ASSESSING THE IMPACT OF AGRONOMIC, GEOGRAPHICAL AND CLIMATIC VARIABLES ON THE SPREAD OF CASSAVA ANTHRACNOSE DISEASE IN COTE D'IVOIRE

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ABSTRACT

The aim of this study was to assess the impact of a set of variables (agronomic, geographic and climatic) on the spread of the cassava anthracnose disease at a national scale in Côte d'Ivoire. Survey conducted between 2014 and 2017 allowed determining the incidence and the severity of this disease in cassava farms using an infection scoring scale. Farms' infection was found increasing from clean farms (1 %) to infected grass ones (4 %). Furthermore, high infestation rates and differences were observed in monoculture (10 %) and intercropping (21 %). The magnitude and severity of anthracnose disease was found higher within farms with planting densities of more than 10,000 cassava plants / hectare. Farms situated between parallels of the fifth and ninth degree at latitude North are severely infested.

Key words : Cassava, Anthracnose, Agronomic Practices, Climatic Parameters, Côte d'Ivoire.

RESUME

L'objectif de cette étude, était d'évaluer l'impact de certains facteurs agronomiques, géographiques et climatiques sur le développement de l'anthracnose du manioc et la distribution des zones d'infestation en Côte d'Ivoire. Des prospections menées entre 2014 et 2017 ont permis de déterminer l'incidence et la sévérité de l'anthracnose dans des parcelles de manioc. Il en ressort que les infestations des parcelles ont augmenté de 1 à 4 % en passant des parcelles Propres aux parcelles Enherbées. Les proportions des parcelles infectées ont augmenté de 10 à 21 % respectivement pour les parcelles en culture pure et les parcelles en association culturale. Les densités de plantation supérieures à 10 000 pieds/hectare ont exacerbé l'ampleur et la gravité de l'anthracnose du manioc. Les parcelles, situées entre les parallèles du cinquième et du neuvième degré de latitude nord, sont sévèrement infestées. Les températures et humidités relatives élevées qui ont prévalues, dans les différentes localités, ont amplifié la pression parasitaire. Les pluviométries élevées ont moins favorisé la propagation et l'intensification des infections.

***Mots clés :** manioc, anthracnose, pratiques agronomiques, paramètres climatiques, Côte d'Ivoire.*

INTRODUCTION

Côte d'Ivoire is located in the tropical zone between parallels at latitude 4°30 and 10°30 North. It has seven agro-ecological areas marked by a variability of geographical, climatic and cultural variables (Halle and Bruzon, 2006). Cassava is grown for food and socio-economic needs. In Côte d'Ivoire, this crop is based on a diversity of local and improved varieties whose choice is subject to agronomic and gastronomic features (Krabi *et al*., 2015 ; N'zué *et al.,* 2013). They are farmed according to various farming practices such as crop rotation, varietal combining and the reuse of cutting without using an appropriate route (Djaha *et al.,* 2018). These systems of production allowed classifying Cassava as second food crop because of its yields in weight of fresh tuber (FAO, 2016). However, its production has declined sharply in the last three years. It decreased from 4, 239,303 tons in 2014 to 3, 674,818 and 3, 210,614 tons respectively in 2015 and 2016 (FAO, 2016). Some farming practices such as the quality and the status (improved and local) of farming equipment and farming conduct could be the cause of a high parasitic pressure (Frangoie *et al.,* 2014 ; N'zué *et al.,* 2013). Also, the spread of farms according to the type of vegetation and environmental conditions could constitute another phytosanitary constraint closed to the production of cassava (Akinwale *et al.,* 2011). Appearing on the number of these constraints closed to the production of cassava, fungal pathologies notably the anthracnose could be favored by biotic and abiotic variables. It could strongly contribute to yield loss in all the areas of high production by the damaging of farming equipment and the death of young cassava plants (Tata Hangy and Mahungu, 2014; Ghini *et al.,* 2011). The spread, incidence and severity of anthracnose in Côte d'Ivoire have reached worrying levels in some agro-ecological areas (Yéo *et al.,* 2017). However, the predominance of local farming practices and environmental conditions on the spread of cassava anthracnose are not very documented or are not yet established.

