growing. In coffee-growing, fungicides are viewed as long-term investments that affect current and future growing seasons by directly affecting the lifecycle of coffee rust (Coffee Rust, n.d.). When applied properly, they can contribute to limiting disease severity and ensuring plant health (Kawabata and Nakamoto, 2021). Controlling the disease with fungicides is currently cited as the most effective strategy to guarantee food security for farmers, and social, financial and environmental sustainability (Sera et al., 2022).

When considering fungicides as a strategy, it is important for farmers to recognize that there are various types of fungicides that control the disease at different points in its lifecycle. Some fungicides are organic, while others contain chemicals. Due to coffee plants' sensitivity to the rust and their environment, depending on the type of fungicide used, application season and intervals between sprays both vary (Sera et al., 2022). These differences imply that it is especially important for farmers to be aware of the types of fungicides that they are applying, and how to do so properly. Some farmers claim that the fungicides no longer work and that coffee rust has become resistant, but experts believe that the fungicides are not being applied at the right time (Drapkin, 2019). Furthermore, this strategy is most effective when the incidence of disease is relatively low (de Melo Virginio Filho, 2015). Perhaps the lack of adequate information on proper fungicide application is diminishing the potential success of this intervention.

Lessons on proper fungicide use can be drawn from Kenya, another coffee-exporting country. According to one study, applying copper-fungicides to upper leaf surfaces provided more protection against coffee rust than did an equal spray across upper and lower leaf surfaces (Rayner, 1961). Other variables associated with successful protection include volume sprayed per acre, concentration of ingredients in the fungicide, time of application, and type of fungicide used. As climate change continues to increase disease presence, it is increasingly important for farmers to become prepared to properly use fungicides and/or other management strategies.

III. Introducing Resistant Varieties

Certain coffee varieties are more susceptible to disease than others; switching to a variety that has proven to be more resistant to coffee rust is a long-term, but potentially effective strategy that farmers can use to combat rust on their farms. When coffee was first planted in the Americas, nearly all plants involved in commercial production around the world could be traced to one tree ("Coffee Rust," n.d.). This implies that coffee initially lacked genetic diversity. However, according to the World Coffee Research variety catalog, there are now myriad varieties that are deemed "resistant" or at least "tolerant" to coffee rust ("Variety Catalog," n.d.). Although, it is also important to note that there are also at least fifty distinct strains of coffee rust, and no variety is resistant to all strains (United States Department of Agriculture, 2020). Therefore, with an unclear picture as to how this disease will continue to evolve over the next several decades, a serious limitation of this strategy is that the varieties chosen may not prove resistant in time.

There is also limited research present on farms that have shifted to growing resistant varieties. This is seemingly a time-consuming and costly endeavor, which would prove prohibitive and risky for a significant portion of Honduran coffee farmers.

IV. Pruning Shade Trees

As discussed in the section on current mitigation strategies, shade plays an important role in coffee farming. However, the relationship between shade and rust is not simple. When there is too much shade, the trees above coffee plants can block rainwater from washing over the leaves below. This minimizes the ability of the rainwater to wash out coffee rust spores, thus harming the plants (Avelino et al., 2020). More specifically, Avelino et al. found that the number of spores produced and preserved under shade was more than two times higher than in full sun. It is hypothesized that increased airflow, lower humidity, and sun exposure contribute to a healthy ecosystem that minimizes rust (United States Department of Agriculture, 2020). Though, shade does also contribute to the sensitive coffee microclimate in providing temperature control and minimizing susceptibility to other diseases and certain pests (World Coffee Research, 2020).

To meet the specific needs of coffee plants by providing enough shade but not too much, the United States Department of Agriculture recommended limiting shade cover to thirty to fifty percent, and pruning shade trees on a specific schedule (United States Department of Agriculture, 2020). Although this recommendation was explored specifically for coffee grown in Hawaii, the broad takeaway can be applied in Honduras as well. The plants providing shade to coffee trees should be pruned, and should not completely obscure the sun. Furthermore, the leaves of coffee plants need to be reachable by rainwater to minimize rust growth.

V. Implementing a Disease Management System

The last of the strategies explored in this review involves a cultural shift at the farm level: implementing a formal disease management system. While managing the disease long-term can prove extremely challenging, farmers can reduce damage by carefully monitoring crops (Soque, 2019). Record-keeping can also help to identify patterns in outbreaks relative to weather and better prepare farmers to handle future infections. Alvaro Gaitan, a doctor in plant pathology who worked at the National Center for Coffee research in Columbia, explained:

We recently had an epidemic, and we think it's bad, but if you look back into the newspapers, you see that maybe twenty years ago you had another epidemic happening in the same place. It's not that something new is happening, it's more that people forget. That means that we must pay attention to the weather conditions [and understand] that sometime in the future we'll have another epidemic. (2019)

Although there are no advanced, technical methods for identifying coffee leaf rust, monitoring can aid farmers in determining what plants need at any given time (Soque, 2019). Early detection of the disease makes management easier, and also improves the likelihood of the plant surviving (United States Department of Agriculture, 2020). Specifically, monitoring should become a primary focus during conditions that promote coffee rust (e.g. high humidity) (Capucho et al., 2013). In summary, formal monitoring systems can and should be combined with other strategies to effectively manage coffee rust outbreaks.

Key Takeaways from the Literature

The above review of current literature on mitigation strategies for coffee rust demonstrates that there are ample options for Farmer to Farmer and Honduran coffee farmers to choose from. Although the amount of empirical research available varies relatively significantly between strategies, there are general lessons that open the floor for evaluation. The general, key takeaways are as follows:

- Adequate disease management requires implementation of multiple strategies
- The most suitable strategy for mitigation will depend on the farm
- A majority of strategies require a shift in current practices (e.g. proper use of fungicides)
- All strategies are susceptible to climate change

Evaluative Criteria

The criteria below are used to evaluate the proposed strategies for mitigating the effects of coffee rust in Comayagua, Honduras. These criteria were chosen based on the goal of achieving the ideal outcome: sustainable income for coffee farmers.

Feasibility

This criterion refers to the ability of Farmer to Farmer to implement the given strategy. Furthermore, this criterion assesses the extent to which farmers will be able to maintain the implementation strategy with continued support from Farmer to Farmer. Both of these stakeholders need to be considered when examining implementation, as they are both necessary for a strategy to be considered feasible.

Each strategy will be assessed using the following scale:

- Highly feasible: the strategy can be implemented relatively easily through the current partnership between Farmer to Farmer and the coffee farmers.
- Somewhat feasible: the strategy will require some additional support or resources outside of the current partnership between Farmer to Farmer and the coffee farmers.
- Unfeasible: the strategy will require significant additional support or resources outside of the current partnership between Farmer to Farmer and the coffee farmers.

Effectiveness

This criterion will directly address the extent to which a farmer's income from coffee is being improved or maintained. Effectiveness in the long-term should be measured through annual impact assessments that look at farmer income in the context of weather patterns, external threats (i.e. political disturbances), and competition. Because this information in the Honduran context does not yet exist, effectiveness will be measured based on available quantitative research and qualitative literature on the strategies applied in other contexts, with the understanding that there are clear limitations with this approach. Namely, there is a lack of reliable studies that reflect similar populations facing the effects of coffee rust. Ideally, the chosen alternative will increase sustainable access to income by building farm-level resilience.

