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INCIDENCE OF BLACK POD DISEASE IN THE COCOA ORCHARD OF CÔTE D'IVOIRE

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ABSTRACT

Black pod, caused by *Phytophthora* spp., is the most widespread and significant disease in Ivoirian cocoa plantations. However, the levels of yield losses related to the disease are poorly understood. In order to accurately determine the level of the disease in areas where abnormal yield losses have been reported, observations were made in cocoa plantations in the Sud Bandama, Moyen Comoé, Haut Sassandra, Bas Sassandra, Sud Comoé and Moyen Cavally regions. From this perspective, epidemic observations on-farm were made in 54 rural plantations selected in 9 localities located in 6 main cocoa producing regions. Each observation plot consisted of 100 trees randomly distributed in each cocoa plantation. In each plot, healthy ripe pods infected by black pod, Diplodia pod rot, gnawed pods as well as wilted (physiological drying of very young fruits) cherelles (young pods) were counted biweekly for three years. The results showed that yield losses due to black pod varied depending on the region. The Moyen Cavally region recorded the highest rate of losses (55.22%) compared to 11.44%, 28.84%, 24.44%, 27.04% and 37.25% recorded in the Sud Comoé, Bas Sassandra, Haut Sassandra, Moyen Comoé, and Sud Bandama, respectively. These high rates are similar to those recorded in countries where *Phytophthora megakarya*, a species known for its aggressiveness, is rampant. The epidemiological evolution in those regions showed that black pod attacks occur only during the rainy season. The epidemic phase in the Moyen Cavally stood out from the five other regions by its intensity and duration. The epidemic difference might be due to the progression of *P. megakarya* in this region bordering the new belt previously located in the northern area of Ivorian cocoa plantations. The new outbreak of black pod in that area requires a review of the two-zone subdivision of cocoa plantations, taking into account the structure and dynamics of *Phytophthora* spp populations. Knowledge of the distribution of the incidence as well as the epidemiological evolution in those regions will help develop a regionalized control strategy against black pod.

Keywords: Black pod, *Phytophthora* spp, cocoa tree, epidemic, Côte d'Ivoire.

1. INTRODUCTION

Black pod is one of the most common diseases of *Theobroma cacao* L. It is mainly expressed by trunk and branch cankers as well as brown rot of pods. The impact of cankers takes various forms. They destroy flower cushions on which flowering depends, they weaken the cocoa tree and they form foci from which the parasite reaches the fruits. The damage, however, remains difficult to estimate. But black pod is by far the most damaging disease as it directly attacks the producer's capital (Blaha and Lotodé, 1976, Lass, 1985). The disease is characterized by the appearance of a brown spot on the surface of the pod. After a few days, the spot spreads over the whole fruit. The beans inside are not spared. They take on a blackish coloring which places them in the category of moldy beans, unfit for marketing and are most often destroyed (Lass, 1985, Evans and Prior, 1987). Several species of *Phytophthora* can be the cause of the disease. Two species, *P. palmivora* and *P. megakarya*, are the most important in Africa. The first one, *Phytophthora palmivora* is the most cosmopolite. It is rampant in all cocoa producing countries, causing losses of around 20 to 30%. The second one, *Phytophthora megakarya*, endemic in Central and West Africa, is the most aggressive species. In some countries, this pathogen can cause the loss of all cocoa yields (Flood 2006). In Côte d'Ivoire, this disease is of particular importance. Attack rates of 25 to 30% of yield are commonly recorded each year; in areas where ecological conditions are very favorable for the development of the disease, losses can reach 60% of the yield (Coulibaly, 2014). In Côte d'Ivoire, recent studies have shown the presence of *Phytophthora megakarya* in the eastern sector of the cocoa orchard (Koné 1999, Kouamé 2006); it is considered the most aggressive species (Brasier and Griffin, 1979). Therefore, black pod control in Côte d'Ivoire has become a priority. Generally, the control strategy adopted against black pod integrates the agronomic measures used alone or sometimes in combination with the chemical control and the genetic method. All these phytosanitary measures aim at reducing the yield losses caused by *Phytophthora* spp., and at reinforcing the level of resistance of the plant material. However, the effectiveness of those measures requires investigations to further define the problem of black pod attack in Ivoirian cocoa plantations. Similarly, a better understanding of its impact on cocoa yield and its epidemiological development in cocoa plantations would make it possible to develop regionalized control strategies of this disease.