The aim of this study is to assess the impact of a set of variables (agronomic, geographic and climatic) on the spread of the cassava anthracnose disease at a national scale in Côte d'Ivoire.

EQUIPMENT AND METHODS

STUDY AREA AND FARMS CHOICE

This study has been conducted in all the agricultural areas of the country. Let us note that Côte d'Ivoire is delimited at latitude 4°30 and 10°30 North, and at longitude 2°30 and 8°30 West. We come across the subequatorial climate in the South and East, the sudano-guinean climate in the North, and the mountain climate in the West. The transition area is covered with a sudano-guinean climate and separates the forest belt from the savannah area in the North (FAO, 2015). Average annual temperatures vary between 24 and 32 °C and every year the height average rainfall are between 1150 and 2500 mm (FAO, 2015). Farms were selected according to the distance and the production of cassava in the area. The ones which have been visited were as a matter of urgency on the hedge of the road. These farms had to have a surface area big enough to include a number of young plants superior to 30 plants. Three peasant farms, on average, have been subjected to health assessment on 10-20 km around some visited localities (Wokocha and N'neke, 2011). Every farm is listed by its geographic coordinates (Longitude, Latitude and Altitude) recorded from a Global Positioning System (GPS).

ASSESSMENT OF AGRONOMIC PRACTICES AND DEVELOPMENT OF CASSAVA ANTHRACNOSE

Varietal diversity was assessed on the basis of qualitative and domestic criteria such as the hue of the wadded rod, petiole and the type of tuber use. These criteria and the information collected from the farmers allowed the identification and classification of varieties. Facing anthracnose, the health condition of these varieties has been assessed through the incidence and the severity of infestation. The maintenance level of visited farms was assessed in relation to the importance of grassing. Farms were therefore gathered together according to the status of clean and grassed farms. Clean farms are those with a very low self-propagating flora that does not hide the annulus of stems. Farms whose altitude of self-propagating exceeds the first nodal stages were classified as grassing. The health condition of the growing variety on the farm was considered as that of the farm.

The type of farming adopted in each farm was assessed by considering cassava as the main crop. The modalities that govern this farming parameter are « pure crop » of cassava and « crop rotation » for the combining of crops (Zinsou *et al.*, 2004). Pure crops or monocultures should only consist of one variety of cassava. Crops rotation also consisted of both mixtures of different varieties of cassava and cohabitation with other crops. The incidence and severity of anthracnose on varieties were used to assess the impact of each type of crop in the spread of the disease.

THE DEVELOPMENT OF CASSAVA ANTHRACNOSE ACCORDING TO PLANTING DENSITY

Planting density give an account of the spacing average between the young plants of the farm. It was appreciated by spacing measuring around of 10 young plants following two perpendicular axes whose intersection point was the considered young plant. Three modalities served as a basis for the gathering together of farms. Density « D1 » gathers together farms with spacing averages inferior to 1 m for a number of plants superior to 10,000 plants / hectare. Density « D2 » corresponds to spacing average of 1 m for 10,000 plants / hectare. Density « D3 » represents spacing average superior to 1 m for a number of plants inferior to 10,000 plants / hectare (Frangoie *et al.,* 2014 ; N'Zué *et al.,* 2013). The health condition of farms of these different groups supported the assessment of the spread of anthracnose according to planting density.

ASSESSMENT OF CASSAVA ANTHRACNOSE SPREAD ACCORDING TO LATITUDE LEVELS

Visited farms were gathered together along with delimited bands by the degrees of latitude that cover the country from west to east. This gathering together allowed obtaining seven portions whose superposition from North to South is given as follows : [11°- 10°], [10°- 9°], [9°- 8°], [8°- 7°], [7°- 6°], [6°- 5°] and [5°- 4°]. The different portions were associated to agro-ecological areas and farms. The spread of cassava anthracnose inside different bands of latitude is deduced from the health condition of farms that they cover. The impact of gathering together by band, delimited by the degrees of latitude on the development of anthracnose is assessed from the incidence and severity of the disease.

$$Is = \frac{\sum ab}{N}$$

CLIMATIC DATA COLLECTION FROM THE STUDY ENVIRONMENT

Pluviometry, rainfall, temperature and relative humidity average were calculated from synoptic stations survey of SODEXAM (Aeronautical and Meteorological Airport Operating and Development Company). They were grouped together on monthly and annual averages and according to Standard Precipitation Index (SPI) based on the average of 1971-2000 (Chowdhury et Hossain, 2011; McKee *et al.*, 1993). The development of annual averages of meteorological data was confronted with the development of anthracnose within agro-ecological areas and on a national level.