Each strategy will be assessed using the following scale:

- Highly effective: the strategy is projected to reliably increase sustainable access to income for farmers.
- Somewhat effective: the strategy is likely to increase sustainable access to income for farmers, or the strategy slightly increases sustainable access to income.
- Ineffective: the strategy will not likely increase sustainable access to income for farmers, or the data is limited in such a way that accurately assessing its effectiveness would not be feasible.

Equity

The equity criterion will consider the income levels of farms in Comayagua, Honduras and analyze through good-faith estimates based on literature findings whether or not farms of all income levels could access sustainable income equally. Furthermore, the equity criterion will consider the impact of race and gender on access and ability to build resiliency after the implementation of the given policy option. The Equity criterion will take an intersectional approach by looking at income, race, and gender. An ideal strategy would offer equitable access to sustainable income and resilience-building tools that are equally effective across income status, race, and gender.

Each strategy will be assessed using the following scale:

- Highly equitable: the strategy considers income, race, and gender in the proposal and will create equitable outcomes for farmers with various backgrounds.
- Somewhat equitable: the strategy considers income, race, and gender in the proposal and will likely create equitable outcomes for farmers with various backgrounds.
- Inequitable: the strategy considers income, race, and gender in the proposal, but will not likely create equitable outcomes for farmers with various backgrounds.

Sustainability

This criterion refers to how well the given strategy could be maintained by Farmer to Farmer over the next ten-year period. Furthermore, this criterion will consider the capability of individual farms to continue implementation if Farmer to Farmer is no longer able to continue offering services. More specifically, they will be given the tools to implement the selected alternative for as long as it productively combats coffee rust. Sustainability will be measured in collaboration with the client, taking into consideration the needs of farmers. This criterion will also consider relevant literature to provide background for how sustainable various options have been in other contexts. However, sustainability will be extremely difficult to measure due to the unexpected nature of climate change and its impact on coffee rust at any given time. Ideally, the chosen alternative will provide a sustainable route to income and resilience after being implemented by Farmer to Farmer, and maintained by local farmers on the ground.

Each strategy will be assessed using the following scale:

- Highly sustainable: the strategy is likely to be sustained over a ten-year period through collaboration between Farmer to Farmer and Honduran coffee farmers.
- Somewhat sustainable: the strategy has the potential to be sustainable over a ten-year period through collaboration between Farmer to Farmer and Honduran coffee farmers.
- Unsustainable: the strategy is unlikely to be sustained over a ten-year period through collaboration between Farmer to Farmer and Honduran coffee farmers.

Cost

This criterion projects the cost of implementing each strategy based on available literature and/or an application of the strategy in another context. Each strategy will be costed and assessed based on the estimate to implement and maintain it. For the purpose of this analysis, costs reported will include any startup costs along with the estimated cost of maintenance for a one-year period.

Analysis of Mitigation Strategies

This section will outline how each strategy discussed in the review of potential strategies section would work in the context of Farmer to Farmer. Each strategy will then be evaluated on the selected criteria. These specific strategies were chosen to be evaluated due to their relevance in this context, and under the assumption that they will contribute in some way to the mitigation of coffee rust.

Strategy One: Improving Soil Nutrition

Description

One potential strategy for mitigating coffee rust is to improve soil nutrition. This option involves working with farmers to test soil quality throughout the growing season and add supplemental nutrients when deemed necessary. As discussed in the review of potential strategies section, this option would improve plant immune systems and hopefully improve their resistance to coffee rust (United States Department of Agriculture, 2020). During the first year of implementation, Farmer to Farmer would provide the research from this report on various nutrients and their role in plant health, and contribute to the formation of internal mechanisms for farmers to produce the nutrients themselves. The nutrients themselves can be added through fertilizers or adding organic content being grown on the farm. One suggestion from Andrew Gaertner, Treasurer of the Farmer to Farmer Board of Directors, is for farmers to grow their own organic nutrients rather than purchasing it from outside sources (Gaertner, 2022).

Regardless of how the farmers decide to obtain organic matter to improve soil conditions, Farmer to Farmer would offer more extensive support (i.e. strategy-focused meetings) during the first growing season, and provide progress check-ins thereafter. The farmers should keep track of when certain nutrients are being added to ensure adequate application of this strategy. A list of vital soil nutrients and their purposes can be found in Appendix Three.

Evaluation

Feasibility

This strategy is highly feasible and could be implemented relatively easily based on the current partnership between Farmer to Farmer and Honduran coffee farmers. The current scope of their partnership involves regular check-ins, which would create valuable channels for updates and information sharing after the initial implementation phase. In the meetings, farmers would be able to discuss changes in disease presence in response to improved soil nutrition and ask questions when

necessary. Although Farmer to Farmer is not currently funding a soil nutrition program, their interest in its potential and the provided research could make this a priority within the existing partnership.

Effectiveness

Improving soil nutrition is somewhat effective. This is because although a lack of nutrients can lead to more ideal rust conditions, the slow release nutrients from organic sources can create a temporary imbalance that also promotes rust (Resende et al., 2021). Therefore, it is difficult to predict how this strategy would improve rust mitigation initially, even it proves to be a more effective long-term maintenance strategy than what farmers are currently practicing. The performance of regular soil checks under this strategy would help farmers better understand the nutrition cycle in soils throughout the growing season, highlighting times that plants are depleting the soil of vital nutrients (United States Department of Agriculture, 2020). Since this strategy promotes plant productivity and health against disease, it is likely to increase sustainable access to income for farmers.

Equity

This strategy is somewhat equitable. Support from Farmer to Farmer would be uniform across all farms. Unlike some of the other strategies, testing the soil is a task that could be completed by laborers regardless of their education level. Adding the fertilizer could also be completed by any of the farm's employees. However, some day laborers, specifically those who are illiterate, might struggle with keeping notes on when they have added specific nutrients or organic matter to the soil. This could be mitigated by delegating this task to literate workers, but it is an important consideration nonetheless.

Sustainability

This strategy is highly sustainable and could be successfully maintained over a ten-year period through collaboration between Farmer to Farmer and Honduran coffee farmers. After initial implementation, Farmer to Farmer would continue to offer support through regular check-ins where they would be able to help evaluate the effectiveness of this program. Moreover, if farmers were to begin producing their own organic nutrients, this will be a financially sustainable solution as well. This strategy would not need to be altered if a new strain of coffee rust entered the farm, as soil nutrition builds the plant's internal disease readiness (United States Department of Agriculture, 2020). This readiness also means that this strategy could help to prevent other diseases.

Cost

The cost of improving soil nutrition would depend on the method of improvement that an individual farm chose to implement. The cost data on this strategy is sparse; however since farmers would be simply altering the amount of nutrients given to their plant with materials that they likely already have on their farm, this option would be low-cost and does not need to be specifically evaluated. Cost is not negligible, because in certain instances farmers may need to purchase additional nutrients to supplement what they already have.

