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Full Length Research Paper

Assessment of major cassava diseases in Togo in relation to agronomic and environmental characteristics in a systems approach

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A cassava disease survey was conducted in four agroecological zones of Togo. High incidences of cassava bacterial blight, cassava mosaic disease and cercosporioses were observed across ecozones, while anthracnose disease was rare. Bacterial blight field incidences of 90.5% in the dry savanna zone, 70% in the forest savanna transition zone, 64% in the wet savanna zone and 52.6% in the forest zone, were recorded, with plant incidences ranging from 27.4% in the forest zone to 72.7% in the dry savanna zone. Mosaic disease field incidences were nearly 100% in all the ecozones and high plant incidences up to 86.9% were found. Cercospora leaf diseases – brown leaf spot, blight leaf spot and white leaf spot - occurred in all the ecozones with incidences ranging from 68 to 100%. Negative correlations between bacterial blight and mosaic disease, and between mosaic disease and white leaf spot were found, while brown leaf spot and blight leaf spot, brown leaf spot and white leaf spot, and blight leaf spot and white leaf spot were positively correlated. Field incidence of bacterial blight was positively correlated with plant age, ecozones - higher severity in dryer ecozones (P < 0.01), and weed density (P < 0.05). Further significant, but negative correlations occurred between bacterial blight and cercospora brown leaf spot on the other hand and vegetation type in the surroundings field (number of trees) (P < 0.05). *Cercospora* brown leaf spot was also significantly negatively associated with the number of crops in a field (intercropping) (P < 0.05), and *Cercospora* white leaf spot with sandy soils (P < 0.01). Results indicate that agroecological factors such as ecozone, plant age, weed density, vegetation type, intercropping and soil type and moisture influence disease occurrence and should be considered when developing integrated control measures.

Key words: Blight leaf spot, brown leaf spot, cassava bacterial blight, cassava mosaic disease, white leaf spot, *Cercospora henningsii*, *Cercospora caribaea, Cercospora vicosae, Colletotrichum gloeosporioides* f. sp. *manihotis*, *Manihot esculenta, Xanthomonas axonopodis* pv. *manihotis*.

INTRODUCTION

Cassava (*Manihot esculenta*) is a major staple crop in the tropics. Its production is largely reduced by biotic constraints (Hahn et al. 1989) among which diseases are of high importance. Major cassava diseases in Africa include cassava mosaic disease (CMD), cassava bact-erial blight (CBB), cassava root and stem rots, cassava anthracnose disease and *Cercospora* leaf diseases (Hillocks and Wydra 2002).

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Cassava bacterial blight (CBB), caused by *Xanthomonas axonopodis* pv. *manihotis* (Vauterin et al. 1995), previously *Xanthomonas campestris* pv. *manihotis* is worldwide distributed (Lozano 1986). CBB was first recorded in Brazil in 1912 but has since been reported in several countries in South America (Lozano and Sequeira, 1974), Africa (Maraite and Meyer, 1975) and Asia (Leu and Chen, 1972; Booth and Lozano, 1978). CBB distribution was recently established in Ghana, Benin, Nigeria and Cameroon, with variable incidence and severity according to ecozones (Wydra and Msikita, 1998). Severe CBB incidence and severity were observed in all ecozones in Benin, but the disease was rarely found in Ghana (Wydra and Verdier, 2002). In Togo, the disease was reported for the first time by Olympio (1977). Later investigations on the distribution of CBB in Togo revealed that the disease was prevalent and more severe in the forest savanna transition zone and was sporadically recorded in the wet savanna zone, while it was not found in the forest zone. However, in the region of Kara in the South part of the dry savanna zone, CBB was most frequently found with variable severities (Boher and Agbobli, 1992).

Typical symptoms of CBB comprise water-soaked angular leaf spots, blighting, wilting, defoliation, vascular necrosis of the stem, production of exudates on leaves, petioles or stems, and stem dieback (Lozano, 1986). Insects may play a role in disease transmission (Zandjanakou-Tachin et al. 2007). Root yield losses exceeding 50 to 75% depending on the severity of the disease, or complete loss of yield and planting material in case of severe infections were observed (Wydra and Rudolph, 1999; Wydra, 2002; Zinsou et al., 2004a). Yield losses due to CBB in Africa were determined in various studies (Banito, 2003; Zinsou et al., 2004a,b), and estimated up to 7.5 million tons (CIAT 1996). For the development of integrated control measures comprising cultural measures and host plant resistance, the prevalence of the disease and the nature of its causal agent have to be known (Wydra et al., 2001, 2003, 2004, 2007; Zinsou et al. 2004b).

