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Review on Coffee Leaf Rust (*Hemileia vastatrix*) and its Management in Ethiopia

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ABSTRACT

Coffee is the most popular soft drink in the world and the second traded commodity next to oil. CLR is most severe on C. arabica, which is very susceptible to the disease under warm and humid or wet condition. It can cause yield losses in excess of 75% where outbreaks are severe. The first symptom of coffee leaf rust disease is small discolored spots which develop on theunderside of the leaves. These small spotsincrease in size and are powdered with spores ofthe pathogen ranging in color from yellowishorange to bright orange.In experimentsconducted in the Setema district of Jimma Zone,Ethiopia, CLR severity was highest (16.9%) at the lowlandand lowest (5.7%) at the highlands irrespective of the cultivar. Shade effects on coffee rust are controversial, possibly because shade helps to prevent high fruit loads, which decreases leaf receptivity to the pathogen but, at the same time, might provide a better microclimate for germination and colonization. The breeding of coffee plant for resistant to rust is considered to be the best disease management strategy, both environmentally and economically. Cultural practices can have an indirect but beneficial effect in terms of CLR control.There are no commercial biocontrol strategies forcontrolling CLR. However, fungalparasites of the rust pathogen,such as Verticillium lecanii and anumber of Darluca species,occur on CLR pustules in coffee fields. Fungicides are also used for control of CLR.

Keywords: *Coffee leaf rust, management, Verticillium lecanii*

INTRODUCTION

Coffee is the most popular soft drink in the world and the second traded commodity next to oil. It is a source of income for more than 12 million farms worldwide, a quarter of which are operated by women. It provides direct employment to more than 25 million families in producing countries. Coffee remains an export commodity (ICO, 2019).

Ethiopia is the primary center of origin and genetic diversity of C.arabica L. and coffee is well known being the pillar of Ethiopian economy. It accounts for 29 % of the total export and 37% of agricultural export earnings of the nation; 4.7 million small-holders directly involved in producing coffee and about 25 million people directly or indirectly depends on coffee sector for their livelihoods (EIAR, 2017). Ethiopia is the leading producer in Africa, and the 5th in the world, following Brazil, Vietnam, Colombia and Indonesia and produces premium quality coffee. It is tenth coffee exporter with 4.79 percent share of the world total (Bellachew, 2015). If is Arabica coffee consider alone, Ethiopia is the 3rd largest producer after Brazil and Colombia (ICO, 2019).

According to CSA (2015), the total productive coffee area in Ethiopia is estimated at 561,761.82 hectares with annual average production of 419,980 tons and productivity of 748 kg/ha.This is very low in contrast to yield level report usually in some Latin America countries. The factors attributing to such low productivities include lack of resistance varieties to various disease and insect pest and poor agronomic practice (Eshatu et al., 2000).lack of suitable varieties that exhibit stable yield performances across wide range of environment is the major factors among several production constraints contributing to low productivity of Arabica coffee in Ethiopia (Beksisa et al., 2018).

Coffee production across the world is challenged by several insect pest and disease (Avelino et al., 2018). Among the fungal disease coffee leaf rust is the most important coffee disease globally with a worldwide distribution (McCook, 2006) while coffee berry and coffee wilt diseases are limited to the African countries (Avelino et al., 2018). Coffee leaf rust is specific coffee leaf and is characterized by orange powdery spores on the lower side of the coffee leaf. The urediospores of the rust are distributed by wind and coffee workers. Heavy leaf defoliation due to severe infestation by the rust could lead to secondary yield losses (Cerda et al., 2017). The National disease Incidence is 35.3% and disease Severity is 22.5% which is very high. In 1983 estimated national tree attack was 12.9 % (Meseret, 1987). Around 1997, disease severity at Hararghe region was 27 % (Derso, 1997).In forest coffee, CLR infection reaches up to 29.6% (Chala, 2009). This indicates the importance of coffee leaf rust the disease is increasing through time and different ecological area. The objective of this paper is to review Coffee leaf rust and its management in Ethiopia.