ASSESSMENT OF THE INCIDENCE AND SEVERITY OF CASSAVA ANTHRACNOSE DISEASE

Incidence average (Ia) and index average of severity of anthracnose were determined by observations based on 30 plants on each visited farm, following the diagonals of the farm (Wokocha *et al.,* 2010). Incidence average (Ia) gives an account of the proportion of sick plants on all the observed plants. The Severity index (Si) expresses the level of infection gravity according to the notation scale from 1 to 5. The Severity index has been calculated according to the formula of Tchoumakov and Zaharova (1990) modified.

$\sum ab$: the formula sum of the multiplications of the number of sick plants (a) by the degree of affected infection (b) ; N : total number of sick plants.

The notation scale is defined as follows : 1 : Absence of symptoms ; 2 : Little superficial canker on woody stems ; 3 : Numerous deep cankers on the woody stems and the deformation of the stem ; 4 : Numerous cankers and oval lesions on the green stems and severe necrosis in the axil and on the petioles of the leaves 5 :

Wilting, strong defoliation, withering and death of the summits.

SAMPLING AND MICROBIOLOGICAL TREATMENT

Some samples of stems, petioles and infected floral organs were collected and classified according to their diversity, variety and origin. Microbiological analyses consisted of isolating and purifying according to the method of Fokunang and Dixon (2006). Farming, morphological and pathogenic features were focused on qualitative and quantitative criteria used by Fokunang *et al*., (2000).

STATISTICAL ANALYZES OF DATA AND MAPS CONSTRUCTION

Statistical analyzes were performed with the help of Statistica version 7.1. and « R×64 » version 3.0.3 software. Collected data were subjected to descriptive, multivariate and ANOVA variance analyses. The separation and gathering together of different significant averages were done according to Duncan test at the threshold 0.05. Instat Plus software version 3.36 was used to treat climate data.

Illustration maps were established using MapInfo Professionnelle (7.5). Visited areas were digitized from their GPS coordinates. Coloring was adopted by respecting different modalities.

RESULTS

THE EFFECT OF VARIETAL DIVERSITY ON THE PREVALENCE OF CASSAVA ANTHRACNOSE

The denomination of the National Agronomic Research Center (NARC) and the vernacular names collected from farmers permitted identifying 12 varieties of cassava. The improved varieties encountered were Bocou1 and Yavo. Variety Yavo was more encountered than Bocou1 with respective proportions of 9.20 and 0.61 %. Yavo was more infected with an incidence average of 41.33 % and an index average of severity of 2 while Bocou 1 is appeared apparently healthy. Ten local varieties known as Akama, Accra, Agba-biékro, Bonoua, Bâ, Dankwa, Diarrassouba, Kokomakani, Yacé and red unknown 1 had a large spreading in the adopted areas. Anthracnose was more severe on these varieties with incidences average ranging from 40 to 100 % and index average of severity from 1.5 to 4.3. The Akama and Yacé variety are highly infected index average of severity ranging from 2.1 to 4.3. Bâ with an index average of severity of 1.7 underwent an infestation average (Figure 1).