Strategy Two: Increasing Access to Fungicide Spray

Description

Another potential strategy is to increase access to fungicides to help control coffee rust presence. This option involves introducing various types of fungicides, helping to determine the best fit for each individual farm, and funding fungicide use for one growing season. The types of fungicides available are located in Appendix Four**.** The funding ensures that farmers are incurring minimal risk in the initial implementation phase; ideally, farmers will be more likely to use the fungicides if they are provided by Farmer to Farmer. Furthermore, agricultural investments have been shown to improve smallholder farmer yields, and increase rural income and profitability (Sunderji et al., 2020). Thus, this investment could prove critical in sustaining income for coffee farmers. After the first growing season, farmers will have the option to continue purchasing the fungicides independently if it is deemed an effective tool on their farm. During annual farm visits, Farmer to Farmer would provide support and work with farmers to create savings strategies for funding fungicides in future growing seasons.

It would be critical for Farmer to Farmer to assist in creating a spray schedule specific to the type of fungicide chosen to combat the current knowledge gaps discussed in the review of potential strategies (Drapkin, 2019). Initially, this strategy would require significant support from Farmer to Farmer to ensure that coffee farmers are spraying at the correct times and that the fungicides are working to reduce disease presence. In addition to providing the fungicides and initial training, Farmer to Farmer would promote information-sharing among coffee farmers about the use and effectiveness of the sprays to ensure that they are being used properly. This would hopefully increase reach to coffee farms that are not currently working with Farmer to Farmer.

Evaluation

Feasibility

Strategy two, increasing access to fungicide spray, is highly feasible. This strategy could be implemented relatively easily through the current partnership between Farmer to Farmer and Honduran coffee farmers. The current scope of their partnership involves solidarity, resource-sharing, and in some cases, providing financial support. Although Farmer to Farmer does not currently have a fungicide-purchasing program, it does not fall outside of “highly feasible,” as the mechanism for funding this project exists. With continued support from Farmer to Farmer, coffee farmers are likely to continue fungicide use if they are able to see results in the first growing season.

Effectiveness

Increasing access to fungicide spray scores as somewhat effective, because it is likely to increase sustainable access to income for coffee farmers. As discussed in the review of potential strategies section, some farmers claim that there is a fungicide-resistant strain of coffee rust, however experts tend to believe that farmers are simply applying the fungicide spray too late (Drapkin, 2014). Many farmers in Latin America, however, choose not to use their resources to prevent coffee rust, but rather

prefer to react once it's begun infecting their plants; this often leads to further, less-controllable outbreak. Based on these current, predominant practices, this option may not be highly effective. However, with the support and advice of Farmer to Farmer, it is possible for farmers to shift current practices over time.

The current knowledge gap on proper fungicide use could be remedied by support from Farmer to Farmer, but assuming that it will be is presumptuous. The fact that this strategy is deemed most effective in minimizing disease presence is hindered by its sensitivity to error (Sera et al., 2022).

Equity

This strategy scores somewhat equitable. Although the fungicides would be provided to all farms regardless of farmer demographics, an important component of this strategy involves information sharing. Certain farms, likely smaller farms with less-educated farmers, would likely need extra support to implement the fungicide sprays effectively. Despite there being inconclusive empirical evidence on the effects of education on agricultural productivity and efficiency, it has been demonstrated that a baseline education can prove valuable in agricultural settings, as it enables farmers to follow written instructions, specifically about the application of new technology (Huang and Luh, 2009). For farms that have illiterate day laborers, it will likely prove more challenging to communicate efficiently about fungicide use. Since Farmer to Farmer would only be incurring the risk of purchasing fungicide sprays for one growing season, smaller farms with less-educated workers might be less likely to continue using them independently after the trial period.

Sustainability

This strategy is highly sustainable. After financial support for the first growing season of this strategy, Farmer to Farmer would offer continued technical assistance to farmers over multiple growing seasons to ensure that the strategy would prove successful in the long-term. Furthermore, it is likely that if farmers could see the long-term benefits of the fungicide sprays while getting support, they would be more likely to continue their use even if Farmer to Farmer was no longer capable of providing the same level of support. This assumption comes from the idea that operating in a relatively risk-free environment enhances learning opportunities, and that free access to costly products increases adoption for first-time users (Yigezu, 2018). Although many of these farmers have likely worked with fungicides before, free access to this trial will give them space to learn proper application techniques. Moreover, having the ability to experiment in a setting with limited risk can improve a farm's resiliency (Kummer et al., 2012).

Cost

Increasing access to fungicides would cost between $100 and $400 per hectare per year depending on the type of fungicide and frequency of application (Soque, 2019). The cost depends on the type of fungicide used, the method of application chosen, and the number of times that it needs to be applied. Based on how coffee rust works, it can be assumed that the cost will also vary season to season, as weather conditions can change.

Strategy Three: Introducing Resistant Varieties

Description

The third strategy is to encourage and assist with the introduction of coffee varieties that are more resistant to coffee rust than what is currently being planted. Since there is no variety resistant to all strains of coffee rust, farmers would need to work with Farmer to Farmer to select the variety that they would like to begin planting on their farm (United States Department of Agriculture, 2020). Potential varieties are located in Appendix Five. After selecting the new variety, Famer to Farmer would offer support in planting and maintaining the new coffee plants throughout the first growing season. However, depending on the farm, this process would likely be gradual due to financial constraints and the goal of minimizing risk. Moreover, if purchased and planted as seedlings, farmers will have to wait many growing seasons before their new plants become as profitable as their current ones.

Evaluation

Feasibility

This strategy is somewhat feasible. Farmer to Farmer would provide information regarding the various resistant varieties that can be grown, but the implementation would fall mostly on the farmers themselves. The role that Farmer to Farmer could play in this strategy would be minimal, meaning that to some extent, it would require additional resources outside of the current partnership between Farmer to Farmer and the farms that they work with. However, similar to other options, Farmer to Farmer would be able to provide check-ins to stand in solidarity with farmers as they work to change what they are currently growing. These check-ins would prove valuable, as they can discuss successes and failures of this strategy.

Effectiveness

This strategy is somewhat effective in preventing coffee rust, and therefore somewhat effective in increasing access to sustainable income. Introducing resistant varieties would likely prevent rust from growing in many cases, and in the case of an outbreak, would lower the instance of spread. However, being that no variety is resistant to all strains of rust, and the disease can mutate at any time, this strategy cannot be evaluated as highly effective (United States Department of Agriculture, 2020). This method is almost completely preventative rather than reactive, which would improve financial success in future growing seasons by saving time and money on other strategies.

Equity

This strategy is somewhat equitable. Although all farms would be able to access support through Farmer to Farmer, smaller farms would likely struggle to switch the current varieties being planted due to cost. Furthermore, this is a risky endeavor in terms of the coffee market, as farmers cannot be sure how income will compare when selling different varieties. Farmers with higher education levels have been shown to be more likely to innovate and less risk-averse than their less educated counterparts (Knight et al., 2010). This puts lower income, more-remote farmers at a disadvantage under this strategy.

