Preliminary results on epidemiology of Coconut Lethal Yellowing in Ghana

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Abstract: *Epidemiological studies are of major importance in understanding the determinants of plant diseases in order to control the risks of their spreading. A research programme on the epidemiology of coconut lethal yellowing, or Cape Saint Paul Wilt Disease (CSPWD), in Ghana was launched in March 2007. The objective was to characterize the distribution and spread of the disease in space and time at various scales, and their relation with the environment. This article presents the general strategy used to evaluate the incidence of CSPWD along with the environmental, ecological and agronomical variables at regional level. A survey was undertaken on 1,166 plots of Coconut Sector Development Project (CSDP) planted with Malayan Yellow Dwarf (MYD) × Vanuatu Tall (VTT) hybrids in Western Region and Central Region. Preliminary results on the distribution of CSPWD and outside variables at regional scale, along with their relations, are given.*

Key words: *coconut, Lethal Yellowing, Cape Saint Paul Wilt Disease, epidemiological survey*

Epidemiological studies are of major importance in understanding the determinants of plant diseases in order to control the risks of their spreading. Over the last 10 years, the Oil Palm Research Institute (OPRI) and the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) made few observations on the distribution and spread in space and time of coconut lethal yellowing, or Cape Saint Paul Wilt Disease (CSPWD), and on the relations of the disease with the environment. However, worth mentioning is the work undertaken to monitor the phytosanitary condition of several hundred coconut palms at Ayensudu (Central Region) for several months between 1992 and 1994, and the annual plot records kept between 1993 and 2000 on around a thousand plots [5]. But those observations, however interesting they might be, were not very precise, and provided mainly qualitative knowledge about the epidemiology of CSPWD: they showed that the disease can start from a few infested coconut palms and that it spreads by leaps over variable distances, in any direction and also that foci occur in patches that can sometimes merge. Few quantitative data about the disease are available. For example, the incidence of the disease or the speed with which it spreads at a given site or for a given variety of coconut palm are rarely known, yet those parameters are necessary for estimating the risk of the disease spreading to a neighbouring site. In addition, the appearance and development of the disease result from changes in a complex system, which probably brings into play a multitude of outside factors that may be biotic (wild flora, intercrops, fauna) or abiotic (climate, hydrography, topography, soil and so forth), in addition to the three components, coconut-vector-phytoplasma. The observations carried out in these plots cannot therefore be used to relate the disease to outside variables or steer research towards one avenue rather than another. Consequently, in order to provide a scientific conclusion backed up by a statistical analysis, it is necessary to carry out more numerous and more structured observations. A research programme on the epidemiology of coconut lethal yellowing or CSPWD in Ghana was launched in March 2007 [2]. The objective was to characterize the distribution and spread of the disease in space and time at various scales, and their relation with the environment. This article gives preliminary results on the distribution of CSPWD and outside variables at regional scale, along with their relations.

Material and methods

Plots

Between April 1999 and the end of 2004, 1,300 hectares of MYD × VTT hybrids divided between 1,166 one- to two-hectare plots on 1,012 farms were planted in the Central and Western regions as part of a project assigned to the Coconut Sector Development Project (CSDP) with funding from Agence Française pour le Développement (AFD). The MYD × VTT hybrid had been recommended for its good agronomic performance and assumed resistance to CSPWD. It subsequently proved to be quite susceptible to the disease.

Data collection

A questionnaire was established in order to obtain information from every plot of the CSDP project. Categories of data were plot identity, hydrography, topography, soil, agronomical and ecological data, agronomical and diseased situation around the plot. Each category contained a set of questions simple enough to be answered by discussion with the farmer and observation of the plot. The survey based on the questionnaire was launched in April 2007, involving six technical officers (TO). Each TO was in charge of, approximately, one district. Each farmer was visited by a TO. During the visit, the precise geographical location was spotted with a Global Positioning System (GPS receiver). Phytosanitary data, including the numbers of planted and diseased trees, were collected apart from the questionnaire. Data of the questionnaire (outside variables), GPS coordinates and phytosanitary data were merged into a unique file in order to be analysed. Because of correspondence problems not yet solved between the three original data

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sets, not all the data could be used for this preliminary study. Data available concern 881 questionnaires with identified GPS coordinates, 597 questionnaires with identified phytosanitary data, 590 questionnaires with both GPS coordinates and phytosanitary data, 36 plots with lethal yellowing, 30 plots with lethal yellowing and GPS coordinates.