Cassava mosaic disease (CMD) is the most widespread cassava disease and commonly found in Africa and Southern India causing important yield losses (Thresh et al., 1994; Calvert and Thresh, 2001). The disease is caused by Begomoviruses [Geminiviridae: Geminivirus Sub-group III] transmitted by the whitefly *Bemisia tabaci* Genn (Legg et al. 2001; Fargette et al., 2006). CMD occurred frequently in all ecozones of Ghana and Benin, with higher incidence in all ecozones of Ghana (Wydra and Verdier, 2002). In all ecozones of Benin, Cameroon and Ghana, cassava mosaic disease was most prevalent with field and plant incidences near 100% (Wydra and Msikita, 1998). During the 1990s, East African cassava mosaic virus Uganda variant (EACMV-Ug) spread through Uganda and into the neighbouring countries of Kenya, Rwanda and Tanzania, causing a devastating pandemic of unusually severe cassava mosaic disease (Legg, 1999; Legg et al., 2001; Fargette et al., 2006). Recent molecular studies revealed a recombination of the African cassava mosaic virus (ACMV) and EACMV, resulting in the EACMV-Ug, the latter also occurring in mixtures with the other variants in East and Central Africa (Fargette et al., 2006). The outbreaks of CMD curbed cassava production in the Democratic Republic of Congo, the second largest producer in the region (FAO/GIEWS 2001). The average annual yield loss caused by cassava mosaic disease to cassava production in Africa is estimated to about 25 - 50% of the total (Thresh et al., 1997).

CMD is characterized by a mosaic pattern of chlorotic areas on the leaves which vary in size depending on the severity of the disease, and by stunting of the plant when severely infected. The most promising methods of controlling CMD are by using resistant cultivars (Calvert and Thresh, 2001).

Cassava anthracnose disease caused by *Colletotrichum gloeosporioides* f. sp. *manihotis* Henn. (Penz) Sacc. is characterized by development of cankers on stems, branches and fruits, leaf spots and tip dieback (Hillocks and Wydra, 2001). The disease is favoured by humid, wet conditions (Fokunang et al., 1999). The disease has been reported from cassava in many countries of Latin America, Africa and Asia (CIAT, 1972; Chadrasekharan-Nair et al., 1979; Makambila, 1994). Makambila (1979) found anthracnose disease in all cassava-growing regions in the People's Republic of Congo, but disease severity varied across regions. In a recent disease survey in Benin and Ghana cassava anthracnose was observed in up to 30% of fields, but generally with low disease severity (Wydra and Verdier, 2002). Therefore, cassava anthracnose disease was generally estimated to be of minor importance (Lozano and Booth, 1976; Wydra and Verdier, 2002).

Cercospora leaf diseases are essentially confined to the foliage where they cause spots and blight: brown leaf spot (BLS) caused by *Colletotrichum* [*Mycosphaerella*] *henningsii* Allesch, white leaf spot (WLS) caused by *Colletotrichum caribaea* Cif. [*Phaeoramularia manihotis*] and blight leaf spot (BlLS) by *Colletotrichum* [*Mycosphaerella*] *vicosae* Muler and Chupp (Lozano and Booth 1976). Cercosporioses are widely distributed in all cassava-growing areas, but are mostly of minor importance (Lozano and Booth, 1974; Silva et al., 1988).

While surveys on the status of cassava diseases were recently carried out in ecozones of several African countries (Wydra and Msikita, 1998; Wydra and Verdier, 2002), the distribution of cassava diseases has never been established in all agroecological zones of Togo. Since the surveys on CBB by Boher and Agbobli (1992) covering some ecozones of Togo, no suitable control measures have been used in the country. The present aimed at (i) determining the incidence, severity and geographic distribution of cassava diseases in the major ecological zones of Togo, (ii) in a systems approach including the evaluation of cultural, soil and agroecological factors in relation to disease occurrence in a tropical environment, and (iii) to elucidate conditions that could influence and determine disease outbreaks, in order (iv) to give basic information for the development of integrated control measures.

MATERIALS AND METHODS

Survey area

Cassava is grown in four main agroecological zones in Togo: in the forest savanna transition zone in the South part of Togo, which is characterized by a shrubby vegetation with few trees, the forest zone in the South-West with a rainforest vegetation, the wet savanna in the Center part, characterized by more shrubby vegetation and the dry savanna zone in the North part with herbaceous vegetation. The savanna transition and the forest zones are characterized by a sub-equatorial climate with one long rainy season (March – June), one short dry season (July – August), one short rainy season (September – October) and one long dry season (November – March); whereas the wet savanna and the dry savanna zones are characterized by a tropical climate with one long rainy season (April – September) and one long dry season (October – March) (Lamouroux, 1979). The average annual rainfall is about 1,200 mm in the forest savanna transition zone, 1,400 mm in the forest and wet savanna zones, and 1,300 mm in the dry savanna zone, with the average temparature of 28, 24, 27 and 28°C respectively. Annual rainfall up to 2,027 mm in the forest, 1,810 mm in the wet savanna and 1,651 mm in the dry savanna zones were recorded (DMN 2001).