Sustainability

This strategy is somewhat sustainable. After the new varieties are introduced and the farmers have had time to adjust, this option would require minimal long-term support from Farmer to Farmer, as they would be able to continue business as usual through care and maintenance. However, the adjustment period would require some support in ensuring that farmers know how to properly care for the new varieties. This option is only somewhat sustainable due to the risk outlined above: coffee rust unpredictability. Being that some farmers believe that there is a fungicide-resistant strain of rust, there is likely a gap in knowledge on the types of strains that are present and how the disease mutates over time (Drapkin, 2014). If the variety chosen is not resistant to a newer strain of rust, this option could prove financially detrimental to farmers over time.

Cost

The cost of this option depends significantly on the variety of coffee chosen by the farmer. Costs for one plant can range between $.32 and $1.95 depending on the variety chosen. Coffee plots typically require around 3,200 coffee plants and 50 shade trees, which means that for coffee alone, farmers could spend between $1,038 and $6,262 (Daggett, 2015). For shade trees, farmers commonly use banana plants; at $1.30 per plant, farmers will spend an additional $65. However, it is important to note that depending on how farmers approach implementing this strategy, they could continue using preexisting shade trees on their property. This strategy also implies that farmers will need to care for and maintain their new plants.

Strategy Four: Pruning Shade Trees

Description

The fourth potential strategy for mitigating coffee rust is pruning shade trees. This option requires an initial information-sharing meeting between Farmer to Farmer and Honduran coffee farmers to discuss the efficacy of this strategy. Thereafter, farmers would begin pruning their trees once or twice each year, ensuring that canopies do not touch (United States Department of Agriculture). The ideal farm would limit shade coverage to thirty to fifty percent to avoid promoting conditions for rust to thrive. A suggested piece of this strategy is maintaining as few trees as possible, however this seems impractical in this context due to the nature of the farms that Farmer to Farmer partners with (de Melo Virginio Filho et al., 2015).

The primary investment in this option would be time, as farmers would need to dedicate a few days per year to properly prune the shade trees back.

Evaluation

Feasibility

Strategy four is highly feasible, as it fits neatly into the scope of the current partnership between Farmer to Farmer and Honduran coffee farmers. Information-sharing is one of the primary pieces of the current partnership, and for this option, that is the only support required. The pruning process

would likely rely on farm workers and day laborers, but could easily fit into current farm maintenance. Although farmers are not currently trimming shade trees to specifically reduce rust presence, it would not require significant change to implement.

Effectiveness

Pruning shade trees is ineffective on its own at mitigating coffee rust's effect on income. There is limited research, especially in a Honduran context, of the effects of reducing shade on coffee rust. Furthermore, because it would be most effective when farms maintain fewer coffee trees, this would likely counteract any income saved by minimizing rust (de Melo Virginio Filho et al., 2015). Also, shade grown coffee is a cultural decision made by farms, and is common practice in Honduras (Bunn et al., 2018). It could therefore damage the culture surrounding coffee on the farms that Farmer to Farmer works with, and might not be effective with the coffee varieties being grown.

Equity

This strategy is highly equitable, as it creates equitable outcomes for farmers across all backgrounds. In this case, Farmer to Farmer would help to disseminate information on how to prune trees, and farmers on the ground would supply labor a few times a year to prune the trees. Regardless of gender, race, income-level, and literacy rate, all farmers working at a given farm would be able to participate in this method equitably.

Sustainability

This strategy is highly sustainable. After the initial information-sharing meeting, Farmer to Farmer would not need to provide additional support. If farmers see value in this method, they will be able to carry it out completely independently of Farmer to Farmer if they so choose. During annual farm visits that Farmer to Farmer already makes, farmers could give status updates on the success of this strategy, but because it requires such little maintenance, this would not be necessary. If Farmer to Farmer ended their partnership with a farm, the farm would be able to continue pruning trees completely independently.

Cost

The cost of implementing this alternative is negligible, as it would simply require the time necessary to prune the coffee trees.

Strategy Five: Implementing a Disease Monitoring System

Description

Strategy five involves implementing a disease monitoring system. This system would come in the form of a checklist for farmers to ensure that there are adequate preventative measures in place to protect plants from coffee rust. The checklist would be developed in conjunction with coffee farmers and Farmer to Farmer, as the farmers on the ground are in-tune with how their individual farms operate and what their plants need. However, this checklist should be completed at the beginning of

the rainy season and be used to estimate the risk level based on site, crop management, and biological criteria of the plant (Avelino et al., 2004). Furthermore, farmers should increase monitoring measures when weather conditions are favorable for rust development (e.g. presence of high humidity). Because of how coffee rust spreads and affects plants, farmers should primarily focus on examining the bottom third of leaves on the plant (United States Department of Agriculture, 2020).

Checklists can be used for various purposes in agriculture. In Japan, rice farmers use checklists for integrated pest management (IPM) (Tsushima, 2014). IPM checklists were developed by farmers based on guidelines from the Japanese Government, and have been powerful and popular management tools since the 2000s. Although the application in this context is slightly different, Honduran coffee farmers can apply the same mechanisms to control coffee rust with Farmer to Farmer's support. In addition to providing a warning system for coffee rust, this strategy would also help with pest control, management of other diseases, and provide a better understanding of how climate change is affecting growth patterns across seasons.

Evaluation

Feasibility

This strategy is highly feasible. This strategy could be implemented relatively easily based on the current partnership between Farmer to Farmer and Honduran coffee farmers. The checklist itself would be based on the existing Japanese IPM checklists (see Appendix Six), the needs of Honduran coffee farmers, and input from Farmer to Farmer. After developing and implementing the checklists, farmers on the ground will be able to continue using this strategy with limited support. During the first growing season, Farmer to Farmer can help to demonstrate this strategy's importance so that it continues being used in the future.

Effectiveness

This strategy scores as somewhat effective. Although it is not directly combatting coffee rust through biological means, this strategy gives farmers the opportunity to formally assess their farm's susceptibility to the disease so that they can best prepare their plants and devise strategies for future growing seasons. There is limited evidence specifically supporting the role of checklists in mitigating coffee rust, but research shows that monitoring is the predominant predictor for future incidences (Lasso et al., 2020). Therefore, not only will this strategy point to patterns in coffee rust and help farmers address current outbreaks, it will help to prevent future outbreaks. The checklist can build targeted surveillance competency and create a powerful reference in improving current management practices and implementing new ones (Bondad-Reantaso, 2021).

Equity

This strategy scores highly equitable. The checklist would be developed and used by all farms owned by farmers with varying education levels, different sized farms, and of various backgrounds. However, it is important to note that day laborers who do not own the farms could struggle to read

and complete the checklists, as roughly two in ten Hondurans are illiterate in rural areas (Inter-American Diaglogue, 2017). This equity pitfall could be mitigated by having literate day laborers and farm owners manage the checklists, and delegate other tasks to illiterate workers. Therefore, this strategy would require minimal support to ensure equity across the farms that Farmer to Farmer works with.