Data analysis

Only preliminary descriptive analyses of outside variables were performed. Outside variables were tabulated and crossed with districts. Independence of district and outside variables was tested using the Fisher's exact test [1]. Two definitions of incidence of the disease were used [3]. Within a group of plots, "Tree incidence" was defined as the ratio of the number of trees infected or dead divided by the number of planted trees. "Plot incidence" was defined as the number of attacked plots divided by the total number of plots within the group. In the latter case, a plot is considered as attacked if at least one palm is attacked by the disease. GPS coordinates of the plots were used to map the healthy and diseased plots along with incidence. Independence between outside variables and Plot incidence was tested using Fisher's exact test. Effect of outside variables on Tree incidence was tested using a logistic regression with estimation of overdispersion parameter [4].

Results

Outside variables

The distribution of plots according to outside variables and districts is presented in *tables 1* to *6*. Fisher's exact test rejected independence between district and every outside variable at

Table 1. *Distribution of plots according to planting year and district.*

Year	Nzema East		Wassa West		Ahanta West		SAEMA		KEEA		AAK	
1999	0	0.000	0	0.000	11	0.125	1	0.007	11	0.046	0	0.000
2000	109	0.399	7	0.103	41	0.466	16	0.117	39	0.165	10	0.109
2001	6	0.022	3	0.044	27	0.307	32	0.234	28	0.118	21	0.228
2002	58	0.212	31	0.456	3	0.034	12	0.088	68	0.287	19	0.207
2003	10	0.037	6	0.088	4	0.045	70	0.511	80	0.338	31	0.337
2004	90	0.330	21	0.309	2	0.023	6	0.044	11	0.046	11	0.120

In each district, left column refers to number of plots and right column to proportion of plots in the district.

Table 2. *Distribution of plots according to hydrography variables and district.*

Hydrography variables	Nzema East		Wassa West		Ahanta West		SAEMA		KEEA		AAK	
Presence of water												
No water	141	0.516	62	0.912	53	0.602	55	0.401	35	0.148	27	0.293
River	82	0.300	5	0.074	14	0.159	46	0.336	38	0.160	42	0.457
Swampy area	50	0.183	1	0.015	21	0.239	36	0.263	164	0.692	23	0.250
Distance of water from the plot												
Less than 10 m	65	0.500	1	0.167	6	0.171	44	0.537	15	0.074	54	0.818
From 10 to 50 m	35	0.269	3	0.500	11	0.314	30	0.366	54	0.267	7	0.106
More than 50 m	30	0.231	2	0.333	18	0.514	8	0.098	133	0.658	5	0.076
Is the plot floodable?												
Never	209	0.913	64	0.941	46	0.730	117	0.907	214	0.907	50	0.549
Less than 1 week a year	12	0.052	1	0.015	5	0.079	0	0.000	9	0.038	15	0.165
Between 1 week and 1 month a year	3	0.013	3	0.044	9	0.143	12	0.093	13	0.055	25	0.275
More than 1 month a year	5	0.022	0	0.000	3	0.048	0	0.000	0	0.000	1	0.011

In each district, left column refers to number of plots and right column to proportion of plots in the district.

Table 3. *Distribution of plots according to topography variables and district.*

Topography variables	Nzema East		Wassa West		Ahanta West		SAEMA		KEEA		AAK	
Location of the plot												
In the bottom of a valley	5	0.027	0	0.000	1	0.018	44	0.333	0	0.000	36	0.396
At the bottom of a slope	2	0.011	2	0.053	9	0.158	43	0.326	40	0.199	11	0.121
Along a slope	167	0.893	36	0.947	38	0.667	45	0.341	148	0.736	37	0.407
On top of a hill	13	0.070	0	0.000	9	0.158	0	0.000	13	0.065	7	0.077
Slope												
Flat	102	0.382	39	0.574	33	0.379	78	0.569	190	0.819	16	0.302
Low	80	0.300	19	0.279	21	0.241	50	0.365	14	0.060	13	0.245
Medium	59	0.221	10	0.147	28	0.322	9	0.066	27	0.116	24	0.453
Steep	26	0.097	0	0.000	5	0.057	0	0.000	1	0.004	0	0.000

In each district, left column refers to number of plots and right column to proportion of plots in the district.

level lower than 0.0001, leading to the conclusion that districts are strongly characterized by the outside variables.