Survey methodology

A country-wide survey was carried out shortly after the rainy season in November 1998. Eighty-five fields covering the four ecozones were visited: 20 fields in the forest savanna transition zone, 19 fields in the forest zone, 25 fields in the wet savanna zone, and 21 fields in the dry savanna zone. Fields of about 1/16 ha minimum size were selected from the cassava-growing areas at a minimum of 10 km intervals (rarely less than 10 km) along the main practicable roads. CBB symptoms were evaluated on plants following two diagonals across the field. Fifteen plants randomly selected within two diagonals of the field were assessed for CBB incidence and severity by scoring the expression of symptoms in five severity classes: class 1 - no symptom, class 2 - angular leaf spots, class 3 – angular leaf spots, blighting, wilting, defoliation, and sometimes exudates on stems, petioles or leaves, class 4 - blighting of leaves, wilting, defoliation, exudates and tip dieback, class 5 - blighting of leaves, wilting, defoliation, exudates, abortive lateral shoot formation, stunting, complete dieback. The 15 plants were also assessed for cassava mosaic disease (CMD) and Cercospora diseases (brown leaf spot, blight leaf spot and white leaf spot), while anthracnose disease was generally not scored due to its low occurrence. Cassava mosaic disease symptoms were scored in five severity classes, 1 = no symptom, 2 = mild chlorotic patterns and slight distortion of only the base of leaves, 3 = mosaic patterns on all leaves, leaf distortion, 4 = mosaic patter ns on all leaves, leaf distortion, and general reduction in leaf size, 5 = leaves twisted/misshapen, and stunting of the whole plant. For anthracnose disease and Cercospora diseases, one severity score was given for all the 15 plants: 1 = not present, 2 = symptoms of low severity on plants, 3 = symptoms of medium severity on many plants, 4 = severe symptoms on all the plants (Wydra and Verdier 2002).

Vegetation type in surroundings 1 = herbaceous savanna 2 = herbaceous savanna with few trees 3 = forest savanna 4 = forest	**Ecozones (months without rain in year 1998)** 1 = (0 month) forest 2 = (0 - 2 months) forest savanna transition 3 = (1 – 3 months) wet savanna 4 = (2 – 5 months) dry savanna
Soil texture 1 = clay 2 = sandy loam 3 = loamy sand 4 = sand 5 = lateritic soil	**Type of branching** 0 = no branching 1 = late branching 2 = profusely branching
Soil moisture 0 = dry 1 = humid 2 = temporary waterlogged 3 = waterlogged	**Plant age in months** **Weed score** 0 = no weeds 4 = abundant weeds
Crop system 1 = monoculture 2 = 2 to 3 associated cultures 3 = more than 3 associated cultures 4 = cassava plants as field border only	**Variety mixture** 1 = one cassava variety 2 = mixture of cassava varieties **Field size** Estimated in ha

Additionally, agronomic, varietal and ecological characteristics were recorded in each field, and coded for statistical analysis following the method of Cardwell et al. (1997), modified by Wydra and Verdier (2002):

For each disease surveyed, field incidence was calculated as the percent of infected fields in an ecozone, and plant incidence as the percent of plants per field showing disease symptoms.

Statistical analysis

Field incidence, plant incidence and severity were determined using the SAS software system (SAS Institute Inc., Release 6.12., Cary, NC, USA). The relationship among cassava diseases and their interactions with the agronomic, ecological and varietal characterristics was established. Using the SAS program, canonical correlations analysis (CANCORR) was performed between disease variables (Y-variables) on the one hand and agronomic, ecological and varietal variables (X-variables) on the other hand, to determine the extent of the association between these two sets of variables. CANCORR is a powerful multivariate statistical tool useful in exploring association between two sets of related variables. The technique consists of finding several linear combinations of the disease variables and the same number of linear combination of the agronomic, ecological and varietal variables in such a way that these linear combinations best express the correlations between the two sets. CANCORR finds a linear combination from each set, called canonical variables, such that the correlation between the two canonical variables is maximized (Afifi and Clark, 1990). The resulting canoni-

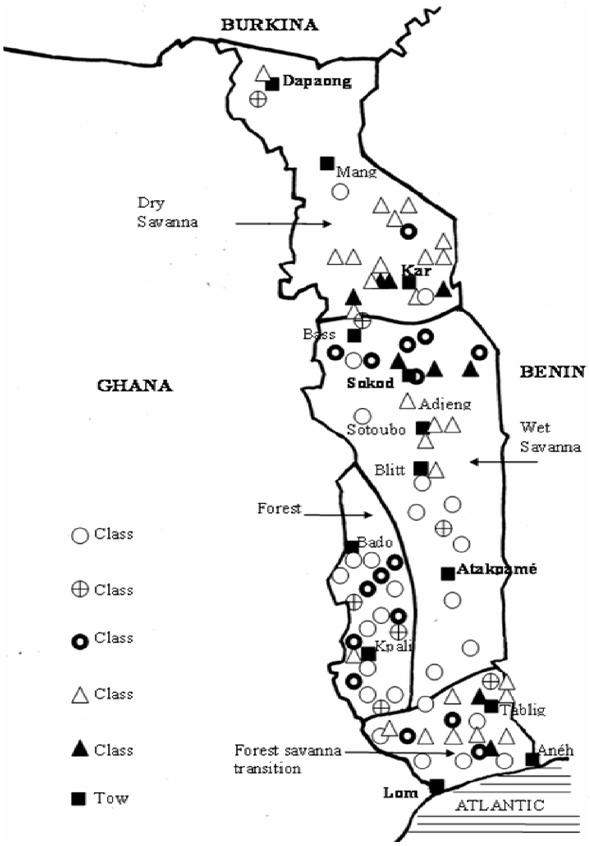

Figure 1. Distribution of cassava bacterial blight in severity classes in cassava fields across four ecozones of Togo. Symptom classes: class 1 - no symptom, class 2 - angular leaf spots, class 3 - angular leafspots, blight, wilt, defoliation, and sometimes exudates on stems, petioles or leaves, class 4 –blight on leaves, leaf wilt, defoliation, exudates and tip dieback, class 5 - blight on leaves, leaf wilt, defoliation, exudates, abortive lateral shoot formation, stunting, complete dieback.