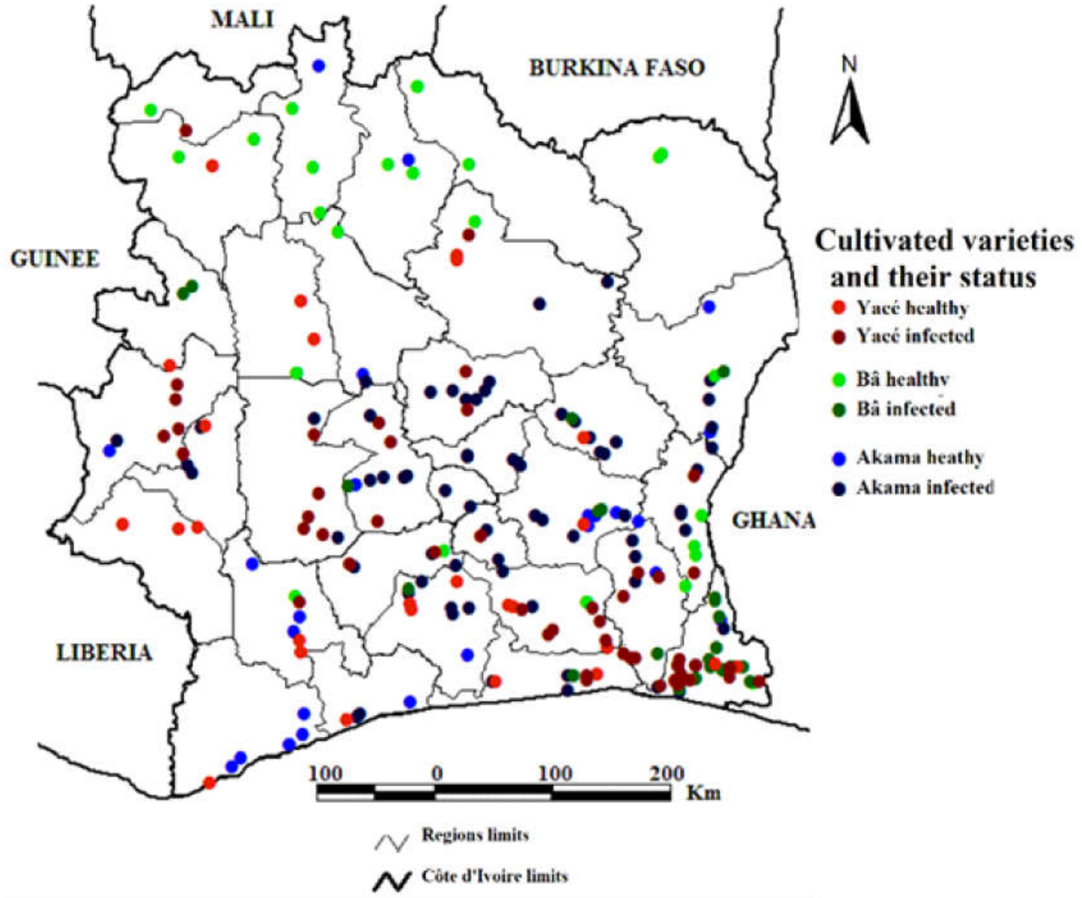

Figure 1 : Geographical Distribution of Three Cultivated Cassava Varieties in Côte d'Ivoire.

Répartition géographique de trois variétés de manioc cultivées en Côte d'Ivoire.

These incidences and index averages of severity were different from a farm to another within an agro-ecological area and also different from an agro-ecological area to another.

FARMS MAINTENANCE IMPACTS ON THE DEVELOPMENT OF CASSAVA ANTHRACNOSE DISEASE

For all visited farms in 2016 and 2017, respectively, 60 and 59.2 % were infected. For all infected farms, 52 % in 2016 and 50.26 % in 2017 were grassed farms against 48 and 49.74 % of clean farms, respectively in 2016 and 2017. Infestation proportions increased from 1 to 4 % passing from clean infected farms to infected grassed farms.

IMPACT OF CROP TYPE OF FARMS ON THE DEVELOPMENT OF CASSAVA ANTHRACNOSE DISEASE

The spread of infection to *Colletotrichum gloeosporioides* Penz *manihotis,* according to the crop type, of which the pure crop and crop rotation, has shown a highly significance difference ($P = 0.01$). The infestation proportion in pure crop was 57 % in 2016 and 67 % in 2017. The ones of farms in crop rotation were 67 and 88 %, respectively, in 2016 and in 2017. The proportion of infected farms increased from 10 to 21 %, passing from pure crops to crop rotations according to the different crops (Table 1).