Sustainability

This strategy is highly sustainable. After the formal checklist is developed, farmers can begin implementing it immediately with limited support from Farmer to Farmer. After the initial checklist-devising and sharing phase, this strategy would run completely through the farmers themselves. Check-ins from Farmer to Farmer would help to demonstrate the importance of this strategy, and give farmers the opportunity to get feedback on what they decide to change based on the checklists. However, if this feedback loop does not continue after implementation, farmers would be able to manage this strategy without support if they decide it is worthwhile on their farms.

Cost

Implementing a disease management system itself is free, however it is important to note that depending on the needs of the farm, it could point to further necessary actions and investments. The cost of developing the checklist would be free, and additional costs would highly vary depending on the growing season, the farm's financial capital, and farm-level decision-making.

Outcomes Matrix[3]

This outcomes matrix compares each potential strategy across all selected criteria.

	Feasibility	Effectiveness	Equity	Sustainability	Cost
Strategy One: Improving Soil Nutrition	Highly Feasible	Somewhat Effective	Somewhat Equitable	Highly Sustainable	Varies; Limited Data
Strategy Two: Increasing Access to Fungicide Spray	Highly Feasible	Somewhat Effective	Somewhat Equitable	Highly Sustainable	$100-$400 Per Hectare
Strategy Three: Introducing Resistant Varieties	Somewhat Feasible	Somewhat Effective	Somewhat Equitable	Somewhat Sustainable	$1,103-$6,327 Per Coffee Plot
Strategy Four: Pruning Shade Trees	Highly Feasible	Ineffective	Highly Equitable	Highly Sustainable	Negligible
Strategy Five: Implementing a Disease Monitoring System	Highly Feasible	Somewhat Effective	Highly Equitable	Highly Sustainable	Low-Cost Initially, Varies Thereafter

Figure 5: Outcomes Matrix

[3]Outcomes Matrix Key
- An outcome that is less than ideal
- An outcome that is not quite ideal, but is not less than ideal
- An outcome that is ideal

Recommendation

The strategy recommended to mitigate the effects of coffee rust on sustainable income for coffee farmers is a combination between strategy two, increasing access to fungicide spray and strategy five, implementing a disease management system. Increasing access to fungicide spray is a highly feasible option as its implementation falls within the current partnership between Farmer to Farmer and Honduran coffee farmers. Although option three, introducing new coffee varieties, is scored as being more effective than option one, feasibility must be considered critical as it is vital for successful implementation. Increasing access to fungicide sprays would effectively increase sustainable access to income for farmers if used properly, however it was important to consider current fungicide practices when scoring this option on effectiveness. This option is somewhat equitable, which in combination with option five, would be a highly equitable set of alternatives when considering reach and scope of implementation. Increasing access to fungicides is highly sustainable, which is important in creating long-term change at the farm level. Lastly, the cost of this alternative does vary depending on the type of fungicide chosen, but is not considered prohibitive, especially relative to potential payoff. Although this strategy ranks the same as improving soil nutrition, there is more empirical research available on increasing access to fungicides, which is why it was chosen.

The second part of this recommendation involves implementing a disease management system, which is a highly feasible strategy, as it falls within the boundaries of the current partnership. Although it is somewhat effective in reaching sustainable income for coffee farmers, when combined with proper use of fungicides and implementation of other strategies deemed useful by the checklist, this recommendation would be highly effective at increasing access to sustainable income for farmers. Furthermore, this option is highly equitable, unlike some of the other strategies, as it would reach all farmers and provide them with equitable measures to analyze disease on their farms and build strategies to combat them. This option is highly sustainable and with option two, would create a long-term strategy for disease prevention and control on each farm. Lastly, the cost of creating and implementing the checklist would be negligible, although costs would vary thereafter depending on further actions.

Implementation

Steps of Implementation

To implement the above recommendation, increasing access to fungicides and implementing a disease monitoring system, a backward mapping approach will be used. This system of implementation focuses on factors that can be indirectly controlled by Farmer to Farmer, knowledge and problem-solving strategies and use of funds (Elmore, 1979). Much of the implementation relies on buy-in from the farmers themselves, thus it is vital for Farmer to Farmer to consider the desired outcome when preparing to implement this project.

The first step in increasing access to fungicides involves working with coffee farmers to determine the need on their farms. Farmer to Farmer would need to survey the farms that they work with to determine answers to the following questions:

- How many hectares is your farm and roughly how many plants do you have?
- How did coffee rust affect coffee growth on your farm in the last few seasons?
- What is your current strategy for combatting coffee rust? Does it work effectively?
- Are you open to implementing new strategies to combat coffee rust?
- How much and what kind of support would you need to introduce fungicide sprays?

In getting these answers, Farmer to Farmer will have a better understanding of how implementation would look on each farm that they work with, as each farm likely operates differently.

Second, Farmer to Farmer will want to work with individual coffee farms to determine the fungicide that best fits their farm and plants. This step is vital to ensuring buy-in from the farmers, as tailoring information and recommendations to being farm-specific often increases the effectiveness of the program (Abdul Latif Jameel Poverty Action Lab, 2018). A breakdown of various fungicides that can be chosen is in Appendix Four.

Implementing the disease monitoring system can happen simultaneously. Although Farmers might currently use informal methods of monitoring coffee rust, providing farmers with tools that simplify [and specify] new practices can increase program effectiveness (Abdul Latif Jameel Poverty Action Lab, 2018). This monitoring system will be implemented through providing a checklist to farmers and hosting remote check-ins with Farmer to Farmer to discuss management strategies specific to issues present on each farm.

To develop the checklist, Farmer to Farmer should prioritize learning about disease management strategies that the farms they support are currently using. From there, they should work to develop a checklist that accounts for these strategies, and includes additional criteria that farmers in their

own experience and research. After sharing the checklist with farmers, Farmer to Farmer should begin a testing phase to see if the monitoring system is useful for the farmers that they work with. After the initial testing phase, Farmer to Farmer can request feedback and adjust as needed. Finally, they can discuss a timeline for roll-out with the farmers that they support by asking the following questions:

- How frequently would you like to check-in?
- Is there anything else that you would like to add to your checklist?
- Who on your farm will be filling out the checklist?

At the check-ins, Farmer to Farmer should encourage farmers to keep their lists across seasons to compare and contrast for a better understanding of how various disease patterns are emerging on their farms. Furthermore, on the farms that elect to use fungicides, this checklist can be used to analyze their effectiveness.

Although Farmer to Farmer is only able to work with a finite number of farms in Comayagua, the implementation of this recommendation can spread between farmers, or Campesino a Campesino. Farmers can share knowledge and information that they have received from Farmer to Farmer that will improve the situation for other farmers. This strategy was employed by The Coffee Trust in their Roya Recovery Project in Guatemala to increase reach and trust among farmers (The Coffee Trust, n.d.). Relevant Implementation Stakeholders can be seen in Appendix Seven.