COFFEE LEAF RUST (*HEMILEIA VASTATRIX*)

History

Coffee leaf rust (CLR) has likely been around since Arabica coffee was only growing wild in Africa, but was not 'officially' detected there until the 1870's. Its first recorded impact began in the end of the 19th when a large outbreak in Ceylon (now Sri Lanka) devastated the coffee industry on that small island, ending in the crop being replaced with tea (Abbay, 1876).CLR was first reported in Ethiopia in 1934 (Sylvain PG., 1958), but the disease had existed for a longtime in other countries without causing epidemics or eradications of certain varieties of *C. arabica*. The long-term coexistence of coffee and rust coupled with the high genetic diversity of coffee populations and a high level of horizontal resistance might have kept the rust at low levels (Van der Graaff NA., 1981).

Taxonomy

CLR is the genus *Hemileia*, a member of the phylum Basidiomycota, class Pucciniomycetes, order Pucciniales (rust fungi). It comprises 42 species occurring mainly in tropical to sub-tropical regions of Africa and Asia, mostly on uncultivated Rubiaceae and Apocynaceae plants (Ritschel, 2005). The genus Hemileia is distinguished from other rust genera by the unique combination of three morphological features: suprastomatalbouquet-shaped sori; ovoid to reniform urediniospores with a smooth ventral side and a delicately to coarsely echinulated convexdorsal side; and angular-globose to very irregular teliospores (Ritschel, 2005). Molecular evidence consistently places the genus Hemileia among the more basal phylogenetic group of the Pucciniales (McTaggart et al., 2016; Silva et al., 2015a). Hemileia is presently included in the Mikronegeriaceae (McTaggart et al.,2016), a family which probably represents the most ancient rust lineages and diverged at c. 91–96 million years ago.

Pathogen Biology

The Coffee Rust is an obligate parasitic fungus, which means it is a microorganism that must take energy and nutrients from a specific live host (coffee) and reproduces differently than either plants or animals. It belongs to the family of Pucciniaceae in the order of Uredinales of the class Basidiomycetes (Mayne WW., 1932). The genus has unknown pycnidial and aecidial stages and only the dikaryotic uredospores are responsible for the disease development (Kushalappa and Eskes, 1989). The pathogen exists primarily as dikaryotic (having pairs of haploid nuclei that divide in tandem), nutrient-absorbing mycelium ramifying intercellular within the leaves of its coffee host. Clusters of short pedicels bearing dikaryotic urediniospores stick out through the stomata on the undersides of the leaves. Occasionally under cool, dry conditions toward the end of the season, teliospores are produced among the urediniospores on older, attached leaves. Following karyogamy and meiosis, the teliospores germinate to produce basidia, each of which forms four haploid basidiospores.

Ecology of CLR

CLR is most severe on *C. arabica*, which is very susceptible to the disease under warm and humid or wet condition as these aid initial infections, growth of the fungus and urediniospores production. In order to germinate urediniospores of *H. vastatrix* require liquid water and the optimum temperature for germination is between 22°C and 24°C (Rozo *et al*., 2012). In eastern Africa most infection of coffee plants seems to occur at night when the duration of wetness is adequate and can support spore germination. Within hours the new fungal mycelium developing from the spore penetrates the coffee leaves and grows within the plant. Fresh spores are usually produced on this mycelium between two weeks and two months after leaf infection.

Spore Dispersal

The urediniospores can be dispersed by both wind and rain. By observing pattern of infection on individual leaves within the canopy, it is clear that splashing rain is an important means if local dispersal. The pattern of infection on a regional scale, particularly in those areas where the fungus was newly introduced, has shown that the long- range dispersal is primarily wind. A small, perhaps epidemiologically insignificant amount of urediniospores dispersal is by thrips, flies, wasps and other insects. Movement across the oceans, deserts and mountain ranges has very likely been caused by human intervention.

