Ecology of Cadang-Cadang Disease of Coconut Palm in the Philippines

B. Zelazny

UNDP/FAO Coconut Research and Development Project, PCA, Albay Research Centre, Guinobatan, Albay 4908, Philippines.
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ABSTRACT

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The relationship between the incidence of the cadang-cadang disease of coconut palm and variables such as elevation above sea level, abundance of different vegetations, palm density, palm age, soil conditions, and rainfall were studied in up to 574 1 × 1-km plots. Multiple regression models were constructed to determine which factors affect the variation in the incidence of cadang-cadang. However, the best five-variable model accounted for only 21% of this variation. The two most significant variables were elevation and age of the palms, the first was negatively the second positively correlated to the disease incidence.

Additional key words: disease survey, viroid-like pathogen.

Cadang-cadang (which is caused by a viroid-like pathogen) is a destructive disease of coconut palm in some parts of the Philippines (3, 6–8). Little is known about environmental factors influencing the spread of the disease. Holmes (4,5) noted that the incidence of cadang-cadang varies considerably between locations, and suggested that an inoculum reservoir of the pathogen in some weeds might account for some of this variability. The present studies were designed to investigate the relationship between different environments and the incidence of cadang-candang.

MATERIALS AND METHODS

Between mid-1975 and early 1977, a 1,492-km^2 area located in the southern Luzon Provinces of Camarines Sur and Albay was surveyed. Fig. 1 shows the shape of the survey area and some geographical points of reference. The borders were aligned in north-south and east-west directions, and the most northern, southern, eastern, and western borders were located at latitudes 13°32′15″ N and 13°5′46″ N, and longitudes 123°47′11″ E and 123°15′0″ E, respectively. The area was divided into 1 × 1-km plots and readings were made in every second plot, provided it contained more than 50 coconut palms; 574 plots qualified. In the field, the plots were located by using a compass and the standard 1:50,000 topographic maps of the Philippines. Each plot was traversed by using the paths or roads which bisected it most equally. At three stops a total of five 50 × 50-m squares were surveyed, and in each square the number of coconut palms and other palm species were counted. The portions of the squares occupied by various types of vegetation other than palms were estimated. Fifty coconut palms in and nearest to each 50 × 50-m square were examined for symptoms of cadang-cadang infection (3,6,7) and their ages were estimated from their heights. Often coconut palms were only located in one part of the 1 × 1-km plot and palms some distance from the 50×50-m squares had to be surveyed. The total of 250 surveyed palms per 1 × 1-km plot was not reached in 42 of the 574 plots due to lack of palms, however not less than 50 palms were surveyed in any plot. The predominant vegetation surrounding each surveyed coconut palm was recorded in 432 of the 574 plots. Vegetation types that were not recognized as crops either were classified as "rough grazing" (grasses and weeds) or as "forest" (bushes and trees). The mixed vegetation around houses, consisting of small patches of vegetables, fruit trees, and ornamental plants, was classified as "homegarden crops." The abundance of the weed *Elephantopus mollis* was recorded in 70 1 × 1-km plots by estimating at five locations the portion of the "rough grazing" vegetation consisting of this weed.

For each 1 × 1-km plot the readings from the five 50 × 50-m squares and the 5 × 50 palms were pooled to obtain estimates of the abundance of different types of vegetation throughout the whole plot as well as near the surveyed palms, the palm density, and the incidence of cadang-cadang. The average elevation above sea-level was read from the topographic maps. Data on rainfall and soil condition were obtained from other sources (1,2), however the soil data were available only for 390 of the 574 plots. From the estimated ages of the surveyed palms the mean age, the variance of the ages, and the third moment of the age distribution were calculated to characterize the age distribution.

The data were analyzed by calculating standard parametric correlation coefficients (product-moment correlations), as well as Spearman's nonparametric correlation coefficients. Multiple regression models were obtained by a stepwise method called "maximum R^2 improvement for the dependent variable."