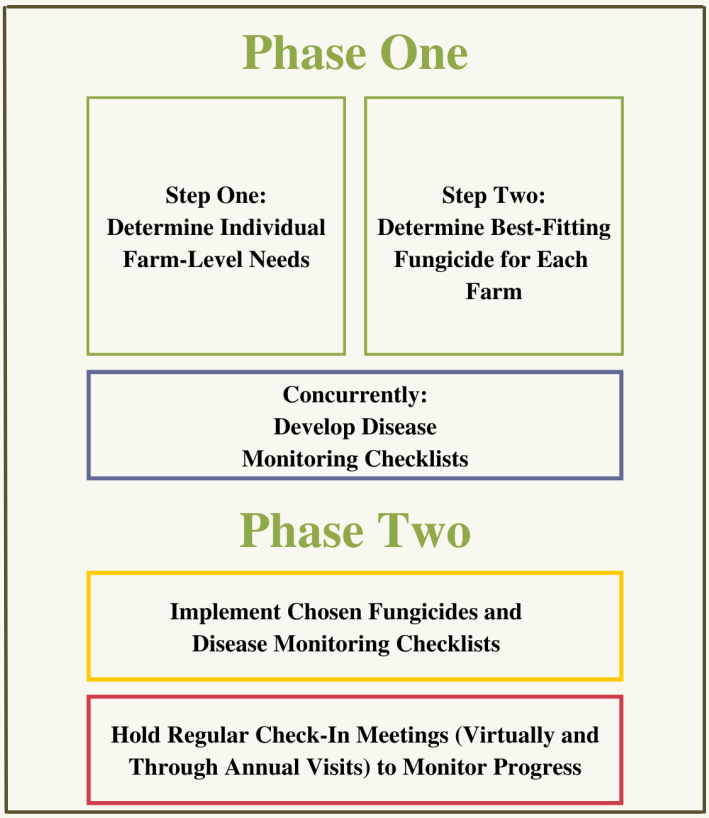

Figure 6: The Phases of Implementation

Potential Implementation Pitfalls

The most likely potential pitfall in the implementation process is a lack of farm level buy-in, briefly mentioned above. However, based on the long-term, trust-based relationship that exists between the client and the farms that they work with, this is not overly likely. To best mitigate this pitfall, Farmer to Farmer can share success stories of other farms that have seen an improvement in sustainable access to income after implementing a disease monitoring system and using fungicides correctly. The positive deviance approach is based on the idea that in every community, there are certain groups or individuals that are able to innovate and find creative, better solutions to problems than their peers, despite having access to the same resources and facing similar challenges (Positive Deviance Collaborative, n.d). Applying this concept, Farmer to Farmer will be able to effectively share the recommendation and achieve farm level buy-in. Furthermore, Farmer to Farmer should focus their initial energy and resources on farms that are willing to implement the recommendation and hope that other farms will follow once there are results.

A second pitfall that must be considered, and also lies out of the control of Farmer to Farmer, is unpredictable weather patterns and how they might affect implementation. For instance, in November 2020, Hurricanes Eta and Iota destroyed roughly 3,500 hectares of coffee farms (International Coffee Organization, 2020). Although sporadic, risks stemming from climate disasters are extremely likely and must be considered during the implementation process. Although there is not much that can be done to directly address hurricanes or weather patterns as they relate to implementing this recommendation, Farmer to Farmer should remain prepared to pivot and work with farmers to address unpredictable crises in a timely manner.

Conclusion

Farmers in developing countries will continue to be disproportionately harmed by the effects of climate change. This is clearly seen in the coffee industry, as climate change promotes the types of weather conditions that allow diseases like coffee rust to thrive. Truth be told, the recommendations above will only work if coffee farmers are able to mitigate other effects of climate change concurrently. In the Global North, we have the privilege of ignoring environmental degradation in many cases; farmers, however, are not so lucky.

Farmer to Farmer is a bright spot in the darkness of our future plagued by climate change. Their work with Honduran (and Guatemalan) coffee farmers is a shining example of a solidarity economy at work. It is my hope that the farms that Farmer to Farmer works with in Honduras can gain something from this report. These recommendations cannot change the realities of the coffee industry for these farmers, but they can begin to chip away at the change sought in the world.

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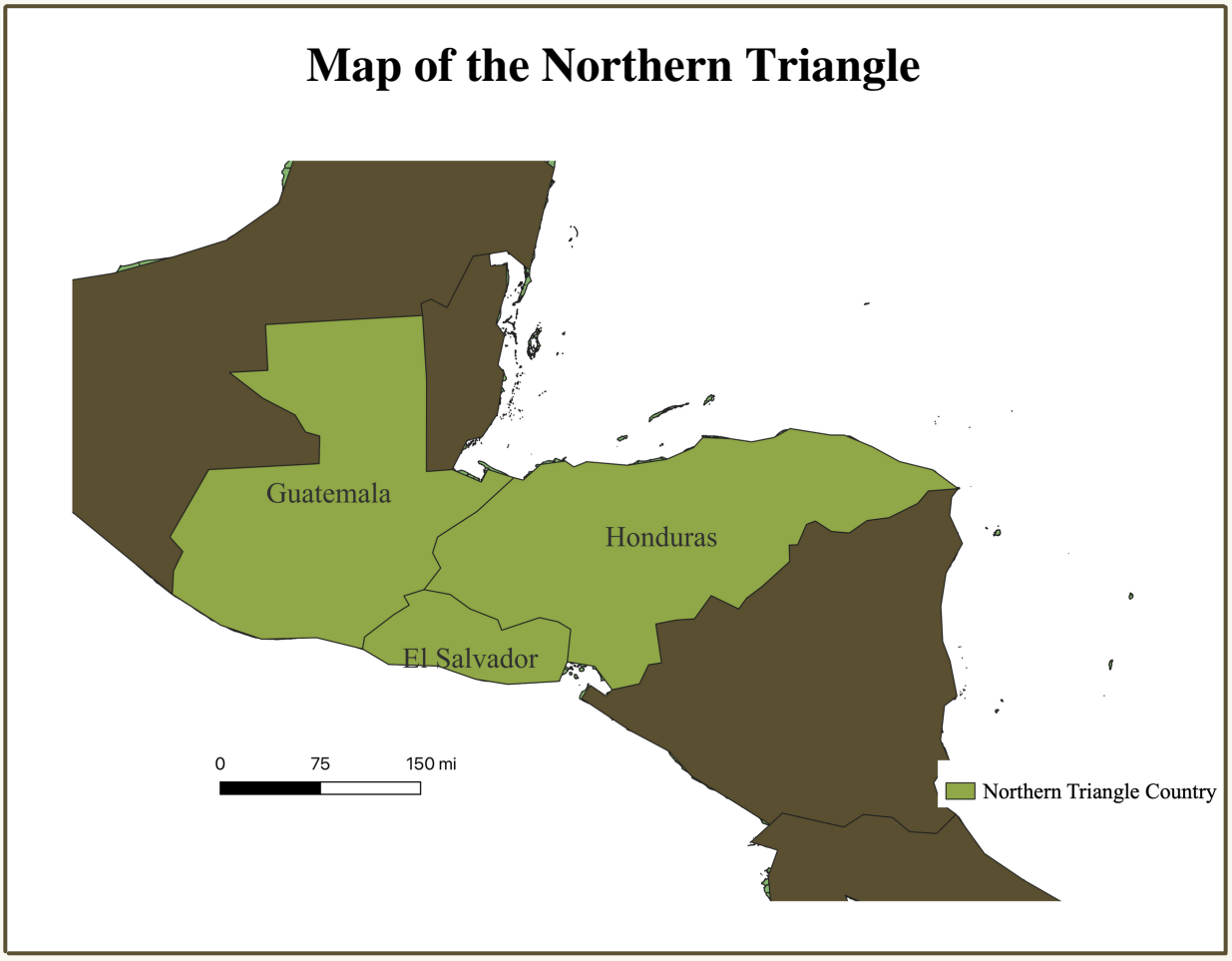
Appendix One

