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The effect of temperature on the development of epidemics of coffee leaf rust in Papua New Guinea

J. S. Brown,* M. K. Kenny,† J. H. Whan‡ and P. R. Merriman‡

*Department of Agriculture, Victorian Institute for Dryland Agriculture, Private Bag 260, Horsham 3401, Australia, †Coffee Industry Corporation, Coffee Research Institute, P.O. Box 105, Kainantu, Eastern Highlands Province, Papua New Guinea, and ‡Department of Agriculture, Institute for Horticultural Development, Burwood Highway, Knoxfield, Victoria 3180, Australia

Epidemics of coffee leaf rust (CLR) were monitored to establish the seasonal pattern of epidemic development in various coffee growing regions of Papua New Guinea (PNG) and to determine the effect of temperature on those epidemics. There is a seasonal pattern to the epidemics of CLR in PNG. Rust incidence (% infected leaves) is lowest during the October–November to January–February period. Thereafter rust incidence increases and reaches a peak in May–June–July, after which the disease incidence declines. The average maximum disease incidence (MDI) was less than 20% leaves infected. MDI was positively correlated with the mean minimum monthly temperature five months before the MDI. This association indicated that if the average minimum temperature is less than 15°C in January, epidemic development 5 months later will not reach levels which require chemical control. The minimum temperatures recorded in PNG suggest that conditions are sub-optimal for the development of epidemics of coffee leaf rust in the main coffee growing areas of the country. The possibility that CLR became established in the main coffee growing regions of Papua New Guinea before 1986 and remained undetected for a number of years is discussed.

Keywords: coffee leaf rust; epidemiology; temperature; Papua New Guinea

Introduction

Coffee leaf rust (CLR) (caused by the fungus *Hemileia vastatrix* Berk & Br.) was first detected in the main coffee growing regions of Papua New Guinea (PNG) in 1986 (Waller and Turner, 1986). The major aspects of the epidemiology of CLR are known from work undertaken in parts of Africa and south and central America, where rust is now endemic. These include the infection process, incubation period and spore dispersal, and the influence of climate, location and host (Waller and Turner, 1986). Although this knowledge can be used to predict, by extrapolation, how coffee rust *might* develop in PNG, any predictions must remain tentative and await confirmation through direct monitoring of the disease (Waller and Turner, 1986).

Factors such as altitude, temperature and rainfall all play significant roles in the development of CLR epidemics by affecting one or several processes of the infection cycle. For instance in parts of Kenya, Bock (1962) showed that the disease severity decreased with increasing altitude. This was attributed to generally lower night temperatures at higher altitudes because temperatures below 15°C adversely affect the germination and infection process (Nutman and Roberts, 1963; Kushalappa, Akutsv and Ludwig, 1983; Jong, Eskes, Hoogstraten and Zadock, 1987). Temperature is important because it affects the length of the infection period: Raynor (1961) related the length of the incubation period (Y) to the mean maximum (x_1) and minimum (x_2) diurnal temperatures ($Y = 90.61 - 0.408x + 0.440x_2$). Kushalappa and Eskes (1988) reviewed South American research which indicated that this equation was not a good predictor of disease incidence in Brazil and commented on several other regression equations relating disease development to temperature and rainfall in that environment.

The objective of the study described in this report was to obtain information on the epidemiology of CLR in PNG. This is a necessary prerequisite to the development of control strategies. Epidemics of CLR were monitored to establish the seasonal pattern of epidemic development in various coffee growing regions of PNG and to determine the effect of temperature on those epidemics.

Materials and methods

The seasonal pattern of CLR epidemics and its relationship to temperature

The seasonal pattern of epidemic development in PNG was determined by monitoring epidemic development in coffee blocks located in different regions of the main coffee growing areas of the country.

Experimental sites

Five newly rehabilitated smallholder coffee blocks [Onaningka and Kayokite in the Eastern Highlands Province (EHP) and Ugini, Nengil and Kwinga in the Western Highlands Province (WHP) and two plantation sites (Bena Bena in the EHP and Kudjip in the WHP) were included in the study. Sites were selected to represent the range of altitudes and climatic zones in which the majority of the arabica coffee (*Coffea arabica* L.) is grown in PNG (*Table 1*). Each experimental unit comprised a fenced block of 100 coffee bushes, which was maintained by the grower. This included hand-weeding as required and maintenance pruning in the November–December period. The trees on which observations were made were not sprayed with any fungicides during the study period.