RESULTS

Fig. 1 shows the survey area being divided into 2 × 2-km squares and the average incidence of the cadang-cadang disease in these squares. (In each 2 × 2-km square two 1 × 1-km plots had been surveyed.) The distribution shows three main areas of aggregation of the disease, one in the northwestern part, one in the center, and one along the eastern border of the survey area. The frequencies of different cadang-cadang incidences in these 2 × 2-km squares deviated greatly from a Poisson distribution ($\chi^2 = 2,414$, 11 d.f., $P \ll 0.01$) indicating that the disease is not randomly distributed.

Table 1 lists the variables surveyed together with their means and standard deviations. Vegetation types which were rare were not included in the analyses. Product-moment correlations between the incidence of the cadang-cadang disease and many variables differed significantly ($P < 0.05$) from zero (Table 1). However the data were very heterogeneous and Spearman's nonparametric correlation coefficient (r_s) was considered a better indicator of the degree of relationship between the cadang-cadang incidence and the variables. The r_s-values are given in Table 1 for variables which were more significantly correlated with the cadang-cadang incidence. In most cases the r_s-values were similar to or exceeded

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the normal r-values, but for variables 14 and 25 they were smaller. After some of the data were grouped and illustrated it appeared that variables 3, 4, 7, 11, 13, 14, 24, and 25 might be nonlinearly correlated to the incidence of the cadang-cadang disease. Therefore, the data were transformed to see if these variables fitted a logarithmic curve better than a straight line. Logarithmic curves were fitted by transforming the data of these variables into ln(X + 1), while leaving the cadang-cadang incidence unchanged. For variables 3, 13, 14, 24, and 25 the sums of squares of deviations of the data from the logarithmic curve were significantly ($P < 0.005$) smaller than the sums of squares of deviations from the straight line (F = 23.82, 15.33, 16.51, 5.33, and 4.50, respectively, d.f. 1 and 572 or 430). The differences were not significant for variables 4, 7, and 11.

Two stepwise multiple regression analyses were calculated with cadang-cadang incidence as the dependent variable and the following environmental factors as the independent variables: for the first analysis data for variables 2–5 and 7–20 from 574 plots were used, with variables 3, 13, and 14 entered in the form ln (X + 1); for the second analysis, data for variables 2–4, 10–20, and 36–40 from 390 plots were used with no logarithmic transformations. The best two-variable model obtained in the first analysis included the independent variables elevation (variable 3, in logarithmic form), and mean palm age (variable 4). The R^2 was 0.167. When the best three-, four-, and five-variable models were calculated the independent variables maize (variable 17), abaka (variable 14, in logarithmic form), and kamote (variable 19) entered the model successively, and the R^2 increased to 0.199, 0.209, and 0.214, respectively. The best five-variable model in the first analysis had the form:

$$Y = 5.928 - 1.345 \ln(X_3 + 1) + 0.212 X_4 + 0.118 X_{17} - 0.457 \ln(X_{14} + 1) - 0.150 X_{19}$$

in which Y is the percentage of cadang-cadang infected palms, and X_3, X_4, X_{17}, X_{14}, and X_{19} are the independent variables given above. The total regression and the partial regression coefficients of the first three independent variables were statistically significant, $P = 0.01$, and those of the last two independent variables were statistically significant, $P = 0.05$.

In the second analysis, the best five-variable model included in order of significance the variable mean palm age, and the vegetation variables rice, maize, abaka, and bananas. The value of R^2 was 0.180. Many of the variables which were significantly correlated to the cadang-cadang incidence, but which were not included in the best five-variable models, were significantly correlated with elevation (Table 1).