Planting year

In Ahanta West, most plots were planted between 1999 and 2001. In districts SAEMA, KEEA and AAK, planting occurred principally between 2000 and 2003, with a maximum in 2003. In Nzema East and Wassa West, most plots were planted in 2000, 2002 and 2004.

Hydrography

Western districts (Nzema East, Wassa West, Ahanta West) have more than 50% of the plots without presence of water (91% of plots in Wassa West), whereas eastern districts (SAEMA, KEEA, AAK) have more than 50% of the plots with presence of water (only 14.8% of plots without water in KEEA). In AAK, 27.5% of the plots are floodable between 1 week and 1 month a year.

Topography

In districts Nzema East, Wassa West, Ahanta West and KEEA, more than 80% of the plots are located along a slope or on the top of a hill, with sometimes more than 30% of medium or steep slopes (Nzema East and Ahanta West). In SAEMA and AAK, more than 50% of the plots are located in the bottom of a valley or at the bottom of a slope.

Soil

In districts Nzema East, Wassa West and SAEMA, more than 80% of the plots have light-coloured soil and more than 80% have a soil with light texture. In KEEA and AAK, more than 40% of the plots have dark-coloured soil. In KEEA, 39% of the plots have a heavy texture and only 3% have no coarse elements, against more than 60% for the other districts. Ahanta West has intermediate characteristics, with 16% of plots with dark brown soil and 26% with heavy texture.

Agronomical and ecological data

Previous land occupation was principally forest in Nzema East, Wassa West and AAK, coconut in SAEMA and KEEA, oil palm and coconut in Ahanta West. Herbicide is used principally in Nzema East, Wassa West and AAK (around 20% of the plots). The best maintenance is observed in Nzema East, Wassa West and SAEMA,

Table 4. *Distribution of plots according to soil variables and district.*

Soil variables	**Nzema East**		**Wassa West**		**Ahanta West**		**SAEMA**		**KEEA**		**AAK**	
Soil colour												
Black	1	0.004	2	0.029	6	0.068	1	0.007	0	0.000	37	0.402
Dark brown	3	0.011	0	0.000	14	0.159	2	0.015	104	0.439	0	0.000
Dark grey	28	0.103	0	0.000	0	0.000	11	0.080	19	0.080	3	0.033
Dark red	2	0.007	0	0.000	7	0.080	0	0.000	25	0.105	0	0.000
Light brown	52	0.190	16	0.235	36	0.409	17	0.124	60	0.253	28	0.304
Light grey	151	0.553	41	0.603	15	0.170	106	0.774	1	0.004	20	0.217
light red	36	0.132	9	0.132	10	0.114	0	0.000	28	0.118	4	0.043
Soil texture												
Heavy	54	0.199	6	0.088	23	0.261	3	0.022	93	0.392	20	0.217
Light	218	0.801	62	0.912	65	0.739	134	0.978	144	0.608	72	0.783
Coarse elements												
Absence	139	0.509	40	0.588	57	0.648	132	0.964	8	0.034	58	0.630
Few	100	0.366	28	0.412	24	0.273	3	0.022	228	0.962	34	0.370
Many	34	0.125	0	0.000	7	0.080	2	0.015	1	0.004	0	0.000

In each district, left column refers to number of plots and right column to proportion of plots in the district.

