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Ecological factors influencing incidence and severity of Coffee Leaf Rust and Coffee Berry Disease in major Arabica coffee growing districts of Uganda

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Abstract

Coffee Leaf Rust and Coffee Berry Disease are the most devastating diseases of Arabica coffee in Africa. The importance of coffee in economies of many African countries like Uganda, presents urgent need for cost-effective disease control strategies. In this study, 192 coffee farms were surveyed and their corresponding incidence and severity recorded. Nebbi district had the highest CLR incidence (90.2%) and severity (2.2%) followed by Sironko (67.9% and 1.9%) and least in Kapchorwa (20.4% and 1.3%) respectively. CBD incidence was highest in Kapchorwa (6.0%) followed by Nebbi (1.7%).There was no CBD incidence observed in Sironko. There was a significant (pd"0.05) interaction between altitude and disease severity. Thin and medium shade intensity had highest CLR incidence followed by thick and no-shade levels. CLR was highest in farms under mono-shade followed by farms under mixed-shade and least in open-farms. CLR severity was found to be highest at very steep slopes and medium slopes and least on gentle slopes. In conclusion, CLR was present in all surveyed districts while CBDoccurred in Kapchorwa and Nebbi districts at intensity levels enough to trigger economic losses.

Key words: Coffee Berry Disease, Coffee Leaf Rust, ecological factors, pathosystem, Uganda

Introduction

Uganda is the second biggest coffee producer and exporter in Africa after Ethiopia (ICO, 2009), contributing an estimated 2.97% of its crop to the world market (ICO, 2011). In the coffee year 2010/2011, Uganda exported 3.15 million 60-kilo bags valued at $448.89 million, constituting 78.87% Robusta and 21.13% Arabica coffee, (UCDA, 2011). Over 13 million Ugandans derive a substantial proportion of their livelihood from coffee earnings either directly or indirectly along the value chain (Sayer, 2002).

Two major coffee diseases that have ravaged Arabica coffee production in Uganda are Coffee Leaf Rust (CLR) caused by the biotrophic fungus *Hemilea vastatrix* (Berkeley and Broome) and Coffee Berry Disease (CBD) caused by *Colletotrichum kahawae* (Bridge and waller) (UCDA,2011). Coffee Leaf Rustis capable of infecting both commercial coffee species; *Coffea arabica* and *Coffea canephora*, although the former is more susceptible. On the other hand, CBD infects only *C.arabica* at elevations above 1500 meters above sea level (a.s.l) (Hakiza, 1997).

Coffee Leaf Rust causes about 10 to 50% yield loss in farms with susceptible coffee varieties especiallyif no control measures are undertaken (Van der Vossen, 2001; Silva *et al.*, 2006). In contrast, CBD may cause up to 70 to 80% losses if no control measures are adopted, especially, in years when berry yield is high (Waller, 1985; Silva *et al.*, 2006). Coffee Leaf Rust manifests itself as yellow pustules on the lower surface of leaves turning orange-yellow with powdery masses of uredeniospores in later stages. Defoliation of affected plants is a common symptom, which leads to loss of yield and quality of coffee. Coffee Berry Disease infects all stages of the crop from flowers to ripe fruits and seldom leaves. Major losses are observed following infection of green immature berries which then develop dark sunken lesions with sporulation, causing premature dropping and mummification (Silva *et al.*, 2006; Gichimu and Phiri, 2010). Control of CLR by fungicide application with Orius (Tebuconazole) following a bi-weekly spray regime has proved very effective, although copper based fungicides such as Copper oxychloride and Nordox 75% have exhibited moderate potency (Matovu, unpublished data). Unfortunately, fungicide use is fraught with resources constraints since most coffee farmers are small-holders hence making it economically unfeasible. Cultural control measures such as pruning, stumping, de-suckering, fertilizer application and coffee tree spacing, have also shown promise although they cannot stand alone if effective control is to be achieved (Bigirimana *et al.*, 2012). Host resistance remains the most economically viable option especially for resource constrained farmers (Omondi *et al.*, 2001; Gichuru*et al.*, 2008). This control strategy, however, is challenged by resistance erosion presumably due to an evolutionary response by pathogens to host defense mechanisms through mutation and recombination (Hulbert *et al.*, 2001; Vleeshouwers *et al.*, 2001).

Agrios (2005) and Okori (2004) elucidate the significance of monitoring populations of pathogens and host plants in an evolving environment. Most importantly, such studies should give special emphasis to biotic and abiotic factors in the environment under going strong influence by human activity as a result of disease management. Proper understanding of the interaction of the elements of disease triangle in the pathosystem enables formulation of efficient and cost-effective disease management strategies before disease progress reaches economic injury level. The aim of this study was therefore to determine incidence and severity of Coffee Leaf Rust and Coffee Berry Diseases in major Arabica coffee growing districts of Uganda, and to study the relationship between the observed disease incidences and existing ecological factors.

