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ORIGINAL ARTICLE

# INFLUENCE OF THE STRUCTURE OF COCOA AGROFORESTRY SYSTEMS ON THE DEVELOPMENT OF BLACK POD DISEASE IN CENTRAL REGION OF CAMEROON

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## ABSTRACT

**Background:** Since the beginning of the 20th century, agronomic research on cocoa cultivation is focused on the formulation of an ideal ecological environment for the cocoa to best express its potential. **Objectives:** This study aims to contribute to the understanding of agroforestry systems based on cocoa trees (ASBCT) and evaluate agro-ecological factors involved in the development of cocoa black pod disease in central region of Cameroon. **Methods:** Four plantations (ASBCT 1; 2; 3 and 4) of more than 1 ha were selected. Four plots of 1250 m² were defined in each plantation that makes 16 plots in total, in which the observations were made in three periods during 2015 (April, July and October). The work consisted to determine the density of plant species, spatial structures, level of shading, assess the epidemiological parameters of cocoa black pod disease (incidence and severity) and to evaluate the cocoa production by counting pods. **Results:** The results show that cocoa is still the most abundant species in the ASBCT studied with an average representation of 91.28 %, while fruit, forest trees, and others plants (Arecaceae and Musaceae) were represented respectively 3.91; 3.18 and 1.63 %. Mapping reveals three types of spatial structures in each ASBCT (regular structure for cocoa, random and aggregated for fruit and forest trees). Tree level of shading were determine: dense shading (ASBCT 2); Average shading (ASBCT 1 and 3); light shading (ASBCT 4). This level of shading decrease according to passing from aggregated structures to regular structures. The incidence of black pod varies from 9 to 26.08 % overall in the ASBCT. The disease severity on pods is very high in the ASBCT and ranges from 39.61 to 86.21 %. This incidences and severities decrease proportionally with the level of shade, tree density and the horizontal spatial structure of ASBCT. Nevertheless these parameters are inversely proportional to healthy pod production. **Conclusion:** this work has improved understanding of the ecological mechanisms involved in the regulation of black pod disease across the plantation and offers prospects for their agro-ecological management.
***Keywords:*** *agroforestry systems based on cocoa trees, cocoa, spatial structure, shade, black pod disease*

## 1. INTRODUCTION

Cacao (*Theobroma cacao*), also called cocoa, a tropical evergreen tree in the family Malvaceae is grown for its edible seeds, which can also be used as primary material in several industries [1]. Worldwide, cocoa is one of the most valuable agricultural product, accounting for about 57 % of exportations in West African countries (Ivory Coast and Ghana), and is produced by more than 50 developing countries in Asia, Africa, and Latin America [2]. Cameroon, being one of the major cocoa producing countries presently occupies the fifth and fourth place worldwide and in Africa respectively [3]. Since the beginning of the 20th century, agronomic research on cocoa cultivation is focused on the formulation of an ideal ecological environment for the cacao to best express its potential. In traditional agroforestry systems, agronomists' recommendations face the problem of "associated trees" [4]. Whether they are coconut growth antagonistic species such as *Ricinodendron heudelotii* that creates excessive shade in cocoa trees in Africa [2, 5], or species with too much competition for nutrients or, finally, host species of bio-aggressors that affect both the yield of cocoa trees and associated plant species [6] These agro-ecosystems, mostly traditional, poorly maintained and controlled, have a great influence on the development of cocoa diseases. Thus, about 40 % of cocoa production is lost annually due to five diseases, adding also losses caused by insects and vertebrae [7]. Black pod caused by fungus of *Phytophthora* genus, is the most important disease affecting cocoa in the world [8]. However, the most aggressive species in Africa is *Phytophthora megakarya*. In areas of high pressure, losses can reach 90 % if no precaution is taken [9]. In Cameroon, many studies have described the cocoa-based of agrofesrestry system from an agronomic perspective [11], ecological perspective [12] and socioeconomic perspective [13]. Despite of these researches, the agroforestry system based on coca are not very productive (± 300 kg of cocoa merchant/ha/year) due to the attack of *Phytophthora megakarya* and does not ensure sufficient income to farmers. Therefore, the analysis of the influence of these systems on the development of cocoa pod disease in the Center production basin of Cameroon, will thus contribute to give information on the profitability of such an ecological environment in the control of black pod disease. The general objective of this study is to evaluate the influence of structure of agroforestry systems on the development of black pod disease.

