INSECT POLLINATION OF CACAO IN COSTA RICA: 2. SEASONAL FLUCTUATION OF Forcipomyia MIDGES (DIPTERA-CERATOPOGONIDAE) AS COMPARED TO FLOWERING AND METEOROLOGICAL PARAMETERS IN TURRIALBA AND LA LOLA,LIMON

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Resumo

A flutuação anual do número de flores polinizadas por *Forcipomyia* Meigen, 1818, indicou que o número de insetos ativos esteve em proporção direta com a floração, mostrando um pico alto em maio e um pico menor em novembro de cada ano. O percentual de polinização, por outro lado, esteve inversamente proporcional ao número de flores presentes e, a pesar de ser mais fácil coletar mosquitinhas quando as flores eram escassas, o percentual elevado de polinização em tais condições resultou enganoso quanto ao total de polinização efetiva obtida no período. Os picos de polinização efetiva ocorrentes durante os dois ciclos vegetativos de cacau estudados na zona atlântica de Costa Rica (Turrialba e Limón) aconteceram simultâneos aos períodos de horas de brilho solar (B) decrescente e de precipitação pluviométrica (P) e balanço calórico (P/B) ascendentes. As mosquitinhas Forcipomyia tornaram-se muito escassas durante períodos de tempo seco prolongado (veranicos).

Palavras-chave: Theobroma cacao, polinização entomófila, Forcipomyia, dinâmica populacional, Ceratopogonidae

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Abstract

Annual fluctuations in the total number of flowers pollinated by *Forcipomyia* Meigen,1818, showed that the number of midges present was in direct proportion to the flowering with a very high peak of both in May and a much lower peak in November of each year. The % pollination on the other hand was inversely proportional to the number of flowers present and although it was much easier to collect midges when flowers were scarse , the very high % pollination under these conditions was misleading as to the total amount of pollination occurring. The peaks of pollination accompanying the 2 annual vegetative cycles of cacao in the Atlantic zone of Costa Rica , occurred at times of decreasing sunshine hours and increasing rainfall and caloric balance (rainfall/sunshine). *Forcipomyia* midges became very scarse during periods of prolonged dry weather (dry spells).

Key words: Theobroma cacao, pollination, Forcipomyia, population dynamics, Ceratopogonidae

Introduction

The aim to study *Forcipomyia* midge populations was born in relation to severe cacao production constraints caused by unsatisfactory levels of natural pollination in several countries throughout central and south America in the sixties (1960). The first evidence of the involvement of *Forcipomyia* midges in the natural pollination of *Theobroma cacao* L. was documented by Billes, 1941, in Trinidad. Thereafter, insect pollination studies were continued by L.G. Saunders (1959) who developed the first method to rear *Forcipomyia* midges in the laboratory. Hernandez (1965) reported tight insect-plant relationships between the midges and the cacao plant. Soria, Wirth and Chapman (1980) carried out a survey on the midges involved in cacao pollination in Costa Rica (Soria, 1970) and published the first list of midges, being the present report a continuation of the same work.

The abundance of insect pollinated flowers in this work is being understood as a manifestation of the actual field activity of *Forcipomyia* midges . Midge activity as isolated variable, on the other hand, was studied by other authors, as extensively documented in relation to microclimatic factors (Soria and Butler, 1999).

Determination of fluctuations of numbers in various plots or areas or throughout the season in one area, might provide information on the type of breeding sites and the ecological conditions necessary for good midge reproduction. Fluctuations in numbers of *Forcipomyia* (Diptera, Ceratopogonidae),as measured by counting midge-pollinated flowers were noted, to the level of field observation, by previous investigators (Saunders & Bowman, 1956; Saunders, 1959 and Hernandez, 1965).

During the last thirty years, time that elapsed since the present research was carried out in Costa Rica in 1970, population dynamics of *Forcipomyia* midges was studied by several authors, who described population fluctuations using diverse methods of sampling , namely midge hand picking (DelaCruz & Soria, 1973; Soria & Abreu, 1976; Soria, 1977a,b; Soria & Chapman, 1984), Malaise-adapted traps (Winder & Silva, 1972) and Johnson and Taylor automatic suction traps (Soria & Butler,1999). Midge pollination that includes abundance of flowers as a part of the parameter was never used to interpret *Forcipomyia* population fluctuations. Among density independent factors studied, Trojer's caloric balance (rainfall/sunshine)(Trojer, 1968)was never used, so this paper introduces this interaction in the hope it may help to interpret *Forcipomyia* population fluctuations.