Materials and methods

Study area

The study was conducted from August to November 2009 in two major Arabica coffee growing regions of Uganda; Mt Elgon region (Kapchorwa and Sironko districts) which borders with Kenya, and West-Nile region (Nebbi district) which borders Democratic Republic of Congo (DRC). The study area in Mt. Elgon lies approximately between latitudes 1° 17'N and 0° 51'N and longitude 34° 13'E and 34° 25'E at an altitude of 1288-2135M above sea level (van Asten*et al.*, 2011). In Nebbi district, the study area lies between latitudes 2° 14'N and 2° 46'N and longitudes 30° 76'E and 31° 52'E at an altitude of 1450-1800M above sea level. Mt Elgon region receives a mean annual rainfall of more than 1520 mm while West-Nile receives 1100 mm, following a bimodal pattern in both regions. Temperatures at both locations range between 15°C-30°C throughout the year. All soils in Mt Elgon region are derived from volcanic ash and agglomerate. Specifically, Sironko areas generally have dark-brown clays while Kapchorwa has red sandy clay loam soils. On the other hand, the soils in Nebbi are red clay loams derived from amphibolites (Aniku, 2001). A stratified random sampling procedure was adopted where in each district, four sub-counties were randomly selected. From each of the sub-counties, four parishes were chosen and in each of these four villages were selected and subsequently in each village four coffee farms were surveyed. Coffee farmers in each district were contacted and their farms surveyed with the help of district and sub-county agricultural extension officials as guides. The importance of this team was to identify farmers, build trust and provide subsequent follow-ups to the farmers.

Data collection procedures

At each farm, 30 randomly selected trees on a diagonal transect across the farm were assessed for incidence and severity of Coffee Leaf Rust and Coffee Berry Disease. A diagnostic symptom of Coffee Leaf Rust was the presence of yellow-orange pustules on the underside of leaves while for Coffee Berry Disease was the extensive brown to black sunken lesions on both green and red berries leading to mummification of berries. The sampled trees were then physically counted and tagged from 1-30 with the help of conspicuous coloured labels.

Since both diseases cause observable and distinct symptoms to the coffee plant, a comprehensive and robust approach of quantifying disease was adopted. Disease incidence and severity were selected as variables for data collection. In this case, disease incidence accounted for the proportion of coffee trees diseased out of the 30 trees sampled, while disease severity (intensity) for the relative or absolute area of leaf/berry tissue affected by respective disease. Disease severity was visually estimated with the help of a disease rating scale (1-4) to quantify the extent of infection per tree; 1= No coffee leaf rust or CBD, 2= <10% diseased leaves or berries, 3= 10-30% diseased berries or leaves, 4= >30% diseased leaves or berries (Phiri *et al.*, 2001; Bigirimana *et al.*,2012). In addition, data on current agronomic practices and environmental properties such as; soil type, shade nature, farm topography and altitude, were collected to determine their influence on coffee disease occurrence. Data on shade types were collected at 3 levels where coffee farms shaded with more than 1 tree species were recorded as mixed tree species, while those with only one tree species were recorded as mono tree species and un-shaded farms in open sun were recorded as no-shade.The nature of shade at each farm was assessed by visual estimates using a rating scale; No shade = 100% light penetration, thin shade = 99% to 70%, Medium shade = 69% to 40% and Thick shade = 39% to 20%. Soil type was visually assessed by field analysis of soil texture using the 'feeling method'.The nature of topography for each farm was visually assessed based on its degree of inclination; Gentle slope = below 5°, medium slope = 6° to 30°, steep slope = 31° to 50° and very steep slope = 51° to 90°. Altitude in metres above sea level (masl) was recorded, using etrax Ground Positioning System (GPS) at a central point for each farm surveyed.

Data analysis

Completed questionnaires were entered into Microsoft Excel spread sheets where variable codes were assigned. Data were then analysed using Genstat statistical package (13th Edition) and Statistical Package for Social Sciences (SPSS18.0). Analysis of Variance (ANOVA) was used to generate means for disease incidence and severity among discrete independent variables (shade type, shade nature, topography and soil type) were effects were declared significant at 5% level. Least Significant Difference (LSD) was used to determine if there were significant differences among means. Correlation and linear regression analysis were used to test the magnitude and nature of relationships (association) between disease incidence and farm altitude.

Results

Coffee Leaf Rust and Coffee Berry Disease incidence and severity

The survey results indicate a wide distribution of CLR in all major Arabica coffee growing districts of Uganda (Table 1). All surveyed districts had considerable numbers of coffee farms infested with CLR incidence ranging from 20% to over 90%. The highest CLR incidence (90.2%) and severity (2.2%) were observed in Nebbi district while the lowest were observed in Kapchorwa district (20.4 and 1.3%; respectively).

On the other hand, the results reveal a generally low distribution of CBD incidence in surveyed Arabica coffee growing districts. Coffee Berry Disease infested farms were only observed in Kapchorwa and Nebbi districts but not in Sironko district. The highest CBD incidence and severity were observed in Kapchorwa (5.9% and 1.1, respectively) followed by Nebbi district (1.7% and 1.0, respectively).