Table 1 : Health Condition of Farms according to the Types of Cassava Farming in Côte d'Ivoire.

Etat sanitaire des parcelles selon le type cultural en Côte d'Ivoire.

Types of Farming Encountered	Proportion (%) by Health Conditions	
	Healthy	Infected
Pure crops	43	57
Cocoa + Cassava + Banana	50	50
Cassava + Cashew	89	11
Cassava + Yam	33	67
Cassava + Rice	100	0
Cassava + Gumbo	100	0
Cassava + Banana	89	11
Cassava + Hevea	0	100
Cassava + Palm	0	100
Cassava + Corn	33	67
Cassava + Banana + Cashew	0	100
Cassava + banana + Teak	0	100
Cassava + Taro	0	100

PLANTING DENSITY IMPACT ON CASSAVA ANTHRACNOSE DISEASE DEVELOPMENT

Planting density was negatively correlated with incidence ($r = -0.14$) and severity index ($r = -0.12$). Average values of incidence and severity index were significantly different from a density to another. Type « D1 » farms, with the highest densities, recorded the highest average incidence and severity index. The gravity and extent of cassava anthracnose for planting densities « D2 » and « D3 » remained noticeably the same and weak compared to that of « D1 » during both years (Figure 2).

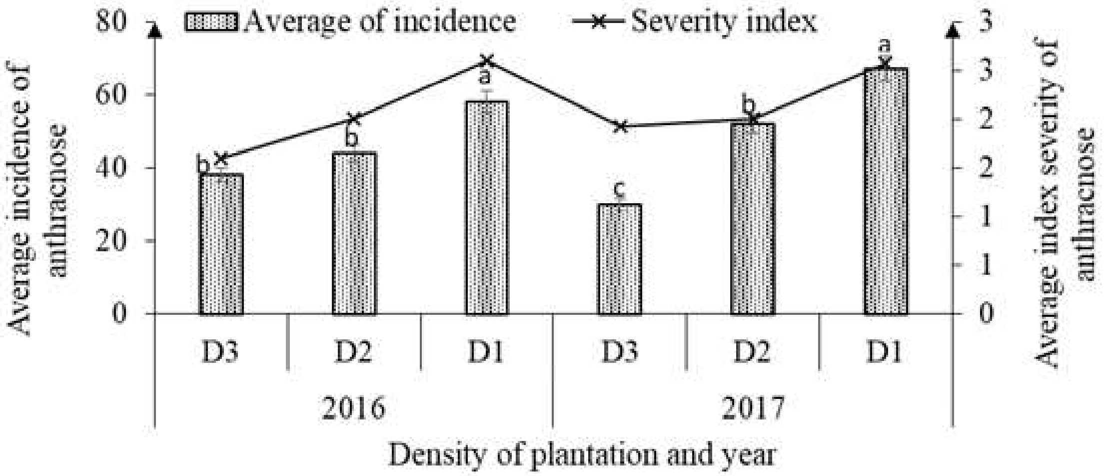

Figure 2 : Development of Anthracnose according to Planting Density (D1 = 20,000 plants / hectare, D2 = 10,000 plants / hectare, D = 6,000 plants / hectare)
(Successive letters refer to classes with significant different averages)

Evolution de l'anthracnose selon la densité de plantation (D1 = 20 000 pieds/hectare ; D2 = 10 000 pieds/hectare ; D = 6 000 pieds/hectare
(Les lettres successives désignent les classes ayant des moyennes significativement différentes)

SPREADING OF CASSAVA ANTHRACNOSE ACCORDING TO LATITUDE LEVELS IN COTE D'IVOIRE

The spreading of average incidence and average severity index according to degrees of north latitude revealed three classes with highly significant difference. Highest values of average incidence and average severity index were concentrated between the fifth and ninth degrees of north latitude. For 2016 and 2017, this portion accounted for 54.67 % and 54.29 % infected farms respectively, that is to say 1 infected farm out of 2. Proportions of farms with average severity indexes greater than 2 were 61.50 and 59.51 % respectively in 2016 and 2017.

