Enumerative and binomial sequential sampling plans for damage caused to coffee by larvae of *Leucoptera coffeella* (Guérin-Méneville) (Lepidoptera: Lyonetiidae) in Guatemala

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SUMMARY

***VILLACORTA A, WILSON LT, CARRILLO E, OCHOA H. 2006. Enumerative and binomial sequential sampling plans for damage caused to coffee by larvae of* Leucoptera coffeella *(Guérin-Méneville) (Lepidoptera: Lyonetiidae) in Guatemala. Rev. perú. Entomol. 45.*- The aim of the present research was to quantify the effects of rainfall on Coffee Leaf Miner (CLM - *Leucoptera coffeella* [Guérin- Méneville]) population dynamics, compare the spatial patterns for CLM in Paraná State (Brazil) and in Guatemala, and develop an efficient sampling program for CLM in Guatemala. CLM larval mortality was significantly correlated with rainfall in a two-year study in Guatemala ($p < 0.01$).Thirty-one, 55 and 54 % of the variability in the larval mortality was explained by the amount of rain occurring in the month during which the mortality estimates were made, the average of the current month and the previous month, respectively. The spatial pattern of CLM lesions on coffee leaves was significantly more aggregated on coffee grown under shaded and high rainfall environment of Guatemala, than observed in the non-shaded and dryer production región of Paraná State, Brazil. Enumerative and binomial (presence-absence) sequential sampling plans are presented for estimating densities of CLM lesions on coffee leaves in Guatemala. The sampling plans enable rapid determination of whether infestations have reached the current treatment threshold of one lesión per leaf.**

Key words: Coffea arábica, ecology, insects, pests.

RESUMEN

***VILLACORTA A, WILSON LT, CARRILLO E, OCHOA H. 2006. Planes de muestreo enumerativo y binomial secuencial de los daños causados porlarvas del minador de la hoja del café* Leucoptera coffeella *(Guérin-Méneville) (Lepidoptera: Lyonetiidae) en Guatemala. Rev. perú. Entomol. 45*- El objetivo del presente trabajo fue cuantificar los efectos de la lluvia sobre la dinámica poblacional del minador de la hoja del café *Leucoptera coffeella* (Guérin- Méneville) y compararla con las observaciones realizadas en el estado de Paraná, Brasil y así desarrollar un programa de muestreo de *L. coffeella* en Guatemala. La lluvia es un importante factor de mortalidad, causando un significativo impacto en la dinámica poblacional del minador de la hoja del café, en dos años de estudio en Guatemala (P<0,01). Treinriún, 55 y 54 % de la variación en la mortalidad de las larvas de *L. coffeella* fue explicada por la cantidad de lluvia ocurrida durante el mes en que la mortalidad fue estimada, por la media del presente mes y por la media del mes anterior, respectivamente. La distribución espacial de las lesiones causadas por el minador del café en las hojas es más agregada en cafetales plantados en ambiente con mucha lluvia y bajo sombra (Guatemala), en relación a regiones con menor distribución de lluvias con períodos secos en plantaciones a pleno sol, como es el caso del estado de Paraná, Brasil. Planes de muestreo enumerativo y binomial (presencia-ausencia) secuencial son presentados para estimar densidades de lesiones en las hojas causadas por el minador de la hoja del café en Guatemala. Los planes de muestreo permiten una rápida determinación del daño de la plaga, en caso que el daño haya alcanzado el umbral de acción de una lesión por hoja.**

Palabras clave: *Coffea arábica*, ecología, insectos, plagas.