Relationship between Arabica coffee diseases and ecological factors

Altitude. The results indicate a significant ($P \leq 0.05$) negative relationship between CLR incidence and altitude (r =

Table 1. Incidence and severity of Coffee Leaf Rust and Coffee Berry Disease observed in coffee fields sampled in the Arabica coffee growing regions of Uganda

District	Farms analysed	Mean CLR incidence (%)	CLR-Severity	Mean CBD incidence (%)	CBD-severity
Sironko	64	67.9	1.9	0.0	1.0
Kapchorwa	64	20.4	1.3	6.0	1.1
Nebbi	64	90.2	2.2	1.7	1.1
P-value		<0.001	<0.001	0.012	<0.001
LSD		8.25	0.157	4.034	0.058

-0.99). This implies that CLR incidence increases with each unit decrease in farm altitude (Fig. 1). This association is more elaborated in the following resultant linear regression equation: Y= -0.083X+182.74 (where Y= percentage CLR incidence and X= altitude in masl). The equation further predicts that, the probability for a susceptible coffee farm to be infested with CLR is low above 2194 masl while the probability for infection is high below 993 masl.

Coffee Berry Disease incidence and severity on the other hand, shows a significant ($P \leq 0.05$) positive relationship with altitude. CBD incidence therefore increases with each unit increase in farm altitude after 1800 meters above sea level (Fig. 1). The linear regression equation depicting this relationship is: Y= 0.018X-26.42 (where Y= percentage CBD incidence and X= altitude in masl). The equation indicates that the probability for a susceptible coffee farm to be infested with CBD is high at 1800 masl while the probability of infection is low at 1501masl.

Effect of tree shade on disease incidence and severity

Results indicate 98.5% of coffee farms analysed had been inter-planted with shade trees at various intensities. There was a significant difference in CLR incidence ($P < 0.001$) and severity ($P = 0.003$) among coffee farms situated under different shade intensities. Coffee Leaf Rust incidence was generally highest in farms under thin (71.4%) and medium (61.9%) shade tree cover and lowest in open farms (no shade; 31.4%) and those under thick shade (36.7%).

There was no significant ($P = 0.662$ and $P = 0.943$ respectively) difference in CBD incidence and severity among coffee farms located under the different shade levels. However, similar to CLR, CBD incidence was found more under thin (4.1%) and medium (2.1%) shade levels and lowest under thick (1.3%) and open (1.9%) coffee farms.

Influence of tree shade types to CLR and CBD incidence and severity is presented in Table 3. There was a

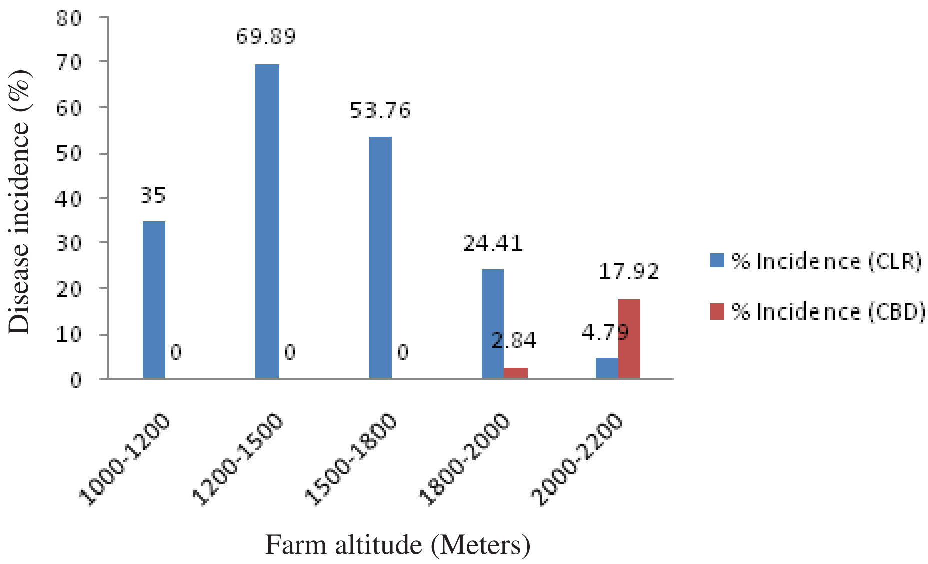

Figure 1. Relationship between altitude and CLR and CBD incidence on coffee farms sampled in the Arabica coffee growing regions of Uganda.

significant (P=0.018) difference in CLR incidence among coffee farms located in various tree shade types. Coffee Leaf Rust incidence and severity were generally highest in farms having only one tree species inter-planted (73.0 and 2.0%), mild (55.4 and 1.7%) in farms with more than one tree species and lowest (49.2 and 1.7% respectively) in farms completely without shade. However, the data reveal no relationship between CBD incidence and severity with tree shade types.