The relationships between the cadang-cadang incidence and the

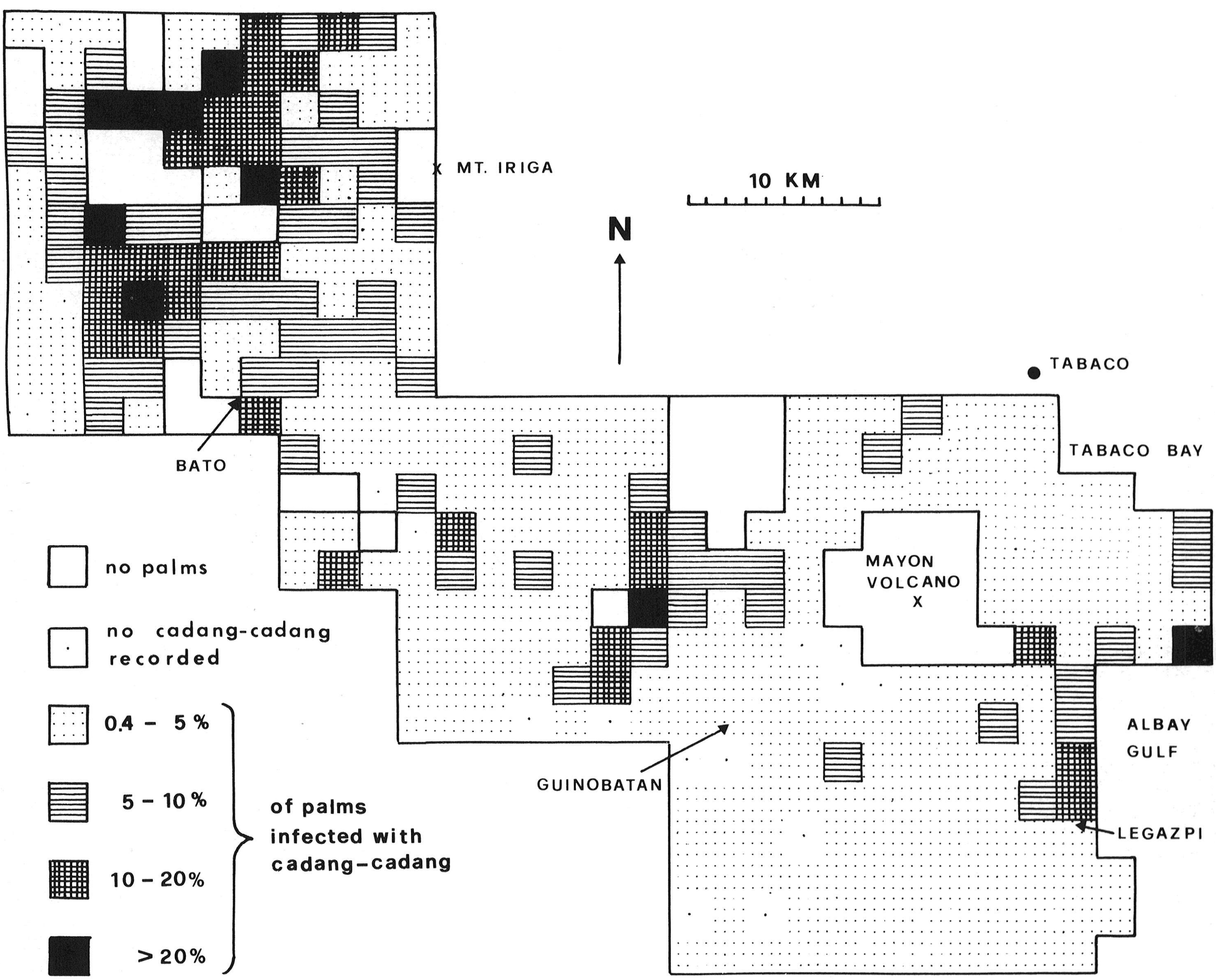

Fig. 1. Incidence of the cadang-cadang disease of coconut palm in a 1,492 km^2 survey area located in the southern Luzon Provinces of Albay and Camarines Sur in the Philippines.