A long term pollination survey was planned to determine the seasonal fluctuation of pollination rates at Turrialba and La Lola, Limon, Atlantic zone of Costa Rica and to correlate pollination rates with sun shine, rainfall, rainfall/ sun shine, and flowering in both locations.

Material and Methods

A comparison of the amount of natural pollination and a study of Forcipomyia population fluctuations (based on pollination) were carried out at Turrialba and La Lola, Limon, Atlantic zone of Costa Rica, from 1964 to 1969. Geographic coordinates for the country and for the sampling locations are illustrated in figure 1.

Seven plots with various agronomical and ecological characteristics were selected at Turrialba and 10 al La Lola (Tab. I) as the sampling areas. The climatic pattern is similar for both Turrialba and La Lola. Turrialba is located within the Tropical Rain Forest vegetal association type , and La Lola within the Tropical Very Rain Forest (Holdridge, 1947). Both Turrialba and La Lola have azonal soils as a result of successive alluvial deposits.

Poor drainage and a minor amount of leaching are general characteristics at the La Lola farm, attributable to the presence of a thick layer of clay that keeps the soil permanently wet. This poor drainage provides relatively poor agrological gift , but excellent conditions for the breeding of midges and mosquitoes (Saunders and Bowman, 1956). Free drainage and excessive leaching are general characteristics at Turrialba, attributable to a porous soil. This soil, however, is able to maintain sufficient humidity for good decomposition of organic matter deposited in the cacao plantations.

The procedure for estimating the midge populations was based upon their pollination. Counting of midge-pollinated flowers does not necessarily provide a true picture of the midge population density because one midge

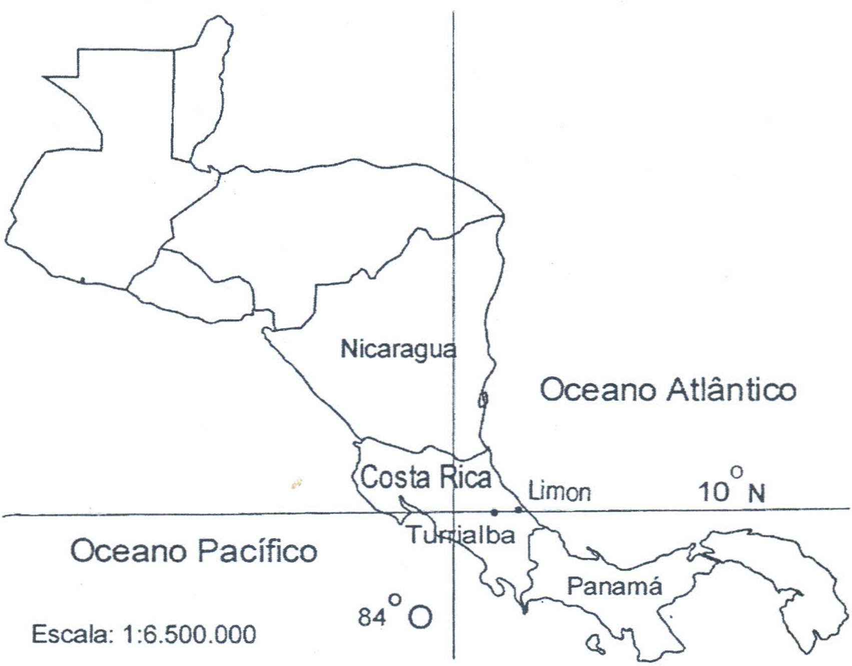

Figure 1: Geographical coordinates for Turrialba and La Lola, Limon, Costa Rica (sampling sites), after Grande Atlas Mundial, Seleciones do Reader's Digest, 1978

may be responsible for the pollination of several flowers , and the number of flowers varies on different trees and at different times. However, *Forcipomyia* pollination is easily detected and is possibly the most reliable method of determining the presence of the midges in the field. Percent *Forcipomyia* pollination can be transformed to figures of total pollinated flowers per tree (if the number of flowers per tree are known), which in turn indicates the number of midges present in a plantation. *Forcipomyia* pollination was therefore used to study fluctuations in midge populations , and also was correlated with associated biological and climatic factors.