Table 5. *Distribution of plots according to agronomical/ecological variables and district.*

Agronomical/ecological variables	**Nzema East**		**Wassa West**		**Ahanta West**		**SAEMA**		**KEEA**		**AAK**	
Previous land occupation												
Coconut	110	0.404	2	0.029	30	0.341	132	0.964	237	1.000	4	0.044
Forest	140	0.515	61	0.897	12	0.136	5	0.036	0	0.000	72	0.791
Oil palm	19	0.070	3	0.044	36	0.409	0	0.000	0	0.000	14	0.154
Other	3	0.011	2	0.029	10	0.114	0	0.000	0	0.000	1	0.011
Maintenance												
Absence	29	0.107	6	0.088	20	0.227	2	0.015	20	0.085	23	0.250
Poor (bushy but accessible)	100	0.368	23	0.338	36	0.409	63	0.460	166	0.703	49	0.533
Good (easily accessible)	109	0.401	23	0.338	15	0.170	69	0.504	47	0.199	16	0.174
Very good (no weeds, no bush)	34	0.125	16	0.235	17	0.193	3	0.022	3	0.013	4	0.043
Use of herbicide												
No herbicide	218	0.810	55	0.809	80	0.920	120	0.960	204	0.919	70	0.787
Herbicide	51	0.190	13	0.191	7	0.080	5	0.040	18	0.081	19	0.213
Frequency of herbicide												
Once	34	0.667	6	0.462	5	0.714	5	1.000	12	0.667	6	0.316
Twice	15	0.294	5	0.385	2	0.286	0	0.000	6	0.333	12	0.632
Thrice	2	0.039	2	0.154	0	0.000	0	0.000	0	0.000	1	0.053

In each district, left column refers to number of plots and right column to proportion of plots in the district.

Table 6. *Distribution of plots according to history after coconut planting and district.*

	Nzema East		Wassa West		Ahanta West		SAEMA		KEEA		AAK	
Pueraria	76	0.278	29	0.426	31	0.352	3	0.022	12	0.051	0	0.000
Chromolaena	125	0.458	32	0.471	61	0.693	67	0.489	213	0.899	22	0.239
Grasses	54	0.198	1	0.015	22	0.250	50	0.365	224	0.945	78	0.848
Shrubs	48	0.176	5	0.074	47	0.534	61	0.445	10	0.042	81	0.880
Cassava	270	0.989	63	0.926	27	0.307	132	0.964	184	0.776	57	0.620
Plantain	74	0.271	28	0.412	9	0.102	32	0.234	9	0.038	10	0.109
Pepper	126	0.462	5	0.074	0	0.000	9	0.066	40	0.169	36	0.391
Tomato	42	0.154	0	0.000	1	0.011	2	0.015	68	0.287	38	0.413
Eggplant	14	0.051	1	0.015	1	0.011	7	0.051	78	0.329	16	0.174
Pineapple	62	0.227	3	0.044	1	0.011	4	0.029	2	0.008	1	0.011
Maize	201	0.736	54	0.794	15	0.170	114	0.832	208	0.878	90	0.978
Oil palm	2	0.007	3	0.044	18	0.205	1	0.007	2	0.008	1	0.011
Sugarcane	5	0.018	0	0.000	2	0.023	14	0.102	2	0.008	9	0.098

In each district, left column refers to number of plots and right column to the ratio (number of plots)/(total number of plots in the district).

where it is good or very good in more than 50% of the plots.

The distribution of crops or weeds after coconut planting is presented in *table 6*. Some of these factors are highly discriminant for districts. As examples, the proportion of plots with *Pueraria* is greater than 0.27 in Nzema East, Wassa West and Ahanta West, whereas it is lower than 0.06 in SAEMA, KEEA and AAK. The proportion of plots with grasses is greater in KEEA (0.945) and AAK (0.848) than in the other districts. The proportion of plots with oil palm is greater in Ahanta West (0.205) than in the other districts (lower than 0.05).

Incidence

Statistical distribution

Tree incidence lay between 0 and 0.7 with only 36 values greater than 0. This gives a very over-dispersed distribution *(figure 1)*, which has to be considered in the statistical analysis procedures.

Geographical distribution

The highest Tree and Plot incidences *(figure 2 and table 7)* occur in AAK and KEEA, whereas Wassa West, Ahanta West and SAEMA have relatively low incidences. Nzema East has an intermediate situation.