TABLE 1. Environmental variables surveyed and their correlations with the incidence of the cadang-cadang disease of coconut palm and the elevation above sea level in southern Luzon in the Philippines

Variable	Plots surveyed (no.)	Variable	Mean	Standard deviation	Correlation with cadang-cadang incidence[a] r	r_s	Correlation with elevation[a] (r)
1	574	Percentage of coconut palms infected with cadang-cadang	4.220	5.709	1.000	1.000	−0.287**
2	574	Number of coconut palms per hectare	53.470	38.533	−0.124**	−0.168**	0.099*
3	574	Average elevation above sea level, meters	105.08	91.34	−0.287**	−0.447**	1.000
4	574	Mean age of palms, years	19.364	5.658	0.279**	0.275**	−0.209**
5	574	Variance of palm ages, years	177.59	119.14	0.212**	0.207**	−0.231**
6	574	Third moment of palm age distribution, years	2,058.9	2,884.5	0.072	...	−0.197**
7	574	Millimeter rainfall per year	274.03	65.79	−0.334**	−0.346**	0.553**
8	574	Number of bunga palms (*Areca catechu*) per hectare	0.699	1.554	0.017	...	−0.154**
9	574	Number of anahaw palms (*Livistona rotundifolia*) per hectare	1.414	4.630	−0.077	...	−0.023
10	574	Percentage of the plot occupied by "rough grazing"	27.354	22.078	−0.105**	−0.154**	0.213**
11	574	Percentage of the plot occupied by rice	19.202	27.738	0.226**	0.334**	−0.476**
12	574	Percentage of the plot occupied by "homegarden crops"	13.155	16.283	0.071	...	−0.394**
13	574	Percentage of the plot occupied by "forest"	12.828	15.888	−0.241**	−0.412**	0.590**
14	574	Percentage of the plot occupied by abaka (*Musa textile*)	6.824	14.937	−0.228**	−0.190**	0.478**
15	574	Percentage of the plot occupied by banana	6.624	7.292	0.093*	...	−0.215**
16	574	Percentage of the plot occupied by sugarcane	3.721	10.675	0.006	...	0.021
17	574	Percentage of the plot occupied by maize	3.601	8.152	0.166**	0.299**	0.002
18	574	Percentage of the plot occupied by bamboo	1.951	3.591	0.044	...	−0.108**
19	574	Percentage of the plot occupied by kamote (*Ipomoea batatas*)	1.314	2.831	−0.113**	...	0.024
20	574	Percentage of the plot occupied by citrus	0.934	3.105	−0.078	...	0.008
21	432	Percentage of coconut palms infected with cadang-cadang	2.840	4.208	1.000	1.000	...
22	432	Percentage of coconut palms found adjacent to "rough grazing"	45.387	25.248	−0.043	...	...

(continued)

surveyed environmental variables might have been significantly influenced by two unrecorded factors: (i) changes in the environment between the time the palms became infected and the time the disease incidence was recorded, (ii) deliberate felling of cadang-cadang infected palms in some areas by farmers in an attempt to control the disease. It was assumed that the effect of these two factors on the correlations would be diminished if only palms in the early stages of cadang-cadang are used for calculating the disease incidence. This would reduce the period between infection of the palms and recording the disease incidence, and disease incidence would not be affected by felling because the farmers usually do not recognize diseased palms at this stage. However, the percentage of early cadang-cadang stages did not give larger product-moment correlation coefficients for any of the environmental variables.

In general, the correlation between the cadang-cadang incidence and one vegetation-type was similar regardless of whether the abundance of the vegetation-type was measured near the surveyed palms or over the whole plot. However, the disease was more strongly related to "homegarden crops" near the surveyed palms than to "homegarden crops" throughout the whole plot (variables 12 and 23, Table 1).

DISCUSSION

The distribution of the cadang-cadang disease deviated strongly from a random distribution suggesting that the spread of the disease is influenced by environmental factors. However, with the environmental variables that were surveyed it was not possible to construct a satisfactory model explaining this variation in cadang-cadang incidence. The best five-variable model accounted for only 21% of this variation. Clearly, other variables, not surveyed, had a significant influence on the cadang-cadang incidence. Among the variables surveyed, elevation and mean age of the palms were found to be most significant in explaining the variation in the disease incidence. The correlation between palm age and disease incidence has been noted before (9).