Effect of farm soil type

There was no significant difference at P=0.05 in incidence of CLR and CBD between coffee farms situated on clay, sand and loam soil types. Coffee located on clay soils had higher mean incidence of CLR (81.7%) than on loam (59.0%) and sand (0.0%) soil types. In contrast, coffee growing on loam soils had higher mean incidence of CBD (2.6%) than coffee on clay soils (0.0%) and sand soil (0.0%). However, there was a significant (P=0.037) difference in mean severity of CLR among coffee farms located on clay,sand and loam soil types. Coffee growing on clay soils had higher CLR mean severity (2.4%) than coffee growing on loam (1.8%) and sand (0.0%) soil types. The data also indicated that 98%

Table 2. Incidence and severity of CLR and CBD as influenced by shade intensity in coffee fields sampled in the Arabica coffee growing regions of Uganda

Shade nature	% Mean incidence (CLR)	Mean severity (CLR)	% mean incidence (CBD)	Mean severity (CBD)	% farms analysed
No shade	31.4	1.8	1.9	1.1	1.5
Thin	71.4	2.0	4.1	1.0	32.5
Medium	61.9	1.9	2.1	1.0	48.4
Thick	36.7	1.5	1.3	1.0	17.6
P-value	<0.001	0.003	0.662	0.943	
LSD	37.41	0.1879	12.469	0.183	

Table 3. Incidence and severity of CLR and CBD as influenced by shade type in coffee farms sampled in the Arabica coffee growing regions of Uganda

Shade type	% Mean incidence (CLR)	Mean severity (CLR)	% mean incidence (CBD)	Mean severity (CBD)	% farms analysed
No shade	49.2	1.7	3.3	1.1	1.5
Mono	73.0	2.0	4.4	1.0	24.6
Mixed	55.4	1.7	2.0	1.0	73.9
P-value	0.018	0.086	0.464	0.794	
LSD	51.47	0.823	16.453	0.2408	

of farms surveyed were located on loam soil type, 2% were located on clay soil and no coffee farm was found located on sand soil.

Effect of farm topography

Table 5 indicates the relationship between farm topography with disease incidence and severity. Majority of coffee farms surveyed (81%) were located on gentle slopes while the rest of farms (less than 19%) existed at medium, steep and very steep topographies.There was a significant (P<0.001) difference between CLR incidence and severity at various farm topographical levels. Coffee Leaf Rust incidence was highest on very steep slopes (81.1%) followed by medium (79.7%) and steep slopes (64.2%) and least on gentle slope (37.6%). Coffee Leaf Rust mean severity was highest on coffee growing on medium slope (2.1%), followed by steep and very steep (2.0%) and least on gentle slope (1.5%). However, the results show no significant difference at P<0.05 in CBD incidence and severity among all topographical levels surveyed.

Discussion

From the results CLR is present in all surveyed Arabica coffee producing districts of Uganda at varying levels. The high incidence and severity observed is

Table 4. Incidence and severity of Coffee Leaf Rust and Coffee Berry Disease by farm soil type

Soil type	% Mean incidence (CLR)	Mean severity (CLR)	% mean incidence (CBD)	Mean severity (CBD)	% farms analysed
Clay	81.7	2.4	0.0	1.0	4.0
Loam	59.0	1.8	2.6	1.0	188.0
Sand	0.0	0.0	0.0	0.0	0.0
P-value	0.233	0.037	0.661	0.690	
LSD	37.330	0.589	11.770	0.172	

Table 5. Incidence and severity of Coffee Leaf Rust and Coffee Berry Disease by nature of topography

Topography	% Mean incidence (CLR)	Mean severity (CLR)	% mean incidence (CBD)	Mean severity (CBD)	% farms analysed
Gentle	37.6	1.5	2.4	1.0	81.9
Medium	79.7	2.1	6.7	1.1	9.5
Steep	64.2	2.0	6.3	1.1	6.3
Very steep	81.1	2.0	0.0	1.0	2.4
P-value	<0.001	<0.001	0.511	0.207	
LSD	19.38	0.3279	6.93	0.126	

partially attributed to favourable ecological conditions created by optimum temperatures and fairly high precipitation in Uganda (Kabeere and Wulff, 2008). According to reviews by Eastburn *et al*., (2011), the above environmental factors affect pathogens directly by altering spore germination and hyphal growth rates which as a result affect rate of inoculum production. Studies by Hakiza (1997) and Eskes (1983) relate CLR severity directly to prevailing ecological conditions such as rainfall, temperature, duration of leaf wetness and wind velocity. Similarly, CBD development depends on climatic factors such as rainfall, temperature, and relative humidity(Guyot*et al*., 2001; MouenBedimo*et al*., 2010). The high disease incidence is also in part attributed to the presence of predominantly susceptible Arabica coffee varieties to both CLR and CBD notably; Bugisu local, SL14, KP423 and SL28 (Musoli *et al*., 2001), which were observed throughout the survey. Most coffee farms surveyed had very old trees (30 years and above) which had not been stamped and pruned in a long time (Matovu *et al*. Unpublished data). As a consequence, poor management coupled with prevailing environmental factors could have enhanced susceptibility of coffee to leaf rust and Coffee Berry Disease. Bock (1962) stresses the influence of some agronomic practices such as pruning, weed management and use of soil amendments on CLR development. Hakiza, (1997), MouenBedimo *et al*. (2007) and Bigirimana *et al*. (2012) observed that high level management including:- pruning, mulching, appropriate fertiliser application and good weed control contribute to masking the adverse effect of CLR and CBD epidemic on Arabica and Robusta coffees. These good management practices increase plant vigour, making them more tolerant to disease attack (Bigirimana *et al*. 2012).