# 2. MATERIAL AND METHODS

**2.1. Presentation of the study area:** The study was carried out in center region of Cameroon in locality of Boyambassa. It presents a vegetation of savannah and herbaceous savannah type. The relief is composed of plains. The cocoa plantations generally located in the gallery forests are associated with young plantations in savannah, accompanied by food and fruit crops. The plantations located in the study site are mostly old plantations and all are traditional agroforestry systems. In the four agroforestry systems based on cocoa trees studied, two (ASBCT 2 and 3) were created less than 30 years ago and the others (ASBCT 1 and 4) were created more than 60 years ago. As part of this study, in order to characterize the different cocoa-based agroforestry systems and to assess the incidence and severity of black pod disease, three observation periods were made in 2015. The first in April, the second in July, and the third in October. The observation of black pod disease was made by the method of visual recognition of symptoms.

**2.2. Device experimental:** Four cocoa plantations taken from the experimental network of the Trade-off in cocoa project of the Agronomic Research Institute for Development (IRAD) were used, each representing a full-fledged agroforestry system based on cocoa trees (ASBCT). In each ASBCT, quadrats of half hectare (50 m X 100 m) were defined to avoid border lines. Subsequently, each quadrat was divided into four plots of 1250 m², P1, P2, P3 and P4 (Fig. 1), making a total of 16 plots. In each plot, 15 cocoa trees were selected and sampled using tags placed on the trunk.

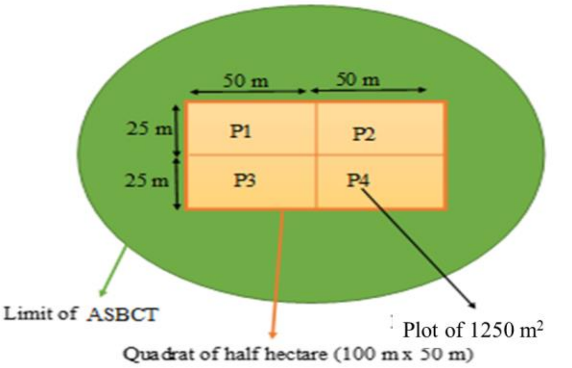


**Figure 1**: The figure presents the experimental design.

**2.3. Density of trees in cocoa trees:** In each plot of the field all trees were identified and classified into two sets: fruit and forest trees and then counted. The plantation densities in cocoa trees were evaluated by counting cocoa trees in each quadrat of 1250 m² and an average per hectare was calculated for each plot of cocoa.

**2.4. Determination of the spatial structure of cocoa agroforestry systems (AFS) studied:** The quadrats of 50 m x 100 m defined at the central of each cocoa AFS as indicated above in the experimental design (Fig. 1) allowed us to obtain an overall map using the X and Y coordinates of each AFS studied. This sampling unit, part of an agroecosystem with larger dimensions, is supposed to be representative of the rest of the plantation and has been considered as a cocoa AFS in its own right. The acquisition of spatially explicit data is indispensable for a study of the spatial structure. It indicates the positions by means of the X and Y coordinates of the individuals constituting the stands of the experimental units. The length (50 m) and the width (25 m) of each study plot were assimilated to an orthonormal coordinate system corresponding respectively to the X and Y axes. Thus, the X and Y coordinates of all perennial plants present in the plot (cocoa trees, forest trees, fruit trees and others) were determined. Subsequently, the type of spatial structure observed after mapping with R version 3.2.2 software was identified from the schematic illustration of various structures listed by Goreaud (2000) [14] (Fig 2).