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Indeed, in Côte d'Ivoire, the world largest producer of cocoa, with more than 44% of supply (Anon, 2000), the estimate of losses is poorly understood which does not make possible the phytosanitary mapping. Moreover, the diagnostic surveys carried out in 1960 have divided the Ivoirian cocoa plantations into a northern zone, less humid and having lower attack levels than the southern zone, more humid. Nowadays, due to the shift of great production areas to the southern zone, black pod now affects a very large part of the cocoa orchard. This shift might have called into question the previous distribution of the disease in cocoa producing areas.

In this study, we propose on the one hand to observe village plantations in Côte d'Ivoire's main cocoa producing regions in order to assess the levels of pod losses due to black pod and on the other hand to follow its epidemiological evolution in those producing regions.

2. MATERIAL AND METHODS

2.1. Description of the study sites

This study was conducted in rural areas in cocoa plantations located in the 6 main cocoa producing regions. These were Moyen-Comoé, Sud-Comoé, Sud-Bandama, Haut-Sassandra, Bas-Sassandra and Moyen-Cavally. The observations were made in the plots located in the localities of Niablé, Aniansué and Abengourou for the Moyen Comoé, the localities of Aboisso, Adaou, Maféré and Ayamé for the Sud Comoé, the localities of Divo, Guitry, Lakota and Tiassalé for the Sud Bandama, the localities of Daloa, Issia, Zoukougbeu and Gonaté for the Haut Sassandra, the localities of Soubré, Gabeadji, Méagui for the Bas-Sassandra and the localities of Dibobly, Guéhéby and Duékoué for the Moyen Cavally. The plantations visited and selected were identified as observation sites.

All these cocoa producing regions are characterized by a sub-equatorial climate punctuated by four seasons of unequal duration. The rainfall regime, which is bimodal, is marked by two rainy periods, interspersed with low rainfall periods or dry seasons: a long rainy season from March to July; a short rainy season from September to November; a long dry season that covers the months of December to February and a short dry season from August to September. The average annual rainfall is between 1300 to 1500 mm. The average annual temperature is 28°C. The average minimum temperature is 26°C. The relative humidity of the air during all the months of the year has an average of 80%.

2.2. Selection of plots

In each of the study regions, three to four different localities were identified. In each locality, a survey was carried out so as to identify 1 to 3 plots representing the observation site. The survey took place on three different directions around the locality. On each direction, a cocoa plantation was selected. Such cocoa plantation should be at least 25 km distant from the other in order to cover the various pedoclimatic conditions of cocoa tree cultivation. Thus, nine cocoa plantations were selected from the localities of a given region, that is, 54 cocoa plantations in the 6 main cocoa producing regions. The plantations selected as observation sites should fulfill the following criteria: have easy access, have a surface area at least larger than 1.5 ha, with a density of at least 1000 cocoa trees per ha, with a uniform shade, a good maintenance condition and the producer should be available and willing to participate in the implementation of the trial. Each cocoa plantation contained trees belonging either to the hybrid ones popularized by the National Center for Agronomic Research (CNRA) or to traditional equipment consisting of West African Amelonado or ordinary material.