Table 1. Field and plant incidence (%), and frequency distribution (%) in four severity classes of bacterial blight-infected cassava plants in four ecozones of Togo.

Ecozones	No. of fields	Field incidence [%]	Plant incidence [%]	Plants in severity classes[1] [%]			
				2	3	4	5
FST[2]	20[3]	70[4]b	42.7[5]b	19.3	14.7	7	1.7
Forest	19	52.6b	27.4b	20.4	6.3	0.7	0
WS	25	64b	45.3b	17.6	16	8	3.7
DS	21	90.5a	72.7a	27.9	24.4	17.8	2.5

[1]Severity classes: class 2: angular leaf spots; class 3: angular leaf spots, blighting, wilting, defoliation, and sometimes exudates on stems/petioles/leaves; class 4: blighting of leaves, wilting, defoliation, exudates and tip dieback, class 5: blighting of leaves, wilting, defoliation, exudates, abortive lateral shoot formation, stunting, complete dieback; [2]FST = forest savanna transition; WS = wet savanna; DS = dry savanna; [3]Total number of fields visited in the ecozone; [4]Percentage of infected fields in the ecozone; [5]Percentage of infected plants from all plants sampled in the ecozone.

canonical correlations are tested for significance using F-statistic approximation.

For the stepwise regression, the level of significance was set to 5%. However, higher probability of 6% levels were used in the preliminary analyses in order to check for and further examine any marginal variables and interactions that might be lost at the restrictive probability level of 5%. The frequency of diseased plants in severity classes was determined for CBB and CMD. Analysis of variance (ANOVA) of disease incidences was performed to compare ecozones.

RESULTS

Field incidence, plant incidence and severity of cassava diseases

Cassava bacterial blight: was observed in 70% of the fields visited, and occurred in all the four agroecological zones of Togo, but with variable severity between ecozones (Figure 1). Highest symptom severities were scored at Davié, Kpogamé, Ahépé, Tabligbo and Tokpli. In the forest zone, the disease was generally lower than in the other zones (Table 1). In the wet savanna, where cassava is one of the main crops, CBB severity was less than in the forest savanna transition zone, but higher than in the forest zone. High disease severities were recorded in Blitta, Sotouboua, Bassar, and in the region of Sokodé, where some fields were scored with the highest CBB symptom class 5. The highest severities of CBB were observed in two fields of 16 years monoculture cassava in the wet savanna zone. In the dry savanna zone, where cassava production is less important, CBB field incidence was highest, with highest disease severities occurring in the region of Kara, where one field of 18 years monoculture cassava showed the highest severity level.
From this region to the extreme North of the country, CBB was rarely found, with only low incidence in the region of Dapaong.

The plant incidence of CBB by field was high in all ecozones except in the forest zone with field and plant incidences being significantly higher in the dry savanna zone than in the other ecozones ($P < 0.01$). A plant incidence of 100% was observed in six fields in the wet savanna zone, 5 fields in the dry savanna zone and one field in the forest savanna transition zone (data not shown). Systemic infection of CBB - classes 3 to 5, with most of the plants in class 3 - occurred in the four ecozones including the forest zone. Plants with the highest symptom severity of class 5 - corresponding to dieback of the plant - were recorded in the savanna and forest savanna transition zones - mainly in the region of Sokodé (Figure 1), but no plant with dieback symptoms was observed in the forest zone.

Cassava mosaic disease (CMD) was widely observed across all ecozones surveyed with an ecozonal field inci dence of about 100%. A higher plant incidence of 86.9% was recorded in the wet savanna zone, while it was lower

Table 2. Field and plant incidence (%), and frequency distribution (%) in four severity classes of cassava mosaic disease-infected cassava plants in four ecozones of Togo.

Ecozone	No. of fields	Field incidence [%]	Plant incidence [%]	Plants in severity classes[1] [%]			
				2	3	4	5
FST[2]	20[3]	95[4]a	63.7[5]b	36.0	16.3	10.0	1.3
Forest	19	94.7a	78.9ab	41.1	17.5	13.0	7.4
WS	25	100a	86.9a	42.9	22.4	18.7	2.9
DS	21	100a	75.2ab	52.1	18.4	4.4	0.3

[1]Severity classes: class 2: mild chlorotic patterns and slight distortion of only the base of leaves,class 3: mosaic patterns on all leaves, leaf distortion, class 4: mosaic patterns on all leaves, leaf distortion, and general reduction in leaf size, class 5: leaves twisted/misshapen, and stunting of the whole plant; [2]FST = forest savanna transition; WS = wet savanna; DS = dry savanna; [3]Total number of fields visited in the ecozone; [4]Percentage of infected fields in the ecozone; [5]Percentage of infected plants from all plants sampled in the ecozone.