Zambolim *et al*. (2005) concluded that there exists a relationship between CLR incidence and altitude which is more or less opposite to CBD. This observation agrees with findings of this study. This relationship could be due to varying temperatures and moisture conditions as altitude increases. This subsequently translates into successful spore germination and colonisation of CLR and CBD at different altitudes. For instance, in Kenya, CLR is almost not an economic problem at higher altitudes especially if the intensity of rainfall is low (Kushalapa and Eskes, 1989). Similarly, Rivera (1984) and Bigirimana *et al*. (2012) observed a lower level of CLR intensity at higher altitudes in Guatemala and Rwanda respectively. At lower altitudes, CLR may benefit from higher temperatures (Lamoroux *et al*., 1995). Hindorf and Omondi (2011) stated that CBD occurrence depends mostly on altitude ranges, with high incidences in higher sites with favourable climatic conditions than lower sites. This explains the observation of CBD only in high altitude areas (above 1800 masl) of Kapchorwa and Nebbi districts and not in Sironko district which lies at the foot of Mountain Elgon. These results are in agreement with Mulinge (1971) and Zeru *et al*., (2009) who observed higher CBD incidence in elevated coffee growing areas than in low areas. Thus, the findings of this study provide vital baseline information which could be used in prioritising research efforts in order to breed resistant varieties with adaptability to such conditions (Bigirimana *et al*. 2012).

The results present a complex relationship between CLR incidence and severity with shade intensity. Our results are in agreement with López-Bravo *et al*. (2012), who reported that shade effects on coffee rust are often controversial, with two probable pathways antagonising each other. High incidence and severity within thin and medium shade intensities can be explained by presence of optimum micro-climate conditions that favour CLR pathogen infection and colonisation of coffee leaves (Beer *et al*., 1998). In addition, efficient light penetration under such conditions keeps temperatures well regulated. Temperature is one of the most important environmental factors that determines spore germination and penetration of *Hemileia vastatrix* (Beer *et al*., 1998). According to Avelino (2010), shade trees tend to reduce berry load on coffee trees, which in turn reducesplant stress and consequently translates into increased plant resistance to CLR. Conversely, the low levels of CLR incidences and severity under thick shade can be explained by the low light penetration under such conditions. This translates into low temperatures which enhance host recognition by the pathogens and eventually successful infection. Shade systems in coffee mainly act on environmental parameters in limiting disease incidence (MouenBedimo *et al*., 2008). The low CLR incidence in open coffee farms can be attributed to less competition for resources such as soil nutrients, moisture and light which occurs among coffee inter-planted with shade trees. Nutrient stress predisposes coffee to disease infection especially during heavy bearing stages of growth (Agrios, 2005; Waller *et al*., 2007; McMahon, 2012). Additionally, open coffee farms possess lower humidity levels than shaded farms an environmental factor required during successful penetration of host tissue by coffee rust.However, our results contrast work by Eskes (1982) who reported a weak correlation between the level of shade and incidence of *Hemileia vastatrix*. In his study, coffee leaf rust caused serious defoliation to both sun grown and shaded coffee. Furthermore, our results show that mean CBD incidence and severity were not significantly different across the various shade intensities. However, the low mean CBD incidence and severity on coffee growing under thick shade cover may be due to reduced rain intensity and subsequently, reduced splash dispersal of *Colletotrichum kahawae* (Ntahimpera *et al*., 1998; MouenBedimo *et al*., 2008)

Our data show that the highest CLR incidence was recorded in farms having only one tree species as compared to farms with no shade and mixed tree species. This can in part be attributed to loss of biodiversity in a mono tree species shade system (Avelino, 2010). In addition, a mixed shade type probably possesses numerous ecological benefits to coffee such as nitrogen fixation, manure addition, improvement of soil water retention, reduction in high solar radiation and suppression of weeds. This combination synergistically curtails pathogen incidence. Our results further show that mean CBD incidence was higher on coffee growing under a mono shade tree species system and no shade as compared to that growing under mixed shade tree species. These results are in agreement with MouenBedimo *et al*. (2007) who reported higher CBD infection rate on coffee grown intensively than coffee trees grown in a traditional manner. Mixed cropping with shade plants are cultural practices that limit CBD development (MouenBedimo *et al*., 2007).