Collection of temperature data

An electronic weather station (Environdata, Warwick, Queensland) was located at each site and temperature was measured with a thermocouple. Dataloggers recorded the temperature at 5 min intervals and calculated and stored the mean hourly temperature, the daily maximum and minimum temperatures. The sites were visited at regular intervals and data from the weather stations were down-loaded from the dataloggers into a portable laptop computer.

Disease assessment

In the January–February period of each season (i.e. after the maintenance pruning in the November–December period) 24 healthy 1-year old, primary-lateral branches were tagged at each site. There was a maximum of four tagged laterals on any one tree. For each of the marked laterals, the number of leaves present, the number of CLR infected leaves (disease incidence) present, and the number of leaf nodes without leaves (fallen leaves) were recorded at monthly intervals.

Table 1. Altitude and climatic type of the sites included in this study

Location	Altitude (m)	Climate	Classification
Smallholder sites			
Eastern Highlands			
Onaningka	1410	C1/C2[a]	8[b]
Kayokite	1770	C1/C2	8
Western Highlands			
Ugini	1210	A1	9
Nengil	1470	A1	9
Kwinga	1880	A1	9
Plantation Sites			
Eastern Highlands			
Bena Bena	1420	C1/C2	8
Western Highlands			
Kudjip	1570	A1	9

Climatic types in the Papua New Guinea Highlands based on rainfall seasonality
[a]Bourke (1987); cited by Shaw *et al.* (1986)
A1 Perennially wet; equable but definite drier season
C1 Wet seasonally dry; equable but definite drier season
C2 Wet seasonally dry; rather seasonal
[b]McAlpine and Keig (1983)
8 Low montane subhumid
9 Low montane humid

Statistical analysis

The Genstat 5 statistical package was used for all statistical analyses. Data was transformed only if there was gross heterogeneity of variance in the data or if there were biological grounds for fitting a particular model.

Results

Seasonal pattern of epidemic development

The seasonal pattern of development of epidemics of CLR at each of the sites included in the study is shown in *Figure 1a–g*.

At all sites there was only one peak in the CLR epidemic (the maximum disease incidence, MDI) each year, and at most sites this occurred in the May–July period, although the precise timing varied with the locality and year. In general, peaks in the epidemics occurred later in WHP than in EHP. The seasonal periodicity of epidemics of CLR in PNG is illustrated in the graph of average monthly disease incidence (*Figure 1h*).

MDI varied from year to year at most sites (*Figure 1*). At Onaningka, Bena Bena, Kayokite, Nengil and Ugini, MDI approached 50% in one year out of the three during which observations were made. At Onaningka and Nengil MDI was greater than 20% in all 3 years; at Bena Bena it was greater than 20% in 2 years. At Kayokite, Onaningka and Kwinga MDI was highest in 1991 and lowest in 1989. At Bena Bena and Nengil MDI was highest in 1989 and lowest in 1991.

The observations at these seven locations provided no evidence of a general increase in the severity of CLR epidemics in the main coffee growing areas of PNG during the study period.

Effect of temperature on CLR epidemics

For this analysis MDI was correlated with various temperature variables. These included the average monthly minimum (M.MinT) and average monthly maximum (M.MaxT) temperatures, the number of days per month on which the maximum temperature was above 30°C (ndMax>30) and the number of days per month on which the minimum temperature was below 15°C (ndMin<15). The latter two variables were selected because temperatures below 15°C and above 30°C are detrimental to rust development (Nutman and Roberts, 1963; Kushalappa and Chaves, 1980).

Data presented in *Figure 1* indicated that, in general, epidemics of CLR in PNG develop over the February to June period and this analysis examined the effect of temperature in each of the 6 months before the peak of the epidemic. The linear correlations between MDI and temperature variables for the month in which MDI occurred ($t0$) and each of the preceding 6 months ($t1$ to $t6$) were determined. Because published infection studies indicate that temperatures below 15°C are unfavourable for infection of coffee leaves by *H. vastatrix*, a logistic model (which allows for a lower limit) was also fitted to the data.