Relation between incidence and outside variables

Significant effects on Plot and/or Tree incidence were obtained for factors planting, district *(table 7)*, slope, soil colour, soil texture, maintenance, Pueraria, Chromolaena, Cassava and tomato *(table 8)*.

Planting

The highest Tree incidence occurred for planting year 2001. Plot incidence was higher for older plantations (planting years 1999, 2000 and 2001) than for younger plantations (planting years 2002, 2003 and 2004) *(table 9)*.

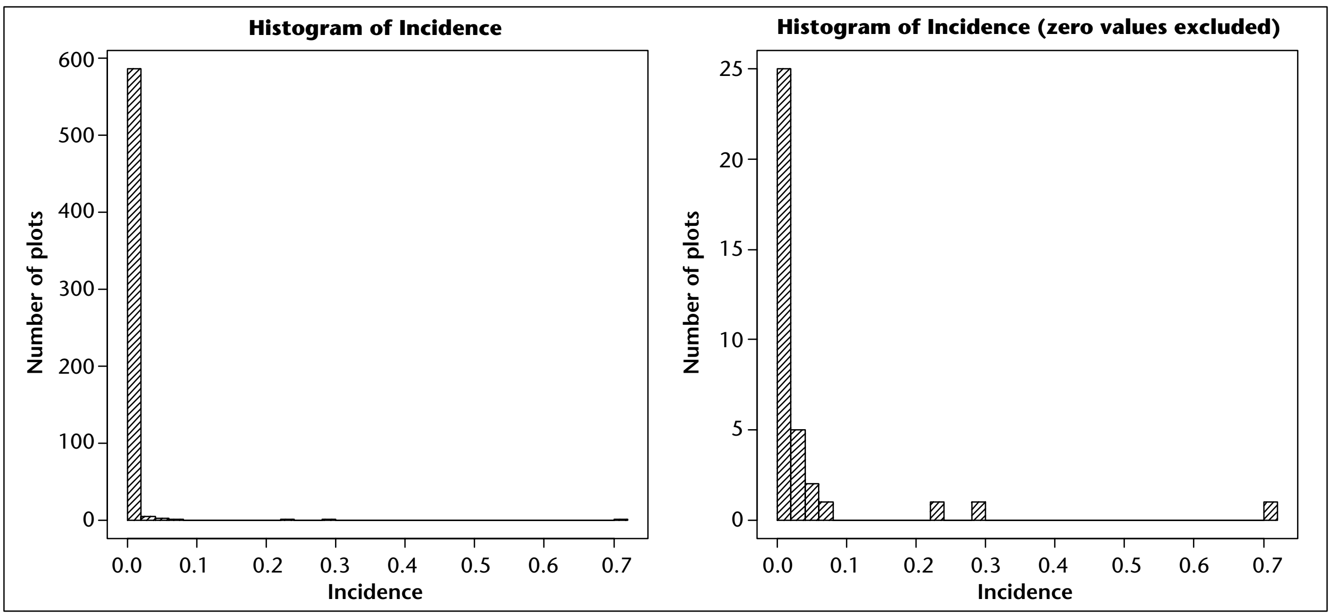

Figure 1. *Distribution of Tree incidence of CSPWD. Left: all values included. Right: zero values excluded.*