The higher mean incidence in CLR and CBD in clay than in loam soils could in part be attributed to the fact that clay soils are very heavy with excessive water retention and hence are mostly affected by leaching (McCauley *et al.*, 2005 and Waller *et al.*, 2007). This in turn affects the ability to retain soil nutrients (Leslie, 2002) which are indirectly responsible for plant vigour and the state of readiness of plants to defend themselves against pathogenic attack (Agrios, 2005; Stone *et al.*, 2003). This renders coffee trees planted in clay soil very susceptible to CLR. Our results are in agreement with Lamoroux *et al*. (1995) and Medina and Ascanio (1995) who reported that CLR was generally associated with poor soil structure. In contrast, results indicated that loam soils may be better for coffee production owing to their good properties such as increased moisture, air and nutrient retention which enable crop production with increased disease resistance (Stone *et al.*, 2003).Our results agree with findings by Ndo *et al*. (2010). The authors reported lower incidence of *Phaeoramularia* leaf and fruit spot disease of citruson trees growing on volcanic soils known for high fertility.

The lowest CLR and CBD incidence and severity was observed in farms located on gentle slopes. Our results are in line with other researchers who have reported inter-relationships between topography and fungal diseases such as *Colletotrichum coffeanum* (Nutman *et al.*, 1960) and American leaf spot, *Mycenacitricolor* (Avelino *et al.*, 2007). Soils in such topographical locations are characterised by deep fertile soils, less soil erosion and high soil moisture. Although these factors may not directly influence rust incidence and severity, the crop can benefit from enhanced soil fertility and reduce chances of stress which predisposes host plants to their pathogens (Hakiza, 1997). In contrast, highest disease incidence was observed in farms on very steep, steep and medium slopes. Similarly, Avelino *et al*. (2007) reported that slopes are conducive for epidemics of some fungal diseases such as the American leaf spot, *Mycenacitricolor* and several leaf spots(Malhi and Kutcher, 2004). Such farms are prone to high surface run-off and in extreme cases landslides may occasionally occur for instance in mountain Elgon ranges of Uganda. Farms in such topographical levels possess fragile soil nutrients unless mitigation strategies are put in place. Steep topographies are very synonymous with river valleys, where a micro-climate which favours disease development is created (Nevalainen, 2002).

Conclusions

Coffee Leaf Rust occurs in all surveyed Arabica coffee growing districts of Uganda damaging coffee at substantial levels, enough to cause economic losses. It is evident that CLR is more severe in susceptible farms at low altitude, which is the reverse with CBD. On the other hand, CBD occurs in high altitude areas of Kapchorwa and Nebbi districts, although it can be very destructive even at low altitudes as long as conditions are favourable. All surveyed ecological factors in some way influenced CLR and CBD incidence and severity at a certain threshold level which presents an opportunity for Integrated Pest Management (IPM).

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References

Agrios, G.N. 2005. Plant Pathology.Academic Press. New York, USA.

Aniku, J.R.F. 2001. Soil classification and pedology.In *Agriculture in Uganda*; Mukiibi, J.K. (Ed.). Fountain Publishers/CTA/NARO.Vol.I. pp.66-103.

Avelino J., Cabut, S., Barboza, B., Barquero, M., Alfaro, R., Esquivel, C., Durand, J.F. and Cilas, C. 2007. Topography and crop management are key factors for the development of American leaf spot epidemics on coffee in Costa Rica. *Phytopathology* 97(12):1532-1542.

Avelino, J. 2010. Effects of shade trees on pests and diseases of Arabica coffee. http://www.agropolis.org/agronomy/Example-Effects-of-shade-trees-on-pests-and-diseases-of-Arabica-coffee-22-Dossier-Agropolis-International-research-expertise-languedoc-roussillon.htm.Last accessed on February 18, 2013.

Beer, J., Muschler, R., Kass, D and Somarriba, E. 1998. Shade management in coffee and cacao plantations. *Agroforestry Systems* 38:139-164.

Bigirimana, J., Njoroge, K., Gahakwa, D. and Phiri, N.A. 2012. Incidence and severity of coffee leaf rust and other coffee pests and diseases in Rwanda. *African Journal of Agricultural Research* 7(26):3847-3852.

Bock, K.R. 1962. Seasonal periodicityof coffee leaf rust and factors affecting the severity of outbreaks in Kenya colony. *Transactions of the British Mycological Society* 45:289-300.

Eastburn, D.M., McElrone, A.J. and Bilgin, D.D. 2011. Influence of atmospheric and climatic change on plant-pathogen interactions. *Plant Pathology* 60:54-69.

Eskes, A.B. 1982. The effect of light intensity on incomplete resistance of coffee to *Hemileia vastatrix. Netherlands Journal of Plant Pathology* 88: 191-202.

Eskes, A.B. and Dacosta, W.W. 1983. Characterization of incomplete resistance to *Hemileiavastatrix* in the Icatu coffee population. *Euphytica* 32:649-657.