There was no significant ($P \leq 0.05$) linear correlations between MDI and M.MaxT in any month (*Table 2*).

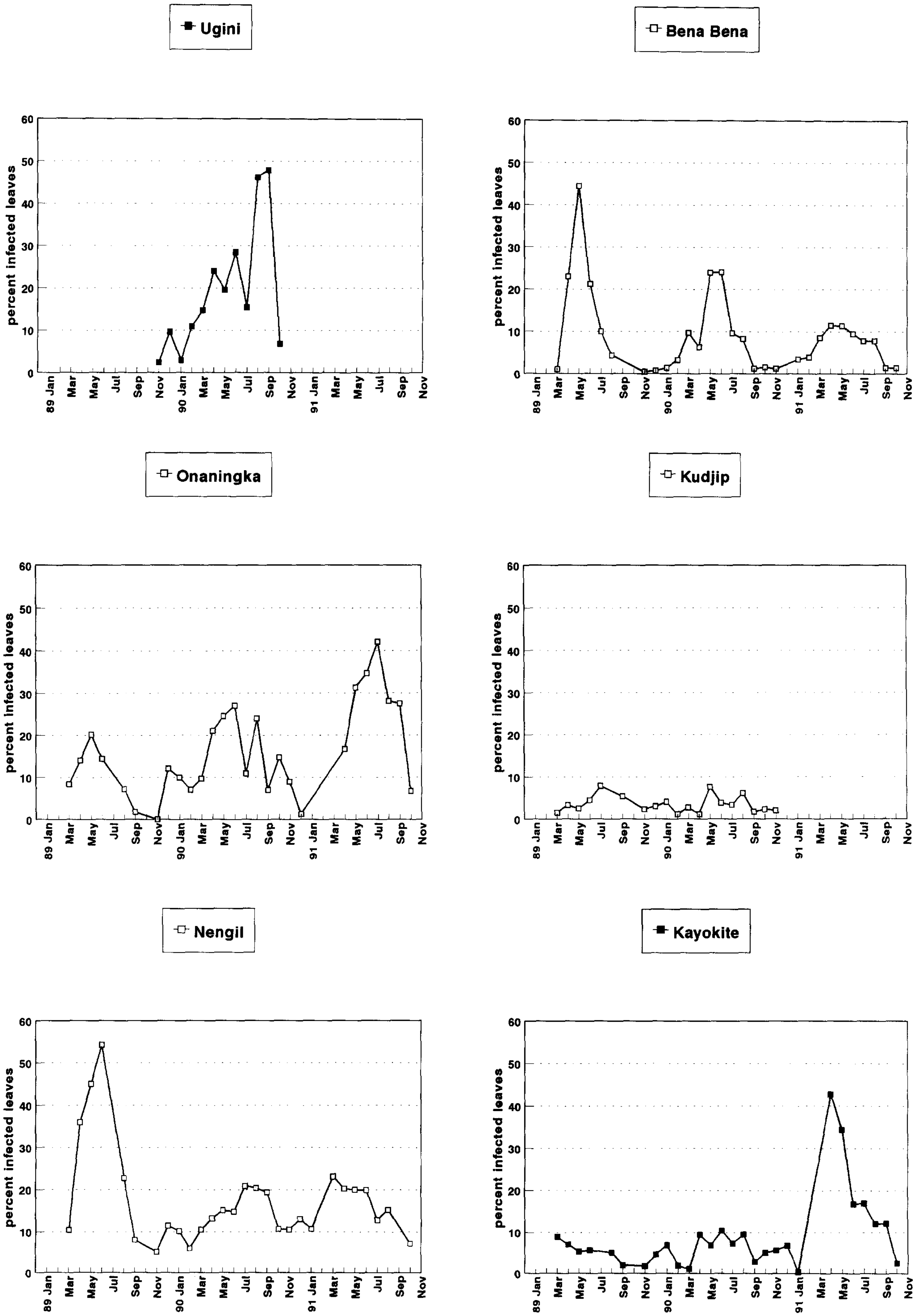
Ugini
Bena Bena
Onaningka
Kudjip
Nengil
Kayokite
percent infected leaves
0
10
20
30
40
50
60
89 Jan
Mar
May
Jul
Sep
Nov
90 Jan
Mar
May
Jul
Sep
Nov
91 Jan
Mar
May
Jul
Sep
Nov

Figure 1.