Introduction

The coffee leaf miner (CLM), *Leucoptera coffeella* (Guérin-Méneville) is an important pest throughout Latin America where coffee *(Coffea arábica* L.) is planted. An action threshold of **0.15** live larvae per leaf is used in Guatemala (A. **GARCÍA** pers. comm.), and a threshold of **20-30** % of infested leaves is used in various states of Brazil (**SOUZA** *et* a*l*.**1998**). However, for the state of Paraná, Brazil, mean densities below **1.1** lesión per leaf, which equals **50** % infested leaves (**VILLACORTA & GUTIÉRREZ 1989**), appear not to cause economic damage, if this damage level is not associated with a long period of dry weather, and levéis above two lesions per leaf cause increasing levéis of defoliation, and affect yield especially during the period of high demand for nutrients by the fruits (**VILLACORTA & SÁNCHEZ-RODRIGUES 1984**). Part of the variation in CLM thresholds across Latin America is due to the dynamic response of both coffee and its CLM populations to environmental and biotic factors. The yield-response of coffee to CLM

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injury is influenced by the amount of rainfall, whether the coffee is grown under shaded or non-shaded conditions, and whether the coffee is planted at a low población (**3 000-5 000** plants/ha) or a high population density (**8 000-10 000** plants/ha). **CLM** population densities are in turn affectedbyrainfall**(ViLLACORTAl980,CAMPOseíflZ.** 1989), which increases larval mortality, thereby reducing larval injury.

In Guatemala, most of the coffee is planted under shaded conditions, at low plant densities, in heavy rainfall áreas (**>3000** mm/yr). Although natural biological control of **CLM** has been reported (E **VELEENS** 1966, **HAMILTON** 1967, **CAMPOS** *et al.* 1989), it is thought not to be effective in regulating **CLM** densities below its action threshold, and insecticides are recommended for control (**RODRÍGUEZ** *et al.* 1966, **CAMPOS** *et al.* 1989). However, to avoid unnecessary prophylactic pesticide applications, which can result in excessive control costs and the rapid development of insecticide resistance to **CLM**, it is important to determine when the lesión density is likely to exceed the action threshold, of one lesión per leaf. This requires a cost-reliable sampling method.

A sampling method that is more cost-reliable than others provides estimates with a given level of reliability at a lower cost than afforded by these other methods (**WILSON 1985, WILSON** *et.al.* **1983**). For the state of Paraná, Brazil, an enumerative sequential sampling was developed for CLM (**VILLACORTA & TORNERO 1982**). **VILLACORTA & GUTIÉRREZ** (1989) presented a binomial (presence-absence) sampling plan, while **VILLACORTA & WILSON** (1994) developed a binomial sequential sampling plan. When using binomial sequential sampling, the **CLM** lesions do not have to be counted, only the proportion of sampled leaves infested with leaf miners needs to be determined. When the number of pest species monitored with a single sampling method are less than five, sequential sampling is consistently more cost-reliable than conventional sampling (**WILSON 1985**). Numerous researchers have found that sequential sampling programs typically save users from about **40** to **65** % in sampling costs, while maintaining a comparable level of reliability.

Because of the different environmental and agronomic conditions in the coffee regions of Guatemala, contrasted with coffee regions of the state of Paraná, Brazil, it is likely that both the seasonal population densities and spatial patterns of **CLM** will be different. The spatial patterns will possibly differ because of the greater rainfall in the coffee regions of Guatemala, which increases CLM mortality. Previous studies on other crops have shown that increased mortality tends to result in a decreased spatial aggregation (**WILSON 1985**). Differences in both the degree of shading and plant density comparing the two regions also may affect differentially the spatial pattern. If the spatial patterns are different, the sampling methods developed for monitoring CLM in Brazil will not be transferrable to Guatemala.

The objective of the present research was to quantify the effects of rainfall on CLM population dynamics, compare the spatial patterns for CLM in Paraná, Brazil and in Guatemala, and to develop an efficient sampling program for CLM in Guatemala.

Material and methods

Field Sampling.- The samples in this study were taken in a commercial coffee plantation, "Finca Chitalon", located in Mazatenango, Suchitepeque, Guatemala, during February 1991 through June 1992, with weather data collected from February 1991 to September 1992. The study área consisted of 400 15- year oíd coffee plants of the cultivar Caturra with a plant density of 5 000 plants/ha, grown under shade, and not treated with insecticides.