The lower band delimited by the fifth and fourth degree of north latitude, gathered together farms with a maximum of 1 infected plant out of 4. Average of severity indexes were less than 2. The upper band delimited by the ninth and eleventh degrees of north latitude gathered together average incidence below 25 % with average severity indexes below 2. According to this gathering together pattern, 1 plant of cassava out of 2 grown in Côte d'Ivoire was affected by anthracnose between 2016 and 2017. Annual average of severity indexes expressed was 2.1 in 2016 and 2 in 2017 (Table 2).

Table 2 : Distribution of Anthracnose according to Geographical and Climatic Parameters. (Successive letters denote classes with significantly different averages)

Distribution de l'anthracnose en fonction des paramètres géographique et climatique (Les lettres successives désignent les classes ayant des moyennes significativement différentes)

LATITUDE (°)	Averages of incidence (%)		Averages of severity index	
	2016	2017	2016	2017
[11-10]	0 c	0	0 c	0 c
[10-9]	15 c	6	2 b	1 b
[9-8]	43 b	28	3 a	2 a
[8-7]	54 a	46	2 a	3 a
[7-6]	39 b	38	2 a	2 a
[6-5]	40 a	51	2 a	3 a
[5-4]	3 c	10	0 c	1 c

CLIMATIC VARIABILITY IMPACT ON THE DEVELOPMENT OF ANTHRACNOSE

Correlation test, between climatic variables (temperature, humidity and pluviometry), incidence and severity, revealed two levels of development. Temperature and average relative humidity were positively correlated with incidence and severity index respectively. However, the pluviometry had a negative correlation with the incidence and severity of cassava anthracnose. Annual averages of rainfall were high in 2014 and 2016 with respectively 1511 and 1313 mm, 2015 and 2017 were less wet, with respectively 1173 and 1163 mm of rain. Annual average of temperature during the same years was 26 and 25 °C, respectively, for 2014, 2015, 2017 and 2016. Relative annual averages of humidity were between 84 and 81 %. Annual averages of incidences of anthracnose were significantly different. The highest values were observed in 2017 with 45, 52 % and in 2015 with 39, 44 %. They were 36.20 and 34.79 % respectively in 2014 and 2016 (Figure 3). Average values of climatic variables were different between agro-ecological areas during assessing periods. Average pluviometry varied from 1950 to 1250 mm. The average temperature was ranged from 32 to 23.5 °C for relative humidity levels of 80 to 55 %. Average incidences and average severity indexes within agro-ecological areas were significantly different (Figure 4).

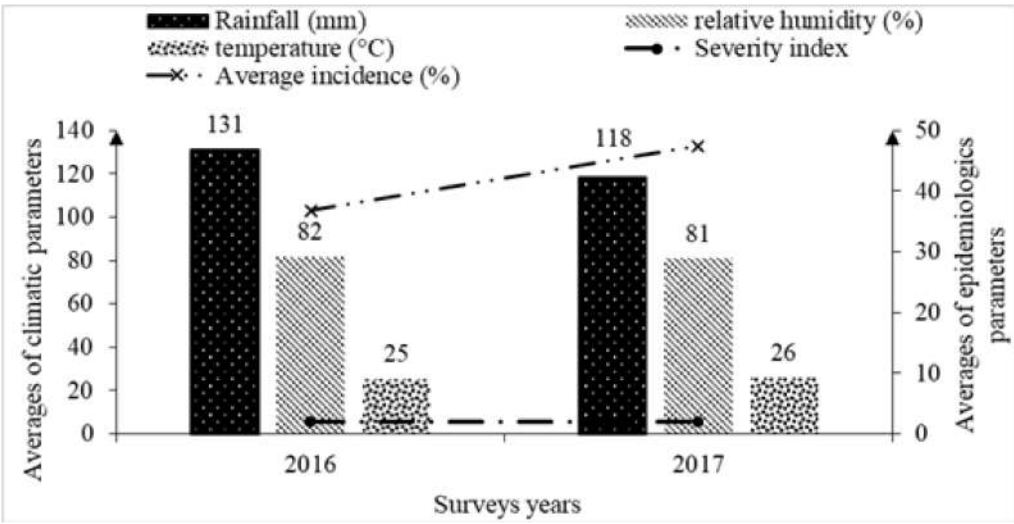

Figure 3 : Development of Climatic Variables and Cassava Anthracnose in Côte d'Ivoire,

Evolution des paramètres climatiques et développement de l'anthracnose du manioc en Côte d'Ivoire.