2.3. Establishment of tests and assessment of yield loss levels.

In each cocoa plantation, the random target method (Despreaux, 1984) was used to estimate losses due to black pod. This method was selected so as to minimize the extremely heterogeneous nature of cocoa plantations, both in terms of trees and soil, shading and the variability of the infectious pressure in space. This method consisted in following the evolution of the disease in a group of 100 cocoa trees. The 100 cocoa trees were randomly selected from the plantation and marked with numbered signs of the same color. Each cocoa tree under trial was surrounded by at least 8 border trees. During the two consecutive years of the trial, the counts were performed every 15 days. This arbitrary choice was justified by the need to have between two periods a sufficient number of rotten pods on trees, especially in localities where the incidence of the disease is lower. The counts consisted in counting all healthy ripe pods infected by black pod, Diplodia pod rot, gnawed pods as well as young wilted (physiological drying of very young fruits) pods. With the exception of pods infected by black pod, all counted pods were removed after counting (healthy ripe pods were returned to the owner). In order to avoid disrupting the development of the epidemic, all pods infected by black pod were not harvested. They were marked in order to avoid being counted several times. The marking consisted in cutting the tip (apex) of the pod with a pruner. The collected data were recorded per plot and yield losses due to black pod were estimated in relation to the potential yield according to the formula of Berry and Cilas (1994):

$$TF = \frac{\sum CPB \times 100}{\sum CMS + \sum CPB + \sum CPN + \sum CR}$$

Where TF is the final rate in percentage, ΣCPB is the cumulative number of pods infected by black pod, ∑CMS is the cumulative number of healthy ripe pods, ∑ CPN is the cumulative number of pods infected by *Diplodia* pod rot, and ∑CR, the cumulative number of pods gnawed during the whole trial period of a plot then of localities and finally of a given region.

2.4. Statistical analysis

The statistical processing of data was carried out using the STATISTICA version 7.1 software. Since average pod loss differentials were high, it was necessary to perform a transformation for data standardization so as to make sensitive the segregation test of averages. Thus, the corrected pod loss rates were transformed by the arcsine formula before being subjected to analysis of variance. The Newman and Keuls test with a 5% probability was used to compare average pod loss rates.

3. RESULTS AND DISCUSSION

3.1. Assessment of pod and yield loss levels

The significance of the damage in Ivoirian cocoa plantations was estimated by pod losses caused by black pod, Diplodia pod rot and rodent attacks. As for black pod, three different groups of regions were identified after losses recorded in the first year of trial. The first group was represented by the Moyen-Cavally region which recorded the strongest attack with 44.79% of losses caused by black pod. The Moyen Comoé, Sud Comoé and Haut Sassandra regions, whose losses were less than 30%, made up the second group. Finally, the Bas-Sassandra and Sud-Bandama regions recorded 7.92% and 5.87% of losses, respectively (Fig.1a). Those losses were lower. In the second year, the Moyen Cavally region recorded 55.22% of losses, against 11.44% in the Sud Bandama. Those losses were statistically identical in the other four regions. They accounted for 37.25%, 27.04%, 24.44% and 24.15% respectively in the Sud Comoé, Bas-Sassandra, Haut-Sassandra and Moyen Comoé. The statistical analysis results showed that losses caused by black pod varied significantly from one region to another. This result revealed three homogeneous groups of regions (a, b and c) of which the Moyen Cavally is the region most infected by the disease. In contrast, the Sud Bandama region recorded the lowest losses (Fig.1b).

Concerning losses caused by soft rot, two distinct groups of regions were identified at the end of the first year of trial. Significant losses were recorded in the Sud Comoé which made up the first group. The second group was made up of the other regions in which very low losses caused by soft rot were reported (Fig. 2a). In the second year, the Bas-Sassandra region accounted for 10% against 3% of losses in the Haut-Sassandra. In this case, analyses of variance revealed a significant loss effect at 5% threshold according to the Student Newman & Keuls test. These analyses revealed 4 homogeneous groups of regions (a, ab, b, bc, and c). More significant losses were obtained in the Bas Sassandra region (Fig. 2b).

The analysis of losses due to gnawed pods in cocoa producing regions did not reveal, in terms of statistics, any significant difference (at 5% threshold) for both years of trial (Fig. 3a and b). The results showed that, for gnawed pods, the losses varied from 3 to 1% and 4 to 0.6% respectively in the first and second year (Fig.3a and b).