Table 3. Field incidence (%) of Cercospora leaf diseases of cassava plants in four ecozones of Togo.

Ecozone	No. of fields	BLS	BILS	WLS
FST	20[1]	95[2]b	100 [2]a	95 [2]a
Forest	19	89.5c	100a	73.7b
WS	25	100a	96b	68c
DS	21	95.2b	95.2b	95.2a

FST=forest savanna transition; WS = wet savanna; DS = dry savanna; BLS = brown leaf spot; BILS = blight leaf spot; WLS = white leaf spot; [1]Total number of fields visited in the ecozone; [2]Percentage of infected fields in the ecozone.

Table 4. Correlation matrix (Pearson correlation coefficients) between the severity scores of cassava diseases in 85 fields across four ecozones of Togo.

	CBB[1]	CMD	BLS	BILS	WLS
CBB	1	-0.220*[2]	-0.074	-0.072	-0.004
CMD		1	-0.099	0.055	-0.237*
BLS			1	0.403***	0.281**
BILS				1	0.226*
WLS					1

[1]CBB = cassava bacterial blight; CMD = cassava mosaic disease; BLS = brown leaf spot; BILS = blight leaf spot; WLS = white leaf spot; [2]* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

(63.7%) in the forest savanna transition zone (Table 2)

Table 5. Pearson correlation between severities of cassava diseases and the agronomic, ecological and varietal characteristics using data from 85 cassava fields across four ecozones of Togo.

	CBB[1]	CMD	BLS	BILS	WLS
Ecozones	0.28**[2]	0.02	-0.15	-0.16	-0.17
Field size	-0.23*	0.12	0.04	-0.03	0.09
Vegetation type	-0.23*	-0.18	-0.23*	-0.06	0.14
Soil texture	0.13	0.15	-0.12	-0.19	-0.28**
Soil moisture	-0.27*	0.22*	0.01	-0.16	-0.12
Weed score	0.26*	0.07	0.11	0.12	0.07
Crop system	0.04	0.02	-0.22*	0.02	-0.17
Variety mixture	-0.16	0.19	-0.12	0.1	-0.21
Branching type	-0.12	0.19	-0.01	0.15	0.04
Plant age	0.29**	-0.14	0.09	0.14	0.09

[1]CBB = cassava bacterial blight; CMD = cassava mosaic disease; BLS = brown leaf spot; BILS = blight leaf spot; WLS = white leaf spot; [2]* $P < 0.05$; ** $P < 0.01$

Severe CMD symptoms (classes 3 - 5) were observed in all the zones with higher severities of 44 and 37.9% recorded in the wet savanna and forest zones, respectively.

Cercospora leaf diseases occurred in all the ecozones with high field incidences (Table 3). BLS and BILS were observed in all the fields visited across ecozones with an incidence between 90 - 100%. WLS was significantly lower in the forest and the wet savanna zones than in the other ecozones ($P < 0.01$), while BLS was significantly higher in the wet savanna zone than in the other ecozones ($P < 0.05$), and BILS was significantly lower in the dry and wet savanna zones than in the forest and forest savanna transition zones ($P < 0.001$).

Cassava anthracnose disease was rarely observed and occurred then only with low severity.

Relationship between cassava disease variables

Negative correlations were observed between CBB and CMD as well as between CMD and WLS field incidences ($P < 0.05$) (Table 4). The severities of Cercospora leaf diseases were positively correlated (BLS/BILS: $P < 0.001$; BLS/WLS: $P < 0.01$; BILS/WLS $P < 0.05$).

Relationship between cassava diseases and the agronomic, ecological and varietal characteristics

In the Pearson correlation analysis (Table 5), significant positive correlations occurred between severity of CBB and plant age, ecozones - higher severity in dryer ecozones - ($P < 0.01$), and weed density ($P < 0.05$).

Table 6. Stepwise regression analysis of severities of cassava diseases on agronomic, ecological and varietal characteristics based on survey data from 85 fields across four ecozones of Togo.