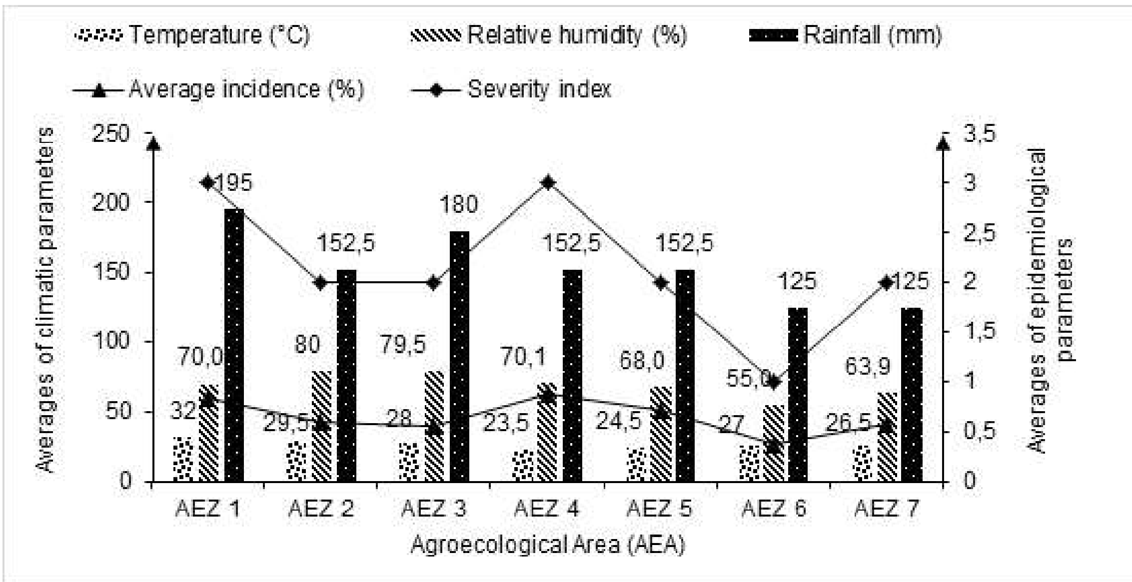

Figure 4 : Development of Climatic Variables and Cassava Anthracnose in Agro-Ecological Areas (AEA) in Côte d'Ivoire.

Evolution des paramètres climatiques et développement de l'anthracnose du manioc dans les zones agro-écologiques (ZAE) en Côte d'Ivoire.

IMPACT OF GEOGRAPHICAL AND CLIMATIC VARIABLES ON THE SPREAD OF *COLLETOTRICHUM GLOEOSPORIOIDES* PENZ *MANIHOTIS* CAUSING CASSAVA ANTHRACNOSE DISEASE IN CÔTE D'IVOIRE

Isolations and purifications carried out on PDA medium (Potato Dextrose Agar) allowed collecting 162 isolates of *Colletotrichum gloeosporioides* Penz *manihotis*. They are spreaded according to three aspects of the aerial thallus with cottony (62.81 %), fibrous (24.79 %) and ras or hyalin (12.4 %). The distribution of these different aspects of the thallus, according to the levels of latitudes, revealed their strong concentration between the fifth and the ninth degree of north latitude. The lower and upper bands, bounded respectively by the fourth and fifth, then the ninth and eleventh degrees of north latitude, contained a small proportion of fungal isolates. Bands between the eighth and fifth degrees of latitude had the greatest number of isolates. These areas were marked by moderate temperatures and higher average of rainfall (Table 3).