The incidence of attacks on yield was assessed by the rate of healthy ripe pods harvested in cocoa plantations infected with cocoa diseases. Very significant rates of healthy ripe pods were observed in the Bas-Sassandra and Sud-Bandama regions (Fig. 4a). Very low losses caused by black pod were recorded in those regions. The Moyen Cavally and Sud-Comoé regions were characterized by a low yield in the first year of observation. The analysis of the healthy ripe pods rate revealed, in terms of statistics, 5 homogeneous groups of regions (a, ab, bc, c and d). The first group included the Sud Bandama region marked by a high yield. This yield gave 79.76% of healthy mature pods (Fig 4a). In the second year, the Moyen Cavally region, which accounts for the largest losses caused by black pod, gave only 49.88% of healthy ripe pods. In contrast, the Sud Bandama region accounted for 87.75% of average yield of healthy ripe pods. The statistical analysis results showed that healthy ripe pods yield varied significantly from one region to another. This result revealed the existence of 5 homogeneous groups (a, b, bc, c and d) of which the Moyen Cavally was the less producing region. The average yield, the highest one was recorded in the Sud Bandama region, which gave the lowest losses caused by black pod (Fig.4b).

This study has helped highlight a high incidence of black pod on the yield in the localities located in the 6 main cocoa producing regions. This incidence varied considerably from one region to another. Similar results were obtained by Dakwa (1984) and Babacauh (1980). In the Moyen Cavally region, the incidence of black pod during the two years of observation remained strong, 44.79% in the first and 55.22% in the second year (Figure 1). The significance losses observed could be explained by the progression of *P. megakarya* in this western region of Côte d'Ivoire neighboring the new cocoa belt. Indeed, a recent study has detected the presence of *P. megakarya* strains in Soubré and Méagui in this cocoa belt (Kébé, 2010). In those localities, some of the strains showed the same profile as those isolated in eastern Côte d'Ivoire (Moyen Comoé regions) and in Ghana. *P. megakarya* strains in Ghana have been found to be more aggressive than those of *P. palmivora* (Djiekpor *et al.*, 1981, Dakwa 1984, Dakwa 1988, Bower *et al.,* 2001, Akrofi 2003). In the Moyen Cavally, the high incidence of black pod resulted in a poor yield (Figure 4). This poor yield would be attributed mainly to attacks of *Phytophthora* spp. because overall losses of soft rot and gnawed pods were low (Figure 2 and 3). The lower

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incidence of black pod in the Sud Bandama region would be attributed to *P. palmivora*. This cocoa cultivation region might be free from *P. megakarya* with higher yield.

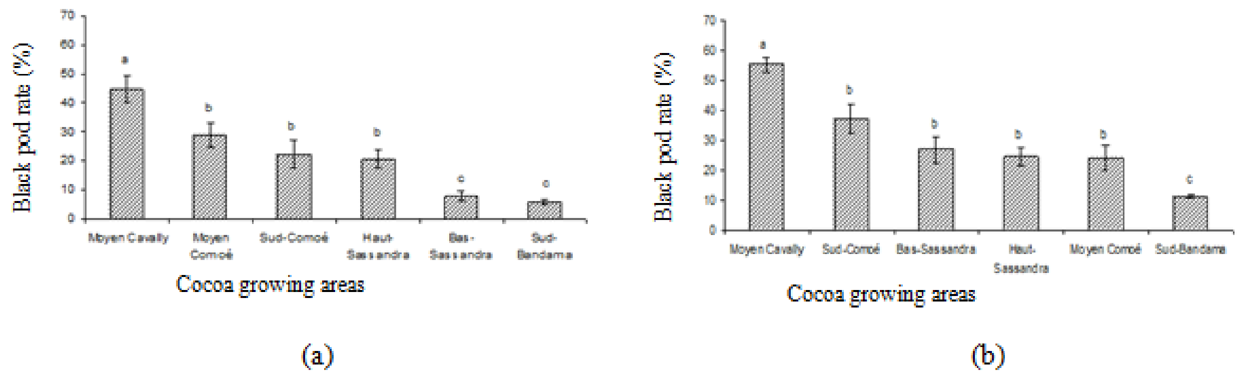


Figure 1: Rate of pods infected by black pod disease depending on cocoa cultivation regions. (a) - first year of observation (b) - second year of observation