Disease	Variable	Parameter estimate	Standard Error	F	Probability
CBB[1]	Intercept	0.08	0.34	0.05	0.8228
(R^2 = 0.25)[2]	Plant age	0.10	0.02	18.91	0.0001
	Ecozones	0.33	0.08	18.20	0.0001
	Intercept	1.34	0.45	8.82	0.0039
CMD	Soil moisture	0.26	0.09	7.62	0.0072
(R^2 = 0.23)	Vegetation type	-0.38	0.11	10.99	0.0014
	Branching type	0.66	0.22	9.01	0.0036
	Variety mixture	0.47	0.19	5.74	0.0189
	Intercept	5.22	0.62	70.22	0.0001
BLS	Vegetation type	-0.36	0.11	9.76	0.0025
(R^2 = 0.16)	Crop system	-0.54	0.23	5.64	0.0199
	Soil texture	-0.19	0.09	4.58	0.0354
	Intercept	3.77	0.47	64.47	0.0001
WLS	Soil texture	-0.24	0.09	7.06	0.0095
(R^2 = 0.12)	Variety mixture	-0.42	0.22	3.75	0.0561

[1]CBB = cassava bacterial blight; CMD = cassava mosaic disease; BLS = brown leaf spot; WLS = white leaf spot; [2]R^2 is approximately the percentage of the total variance (or variation) in the dependent variable (each of the diseases measurements: CBB, CMD, WLS or WLS) explained by the independent variables entered (agronomic, ecological or varietal variables).

Further significant, but negative correlations occurred between CBB and soil moisture, field size and vegetation type in surroundings of the field ($P < 0.05$). The highest CBB incidence and severity were recorded in the herbaceous savanna without trees (dry savanna zone) followed by the herbaceous savanna with few trees (wet savanna zone) and the forest savanna, while severity was lowest in the forest. Cassava plant age and ecozones had highest influence on CBB occurrence. For CMD a significant positive correlation was observed only with soil moisture ($P < 0.05$). Cercospora brown leaf spot (BLS) was significantly negatively associated with the number of trees in surroundings of a field and intercropping cassava with other crops ($P < 0.05$), and Cercospora white leaf spot with more sandy soils ($P < 0.01$), while no significant correlation occurred between Cercospora blight leaf spot and agronomic, ecological and varietal characteristics (Table 5).

The stepwise regression analyses of cassava diseases on each of agronomic, ecological and varietal characteristics confirmed for CBB by significant positive regression coefficients the role of ecozones and plant age ($P < 0.0001$), indicating an increase in CBB severity in older plantations and in dryer ecozones (Table 6). All other variables did not meet the significance criterion for entering the model. The variation in CBB was largely unaccounted for by those two variables as the model R^2 was only 25%.

Cassava mosaic disease (CMD) was significantly related to soil moisture, vegetation type in surroundings of the fields, branching type ($P < 0.01$) and mixture of cassava varieties in a field ($P < 0.05$) (Table 6). CMD occurred more frequently on more profusely branching cultivars. The stepwise analysis showed a significant regression coefficient for variety mixture (growing of more than one cassava genotype in a field). The disease was favor-Favored by soil moisture, whereas trees in surroundings of a field seemed to have a suppressive effect on its occurrence. No other variables measured met the signifycance criterion of the model.

Table 7. Canonical correlations between cassava disease variables and agronomic ecological and varietal variables, and standardized canonical coefficients for these variables based on survey data from 85 fields across four ecozones of Togo.

	1st canvar[1]	2nd canvar	3rd canvar
CBB[2]	0.41	0.88	0.12
CMD	0.86	-0.30	-0.06
BLS	0.52	0.19	-0.26
BILS	0.001	0.05	-0.47
WLS	-0.25	0.003	-0.62
Ecozones	0.23	0.46	0.62
Field size	0.10	-0.12	-0.25
Vegetation type	-0.84	-0.17	0.39
Soil texture	0.08	-0.12	0.63
Soil moisture	0.41	-0.29	0.47
Weed score	0.43	-0.12	-0.34
Crop system	-0.21	-0.11	0.06
Variety mixture	0.29	-0.30	0.15
Branching type	0.65	-0.26	-0.30
Plant age	-0.02	0.76	0.24
Cancorr.	**Standard Error**	**F**	**Probability**
0.603	0.069	2.188	0.0001
0.560	0.075	1.969	0.0014
0.483	0.084	1.655	0.0328
0.405	0.091	1.319	0.2027
0.239	0.103	0.747	0.6139

[1]1st canvar = first canonical variate; 2nd canvar = second canonical variate; 3rd canvar = third canonical variate; Cancorr = canonical correlation; [2]CBB = cassava bacterial blight; CMD = cassava mosaic disease; BLS = brown leaf spot; BILS = blight leaf spot; WLS = white leaf spot

Three variables affected significantly Cercospora brown leaf spot (BLS). The disease was significantly reduced with more trees in surroundings of a field ($P < 0.01$), intercropping cassava with other crops ($P < 0.05$) and in sandy soils ($P < 0.05$). Cercospora brown and white leaf spots were more severe on loamy sand and sandy loam soils than on sandy soils ($P < 0.05$ and $P < 0.01$, respect-tively).

Among the cassava diseases, CBB variation was more affected by the agronomic, ecological and varietal variables left in the model ($R^2 = 0.25$) than CMD ($R^2 = 0.23$), whereas BLS ($R^2 = 0.16$) and WLS ($R^2 = 0.12$) were less influenced, though significant, by these characteristics, indicating a significant contribution of these characteristic to the variation of CBB, CMD, BLS and WLS (Table 6).