One hundred flowers were collected at random twice a week in each plot. Flowers were placed in separate glass bottles and taken to the laboratory where the staminodes were removed with forceps and the stigmata observed under a dissecting microscope for the presence of pollen. All flowers showing a compact mass of pollen adhering to the stylus and stigma , as described by Posnette (1944) and Hernandez (1965), were considered to be pollinated by *Forcipomyia* midges. The samples were taken every Tuesday and Friday from January 1965, to January 1966 at Turrialba, and from May 1965 to February 1966 at La Lola. Pollination data taken by Hernandez (1965) during December 1964 and January 1965 were added to improve the general average (Tab.I).

The total number of pollinated flowers per tree (Tab. II and III) was estimated by multiplying the average number of flowers per tree for each plot and each month by the corresponding % pollination. Whereas the % pollination was an actual reading in each case , the number of pollinated flowers per tree was an estimation derived by multiplying the percent by the annual average number of flowers per tree in each planting (Tab.I) by a correction factor (Tabs.II and III) to adjust to the monthly variation in flowering. Information on the number of flowers per tree for 12 months (Figs.1and 2) was kindly made available for this study by the Agronomy Department of the Inter-American Institute of Agricultural Sciences at Turrialba, Costa Rica. Flowering data were averaged from 13 different varieties including those used in this study.

Results and Discussion

Highly significant differences in pollination (Tabs. II and III) among plots were quite evident at both locations. There was three times as much mean pollination at Hulera 2 than at Pejivallal at Turrialba. There was four times as much pollination in Experiment 7 than in Clonal Nursery at La Lola. Similarly, highly significant fluctuations in pollination occurred among months at both the Turrialba and La Lola plots (Tabs. II and III). A highly significant peak in pollination occurred during May at both Turrialba and La Lola, and a less conspicuous , but still significant peak occurred during November at both locations. The significance of the May and November peaks will be discussed later in relation to harvest.

The estimated values (Tabs. II and III) are much more reliable than % pollination (Tab. I) in indicating *Forcipomyia* population levels and their effect on crop production , as they are much more closely correlated with the natural pattern of cacao development according to literature (Trojer, 1968). The same comparisons (Tabs. II and III) made in terms of percent pollination give contradictory and misleading impressions , as a consequence of the inverse mathematical relationship between percent pollination and the total numbers of flowers and total pollinated flowers per tree (Figs.2 and 3). The numeric trend in numbers of pollinated flowers per tree throughout the year (Figs.2 and 3) indicates that whichever environmental factor determines flowering , also determines abundance and activity of midges. Because counts of pollinator midges were not taken simultaneously with those of % pollination in the field, the discussion has been referred to the estimated midge populations.

Percent pollination is valuable information in assessing midges because it was found that the% pollination values were in direct proportion to the chances of finding the midges. This phenomenon derives from the fact that the ratio no.midges/no.flowers is greater when the population of flowers is smaller. For example it was easier to collect midges at Pejivallal, Turrialba, and at Clonal Nursery at La Lola (where the flowers were the fewest), than at Hulera 2 and Experiment 7 at Turrialba and La Lola, respectively (where the flowers were the most abundant). Similarly it was easier to collect midges in December than in May for the same reasons indicated above.

Monthly pollination values for Turrialba and La Lola (Tabs. II and III) were plotted (Figs.2, 3) to compare the fluctuations with those of precipitation , sun shine and caloric balance (precipitation/hours of sun shine), which according to Trojer (1968) are the weather elements most closely correlated to the physiological history of cacao. Temperature range, as analyzed by Alvim (1956a,b) was not taken into account in this study because of the use of caloric balance that involves temperature in indirect

Tabela I

Agronomic characteristics and percent Forcipomyia pollination for the plots used in pollination studios at Turrialba and La lolo, Costa Rica. 1965 - 1969.