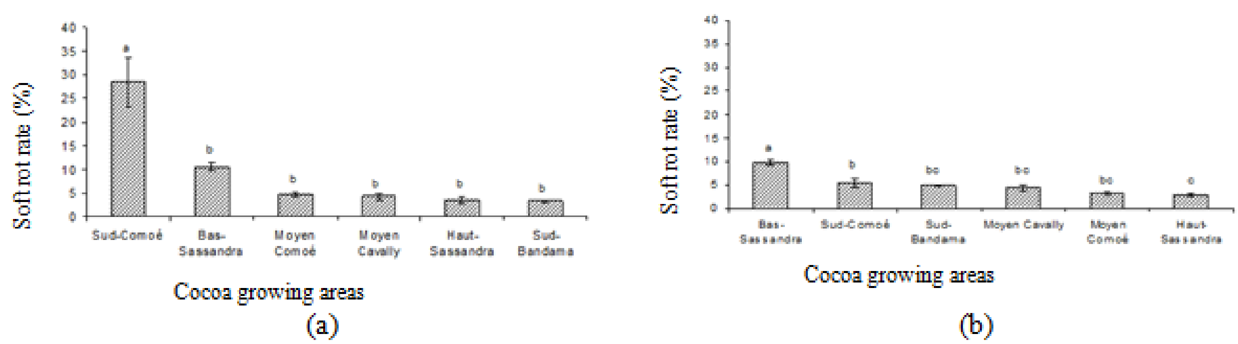
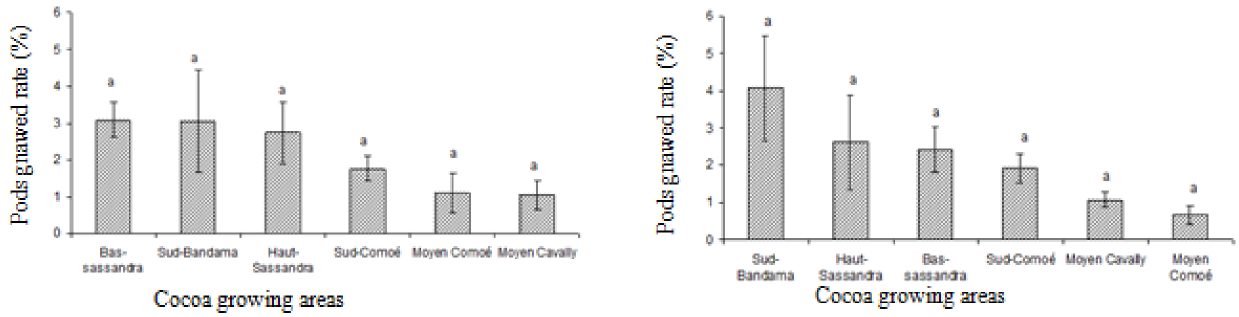
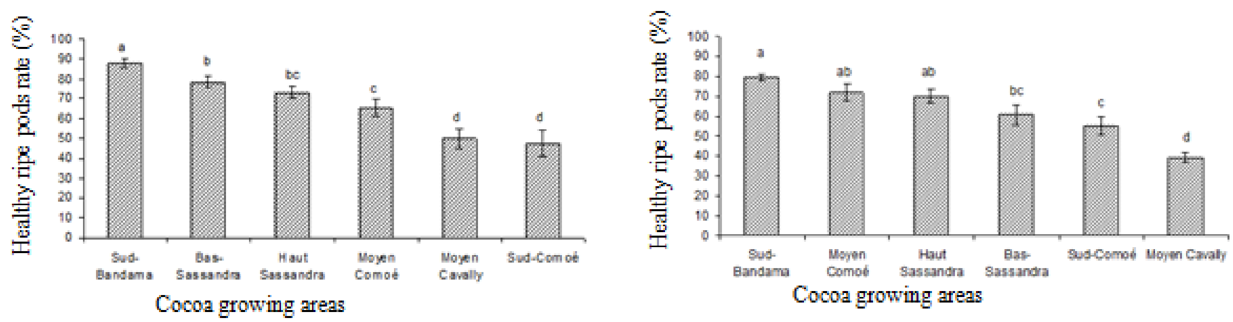