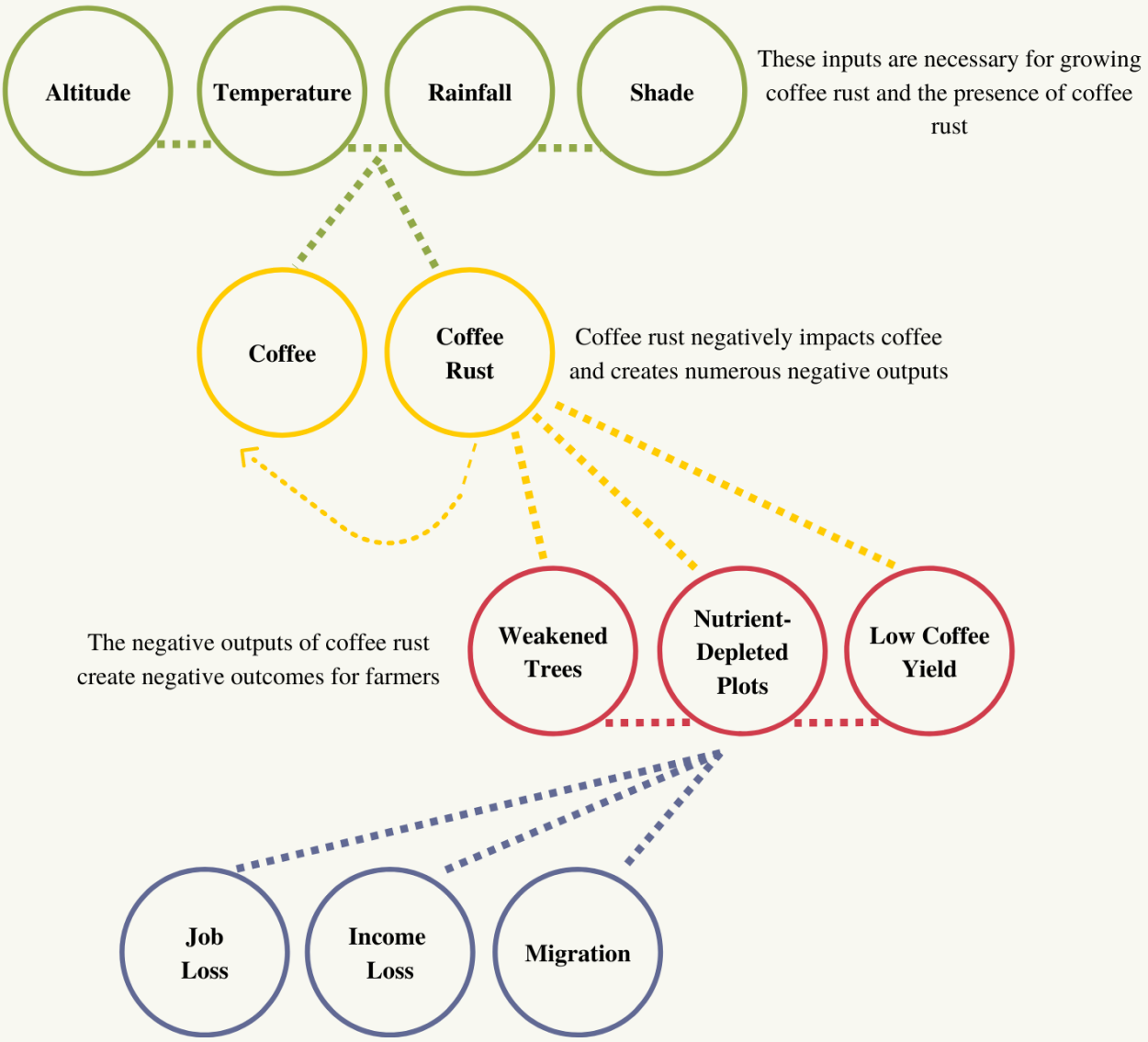
Map of the Northern Triangle



Data Courtesy: Natural Earth

Appendix Two

The Outputs and Outcomes of Coffee Rust



Appendix Three

A List of Vital Soil Nutrients

Nutrient	Role in Disease Preventuion
Nitrogen	Essential component of amino acids, enzymes, hormones, phenolics, phytoalexins, and proteins which work to suppress disease
Phosphorus	Plays significant role in cell division, energy transfer, and regulation; too much can *increase* disease presence
Potassium	No specific patterns related to disease presence; balance is key
Calcium and Magnesium	Vital in cell growth and promotes defense; can suppress disease
Chlorine and Sulfur	Induce disease resistance, enhance micronutrient availability, increase beneficial microorganisms
Micronutrients (Iron, Manganese, Zinc, Copper, Molybdenum, Boron)	Induce disease resistance and assist in producing defense barriers

Information Courtesy: (Elmer, 2015)

Appendix Four

Fungicide Details

Types of Fungicides

Type of Fungicide	Classification	Benefits	Drawbacks
Copper-Containing[4]	Preventative	Very Effective Cost Effective "Tonic Effect"	Must be Applied Prior to Outbreak Copper Can Reach Toxic Levels
Dithiocarbamates	Organic Protective	Effective "Tonic Effect"	Residue Does Not Adhere as Well to Leaf Surface Unstable at High Temperatures and High Humidity
Systemics	Organic	Effective	High Cost Occasional Severe Defoliation

Information Courtesy: APS

[4] The most effective fungicide strategy would likely include copper-containing fungicides along with one of the other two types.