One hundred randomly selected leaves were sampled non-destructively every 15 days in each of 20 randomly selected coffee plants to estímate the mean number of CLM lesions per leaf, and the proportion of leaves with lesions. One hundred randomly selected leaves were also taken from the border área of the experimental site and returned to the laboratory where each CLM lesión was opened and the number of live and dead CLM larvae recorded. Research by **VILLACORTA** (1980) and **CAMPOS** *et al.* (1989) indicares that in the majority of CLM a biotic mortality is due to rainfall, which causes excess free moisture to collect in the leaf mines, which drowns a high proportion of the larvae. Mortality caused by biotic factors such as parasitoids is easily distinguished from mortality caused by rainfall and other factors (**VILLACORTA** 1980, **CAMPOS** *et al.* 1989).

Daily rainfall and temperature estimates were obtained from a weather station maintained by the Asociación Nacional del Café (ANACAFE), Finca Buena Vista, San Sebastián, Retalhuleu, located within **3** km of the experimental área.

CLM *Mortality Analysis.*- Three standard correlation analyses were used to quantify the effect of rainfall on CLM mortality. For the first analysis, the monthly estimated proportion of larvae dying due to drowning was correlated with the corresponding monthly rainfall (mm). For the second analysis, the monthly mortality was correlated with the average of the corresponding monthly rainfall and the rainfall from the preceding month. This analysis assumes mortality was due to rainfall that occurred about two weeks prior to the measurement and not the rainfall that occurred during the entire month. For the third analysis, the monthly mortality was correlated with the rainfall from the preceding month. This analysis assumes that the mortality as due to rainfall that occurred the month prior to the month during which the estimates were taken.

Spatial Aggregation Analysis.- Several authors have developed equations which quantify the effect of density on the spatial pattern of different species, most noticeable of these being Iwao and Kuno's patchiness regression index (IWAO 1968, IWAO & KUNO 1971, KUNO 1991), Lloyd's mean crowding (LLOYD 1967), Morisita's index (MORISITA 1962), and Taylor's equation (TAYLOR 1961, 1984, TAYLOR *et al.* 1978). Citations of these references provides an estimate of the relative usefulness of each index, with Taylor being cited most frequently (n = 1348), followed by Lloyd (576), Iwao and Kuno (556), and Morisita (148) (ISI 1998). The robustness at describing variance-mean data, and its relatively simple and straightforward nature are both responsible for the popularity of Taylor's equation.

First used by FRACKER & BRISCHLE (1944) to study spatial aggregation in a biological system, but independently proposed by HAYMAN & LOWE 1961, and TAYLOR (1961), Taylor's equation estimates the relationship between the variance and mean density of a sample using a power function.

(1). $S^2 = a\,x^b$

WILSON & ROOM (1983) expanded the use of Taylor's equation by incorporating it into a mathematically and biologically tractable proportion infested - mean equation (Eq. 2). This equation is quite robust and has been widely used to describe the relationship between the proportion of infested sample units and mean density for a wide range of arthropod species and cropping systems, in coffee having been used by VILLACORTA & GUTIÉRREZ (1989), VILLACORTA & WILSON (1994) and VILLACORTA *et al.* (1997).

(2). $P(I) = 1 - e^{-\bar{x}\log_e(a\bar{x}^{b-1})(a\bar{x}^{b-1})^{-1}}$

where:

P(I) = proportion of infested leaves

$\bar{x}$ = mean number of CLM lesion per leaf

In our analysis, the coefficients of Taylor's equation were estimated from the Guatemalan data using two procedures. For the first, estimates of Taylor's coefficients were obtained by using a least-squares iterative regression of Eq. (1). These parameters were also used to develop enumerative sequential sampling plans (see Sample Size Analysis below). For the second procedure, estimates of Taylor's coefficients were obtained by used a least-squares iterative regression of Eq. (2). These parameters were also used to develop binomial sequential sampling plans (*see* Sample Size Analysis below).

Variance-mean ratios were estimated for each of 10 CLM densities (0.2 to 2.0 CLM lesions per leaf, in 0.2 increments), for each location (Brazil vs. Guatemala), for each iterative estimation method.