Figure 2: Rate of pods infected by soft rot disease depending on cocoa cultivation regions. (a) - first year of observation (b) - second year of observation



(a) (b)

Figure 3: Rates of gnawed pods depending on cocoa cultivation regions. (a) - first year of observation (b) - second year of observation



(a) (b)

Figure 4: Average healthy ripe pods yield rate depending on cocoa cultivation areas. (a) - first year of observation (b) - second year of observation.

The results of losses caused by black pod on the yield depending on the localities, as determined by percentages of rotten pods, are shown in Figure 5. The analysis showed a significant variation in the disease incidence in the localities of a given region, and yield losses that were variable over the years. Similar results were obtained in Ghana by Akrofi *et al*. (1997) and Dakwa (1973). This variation was very significant in the localities of the Moyen Comoé, Sud Comoé, Haut Sassandra and Bas Sassandra. The percentages of losses in the localities located in said regions ranged from 2.5 to 50.80% in the first year and from 7.5 to 53.79% in the second year (Figure 5). This variation could be explained by the microclimates and the infectious potential of cocoa plantations in the locality. The high density and poor airing of cocoa plantations in rural areas might have contributed to particularly humid microclimates. Moisture related to self-shading of cocoa plantations and rainfall favors the onset and development of the black pod epidemic in a locality (Babacauh 1975, Evans and Prior 1987, Bowers *et al*. Ndoumbé-Nkeng *et al*., 2004).

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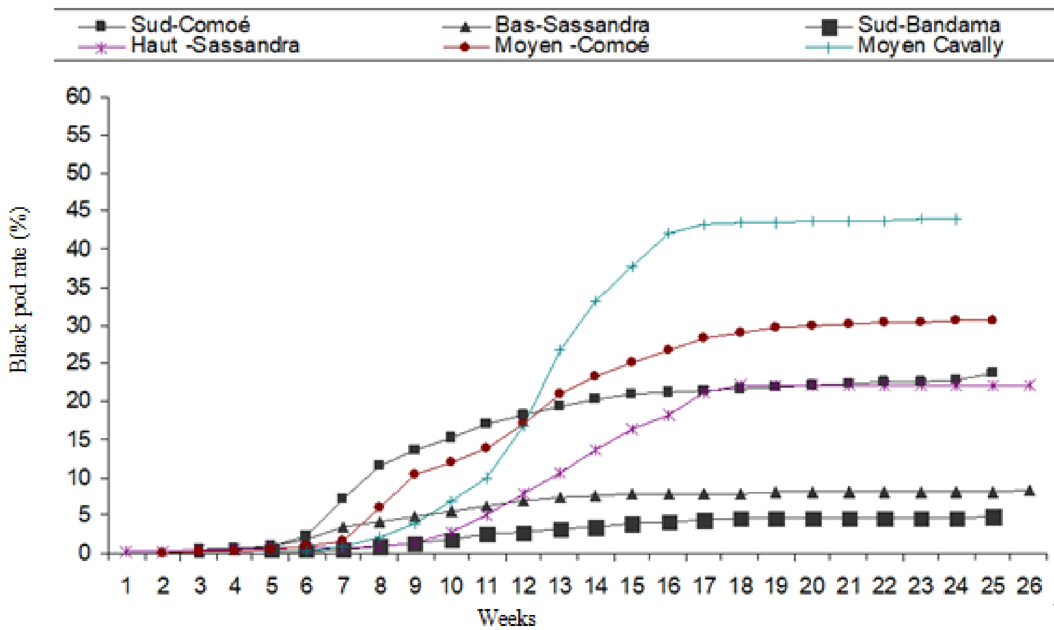