Maize was found to be the third most significant factor in the best five-variable model, and was positively correlated to the disease incidence. It seems possible that the disease or the vector of the disease is somehow influenced by the presence of maize, however maize was quite rare in the survey area and was actually only recorded in 188 of 574 plots. Also maize is not often continuously planted over many years in one area, and it would be expected that its influence on disease incidence would show up more prominently if its abundance is compared with the incidence of the early stages, instead of the incidence of all disease stages. However, this was not so.

The best five-variable model also suggests a small negative influence of the crops abaka and kamote. However, the significance of these two factors was very low.

Altogether it is concluded that the results did not provide clear evidence that plants other than coconut palms can act as a reservoir of the pathogen, the weed *Elephantopus mollis* had been suspected of being an alternate host (5). However, its abundance was not

TABLE 1 (continued)

Variable	Plots surveyed (no.)	Variable	Mean	Standard deviation	Correlation with cadang-cadang incidence[a]		Correlation with elevation[a] (r)
					r	r_s	
23	432	Percentage of coconut palms found adjacent to "homegarden crops"	14.942	19.778	0.161**	0.337**	−0.420**
24	432	Percentage of coconut palms found adjacent to "forest"	10.174	14.497	−0.132**	−0.239**	···
25	432	Percentage of coconut palms found adjacent to abaka (*Musa textile*)	7.833	16.833	−0.180**	−0.091	···
26	432	Percentage of coconut palms found adjacent to bananas	6.595	8.485	0.064	···	···
27	432	Percentage of coconut palms found adjacent to sugarcane	3.606	11.357	−0.002	···	···
28	432	Percentage of coconut palms found adjacent to maize	3.044	7.943	0.252**	0.320**	···
29	432	Percentage of coconut palms found adjacent to kamote (*Ipomoea batatas*)	2.009	3.738	−0.060	···	···
30	432	Percentage of coconut palms found adjacent to rice	1.852	4.511	0.062	···	···
31	432	Percentage of coconut palms found adjacent to cassava (*Manihot esculenta*)	1.637	3.436	0.045	···	···
32	432	Percentage of coconut palms found adjacent to citrus	1.227	5.130	0.000	···	···
33	432	Percentage of coconut palms found adjacent to bamboo	0.572	1.620	−0.012	···	···
34	432	Percentage of coconut palms found adjacent to coffee	0.482	2.544	−0.010	···	···
35	390	Percentage of coconut palm infected with cadang-cadang	5.174	6.370	1.000	1.000	−0.294**
36	390	Average slope of land, percent	11.436	11.255	−0.132**	−0.229**	0.592**
37	390	Fraction of the year during which the ground water table is within 1 m from the surface	0.250	0.276	0.106*	···	−0.567**
38	390	Depth of soil, maximum limit of root penetration, meters	0.972	0.463	0.163**	0.315**	−0.634**
39	390	Clay content of soil, percent	34.087	17.647	0.151**	0.274**	−0.456**
40	390	Fertility of soil, arbitrary grades from 0 to 9	4.905	1.504	0.116*	···	−0.562**
41	70	Percentage of the plot occupied by *Elephantopus mollis*	6.409	6.143	−0.071	···	−0.025

[a] r = standard, parametric correlation coefficient (product-moment correlation); r_s = Spearman's nonparametric correlation coefficient; correlation coefficients marked with one asterisk are statistically significant, $P = 0.05$, and those marked with two asterisks are statistically significant, $P = 0.01$.

significantly correlated with the disease incidence in 70 plots. In the remaining 504 plots the weed was recorded under the vegetation class "rough grazing" which had a significantly negative correlation with the disease incidence.

The second multiple regression analysis was designed to test the influence of the soil variables. These were not included in the best five-variable model. The variable elevation also was not included and was replaced by rice, probably because no logarithmic transformation was used.

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