Gichimu, B.M. and Phiri, N.A. 2010. Response of newly developed and introduced Arabica Coffee genotypes to Coffee Berry Disease (*Colletotrichum Kahawae*) in Kenya. CABI Annual Report.

Gichuru, E.K., Agwanda, C.O., Combes, M.C., Mutitu, E.W., Ngugi, E.C.K., Bertrand, B. and Lashermes, P. 2008. Identification of molecular markers linked to a gene conferring resistance to coffee berry disease (Colletotrichumkahawae) in Coffea arabica. *Plant pathology* 57:1117-1124.

Guyot, J., Ntawanga Omanda, E., Ndoutoume, A., Mbah Otsaghe, A.A., Enjalric, F. and Ngoua Assoumou, H.G. 2001. Effect of controlling *Colletotrichum* leaf fall of rubber tree on epidemic development and rubber production. *Crop Protection* 20:581-590.

Hakiza, G.J. 1997. Characterization of the epidemiology of coffee leaf rust caused by *Hemileiavastatrix* on robusta coffee (*Coffeacanephora*) in Uganda. Doctor's Dissertation, Department of Agriculture, University of Reading, February, 1997.

Hindorf, H. and Omondi, C.O. 2011. A review of three major fungal diseases of Coffea Arabica L. in the rainforests of Ethiopia and progress in breeding for resistance in Kenya. *Journal of Advanced Research* 2: 109-120.

Hulbert, S.C., Webb, C.A., Smith, S.M. and Sun, Q. 2001. Resistance gene complexes. Evolution and utilization. *Annual Review of Phytopathology* 39:285-312.

ICO (International Coffee Organization). 2009. ICO trade statistics, Exports by exporting countries to all destinations (www.ico.org/trade_statistics.asp).

ICO (International Coffee Organization). 2011. ICO trade statistics, Exports by exporting countries to all destinations(www.ICO.org).

Kabeere, F. and Wulff, E. 2008. Seed Sector Country Profile: Uganda-Volume I: Overview of the seed supply systems and seed health issues. Danish Seed Health Center of Developing Countries. Department of Plant Biology, Faculty of Life Sciences, University of Copenhagen, Denmark, December 2008.

Kushalappa, A.C. and Eskes, A.B. (Eds.). 1989. Coffee Rust, Epidemiology and control. CRC Press, Inc. Boca Raton, Florida.

Lamoroux, N., Pellegrini, F., Nandris, D. and Kohler, F. 1995. The *Coffea arabica* fungal pathosystem in New Caledonia: interactions at two different spatial scales. *Journal of Phytopathology* 143:403–413,

Leslie, C.M. 2002. Building soil organic matter with organic amendments: A resource for urban and rural gardeners, small farmers, turfgrass managers and large scale producers. Center for Integrated Agricultural Systems, College of Agricultural and life sciences, University of Wisconsin-Madison, USA. 4pp.

López-Bravo, D.F., Virginio-Filhoa, E. de M. and Avelino, J. 2012. Shade is conducive to coffee rust as compared to full sun exposure under standardised fruit load conditions in a sub-optimal zone for coffee in Costa Rica. The 24th International Conference on Coffee Science, ASIC. November 11-16, 2012, San José, Costa Rica.

Malhi, S.S. and Kutcher, HR. 2004. Effect of topography, N fertilization and fungicide application on leaf spot diseases, yield and seed quality of wheat in North-Central Saskatchewan. Proceedings of the 7th International Conference on Precision Agriculture and Other Precision Resources Management, Hyatt Regency, Minneapolis, MN, USA, 25-28 July, 2004. pp. 1008-1015.

McCauley, A., Jones, C and Jacobsen, J. 2005. Soil and water management Module 1: Basic soil properties, Montana State University: Extension Service: 4481-1 Jan. 2005.

McMahon, P. 2012. Effect of nutrition and soil function on pathogens of tropical tree crops. C.J. Cumagun (Ed.). Plant Pathology. ISBN: 978-953-51-0489-6.

Medina, L. and Ascanio, C. 1995. Epidemiology of coffee rust (*Hemileiavastatrix* Berk and Br.) under two fertility conditions of the soils in Falcon State. 13th Congreso Venezolano de la CienciadelSuelo, Maracay (Venezuela), 15-20 Oct 1995. 11p.

MouenBedimo, J.A., Bieysse, D., Nyassé, S., Nottéghem, J. L. and Cilas, C. 2010. Role of rainfall in the development of coffee berry disease in *Coffeaarabica* caused by *Colletotrichumkahawae* in Cameroon. Plant Pathology V59: 324-329.

MouenBedimo, JA., Bieysse, D., Njiayouom, I., Deumeni, J.P., Cilas C. and Nottéghem, JL. 2007. Effect of cultural practices on the development of Arabica coffee berry disease, caused by *Colletotrichum kahawae*. *European Journal of Plant Pathology* 119(4):391-400.