Plots	Type and age of trees ().	Mean annual no. flowers per tree	Mean annual % pollination 1965-66	1968-69
		Turrialba		
Hulera 2	Hybrids (10)	300	0.3	0.5
Hulera 1	Mixed (20)	250	0.4	--
Turrialba 10	Hybrids (9)	200	0.5	--
Turrialba 5	Hybrids (9)	200	0.5	--
Turrialba 1	UF-667 (13)	200	0.5	--
El Chino	Mixed (20)	100	0.6	--
Pejivallal	Mixed (10)	80	0.7	0.9
		La Lola		
Experiment 7	UF-667 (11)	300	0.2	0.5
Trees near Build.	Mixed (14)	300	0.1	--
Experiment 4	UF-613, -221(13)	250	0.2	--
Experiment 12	Hybrids (8)	250	0.2	0.3
Experiment 2	UF-613 (12)	200	0.4	0.2
Experiment 1	UFs.+Hybds.(14)	200	0.4	0.2
Section 12	Matina (50)	100	0.5	--
Experiment 14	UFs.+Hybds. (8)	80	0.6	--
Experiment 16	Mixed (8)	50	0.8	--
Clonal Nursery	Mixed (-)	50	0.8	--

a Geographic coordinates:
Turrialba: Lat. 9.53°N, Long. 83.30°W, Elev. 602 m
La Lola : Lat.10.04°N, Long. 83.22°W, Elev. 39 m

Tabela II

Estimated monthly total no. of flowers per tree pollinated by Forcipomyia spp in various plantations at Turrialba, Costa Rica. 1964 - 1966.

	1964	1965											1966	
Plot	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Mean[a]
Hulera 2	3.1	3.6	2.4	3.2	6.1	14.4	7.8	2.4	1.8	2.4	2.3	3.6	1.8	2.3	4.08^{a}
Hulera 1	2.8	3.0	2.2	3.1	5.6	12.0	6.5	1.7	1.7	2.5	1.8	3.0	1.5	1.8	3.51^{a}
Turrialba 10	3.3	2.4	1.7	2.8	6.2	12.7	5.7	1.4	1.7	2.0	1.6	2.1	1.1	1.7	3.31^{b}
Turrialba 5	2.4	1.8	2.4	2.6	6.5	11.7	5.7	1.6	1.5	1.4	1.8	2.1	1.5	1.8	3.20^{b}
Turrialba 1	1.8	2.6	2.4	2.1	5.2	10.7	5.7	1.2	1.4	1.6	1.4	2.6	1.4	1.8	2.99^{b}
El Chino	1.1	1.1	1.1	1.5	3.2	6.8	3.0	0.8	0.6	0.9	1.0	1.3	0.6	0.6	1.68
Pejivallal	1.5	1.4	1.0	1.1	1.8	3.8	1.9	0.5	0.6	0.7	0.7	1.1	0.5	0.6	1.22
Mean[a]	2.28^{b}	2.27^{bc}	1.88^{bcd}	2.34^{b}	4.94^{a}	10.3	5.18^{a}	1.37^{cd}	1.32^{d}	1.64^{bcd}	1.51^{bcd}	2.25^{bc}	1.20^{d}	1.51^{bcd}	
Mean % pollination	2.54	1.87	1.11	1.14	0.39	0.18	0.17	0.19	0.19	0.28	0.17	0.16	0.20	0.45	
Correction factor[b]		0.81	0.84	1.00	2.86	6.75	3.34	0.87	0.87	1.00	1.00	1.50	0.75	0.81	

[a] Means having common letters have no significant difference at o.05 probability based on Duncan's New Multiple Range test.

[b] Correction factor, indicative of no. of flowers present, by which % pollination was multiplied in each location and month to derive estimated no. of flowers pollinated per tree.

Tabela III

Estimated monthly total number of flowers per tree pollinated by Forcipomyia spp. at La Lola, Costa Rica. 1965 -1966.

Plot	1965									
	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mean
Experiment 7	17.2	8.0	1.8	2.1	2.1	2.8	3.6	1.6	2.2	2.4	4.38^{a}
Trees near building	14.4	8.0	2.0	2.1	3.0	2.1	3.6	1.6	1.9	2.2	4.09^{a}
Experiment 4	13.2	6.7	1.7	1.7	1.8	2.4	3.0	1.8	2.0	1.5	3.58^{a}
Experiment 12	13.2	5.9	1.7	1.7	1.8	2.2	3.5	1.6	1.7	2.1	3.54^{a}
Experiment 2	10.5	7.8	1.4	1.4	1.7	1.6	3.7	1.8	1.6	1.6	3.31^{a}
Experiment 1	12.3	5.3	1.2	1.4	1.7	1.9	3.2	1.8	1.7	1.6	3.21^{a}
Section 12	6.6	3.2	0.7	0.8	0.9	1.1	1.7	0.8	0.8	0.8	1.74^{b}
Experiment 14	5.5	2.9	0.6	0.6	0.9	0.9	1.5	0.7	0.7	0.6	1.49^{b}
Experiment 16	3.3	1.6	0.4	0.4	0.8	0.6	1.0	0.4	0.5	0.5	0.95^{b}
Clonal nursery	2.9	1.8	0.5	0.4	0.4	0.6	0.7	0.5	0.6	0.7	0.91^{b}
Mean	9.91	5.12	1.20^{b}	1.26^{ab}	1.51^{ab}	1.62^{ab}	2.55^{a}	1.26^{ab}	1.37^{ab}	1.40^{ab}	
Mean % pollination	.25	.37	.21	.26	.40	.46	.59	.61	.55	.56	
Correction factor[b]	6.75	3.34	0.87	0.87	1.00	1.00	1.50	0.75	0.81	0.84	