Appendix Four

Fungicide Details

Classified Fungicides and Application Recommendation

Copper-Containing	Dithiocarbamates	Systemics
Basic Copper Sulfate (N/A)	**Ferbam (N/A)**	**Triademifon (Bayleton) (0.2-0.6 kg a.i./1000 plants/ha; May Stimulate Coffee Berry Disease)**
Copper Oxychloride (1.5 kg a.i./1000 plants/ha)	**Ziram (0.75 1 a.i./ha)**	**Pyracarbolid (Sicarol) (N/A; May Provoke Severe Defoliation)**
Cuprous Oxide (1.9-3.0 kg a.i./ha, Microgranular Formulation Best)	**Maneb, Manzate (1.6 kg a.i./ha)**	**Oxycarboxyn (Plantvax)**
Copper Hydroxide (N/A)	**Zineb (N/A)**	

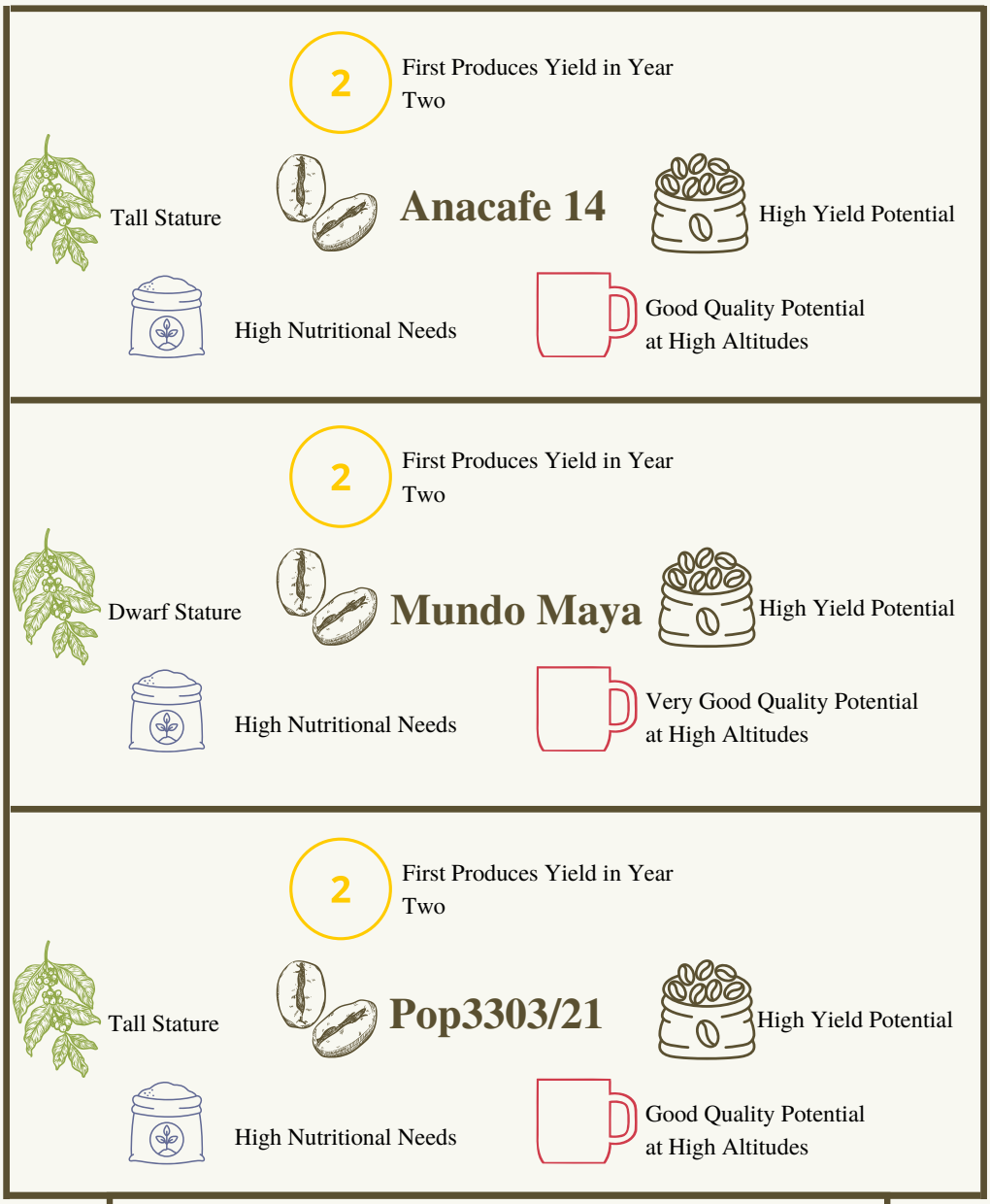
Information Courtesy: (Ferreira et al., 1991)

Application Information

Generally, sprays should be less than twenty one days apart to ensure that new growth is covered (Arneson, 2000). Sprays should be focused on the underside of leaves based on how coffee rust spreads, and farmers should take care not to spray too hard and spread rust further. Depending on the type of fungicide chosen, rainfall and temperature patterns should be verified prior to spraying to ensure success.

Appendix Five

Coffee Rust Resistant Varieties



These varieties were chosen because they are rust-resistant, and can be grown in high altitude regions. Thus, they are suitable for the Honduran context.

Information Courtesy: World Coffee Research

Appendix Six

Integrated Pest Management Checklist

Management item	Point of Management	Score	Check		
			Status of implementation last year	Goal for this year	Status of implementation in this year
Manage paddy field and its environment	Prevent water leakage from paddy fields by improving ridge between paddy fields, ridging to increase control efficacy of pesticide and prevent water pollution	1	✓	✓	✓
	Eliminate overwintering insects by weeding ridge between paddy fields, farm road, fallow field, and decrease disease severity next year.	1	✓	✓	✓
	Except for non-tillage cultivation, till and harrow just after reaping to prevent growth of perennials such as *Sagittaria trifolia* L., *Eleocharis kuroguwai* Ohw.	1			
	Apply silica fertilizer, if needed according to soil diagnosis	1	✓	✓	✓
Proper variety	Use rice blast-resistant and lodging-resistant variety where rice blast and lodging always occurs	1			
Participation in the training course	Participate in the training course held by prefectural office or agricultural cooperatives	1			
Total number					
Total of target IPM contents a)					
Assessment b)					

a When a management point is practiced in a field during the season, the farmer gets a score for that point. The IPM index is then calculated using the score for each management point as follows: IPM index = Total number of scores that a farmer gets/Total number of scores for all management points listed × 100.

Checklist Courtesy: (Tsushima, 2014)

Appendix Seven

Relevant Stakeholders

	Short-Term Stake	Long-Term Stake
Farmer to Farmer	Exercise Solidarity with Partners	See Support Pay Off Create a More Sustainable Industry
Coffee Farmers	Change Current Strategies Mitigate Coffee Rust	Generate Sustainable Income Create a More Sustainable Industry
Coffee Families	Provide Support on the Farm Mitigate Coffee Rust	Generate Sustainable Income Continue Family Traditions
Coffee Research Institutes	Contribute to New Research Share Successful Strategies	Create a More Sustainable Industry

Equity Considerations

In considering stakeholders, it is important to address potential equity concerns relevant to this problem and the implementation of the recommended mitigation strategies. The coffee farmers that Farmer to Farmer works with in Honduras are all men. However, these strategies could also be applied on farms run by women. Coffee rust impacts all farmers regardless of race, income level, gender, and education level. However, farmers of higher socioeconomic status and more education are likely to have more access to mitigation strategies. This is an important consideration because as climate change continues to impact the industry, low-income farmers will suffer more than their wealthier counterparts.