Figure 5: Evolution, over time, of black pod disease in cocoa producing regions during the first year of on-farm observation

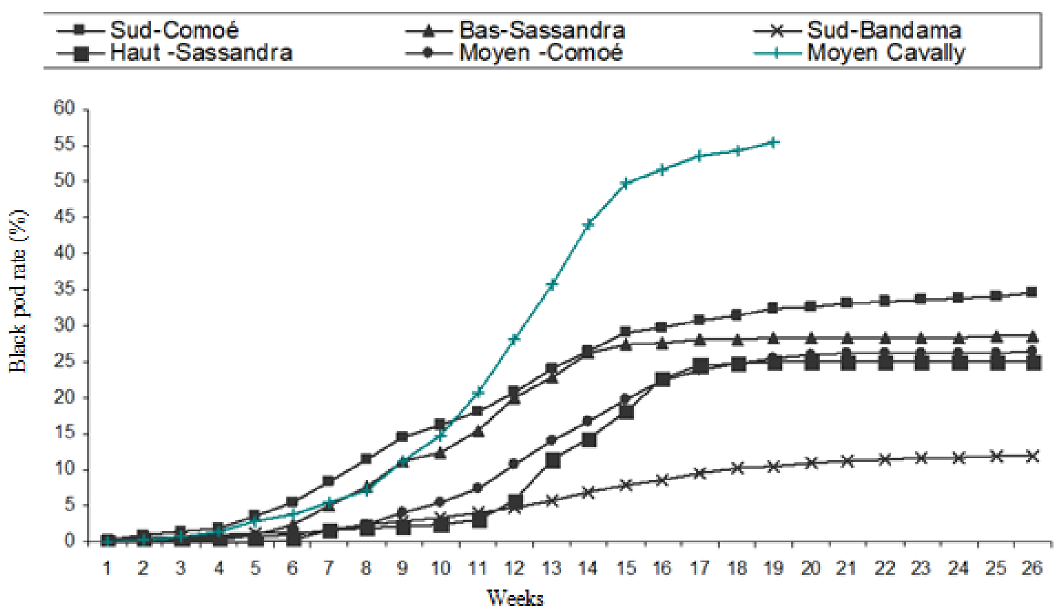

Figure 6: Evolution of black pod disease depending on cocoa producing regions and time (week) during the second year of on-farm observation.

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Furthermore, the potential participation of several sources of primary inoculum (bark, flower cushions, soil) or their importance might vary from one cocoa plantation to another starting from a locality. These primary sources ensure epidermal phase initiation and abundance of the latter, and the short cycle of the parasite causes a long duration of the epidemic (Van Der Plank, 1968, Babacauh, 1980). In contrast, this variation in losses would seem less in the localities of Dibobly, Duékoué and Guéhébly. In these localities, the cocoa plantations might be exposed to the same parasite pressure. The species *P. megakarya* due to its high capacity of sporulation and dissemination might be responsible for the high yield losses recorded in the three localities. These localities traditionally located in the northern part of the cocoa tree orchard recorded losses that reached more than 35% of the yield. Our results do not corroborate those obtained by Bonaventure and Belin (1961), Tarjot (1973), Partiot (1976), Babacauh (1980) and Kebe *et al*. (1996) who showed that in this zone of cocoa plantations, losses did not exceed 20% (15% on average). These results thus call into question the division of the Ivorian cocoa plantations into a northern zone, which is drier and a southern zone, which is more humid and which accounts for 25 to 35% of losses. This division should rather take into account the spatial and temporary distribution of the aggressive species, *P. megakarya* in the Ivorian cocoa orchard.