[a] Means having common letters have no significant difference at 0.05 probability based on Duncan's New Multiple Range test.

[b] Correction factor, indicative of no. of flowers present, by which percent pollination was multiplied in each location and month to derive estimated no. of flowers pollinated.

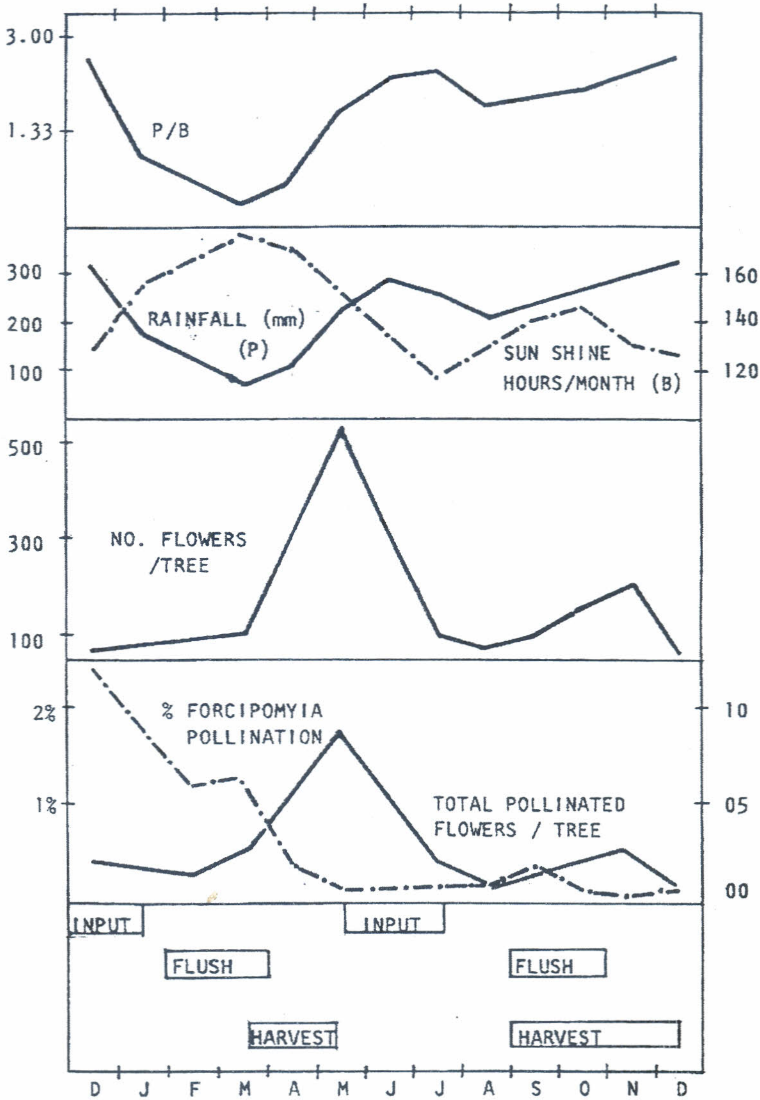

Figure 2: Forcipomyia pollination fluctuation as compared with caloric balance (P/B), sun shine (B), rainfall (P), flowering and other developmental stages of cacao, from top to bottom, at Turrialba, Costa Rica, 1965.