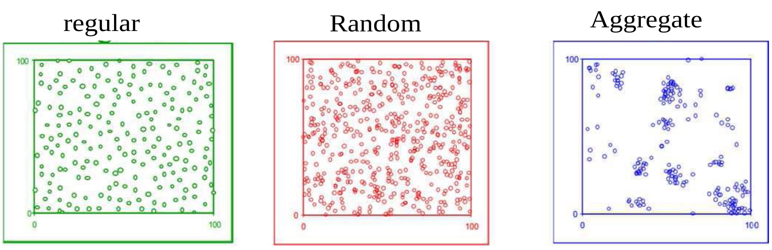


**Figure 2**: Illustration of regular, random and aggregated distributions [13].

**2.5. Evaluation of the shade level in the plots:** The shade of the observation plots was characterized by two methods: (i) trees overlooking the labelled cocoa trees were enumerated and classified in two major groups: fruit trees and forest trees; (ii) a shade rating was made by an observer at 5 to 10 points in each plot. This rating assessed the opening of the canopy above the observation point [15]. Shade levels were assigned on a rating scale ranging from 0 for "no shading canopy" to 4 for "totally enclosed shading canopy" in each plot. Subsequently, the average scores obtained in each ASBCT permit to define four levels of shading: null shading (NS), light shading (LS), average shading (AS) and dense shading (DS) respectively for average scores between ]0; 1], ]1; 2], ]2; 3] and ]3; 4] [15].

**2.6. Evaluation of the development of black pod in orchards:** In the field, a total of four diseases were observed according to the method of visual diagnosis of symptoms (Fig. 3). These are black pod disease (Fig. 3a), black rot (Fig. 3b), dieback (Fig. 3c) and mistletoe (Fig. 3d). However, only the black pod disease with a considerable representation and a heavy impact on production was evaluated by the calculation of incidence and severity using formula of Chumakov and Zaharova (1990) [15].

a b c d

**Figure** 3: Symptoms of cocoa diseases encountered in the Mbam and Inoubou division of Cameroon. (**a**: black pod disease; **b:** black rot; **c:** plant attacked by dieback; **d:** African mistletoe on cocoa stem).

**2.7. Evaluation of the incidence of black pod disease:** In each of the four plots delimited in each ASBCT, fifteen cocoa trees were selected and sampled using the tags placed on the trunk of each cacao tree. Pods attained of disease, regardless of the infection degree at 2.5 m height from the ground, were enumerated as they appeared throughout the observation. The incidence (I) of the disease was calculated per cacao in each plot using the following formula.

$$I = M / (M + S) \qquad (1)$$

With: **M** = Number of infected pods;
**S** = Number of healthy pods.
Subsequently, the average incidence was calculated and compared according to the shading level for each ASBCT studied.

**2.8. Evaluation of the severity of black pod disease:** Infected pods in each of the defined plot were grouped into three general classes, each corresponding to a degree of infection: 1 (less than 25 % of the surface of the pod is affected); 2 (between 25 and 50 % of the surface of the pod is affected) and 3 (more than 50 % of the surface of the pod is affected). The severity (S) was calculated for each cocoa tree by the following equation:

$$S = (\Sigma ab)/N \qquad (2)$$

With: **S** = severity of the infection;
**a** = Number of infected pods;
**b** = Degree of infection corresponding to (a);
**N** = Total number of diseased pods.
An average was obtained for each plot and those values were compared between cocoa ASBCT.

**2.9. Evaluation of pod production:** Real production (Pr) which is considered as production in healthy pods was assessed along each sampled cocoa stock using the following formula.

$$Pr = Ct - Cm \qquad (3)$$

With: **Cm** = Total number of infected pods;
**Ct** = Total number of produced pods.

**2.10. Correlation tests:** In this part of the study, it was proposed to establish a linear regression model to show the linear relationships existing between shade level, tree density, and severity of black pod disease. In this case, the correlation coefficient (r) was determined in order to provide relative information on the degree of linear dependence between these three variables. These different correlations were established from the equation:

$$y = ax + b \qquad (4)$$

with a = slope, b = constant, x and y the different values of the correlated parameters; In this case, if a <0, the slope is negative; if a> 0, then the slope is positive; if r is between 0.8 and 1 then the correlation is perfect and positive; if r is between -0.8 and -1 then the correlation is perfect and negative; if r <0.8 then the correlation is positive but imperfect; if r> -0.8 then the correlation is negative but imperfect.

**2.11. Statistical analyses:** The results obtained were analysed using software R, which uses the standard analysis of variance method (ANOVA). For the tests (Turkey), the level of significance was evaluated at 5 % threshold. The Excel 2010 spreadsheet was used for plotting curves, histograms, and tables.