Sample Size Estimation.- KARANDINOS (1976) presented a series of equations for use in estimating sample sizes. RUESINK (1980) and WILSON & ROOM (1982, 1983) expanded the utility of these equations incorporating Taylor's equation into the Karandinos equations. The decision lines for the enumerative plan were calculated using Eq. (3), while the binomial plan was calculated using Eq. (4).

(3) $n = t^2_{\alpha \text{ or } \beta}(x - T_x)^{-2}ax^b$

(4) $n = t^2_{\alpha \text{ or } \beta}(\bar{x} - T_p)^{-2}pq$

where:

$T_{\bar{x}}$ = the action threshold expressed as a mean number of lesions per unit (=1 lesion per leaf)(see VILLACORTA & SANCHEZ-RODRIGUES (1984) and VILLACORTA & GUTIÉRREZ (1989))

T_p = the action threshold expressed as a proportion of infested units, p = the proportion of infested sample units and q = 1 – p (Action Threshold as a proportion of 0.471)

$t^2_{\alpha \text{ or } \beta}$ = standard normal variate for a one-tailed confidence interval, where α is the probability of treating when the control action threshold has not been exceeded and β is the probability of not treating when the control action threshold has been exceeded.

Error rates should be assigned by considering the CLM lesion density-yield relationship, crop value, insecticides and applications costs, and effects of treatments, CLM resurgence, secondary pests as mites, defoliators and also the development of CLM resistance. We have arbitrarily chosen a nominal error rates of α = β = 0.10 (experimental error).

Results and Discussion

The high percentage of CLM larval mortality was related to periods of high rainfall (fig. 1), thereby reducing the mean number of CLM lesion per leaf . P(mortality) = function of rainfall, r2 = 0.307, prob. = 0.009, n = 21. P(mortality) = function rainfall the previous month, r2 = 0.536, prob.<0.001, n = 20. CLM populations were below the action threshold of one leaf miner lesion per leaf, that we can consider as an static economic threshold (VILLACORTA & SANCHEZ-RODRIGUES 1984). The deleterious effect of rainfall on CLM population have been reported by CAMPOS *et al.* (1989) in Guatemala and by VILLACORTA & GUTIÉRREZ (1989) in Brazil.

Taylor's coefficients a and b were a = 1.950 (TAYLOR *et al.* [1978] consider the coefficient b constant for a species, with only a affected by sample unit size, however BANERJEE [1976] and others [WILSON 1985] show that both a and b are subject to change due to age-specific dispersal, mortality, and sample unit size), and b = 1.034, r^2 = 0.98, n = 36. The dispersion index, b, indicates that the population is randomly dispersed, or that the lesions are randomly distributed among leaves, suggesting that Poisson distribution model (Eq. 5) would be appropriate.

$$PI = 1 - e^{-m} \quad (5)$$

In fig. 2 the Poisson model is shown as the dashed line. This model tends to systematically overestimate PI, hence a modified Poisson model was fit to the data, solid line (model 4 of WILSON & ROOM 1982) (Eq. 6).

$$PI = 1 - e^{-cm} \quad (6)$$

where c = is the forced regression coefficient, and for us c = 0.63597.

The regression coefficients for the data were used in equations 3, and 4, to determine the number of samples required to estimate the mean number of lesions per leaf m with levels of accuracy, D = 0.1 and 0.2. Using equation 3 for binomial sample size at a level of precision (D = 0.2) 87 leaf sample estimates m=1 with a 20 % accuracy, and to achieve a 10 % level of accuracy at m = 1 a sample size of 352 leaves is required (fig. 3). Using equation 4 for numerical sample size at a level of precision (D = 0.2) 80 leaf sample estimates m = 1 with 20 % accuracy, and to achieve a 10 % level accuracy at m = 1 a sample size of 320 leaves is required (fig. 4).