Infection Process

Biotrophic fungi, such as rusts are entirely dependent on plant living cells for their growth and reproduction (Shulze-Lefert and Panstruga, 2003). The initiation of the dycariotic phase of *H. vastatrix* on coffee leaves, as with other rust fungi (Mendgen and Voegele, 2005) involves specific events including appressorium formation over stomata and penetration by inter- and intracellularcolonization (Silva et al., 1999a, 2002). Thus, insusceptible coffee leaves, after urediospore germination and appressorium differentiation over stomata (figure 1C), the fungus penetrates (from 12h after inoculation) (figure 1D) forming a penetration hypha (figures 1E) that growsinto the sub-stomatal chamber. This hypha produces at the advancing tip two thick lateral branches; each hypha andits branches resemble an anchor (figure 1F). Each lateral branch of the anchor bears a hypha (haustorial mothercell – HMC), the subsidiary cells being the first invaded by haustoria (figure 1G), whose formation starts around36h after inoculation. The fungus pursues its growth with formation of more intercellular hyphae, including HMCs, and a large number of haustoria in the cells of the spongy and the palisade parenchyma and even of the upper epidermis. Adense mycelium is observed below the penetration area and a uredosporic sorus protrudes like a "bouquet" through the stomata about 20 days after inoculation.

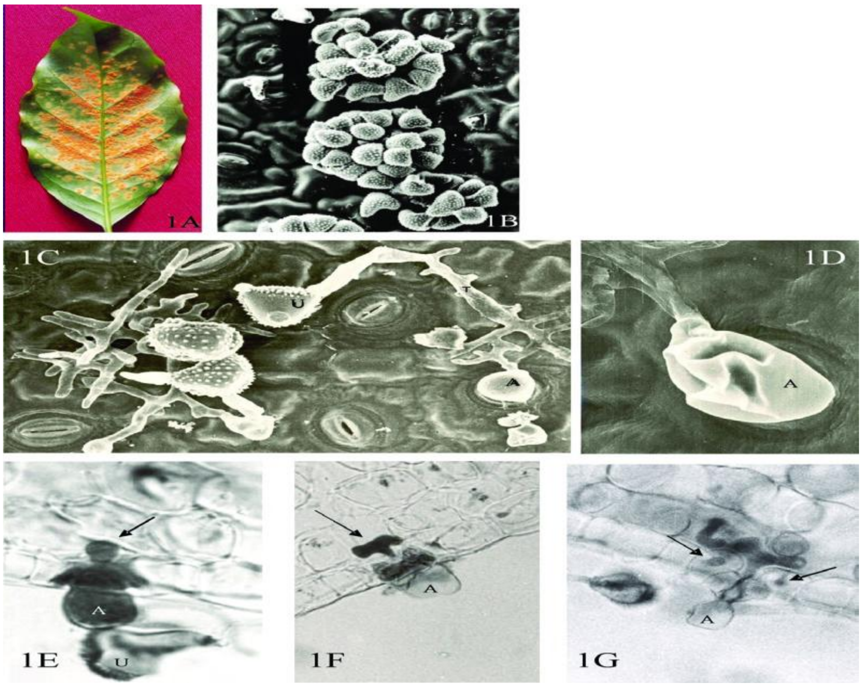

Figure1. *Coffee and H.Vastatrix Interaction*

Figure 1A - Pustules of uredosporic sori on the lower side of the leaf, 21 days after inoculation. Figure 1B. Scanning electron micrograph. Uredosporic sori (x700). Figures 1C-1G - The first stages of fungal infection process in susceptible or resistant plants. Figures 1C-1D - Scanning electron microscope observations. Figs 1E-1G. Light microscope observations, blue lactophenol staining. Figure 1C - Germinated urediospores (U) with germ tubes (T) and appressorium (A) on the lower surface of the leaf, 24h after inoculation (x1,000). Figure 1D - An empty appressorium (A) over leaf stomata, indicating that the fungus already penetrated (x3,300). Figure 1E - Urediospore (U), appressorium (A) over stomata and penetration hypha (arrow), 24 h after inoculation (x800). Figure 1F - Appressorium (A) over stomata and an anchor (arrow), 48 h after inoculation (x650). Figure 1G - Appressorium (A) over stomata and intercellular hypha with haustoria (arrows) in the subsidiary cells, 72h after inoculation (x650).