Mulinge, S.K. 1971. Effect of altitude on the distribution of the fungus causing coffee berry disease in Kenya. *Annals of Applied Biology* 67: 93-98.

Musoli, P.C., Hakiza, G.J., Birinkunzira, J.B., Kibirige-Sebunya, Kucel, P. 2001. *Coffee* (*Coffea* spp.). In: *Agriculture in Uganda*. Mukiibi, J.K. (Ed.). Fountain Publishers/CTA/NARO. Vol. II. pp. 376-436.

Ndo, E., Bella-Manga, F., Ndindeng, S., Ndoumbe-Nkeng, M., Fontem, A. and Cilas, C. 2010. Altitude, tree species and soil type are the main factors influencing the severity of *Phaeoramularia* leaf and fruit spot disease of citrus in the humid zones of Cameroon. *European Journal of Plant Pathology* 128(3):385-397.

Nevalainen, S. 2002. The incidence of *Gremmeniella abietina* in relation to topography in southern Finland. *Silva Fennica* 36(2): 459-473.

Ntahimpera, N., Ellis, M.A., Wilson, L.L. and Madden, L.V. 1998. Effects of a cover crop on splash dispersal of *Colletotrichumacutatum* conidia. *Phytopathology* 88:536-543.

Nutman, F.J., Roberts, F. and Lorence, M. 1960. Investigations on a disease of Coffea arábica caused by a form of *Colletotrichum coffeanum* Noack. II. Some factors affecting germination and infection, and their relation to disease distribution. *Transactions of the British Mycological Society* 43(4):643-659.

Okori, P. 2004. Population studies of *Cercospora zeaemaydis* and related *Cercospora* fungi. Doctor's Dissertation ISSN 1401-6249, ISBN 91-576-6497-8.

Omondi, C.O., Ayiecho, P.O., Mwang'ombe, A.W. and Hindorf, H. 2001. Resistance of Coffeaarabica cv. Ruiru 11 tested with different isolates of Colletotrichumkahawae, the causal agent of coffee berry disease. *Euphytica* 121:19-24.

Phiri, N.A., Hillocks, R.J. and Jeffries, P. 2001. Incidence and severity of coffee diseases in smallholder plantations in northern Malawi. *Crop Protection* 20: 325-332.

Rivera, M.A. 1984. Epidemiological study of coffee leaf rust in Guatemala. *Annals of Applied Biology* 87:97-103.

Sayer, G. 2002. Coffee futures: The impact of falling world prices on livelihoods in Uganda. Uganda Coffee Report.

Silva, M.C., Varzea, V., Guimaraes, L.G., Azinheira, H.G., Fernandez, D., Petitot, A.S., Lashermes, P., Nicole, M. and Bertrand, B. 2006. Coffee resistance to the main diseases: Leaf rust and coffee berry disease. *Brazilian Journal of Plant Physiology* 18(1):119-147.

Stone, A.G., Vallad, G.E., Cooperband, L.R., Rotenberg, D., Darby, H.M., James, R.V., Stevenson, W.R. and Goodman, R.M. 2003. Effect of organic amendments on soilborne and foliar diseases in field-grown snap bean and cucumber. *Plant Disease* 87:1037-1042.

UCDA (Uganda Coffee Development Authority). September 2011. UCDA Monthly report. (www.ugandacoffee.org/resources/12-September_2011_rpt.pdf)

van Asten, P.J.A., Wairegi, L.W.I., Mukasa, D. and Uringi, N.O. 2011. Agronomic and economic benefits of coffee-banana intercropping in Uganda's smallholder farming systems. *Agricultural Systems* 104:326-334.

Van der Vossen, H.A.M. 2001. Coffee breeding practices. In: Clarke, R.J. and Vitzthum, O.G. (Eds.). Coffee Recent Developments. Oxford: Blackwell Science. pp. 184-201.

Vleeshouwers, V.G.A.A., Martens, A., Dooijeweert, W., Colon, L.T., Grovers, F. and Kamoun, S. 2001. Ancient diversification of the P to kinase family preceded speciation in solanum. *Molecular Plant-Microbe Interactions* 14:996-1005.

Waller, J.M. 1985. Control of coffee diseases. pp. 219-229. In: Coffee: Clifford, M.N. and Willson, R.C. (Eds.). Botany, Biochemistry and Production of Beans and Beverage. Croom Helm Ltd.

Waller, J.M., Bigger, M. and Hillocks, R.J. 2007. Coffee pests, diseases and their management. Cambridge, MA: CABI Pub, 2007.

Zambolim, L., Zambolim, E.M. and Varzea, V.M.P. 2005. Durable resistance to coffee leaf rust-*Vicosa*: UFV, DFP, 2005, 540p ,:il;22cm.

Zeru, A., Assefa, F., Adugna, G. and Hindorf, H. 2009. Occurrence of fungal diseases of *Coffea arabica* L. in montane rainforests of Ethiopia. *Journal of Applied Botany and Food Quality* 82:148 - 151.