The data collected for Taylor's power law were used in equation 6 to develop a binomial (presence-absence) sequential sampling plan, in which Ti = PI at m = 1, Ti = 0.471 (= a proportion of leaves infested). The binomial sequential sampling plan is shown in fig. 5 and Table 1 the lower and upper numbers of infested leaves for $\alpha = \beta = 0.10$ and $\alpha = \beta = 0.20$, with a stop sampling at 12 trees sampled, sampling 25 leaves per tree. Numerical sequential sampling plan is shown i n fig. 6 and Table 2 with t = 1.285 and m = action threshold = 1.

Steps to follow to use the enumerative or binomial sampling method:

1. Divide the area to be sampled in sampling areas no more than one ha, and map the coffee plantation giving a number to each sampling unit area;
2. Walk across the sampling unit area and from 12 random trees make visual observations of number of lesions per leaf (enumerative sampling) or on the presence or absence of CLM lesions on 25 random middle-aged leaves per tree. Avoid sampling new leaves from the first two pair of leaves from the branch;
3. Using Table 1 (binomial) or Table 2 (enumerative) take the decision of treat or no treat in the area sampled. In the case falling in the area of continued sampling after 12 trees sampled, either take another round of samples or sample 15 days later;
4. Sampling should begin at time of flower initiation (February/March) and continue at monthly intervals until coffee growth ceases. Four months after flower initiation there is low rates of coffee berry growth, and high rates of leaf production enables the plant to compensate leaf damage. After that there is a period when berry growth rates are at a maximum, and densities of more than one CLM lesion per leaf may cause economic damage. The damage can rapidly increase, if during this period there is a short dry weather condition, if that happens the time between samples must be reduced to 15 days.

The data presented here relate specifically to the CLM phenology as modified by the weather pattern and cultural practices common to Guatemala. the sampling decision rules for CLM presented here are designed for practical utilization by IPM scouts, and we hope that they could greatly reduce the number of pesticide applications against CLM, to reduce cost of production and promote safe environment conditions.

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TABLE 1.- Presence-absence sequential sampling rules for the damage caused by *L. coffeella* for a 25 leaves-per-tree sample size.

		$\alpha = \beta = 0.10$		$\alpha = \beta = 0.20$	
Tree number	# Leaves sample	Don't treat if ≤	Treat if ≥	Don't treat if ≤	Treat if ≥
1	25	8	15	9	14
2	50	19	29	20	27
3	75	29	41	31	39
11	275	118	141	122	137
12	300	130	153	134	149

*** Stop Sampling ***

TABLE 2.- Enumerative sequential sampling rules for the damage caused by *L. coffeella* for a 25 leaves-per-tree sample size.

Number of leaves sampled	Total number of lesions sampled	
	α	β
25	16	34
50	37	63
75	60	91
100	82	118
125	105	145
150	128	172
175	151	199
200	175	225
225	198	252
250	222	278
275	245	305
300	269	331

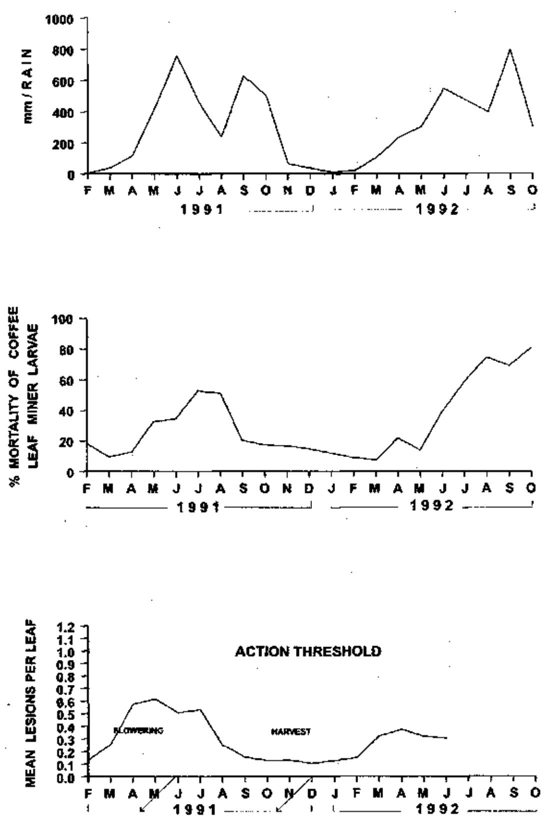

FIGURE 1.- Phenology of L. *coffeella* lesions per leaf and the percentage mortality of the larvae related to the average rainfall. Mazatenango, Suchitepeque. Guatemala.