Symptom of CLR

The first symptom of coffee leaf rust disease is small discolored spots which develop on the underside of the leaves. These small spots increase in size and are powdered with spores of the pathogen ranging in color from yellowishorange to bright orange (Muller *et al.*, 2004). On the upper surface of the leaves, the lesions are lessconspicuous but on lower side of the leaves the lesions increase in size depending on the growth of the fungus inside the leaf (Kushalappa, 1989).It brings loss of physiological activities in the affected part of the leaves and cause leaves to fall (Muller *et al.*, 2004). Potent attack of the disease can cause branches to wither completely and this hinders the plant or even stops its development. If the leaves are unable to supply the needs of the developing coffee berries, which act as powerful sinks, then they draw on the carbohydrate reserves of the roots and stems. Subsequently, badly diseased and weakened coffee plants do not survive (Muller *et al*., 2004). Depending on the severity of the coffee leaf rust, not only fewer flowers are formed but also the flowers and fruits formed fall prematurely and the remaining fruits often do not reach the maximum size; hence, causing reduction in both weight and volume of yield. The lower bean yield and poor bean quality in turn result from sever leaf fall and the general debilitating effect of coffee leaf rust on the tree (Mayne, 1971).

Figure2. *Coffee leaf rust symptoms: A on seedlings, B older leaves, C upper and D on lower site of the leaf*

Epidemiology and Disease Cycle

Epidemiology

The perennial nature of *C. arabica* and its distribution around the equator ensures the presence of CLR throughout the year without a closed season unlike other rusts which undergo a period of survival (Nutman and Robert, 1963). Genetically susceptible coffee plants in rust conducive environments can be attacked at any growth stages (Rodrigues *et al.*, 1975). However, since the spores of the pathogen germinate only in the presence of free water, epidemics are prevalent during the wet season. Rainy spells show an increase in the spread of the disease and period of intense infection corresponds to those of high rainfall (Muller *et al.,* 2004). Generally, the pattern of rainfall determines the pattern of CLR development. In Kenya, to the east of Rift Valley, where there are two periods of rainy seasons, the rust progress curve also had two peaks as against one peak to the west of Rift Valley where there was only one season or rain was continuous (Bock, 1962a).

In Ethiopia, onset of rust in monomodial rainfall at high altitude is October to January with peak period in November to December while in lower altitudes rust increase from August to November with peak in September. Other workers reported the occurrence of maximum rust incidence in November to December (Eshetu *et al.*, 2000). These peak epidemics appeared to occur after heavy rainfall (in amount and distribution) months but just before onset of the dry season. This slight variation over seasons may be due to variation in onset of rainfall that initiates epidemics and early removal of infected leaves eliminating inoculum source. On the other hand, result in Pauna New Guinea indicated an attainment of only single peak epidemic (Brown *et al.,* 1995).

At very low temperature (< 100C) and very high temperature (> 35 0C) lesion enlargement is inhibited and often ends up as chlorotic lesion and perhaps completely inhibit infection (Brown *et al.*, 1995). Altitude influence local climatic conditions, which in turn affect the development of the disease. CLR intensity was reported to decrease with altitude in Kenya (Bock 1962a), in southern American continents (Kushalappa, 1989) in Pauna New Guinea (Brown *et al.*, 1995) and in Ethiopia (Meseret, 1996). High altitudes are associated with lower night temperature and a cooler day temperature that result in lowered disease severity (Kushalappa, 1989).