3.2. Epidemiological evolution of Black pod

The progression curves of the epidemic in the different cocoa cultivation regions during both observation campaigns showed that the attacks of *Phytophthora* spp occured only during the rainy season. These attacks increased from the 4th to the 18th fortnight covering the period from May to November, and reflect epidemic curves in sigmoid. Overall, regardless of the cocoa producing region, three stages of infection caused by *Phytophthora* spp. were detected (Fig. 5). The evolution of the curves showed that the black pod epidemic was expressed with the same intensity in the Moyen Comoé and Sud-Comoé. In the Bas Sassandra and Sud Bandama regions, the curves showed an identical epidemic evolution of the disease (Fig. 5). In the second year, the Sud-Comoé and Bas-Sassandra regions as well as those of Moyen Comoé and Haut Sassandra also showed similar evolution of black pod, but in a different proportion (Fig.6). During the two years of observation, the Moyen Cavally region experienced a strong evolution of the disease with an epidemic phase of 9 to 15 weeks covering the end of the short rainy season (July) and the beginning of the long rainy season (September-October). This evolution was very low in the Sud Bandama.

Epidemiological observations revealed a change in the evolution of black pod in the 6 cocoa producing regions. They also showed that black pod attacks only occur during the rainy season (June to November). This positive correlation between disease incidence and rainfall has been shown in Cameroon, Nigeria, Ghana (Babacauh 1980, Muller 1974, Gregory and Madison 1981, Tarjot 1967, N'doumbe-keng 2002). Water, a decisive climatic factor, is stuck to its dual role as vehicle of parasite propagules. It is also an essential factor in achieving certain asexual phases of the parasite cycle (Babacauh, 1980). In addition to the major role attributed to water, subsistence on cocoa trees of permanent foci which keep on releasing dissemination organs thus creates an endemic situation. The persistence of these foci could explain the strong progression of black pod epidemic in the Moyen Cavally. This region stood out from the 5 others by the duration and intensity of the epidemic phase. In this region, the sanitary harvests appear ineffective because strong attacks let survive on the trees parasite propagules likely to reach the fruit. Thus, the black pod epidemic in this region was expressed from the start at all levels of the tree with the same intensity. This epidemic has increased in the same way regardless of the level of the tree where the fruit was. This epidemic pattern, although observed in the other 5 regions, stood out from the one observed in Central Africa where an intensity gradient was observed from bottom to top of the cocoa tree. Moreover, in the 6 regions, the start of epidemic phases coincided with the main harvest, which extended from September to January, saving the intermediate harvest between April and July. The main harvest represents 80% of the annual yield, thus marking the severity of the attacks caused by *Phytophthora* spp. in the cocoa orchard. In contrast, the development of the epidemic during the most favorable period (July-October) faded between October and November. During this period, the evolution of stationary black pod except for rains is explained by a decrease in the number of fruits on the trees following successive harvests. The similar results were observed by Tarjot (1971) and Babacauch (1980), who showed that a close link might exist between the number of pods on the trees and the significance of the attacks. Furthermore, epidemiological observations indicate that black pod has occurred when there was a conjunction between, on the one hand, the presence of fruits on the tree, regardless of their development stages, and, on the other hand, a rainy period (Muller, 1974, Gregory en Madison, 1981, Asare-Nyako, 1973, Tarjot, 1967). However, the cherelle (small pod) stage remains the most vulnerable of the fruit (Blaha and Lotodé, 1976, Efombagn *et al*., 2004). Similarly, between October and November, cocoa trees bear more ripe fruits than younger fruits. According to Babacauch (1980), fruit maturity would intervene to slow down the epidemic. Thus, the epidemic nature of black pod attacks in 6 major producing regions requires knowledge not only of the components of the environment, but especially the structure and population dynamics of *Phytophthora* spp. populations, in order to develop a strategy for controlling this parasite.

4. CONCLUSION

The results showed a variation in the incidence of black pod in the six major cocoa producing regions. Thus, the Moyen Cavally region has proved to be more attacked by the disease, but low losses were recorded in the Sud Bandama. However, an outbreak of attacks caused by *Phytophthora* spp. was observed in all cocoa producing areas. This outbreak suggests the possibility of permanent and rigorous monitoring of the structure and dynamics of parasite populations in the cocoa orchard. The progression of *P. megakarya* in non-traditional producing areas requires a new approach to black pod control strategy in Côte d'Ivoire.

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