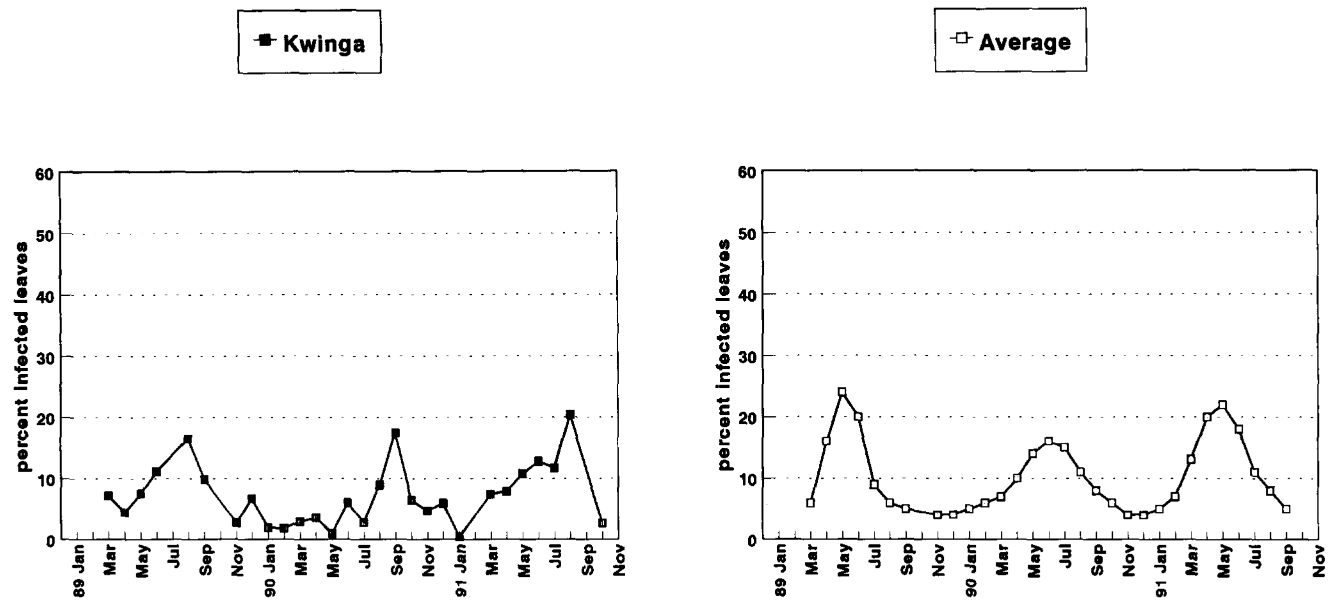

Figure 1. The incidence of coffee leaf rust between March 1989 and October 1991 at seven locations in the Highlands of Papua New Guinea. Records for Ugini in 1989 were not included in the analysis because the coffee trees were still recovering from rehabilitation. The site was abandoned in October 1990 because of vandalism. Data collection at Kudjip ceased in March 1991 because a change in management resulted in excessive weed growth which led to severely stressed and defoliated coffee trees

Table 2. Correlations between maximum disease incidence (MDI) and mean minimum monthly temperatures (M.MinT), mean monthly maximum temperatures (M.MaxT), number of days per month with a minimum temperature <15°C (ndMin<15) in the month of MDI ($mMDI_{(t0)}$), the month before MDI ($mMDI_{(t-1)}$), 2 months before MDI ($mMDI_{(t-2)}$, 3 months before MDI ($mMDI_{(t-3)}$), 4 months before MDI ($mMDI_{(t-4)}$), 5 months before MDI ($mMDI_{(t-5)}$), and 6 months before MDI ($mMDI_{(t-6)}$)