Disease Cycle

The fungal life cycle is a complex and ingenious one, where organisms asexually produce thousands of tiny spores (reproductive bodies) that can travel in water, rain, or air and remain viable for long distances (Kushalappa and Eskes, 1989). The *Hemileia* fungus cycle begins with the process of releasing and landing a spore on the coffee leaf; subsequently, the spore germinates and the infection process begins. In the third stage of the infection, disease symptoms appear, when pale yellow spots appear on the underside of the leaves that, with time, increase in size and join together, forming the characteristic yellow or orange spots with fine yellow dust that produces new fungal spores (Rivillas et al. 2011). The disease cycle is a simple one. Urediniospores initiate infections that develop into lesions that produce more urediniospores.

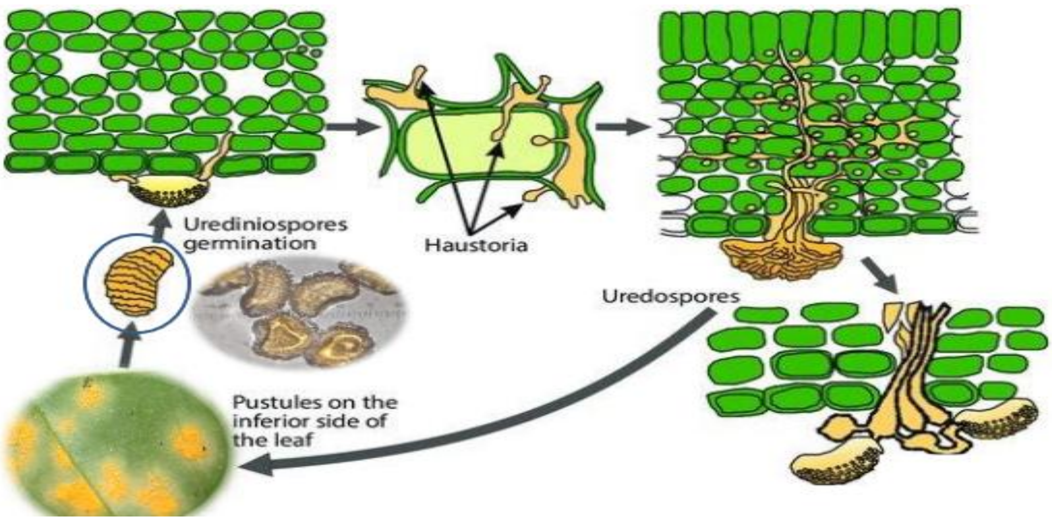

Figure3. *CLR disease cycle*

ECONOMIC IMPORTANCE OF CLR

Coffee Leaf Rust (CLR) is one of the most important diseases of C. arabica in the world. It devastated Arabica coffee plantations in Ceylon at the end of the 19th century and was responsible for its replacement with tea plantations. CLR can cause yield losses in excess of 75% where outbreaks are severe. The costs of controlling the disease are also high and, in relation to the decreasing returns from coffee, are increasing rapidly as a proportion of the crop value. Since 2012, there was a surge of CLR epidemics in Central and South America, losses were estimated in the range of 30 to 90 % (Avelino *et* al. 2015). Costs of control with fungicides, is estimated to 1 to 3 billion USD per year. In Ethiopia CLR first reported in 1934 (Sylvain, 1958). But it is not economically important so far. Now the trend of CLR is increasing and was seen at higher altitudes up to 2100masl which is uncommon before (Kifle et al, 2020). The National disease Incidence is 35.3% and disease Severity is 22.5% which is very high. In 1983 estimated national tree attack was 12.9 % (Meseret, 1987).Around 1997, disease severity at Hararghe region was 27 % (Derso, 1997).In forest coffee, CLR infection reaches up to 29.6% (Chala, 2009).This indicates the importance of coffee leaf rust the disease is increasing through time and different ecological area.