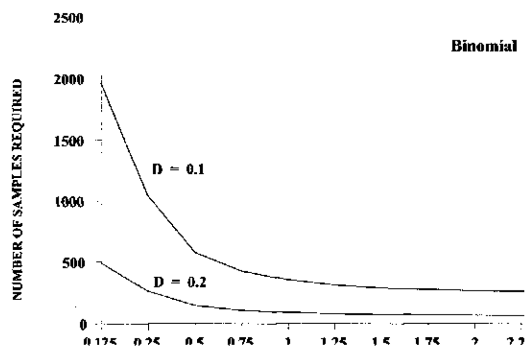

FIGURE 2.- Estimated and observed proportion of leaves infested with *L. coffeella* as a function of lesions density caused by the insect. The dashed line is the Poisson model, and the solid line is the modified Poisson model fit to the data.

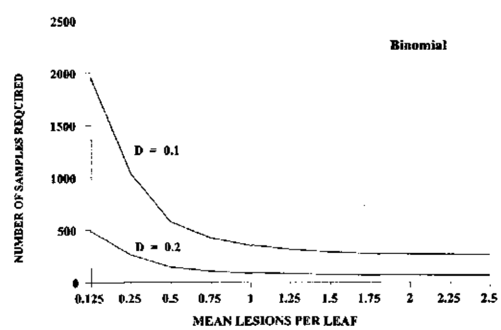

FIGURE 3.- Number of leaves at different L. *coffeella* lesión densities required to meet predetermined levéis of sampling precisión (D = 0.1 and 0.2) for binomial sampling (presence-absence).

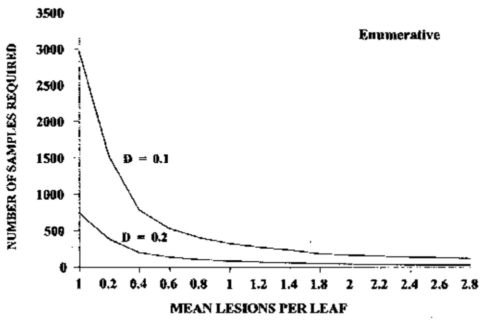

FIGURE 4.- Number of leaves at different *L. coffeella* lesion densities required to meet predetermined levels of sampling precision (D = 0.1 and 0.2) for enumerative sampling.

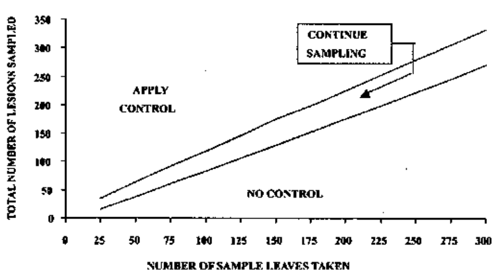

FIGURE 5.- Enumerative sequential sampling plan for *L. coffeella,* with a critical density of one lesion per leaf.

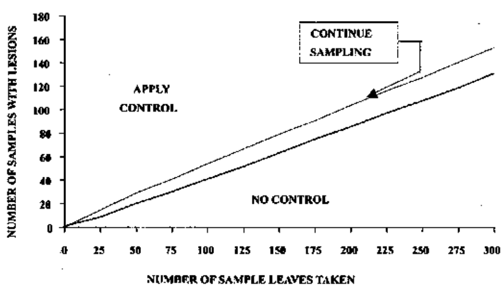

FIGURE 6.- Binomial sequential sampling plan for the damage caused by *L. coffeella* on leaves at a critical density of one lesión per leaf (= a proportion of 0.471 of the leaves infested at D = 0.10).

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