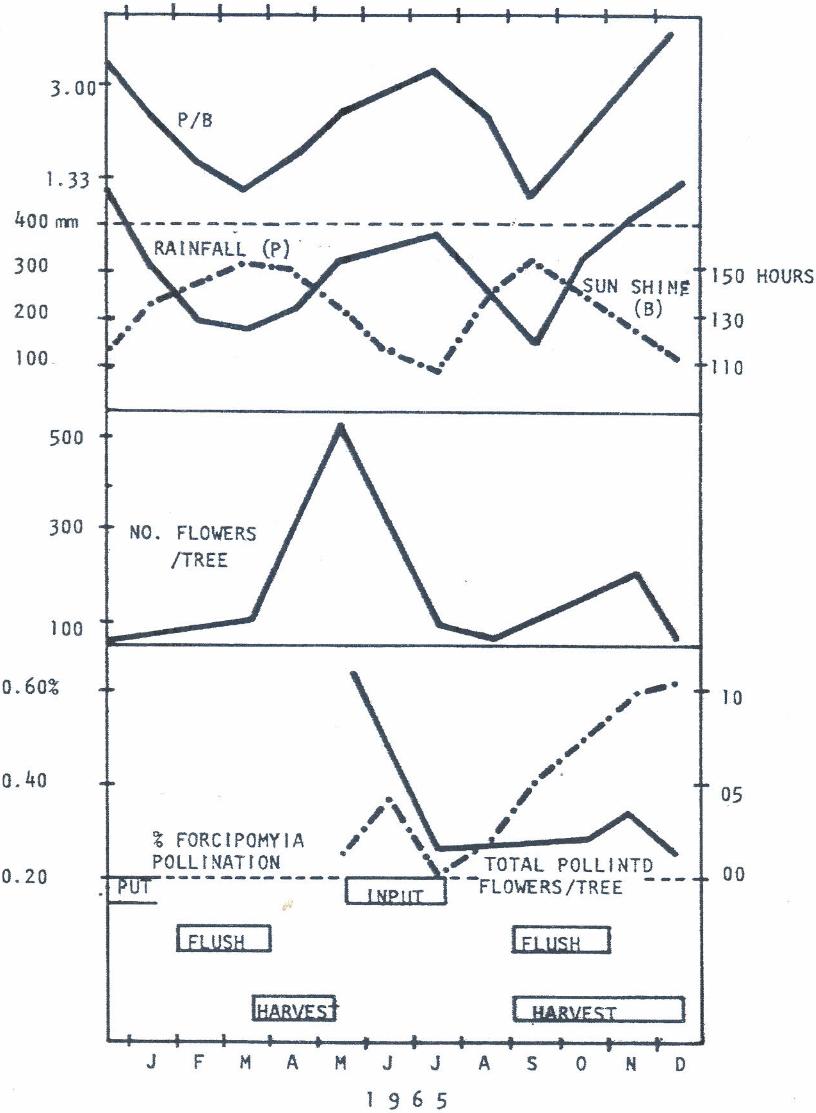

Figure 3: Forcipomyia pollination fluctuation as compared with caloric balance (P/B), sun shine (B), rainfall (P), flowering and other developmental stages of cacao, at La Lola, Limon, Costa Rica, 1965.

way. The plotting of pollination data (Figs.2, 3) and the study of the curves of climatic and biological factors made evident a harmonic sequence of events initiated by a peak of energy (cosmic radiation, langleys/cm2/sec.) in early January (Flohn,1969), followed by a peak of flush in February/ March(Alvim's theoretical proposal of hydroperiodism, 1956a,b; 1966; 1967; 1977), a peak of flowering plus pollination in May , and a peak of harvest five months later in October, for Turrialba and La Lola. There is a second less intensive cycle initiated by a second peak of radiation entering from the sun on early July, that stimulates flushing on September and October, flowering plus pollination on November and a little harvest on April of the following year. This sequence of vegetative phases was already illustrated by Trojer (1968) for La Lola, based on correlations with harvest data.

Conclusions

It was concluded that the peaks of *Forcipomyia* midge activity, in terms of insect pollination, accompanying the two annual vegetative cycles of cacao in the Atlantic zone of Costa Rica, occurred at times of increasing rainfall and caloric balance (rainfall/sunshine) and decreasing sun shine hours. *Forcipomyia* midges became very scarse during periods of prolonged dry weather (dry spells).

It was also demonstrated for the first time the possibility of the use of Trojer's caloric balance (rainfall/sunshine) as a parameter to interpret *Forcipomyia* midge field pollinating activity.

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