MAJOR CONTRIBUTING FACTORS OF CLR

Shade

Shade effects on coffee rust are controversial, possibly because shade helps to prevent high fruit loads, which decreases leaf receptivity to the pathogen but, at the same time, might provide a better microclimate for germination and colonization. Beneficial shade effect on coffee production through the mitigation of microclimate extremes have been quantified and are generally well established (Lin 2007). It has also been acknowledged that the extent to which shaded system is advantageous depends on the biophysical context (Rahn et al 2018). Since shade effect varies across sites and season, its impact on coffee pest are ambiguous (Boudrot 2016). Few studies were conducted across different temporal and spatial scales or focused on the effect of multiple factors and responsible variable. The case of coffee leaf rust illustrates how shade can operate in two antithetic pathways: shade may (i) aggravates the disease due to modifying the microclimate to condition more favorable for the fungus or (ii)regulate yield, which intern could negatively affect the pathogen because attack intensities are more acute when fruit load is high(Lopez Bravo et al. 2012).

Altitude

Several studies conducted elsewhere, including Ethiopia, have shown that CLR severity tends to decrease with the increase in altitude where the fields experience relatively lower night time temperatures (Daba et al. 2018 and Garedew et al. 2019). In experiments conducted in the Setema district of Jimma Zone, Ethiopia, CLR severity was highest (16.9%) at the lowland and lowest (5.7%) at the highlands irrespective of the cultivar (Daba et al. 2018). In CentralAmerica, prior to the recent epidemics in Guatemala in2012, coffee rust epidemics were unlikely to develop at production sites above 1000 m where cooler nights prevail (Avelino et al. 2015). In Rwanda, CLR severity was estimated to decrease 1.5% units per each 100 unitary increase in altitude (from 1400 to 1800 m) (Bigirimana et al. 2012).

Besides the altitudinal variation, the increasing level of human intervention has resulted in various cropping systems used by Ethiopian farmers, currently defined as forest, semi-forest, garden, and plantation (Jefuka et al. 2010).The plantation type has expanded considerably in Ethiopia in the last few years, and this is usually more affected by rust compared with forests(Jefuka et al., 2010).The intensification of management includes soil correction with fertilizers, and improved nutritional status of coffee plants is known to reduce disease risk by boosting canopy growth and host resistance (Avelino et al. 2006). In addition, pruning facilitates light penetration in the canopy that impairs urediniospore germination. On the other hand, shading alleviates leaf stress by reducing the leaf temperature (Avelino et al. 2006).

The interaction of factors that boost crop productivity but can also favor epidemics is quite complex and may vary from region to region or field to field. Whether the previous findings on risk factors driving CLR in Ethiopia can be extrapolated to other major coffee growing areas of the country is unknown given the considerable variation in site characteristics and technology adoption (Teferi and Belachew 2018).

MANAGEMENT OF CLR

Resistant Varieties

Taking economics and minimization of chemical input for disease management into consideration, the most viable and effective option is the development and cultivation of tolerant coffee varieties. Hence, breeding for varieties resistant to coffee leaf rust has been one of the highest priorities in many countries (Prakash *et al.*, 2004). According to Silva *et al.*, (2006) the breeding of coffee plants for resistance to rust is considered to be the best disease management strategy, both environmentally and economically. The first effective effort to select resistant germplasm was conducted in India in 1911, giving rise to the release of the cultivar 'kent's', which replaced the susceptible cultivar 'coorg' (Rodrigues et al., 1975). Several activities in Ethiopia were subsequently conducted, but no effective resistance sources were identified (Rodrigues et al., 197).