Canonical correlations between cassava disease variables and agronomic, ecological and varietal characteristics

The canonical correlation analysis revealed further relations between the groups of variables. The first three canonical correlations between disease variables and agronomic, ecological and varietal variables were significant ($P = 0.0001$, $P = 0.001$ and $P = 0.03$, respectively) using the approximate likelihood ratio significance test (Table 7). In the first canonical variate of the disease variables, CMD had the highest weight, while coefficients of BLS and CBB were lower. WLS had a negative coefficient, indicating a moderately reversed influence on the relationship between disease and agronomic, ecological and varietal variables. BILS did not considerably contribute to the relationship. Vegetation in the surroundings of a field had a reverse influence on the first canonical variate of the non-disease variables that is a disease-decreasing effect, while branching varieties, abundance of weeds in a field, high soil moisture and a mixture of cassava varieties in a field had a positive influence, that is, increasing effect on the severity of cassava diseases (Table 7).

The second canonical correlation between the two groups of variables was significant ($P = 0.001$), and CBB had the greatest influence for the disease variables, while plant age and ecozones had the highest weight for the non-disease variables. In the third canonical variates of the disease variables, WLS and BILS had the highest reverse direction weight, whereas for the non-disease variables ecozones and soil texture had the highest positive influence. These canonical correlations con-firmed the relation between WLS and soil texture (Table 6) and newly revealed an importance of the variables ecozones, soil moisture, vegetation type in surroundings of a field (was shown for BLS also by Pearson correlation analysis) and abundance of weeds for the Cercospora diseases, especially WLS.

DISCUSSION

A country-wide survey for cassava diseases in Togo revealed the occurrence of CBB, CMD and Cercospora leaf spots across ecozones. Statistical analyses indicated the relationship among these diseases, and between the diseases and agronomic, ecological and varietal variables.

Cassava bacterial blight was observed in all the major agroecological zones of Togo. Earlier observations in Togo reported a higher severity of the disease in the forest savanna transition zone than in the wet savanna zone, where it was rarely found, and the absence of the disease in the forest zone (Boher and Agbobli 1992). These authors also reported the frequent occurrence of the disease in the region of Kara in the dry savanna zone which confirms our observations. In other recent surveys, CBB was found in various ecozones across four West African countries, with generally higher incidences in the savanna than in the transition forest zones, and rarely or not described in the forest zones (Wydra and Msikita, 1998; Wydra and Verdier, 2002).

The generally lower severity and incidence of CBB in the forest zone compared to the savanna zones may be due to the climatic conditions, since great differences in night versus day temperatures as they occur in the savanna zones were reported to promote the disease (Takatsu et al., 1978; Lozano, 1986). Nevertheless, our results showed a high CBB incidence of plants in the forest as never reported before from the forest zones in Africa. Although the lowest average disease severity of 1.7 (data not shown) was recorded from this zone, systemic infections (classes 3 - 5) were also observed. Glasshouse experiments revealed that *X. axonopodis* pv. *manihotis* survived longer under dry than moist conditions (Fanou et al., 2001) which may contribute to the lower disease severity observed in the forest zone than in the savanna zones. The incidence of the disease in the savanna transition zone may be favored by two rainfall seasons alternated by two dry seasons (Lamouroux, 1979) supporting a better survival of the pathogen (Fanou et al., 2001), and the old establishment of the pathogen in this area (Olympio 1977).

CBB was not observed in the rainforest of Cameroon (Wydra and Msikita 1998) and in the rainforest - and the Sudan savanna - zones of Ghana in 1993 (Wydra and Verdier, 2002) and hardly found in the rainforest of Ghana and Benin in 1994, with disease incidence of 2 and 4%, respectively. CBB incidences below 10% were reported from few deforested high rainfall areas during a survey in the rainforest zones of southern Nigeria, while in Benin, CBB incidence of 85% in the dry savanna zone (Wydra and Msikita, 1998) and 86% in the Sudan savanna zone (Wydra and Verdier, 2002), and in Congo and in Central Africa higher severity in the savanna zones than in the forest transition and rainforest zones (Daniel et al., 1981; Persley, 1979) were observed.

The increase of the disease in the forest zone of Togo compared to the survey of Boher and Agbobli (1992) may also be due to the continuous introduction of infected planting material deriving from the epidemic areas, especially the forest savanna transition zone, and to the deforestation due to human activities. Epiphytic and systemic survival of the causal agent of CBB on the plants and in the cuttings, respectively, was demon-strated (Lozano and Sequeira, 1974; Fanou 1999). The fact that cassava fields were in close neighbourhood may have increased the transmission of the pathogen by wind-driven rain and insect vectors from infected to healthy plants and from diseased to healthy fields (Daniel and Boher, 1985; Zandjanakou et al., 2001; Zandjanakou-Tachin et al., 2007). Additionally, new strains may have Developed which may overcome the resistance of varieties and, thus, lead to new occurrence of the disease in before disease-free areas, since differences between *X. axonopodis* pv. *manihohtis* strains were observed (Verdier et al., 1998; Wydra et al., 1998), and resistance of genotypes was recently reported be at least partly based on molecular markers with specificity for African strains from diverse geographic origin (Wydra et al., 2004). Aslo the expression of varietal resistance may be variable in different ecozones (Zinsou et al., 2006).