Table 3 : Spread of *Colletotrichum gloeosporioides* Penz *manihotis* isolates by Geographical and Climatic Variables.

Répartition des isolats de Colletotrichum gloeosporioides Penz manihotis *selon les paramètres géographique et climatique*

LATITUDE (°)	Annual Average Temperature (° C)	Annual Average Pluviometry	Proportion of Isolates (%) by Appearance of Aerial Thallus		
			Cottony	Fibrous	Ras or Hyalin
[11-10]	26,70 ± 1,8	1150-1350	0	0	0
[10-9]	26,70 ± 1,8	1150-1350	2,48	0,83	0,83
[9-8]	26,70 ± 1,8	1150-1750	4,13	1,65	0
[8-7]	29,00 ± 5,6	2500-1300	20,66	9,09	4,13
[7-6]	24,50 ± 7,7	2500-1300	14,05	7,44	2,48
[6-5]	29,00 ± 5,6	2500-1300	20,66	4,96	4,96
[5-4]	23,50 ± 13,4	1300-1750	0,83	0,83	0
[11-10]	26,70 ± 1,8	1150-1350	0	0	0

DISCUSSION

Varietal choice, lack of maintenance, mixed farming, planting density and the distribution of farms controlled the precariousness of cassava farming facing anthracnose disease. The lack of maintenance of farms where sensitive varieties cohabited and crops susceptible to be infected by *Colletotrichum gloeosporioides* Penz *manihotis* increased the parasite pressure. The polyphytophagic trait and ubiquity of *Colletotrichum gloeosporioides* Penz *manihotis* would promote its conservation and dissemination facing flora concentration. Indeed, 600 fungal species of the genus *Colletotrichum gloeosporioides* have been identified infesting 703 genuses of 167 families of both monocotyledonous and dicotyledonous crops (Farr and Rossman, 2018). Also, the cohabitation of plants sharing the same genetic pool or the same range of pathogens would maintain the persistence of infestations. The genus of *Colletotrichum* would have the ability to expand or contract its genetic material to adapt to a host range or environment (Baroncelli *et al.,* 2016). Otherwise, any combination of crops in the control of anthracnose should be carefully studied in view of the importance of this practice, in cassava farming Zinsou *et al.*, (2004) advised the appropriate farming combination against banana black leaf streak disease and cassava bacterial disease respectively. In addition, too high planting densities have amplified the infestations, due to poor aeration that would favor the establishment of a microclimate leading to the development of anthracnose (Douglas, 2011). Cultural practices coupled together with geographical and climatic spread of farms were more expressive on the spread of anthracnose. In fact, temperature, wind, rain, from which the relative humidity flows were stigmatized on the development of fungal pathogens, incidence and severity of cassava anthracnose disease (Lamichhane *et al.,* 2015; Akinwale *et al.,* 2011).) However, the bands delimited by the degrees of latitude, would suggest a better understanding of the impact of both geographical and climatic variables in the development of anthracnose. Meteorological variables prevailing within them seem to be distributed in a homogeneous and regular way (Eldin, 1971) favorable to the establishment or repression of the fungal (Chowdhury and Hossain, 2011, Machowicz-Stefaniak *et al.,* 2011). Our results showed a divergence between the impacts of climatic variables in the development of anthracnose. Thus, high pluviometry contributed little to the anthracnose infestation. This low impact is explained by the predominance of larval stages of the vector during rainy season (Boher *et al.,* 1983). In fact, rainy periods coincide with the breeding season of *Pseudotheraptus devastans* (Distant) (Het Coreidae). In contrast, high temperatures and relative humidity are associated to physiological weakening of plants and activation of the pathogenic cycle of *Colletotrichum gloeosporioides* Penz *manihotis* (Meenakshi and Kulshrestha 2015, Gautam *et al.,* 2013).

CONCLUSION

Cassava production systems are based on agronomic practices, which implementation affects the health condition of cultivated varieties as far as anthracnose is concerned. The Incidence and severity of anthracnose that is rampant on the numerous local and improved varieties were different from one farm to another. This spread of anthracnose disease is closely related to the latitudinal positioning and climatic variability of the production areas.

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