Cultural Control

Cultural practices can have an indirect but beneficial effect in terms of CLR control. For example, wider spacing and appropriate pruning help by preventing prolonged wetness and increasing penetration of fungicides sprayed into the tree canopy. It is also known that the severity of rust is lower under optimum shaded conditions possibly because fully exposed trees, by producing higher yields, become more susceptible to the disease. Wider spacing and appropriate pruning help by preventing prolonged wetness. Appropriate shade management may also therefore be of some benefit to limit over bearing and reduce susceptibility to CLR. Proper nutrition management increase vigor and reduce CLR risk significantly

Biological Control

There are no commercial biocontrol strategies for controlling CLR. However, fungal parasites of the rust pathogen, such as *Verticillium lecanii* and a number of *Darluca* species, occur on CLR pustules in coffee fields. Vandermeer *et al.*,

(2010) stated that *Hemileia vastatrix* spores are hyper-parasitized by the Ascomycete fungus Lecanicillium lecanii. Although unable to effectively control CLR, this hyperparasite is capable of reducing spore viability and disease severity. *Lecanicillium lecanii* is primarily an entomopathogen of the green coffee scale Coccus viridis, which, in turn, has a mutuality association with the arboreal nesting ant Azteca instabilis. The relationships between these organisms suggest that complex ecological interactions may play an important role in disease incidence and severity, potentially explaining why CLR is sometimes a severe epidemic and other times a troublesome but not devastating problem (Vandermeer *et al.,* 2014).

Chemical Control

Fungicides are used for control of CLR. The timing of fungicide application is critical for controlling CLR, with maximum effect being achieved through application before the start and during the early period of the rainy season. It is important that fungicide is reapplied should the previous application be washed off by rainfall. Fungicides should be applied for controlling CLR once a disease threshold is reached. This threshold is when either 5% (i.e. 1 in every 20) or more of the coffee leaves show even a single pustule three months after flowering or when an average of two or more pustules are present on each diseased leaf. Fungicides used for the control of CLR are either protectant (kill the fungus on coming into contact with it on the surface of the plant), which are mostly copper based, or systemic (move within the plant and act once the fungus enters the plant tissues). The common copper fungicides used for control are: Cuprous oxide 50% Cu WP (red copper e.g. Copper Nordox) applied at a rate of 3.8 kg per hectare. Cupric hydroxide 50% Cu WP (blue copper e.g. Kocide 101) applied at a rate of 3.8 kg per hectare. Cupric chloride 50% Cu WP (copper oxychloride or green copper e.g. Cupravit) applied at a rate of 7 kg per hectare. All of the above three fungicides are applied at three week intervals, and the application rates shown are based on recommendations in eastern African.

Summary and Conclusion

Coffee Leaf Rust (CLR) is one of the most important diseases of C. arabica in the world. CLR can cause yield losses in excess of 75% where outbreaks are severe. The costs of controlling the disease are also high and, in relation to the decreasing returns from coffee, are increasing rapidly as a proportion of the crop value. In Ethiopia, the National disease Incidence is 35.3% and disease Severity is 22.5% which is very high. In forest coffee, CLR infection reaches up to 29.6% (Chala, 2009). In general the importance of the disease is increasing through time and ecological area.

The disease is most severe on *C. arabica*, which is very susceptible to the disease under warm and humid or wet condition as these aid initial infections, growth of the fungus and urediniospores production. The urediniospores can be dispersed by both wind and rain. By observing pattern of infection on individual leaves within the canopy, it is clear that splashing rain is an important means if local dispersal. The infection process is that, insusceptible coffee leaves, after urediospore germination and appressorium differentiation over stomata, the fungus penetrates, inoculation, forming a penetration hypha and colonizes the leaf.

Regarding CLR management, breeding of coffee plant for resistant to rust is considered to be the best disease management strategy, both environmentally and economically. This area needs great effort to overcome the impact of coffee leaf rust economic loss facing currently. Appropriate and optimum agronomic practices are important to control CLR. In addition, other control measures as biological and chemical control are not excluded in management option and should be practiced as other countries.

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