		M.MinT		M.MaxT		ndMin<15	
		linear	logistic	linear	logistic	linear	logistic
$mMDI_{(t0)}$	$100r^2$ [a]	37.2	38.1	7.0	0.0	0.0	0.0
	F [b]	6.92*	3.05	1.97	0.52	0.87	0.06
$mMDI_{(t-1)}$	$100r^2$	15.4	0.0	3.7	0.0	3.2	0.0
	F	3.37	0.85	1.54	0.45	1.39	0.44
$mMDI_{(t-2)}$	$100r^2$	7.1	1.2	0.0	0.0	0.0	0.0
	F	2.15	1.69	0.41	0.06	0.02	0.08
$mMDI_{(t-3)}$	$100r^2$	11.6	0.0	7.1	0.0	0.0	0.0
	F	2.83	0.84	2.08	0.88	0.74	0.62
$mMDI_{(t-4)}$	$100r^2$	45.8	56.4	12.1	0.0	10.7	0.0
	F	12.81**	7.05**	2.92	0.83	2.56	0.74
$mMDI_{(t-5)}$	$100r^2$	56.7	67.4	20.8	9.9	16.6	73.6
	F	14.09**	7.90*	4.15	1.44	2.79	9.35**
$mMDI_{(t-6)}$	$100r^2$	25.5	0.0	4.7	0.0	17.7	0.0
	F	2.37	0.78	1.35	0.54	2.50	1.05

[a] $100r^2$ = Per cent variance accounted for
[b] F = Variance ratio; statistically significant $P \leq 0.05$ (*) and $P \leq 0.01$ (**)

There were significant linear correlations between MDI and $M.MinT_{(t0)}$, $M.MinT_{(t-4)}$, and $M.MinT_{(t-5)}$) (*Table 2*, *Figure 2*). The logistic model explained more of the variation in MDI (*Table 2*). There were no significant ($P \leq 0.05$) linear correlations between MDI and $ndMin<15_{(t0\ to\ t-6)}$. However the logistic model relating MDI to $ndMin<15_{(t-5)}$ explained 74% of the variation in MDI (*Table 2*).

Effect of altitude on epidemic severity

Because of its influence on climate, the relationship between CLR epidemic severity and altitude was also examined; MDI was significantly negatively correlated ($r = 0.548$; $P \leq 0.05$) with the altitude.

Discussion

This study has shown that there is a definite seasonal pattern to the epidemics of CLR in PNG. The rust incidence is lowest during the October–November to January–February period. Thereafter rust incidence increases and reaches a peak in May–June–July, after which the disease incidence declines. The generation of a single epidemic peak in any one year is similar to CLR epidemics in India (Mayne, 1930; cited by Waller, 1982) and Brazil (Kushalappa and Chaves, 1980) but contrasts to the situation in Kenya, especially east of the Rift valley, where there are usually two peaks in the rust epidemic every year (Bock, 1962).

The severity of CLR epidemics in PNG does not

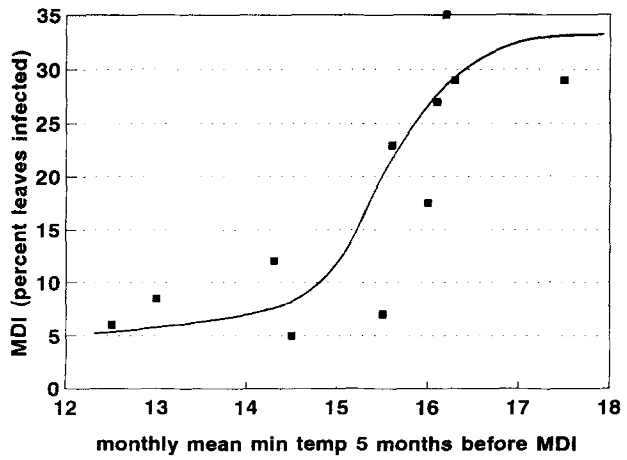

Figure 2. The relationship between maximum disease incidence (MDI, percent leaves infected) and monthly mean minimum temper-ature 5 months before the maximum disease incidence was reached

appear to be as great as in some other countries. Data showed that, on average, MDI was <20% of leaves affected, and that MDIs of >50% were rarely recorded. This contrasts with Brazil where the maximum rust incidence is often as high as 80% (L. Zambolim, pers. comm.).