The statistical analyses confirmed that CBB was positively correlated with ecozones, with decreasing incidence and severity from the herbaceous savanna without trees (dry savanna zone) to the forest zone. The suppressive effect of vegetation and soil moisture was confirmed by Pearson correlation and canonical correlations analyses. A vegetation with many trees may offer high humidity and shade, and low temperature fluctuations between day and night.

CBB was positively associated to increased plant age. Also, Wydra and Verdier, (2002) observed higher severity of CBB in old than in young plantations in Benin and Ghana. A long vegetative period of an infected cassava plant may provide enough time to *X. axonopodis* pv. *Manihotis* for its multiplication and systemic colonization, and for infection of the whole plant, especially in susceptible varieties. CBB was more important in weedy plantations, indicating that weeds could play a role in the spread of the disease. The epiphytic survival and multiplication of *X. axonopodis* pv. *manihotis* on weeds have been reported (Daniel and Boher, 1985; Fanou et al., 2001). Thus, weeds may constitute an inoculum source that can be transferred to cassava plants by insects such as *Zonocerus variegatus* (Fanou, 1999; Zandjanakou et al., 2001, 2007) and by rain splash. However, no weed has been identified as alternative host of *X. axonopodis* pv. *manihotis* (Ikotun, 1981; Fanou et al., 2001).

Cassava mosaic disease incidence and severity were more prevalent than CBB in all ecozones of Togo, as it was also reported from several countries in West and Central Africa (Wydra and Msikita, 1998; Wydra and Verdier, 2002). For CMD and the other cassava diseases, except CBB, no ecozonal differentiation was found. Similar observations were made for CMD in Benin and Ghana by Wydra and Verdier (2002) and in Rwanda by Legg et al. (2001), who did not find clear differences between ecozones. However, CMD was reported to be prevalent in the wet coastal areas in Kenya (Bock, 1994) and in the rainforest of Côte d'Ivoire (Fauquet et al., 1988), and Legg et al. (2001) observed that CMD symptoms were more severe in the North-East administrative region than in the other areas surveyed in Rwanda. Our results revealed an average CMD incidence of 76%, while Wydra and Verdier (2002) observed incidence of 31 and 80% in Benin and Ghana, respectively. The differences in CMD incidence observed between Benin, Ghana and Togo may be due to population differences of the whitefly (*Bemisia tabaci*), the vector insect of the disease. Legg (1999) and Legg et al. (2001) reported that the spread into Rwanda of the EACMV-Ug variant associated pandemic of severe CMD was evident through migration of viruliferous whitefly populations from the neighbouring countries of Uganda and/or Tanzania, which had been affected in previous years. Our results revealed that CMD severity increased when several cassava varieties were grown in mixture in a field and in fields with abundant weeds as confirmed by the observations of Wydra and Verdier (2002) in Benin and Ghana. Fargette et al. (1994) found that CMD was less severe in old cassava plantations, while the present analysis did not reveal this relationship.

Cercospora leaf diseases occurred in all the ecozones of Togo with high field incidences. An increasing susceptibility to the disease on sandy loam and loamy sand soils was observed. Also, few trees in the surroundings of a field and intercropping systems favored the infection by *Cercospora henningsii,* while a mixture of cassava varieties in a field had a suppressive effect on white leaf spots. Lozano and Booth (1974) and Boher et al. (1978) observed that Cercospora brown leaf spots occurred more in dryer areas, while Wydra and Verdier (2002) found BLS associated with trees in the surroundings of a field. In Congo, Cercospora white leaf spots occurrence showed no ecological preference (Boher et al., 1978), but Lozano and Booth (1974) found that the disease was associated to more humid and cooler ecozones in Latin America.

Correlation analysis on a field basis revealed significant negative correlations between CBB and CMD incidences and between CMD and Cercospora white leaf spots, while no significant correlation was found between CBB and Cercospora leaf diseases. Evaluating cassava genotypes for reaction to major diseases, Fokunang et al. (2000b) found that CBB and CMD incidence were not significantly correlated. However, significant correlation was observed between CBB and CMD severity in a cassava germplasm collection (Fokunang et al., 2000a).

Cassava anthracnose disease was found in few fields, generally with low severity, as also reported from the surveys in Benin and Ghana by Wydra and Verdier (2002). Symptoms of anthracnose disease were observed in older plantations, but most of the visited fields were planted with cassava of less than one year. Additionally, it may be difficult to distinguish in the rainy season, when CBB symptoms are prevalent, anthracnose symptoms from CBB symptoms on stems of a plant which clearly carries CBB, which is identifiable by the additional leaf and systemic symptoms on petioles.

The cassava disease survey provided information on cassava bacterial blight, cassava mosaic disease and cercosporioses, never reported at this disease level before in Togo. Some of the evaluated agroecological factors such as ecozone, plant age, weed density, vegetation type, intercropping and soil type and moisture influenced disease occurrence and should be considered when developing integrated control measures. Nevertheless, it should not be neglected, that conclusions based on data from a survey of one year may not be valid for other years under changing climatic conditions.

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