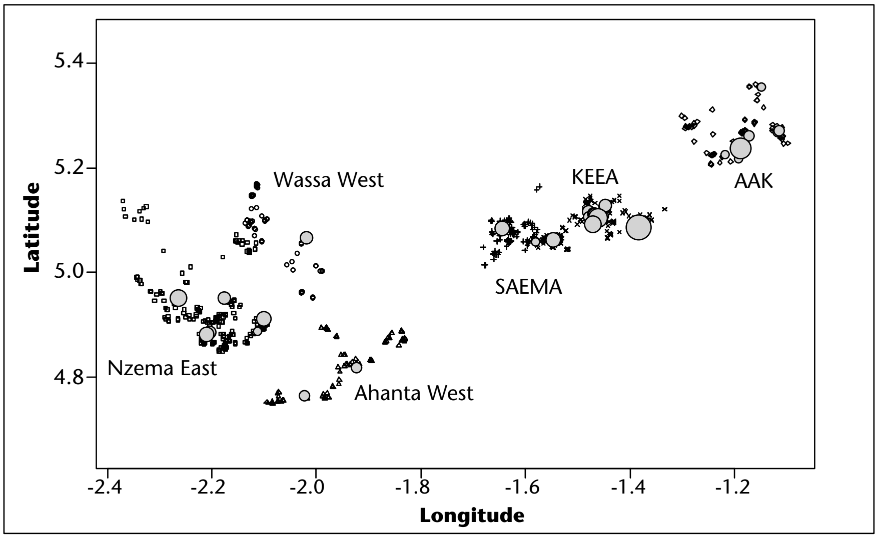

Figure 2. *Geographical distribution of CSPWD in Western and Central regions in Ghana. Black symbols: healthy plots. Grey circles: diseased plots. The larger the radius, the higher the incidence.*

Table 8. *P values of Fisher's exact test (Plot incidence) and logistic regression (Tree incidence).*

	Plot incidence	Tree incidence
Planting year	0.0283*	0.0175*
District	0.0002**	0.0795
Presence of water	0.1718	0.8884
Distance of water	0.0979	0.0782
Is the plot floodable?	0.1379	0.8723
Location of the plot (topography)	0.3514	0.8328
Slope	0.3457	0.0239*
Soil colour	0.0125*	0.0014**
Soil texture	0.0780	0.0179*
Presence of coarse elements	0.2906	0.7223
Previous land occupation	0.3179	0.8170
Year when LY killed the first coconut	0.9270	0.5821
Maintenance	0.2854	0.0149*
Use of herbicide	0.1697	0.4615
Frequency of herbicide	0.5676	0.5462
Use of fertilizer	1.0000	0.7636
Is there LY around?	0.0549	0.5776
Pueraria	0.0298*	0.2122
Chromolaena	0.0085**	0.0060**
Grasses	0.0862	0.8854
Shrubs	0.1293	0.7475
Cassava	0.0077**	0.0014**
Plantain	0.5167	0.4624
Pepper	0.0588	0.4990
Tomato	0.0389*	0.6624
Eggplant	0.4426	0.6380
Pineapple	0.7563	0.5834
Maize	0.6867	0.1777
Ooil palm	0.6196	0.5861
Sugarcane	0.1206	0.7671

*Significant at level 0.05; **significant at level 0.01.

Slope

Plot and Tree incidence are higher on flat slopes and are decreasing when the slope becomes steeper *(table 10)*.

Soil colour

Tree incidence is higher on dark-coloured soils (black, dark brown, dark grey) than on light-coloured soils *(table 11)*.

Soil texture

Tree and Plot incidence are higher on heavy soils than on light soils *(table 12)*.

Maintenance

Tree incidence is increasing from absence of maintenance to good maintenance *(table 13)*.

Pueraria, Chromolaena, Cassava, Tomato

There is a negative correlation between Tree or Plot incidence and presence of Pueraria, Chromolaena and Cassava. For Tomato, the correlation is slightly positive *(table 14)*.

Discussion

This preliminary study made it possible to characterize the distribution of CSPWD incidence and the distribution of hydrography, topography, soil, agronomical and ecological data. Relations between incidence and outside variables were investigated. The values of the outside variables as well as incidence of CSPWD were found to differ strongly according to the district. The highest incidences of CSPWD were found in AAK and KEEA, and the lowest incidences in Wassa West, Ahanta West and SAEMA. A correlation was detected between Plot and/or Tree incidence and factors planting, district, slope, soil colour, soil texture, maintenance, Pueraria, Chromolaena, Cassava, tomato. However, these correlations are not easy to interpret. The correlation of incidence with planting date could merely reflect the natural increase of incidence with time. The correlation with topographic and soil variables could be only a consequence of very different situations in different districts, without any direct causal relation. Indeed, it can be verified that outside variables are very correlated, so that it is difficult to separate their effects. This could be done by introducing together many factors into the model. This has been tried, but several difficulties then arise because of no convergence of algorithms or high dependence of order of introduction of the factors on the results. The negative correlation of incidence with Chromolaena and with Pueraria (although lower in the latter case) could be due to a