While there was variation in epidemic severity between locations and between seasons at the same location, there was no evidence of a general increase in the severity of CLR epidemics in the main coffee growing area of PNG during the study period (1989–1992). However, 6 years after the first confirmed reports of CLR in the main coffee growing areas of PNG in 1986, it would appear that the disease is not going to be as destructive as it was in Ceylon where coffee production virtually ceased within 10 years of the first outbreak of the disease (Large, 1940).

Because there has been no spectacular destruction of coffee trees, it is conceivable that the disease had established in PNG before 1986 and remained undetected for a number of years. This conclusion is supported by the detection of CLR throughout the Western Highlands, and in the Enga and Chimbu Provinces, as well as in Madang Province, soon after it was first reported in the Baiyer River Valley in April, 1986 (Waller and Turner, 1986).

Agronomic factors have been reported to influence the development of CLR epidemics. Kushalappa (1989) reviewed studies showing that 20% of the variation in the rate of development of CLR epidemics could be explained by variations in berry production. Logistics prevented recording of yield at all sites in the present studies. Harvesting also indirectly affects the incidence of CLR epidemics because infected leaves are easily involuntarily removed by pickers. Pruning further reduced the severity of the epidemics and contributes to disease control through removal of inoculum available for reinfection. One observation in the study reported here indicated that the level of management has a major influence on the severity of the CLR epidemic. This was at Kudjip where, in 1989 and 1990 there was a high level of management (good weed control, appropriate fertiliser application and timely pruning) and the MDI was less than 10%, but when the level of management deteriorated in 1991 (no weed control or fertiliser application or pruning) the MDI rose to more than 80%.

A major emphasis of this study was an examination of the effects of the temperature thresholds, >30°C and <15°C, which are detrimental to the development of the disease because of their adverse effect on the germination and infection processes (Rayner, 1961; Nutman and Roberts, 1963; Kushalappa *et al.*, 1983). The severity of epidemics was positively correlated with the mean minimum temperature, and negatively correlated with the number of days in a month on which the minimum temperature was below 15°C over the main period of epidemic development (January–June). In the highlands of PNG the mean monthly maximum temperatures rarely exceed 30°C, but mean monthly minimum temperatures below 15°C are very common. The demonstration of the close association between the severity of CLR epidemics and temperatures below 15°C is not unexpected and confirms the previous conclusions of Kushalappa and Chaves (1980).

The severity of epidemics of CLR are reported to decrease with increasing altitude in Kenya (Bock, 1962; Becker-Raterink, 1982) and in South American countries (Kushalappa, 1989). This effect was also observed in these studies in PNG. This is an indirect effect; altitude influences the local climatic conditions, particularly temperature, which in turn affect the development of the disease. McAlpine and Keig (1983) reported that in PNG there is a decline in temperature with altitude above 500 m and at altitudes greater than 1300 m the annual average minimum temperature is expected to be below 15°C. Thus minimum temperatures in the main coffee growing areas of PNG are likely to be suboptimal for the development of epidemics of CLR and it is therefore possible that coffee grown at altitudes greater than 1300 m will not normally be badly damaged by CLR. The upper limit for CLR in PNG therefore seems to be lower than that in Colombia (in that country CLR develops only slowly above 1500 m and has caused little damage in such locations; Waller and Turner, 1986) and Kenya where disease development is restricted at altitudes in excess of 1700 m.

The relationships between maximum disease incidence (MDI) and temperature in the months preceding MDI offer the possibility of a simple forecasting system to determine the need to use foliar sprays to control CLR. These studies suggest that by recording minimum temperatures in January it is possible to estimate the MDI of the epidemic in that year. On the basis of these studies, an average minimum temperature of less than 15°C in January suggests that the disease will not reach levels that warrant spraying. Such a predictive system should be practical because it provides adequate warning to apply foliar sprays. However, before it is implemented it needs to be verified with further studies.

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