Table 7. *Plot and Tree incidence according to district.*

District	Healthy plots	Diseased plots	Plot incidence	Healthy trees	Diseased trees	Tree incidence
Nzema East	161	6	0.036	39,710	34	0.00086
Wassa West	52	1	0.019	13,271	2	0.00015
Ahanta West	60	2	0.032	14,717	3	0.00020
SAEMA	78	2	0.025	19,493	11	0.00056
KEEA	165	11	0.062	36,080	168	0.00463
AAK	58	14	0.194	16,432	128	0.00773

Table 9. *Plot and tree incidence according to planting year.*

Planting year	Healthy plots	Diseased plots	Plot incidence	Healthy trees	Diseased trees	Tree incidence
1999	17	2	0.105	4,956	12	0.00242
2000	149	12	0.075	42,047	49	0.00116
2001	74	10	0.119	22,125	201	0.00900
2002	128	7	0.052	29,194	24	0.00082
2003	141	3	0.021	26,991	57	0.00211
2004	65	2	0.030	14,390	3	0.00021

Table 10. *Plot and Tree incidence according to slope.*

Slope	Healthy plots	Diseased plots	Plot incidence	Healthy trees	Diseased trees	Tree incidence
Flat	293	23	0.073	71,079	295	0.00413
Low	117	5	0.041	30,093	23	0.00076
Medium	108	4	0.036	24,016	7	0.00029
Steep	21	0	0.000	4,968	0	0.00000

Table 11. *Plot and Tree incidence according to soil colour.*

Soil colour	Healthy plots	Diseased plots	Plot incidence	Healthy trees	Diseased trees	Tree incidence
Black	30	6	0.167	8,629	101	0.01157
Dark brown	88	8	0.083	19,905	151	0.00753
Dark grey	35	2	0.054	7,713	15	0.00194
Dark red	21	1	0.045	4,783	1	0.00021
Light brown	129	11	0.079	32,035	23	0.00072
Light grey	208	8	0.037	53,860	55	0.00102
Light red	63	0	0.000	12,778	0	0.00000

Table 12. *Plot and Tree incidence according to soil texture.*

Soil texture	Healthy plots	Diseased plots	Plot incidence	Healthy trees	Diseased trees	Tree incidence
Heavy	144	14	0.089	33,889	213	0.00625
Light	429	22	0.049	105,446	133	0.00126

Table 13. *Plot and Tree incidence according to maintenance.*

Maintenance	Healthy plots	Diseased plots	Plot incidence	Healthy trees	Diseased trees	Tree incidence
Absence	76	1	0.013	14,800	2	0.00014
Poor (bushy but accessible)	281	21	0.070	69,726	53	0.00076
Good (easily accessible)	166	11	0.062	41,754	240	0.00572
Very good (no weeds, no bush)	50	3	0.057	13,055	51	0.00389

Table 14. *Plot and Tree incidence according to presence of Pueraria, Chromolaena, Cassava and tomato.*

	Healthy plots	Diseased plots	Plot incidence	Healthy trees	Diseased trees	Tree incidence
Pueraria						
Absence	481	35	0.068	11,7193	344	0.00293
Presence	93	1	0.011	22,510	2	0.00009
Chromolaena						
Absence	221	22	0.091	59,099	294	0.00495
Presence	353	14	0.038	80,604	52	0.00064
Cassava						
Absence	106	14	0.117	29,232	229	0.00777
Presence	468	22	0.045	110,471	117	0.00106
Tomato						
Absence	480	25	0.050	115,692	253	0.00218
Presence	94	11	0.105	24,011	93	0.00386

competition between these species and weeds, potentially, the hosts of the vector. However the main issues remain the reliability of data and the relatively low number of CSPWD cases observed, which cannot lead to strongly significant results. More sophisticated statistical procedures need to be investigated in order to take into account the overdispersion and the possible spatial autocorrelation of the incidence of the disease.

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