## 3. RESULTS

### 3.1. Density of trees

In different ASBCT, 91.28 % cocoa trees, 3.18 % forest trees, 3.91 % fruit trees, and 1.63 % of Musaceae and Arecaceae were determined (Table 1). ASBCT 2 has the lowest percentage of cacao (88.64 %) and the highest rate of forest trees (4.90 %), unlike other ASBCT where the percentage of cacao is greater than 90 %. ASBCT 4 shows a high percentage of fruit trees (5.90 %) and the lowest rate of forest trees (1.97 %) and other trees (0.74 %). Overall, the study site is very diverse and the distribution of species in the different areas is relatively heterogeneous.

**Figure 1**: Proportions of trees in cocoa agroforestry systems.

| Agroforestry systems | Cocoa (%) | Fruit trees (%) | Forest trees (%) | Other (%) |
|---|---|---|---|---|
| **ASBCT 1** | 92.06 | 2.73 | 3.23 | 1.99 |
| **ASBCT 2** | 88.64 | 3.79 | 4.90 | 2.67 |
| **ASBCT 3** | 93.01 | 3.21 | 2.65 | 1.13 |
| **ASBCT 4** | 91.40 | 5.90 | 1.97 | 0.74 |
| **Average** | 91.28 | 3.91 | 3.18 | 1.63 |

**ASBCT**: Agroforestry System Based on Cocoa Trees.

### 3.2. Spatial structure of agroforestry systems based on cocoa trees

Analysis of the horizontal structure of ASBCT confirms the intermediate situation of agroforests, located between managed agroecosystems and natural ecosystems. The spatial structure analysis yielded four maps showing the spatial distribution of cocoa trees in each of ASBCT studied by illustrating the different species associated with distinct signs. These maps illustrate the spatial structure of all point seeding in these plots. They all have a regular spatial structure from cocoa tree in the study site, unlike forest and fruit trees, whose horizontal structure varies from aggregation to random structures, but without presenting any regular structure such as those of cocoa trees (Fig. 4).

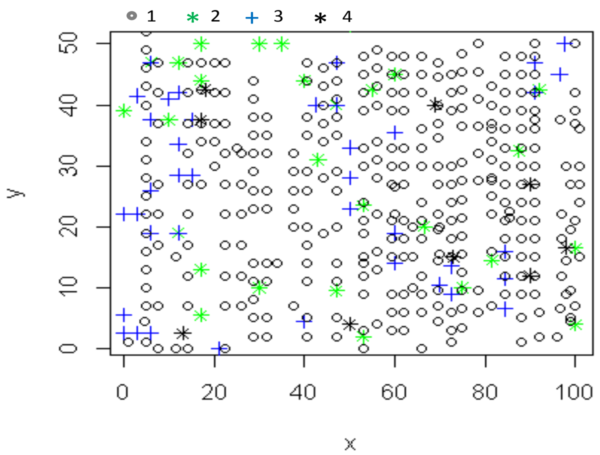


**Figure 4**: The figure showed the agroforestry System Based on Cocoa Trees 3 mapping of the network. (**1**: cocoa trees; **2**: fruit trees, **3**: foresters; **4**: Other).

### 3.3. Level of shading in the plots according to the structure of the agroforestry systems

In ASBCT, shade is composed of a relatively balanced mixture of fruit trees and forest trees. Shading of the site plots is mainly due to forest trees (Table 2). Average shade scores of fruit trees are low in all ASBCT studied compared to forest shade scores that are high and relatively homogeneous.

**Table 2**: the table presents the shading levels in ASBCT.

| Agroforestry systems | Average shading notes | | |
|---|---|---|---|
| | **forest tree** | **fruit tree** | **Shade** |
| ASBCT 1 | 3.30 ± 0.85 | 1.63 ± 0.67 | average shading (AS) |
| ASBCT 2 | 3.68 ± 0.47 | 1.50 ± 0.84 | dense shading (DS) |
| ASBCT 3 | 3.15 ± 0.68 | 2.05 ± 0.53 | average shading (AS) |
| ASBCT 4 | 2.62 ± 0.91 | 1.42 ± 0.80 | light shading (LS) |

**ASBCT**: Agroforestry System Based on Cocoa Trees.

On a scale of 0 to 4, the shading level is relatively heterogeneous in the different systems studied (fig. 5). ASBCT 2 has a higher level of shading with average scores ranging from 3 to 4 (dense shading: DS) followed by ASBCT 1 and 3 with a distinctly uniform shading range of 2 to 3 (Average shading: AS). ASBCT 4 has a shading level range between 1 and 2 (light shading (LS)) compared to others.

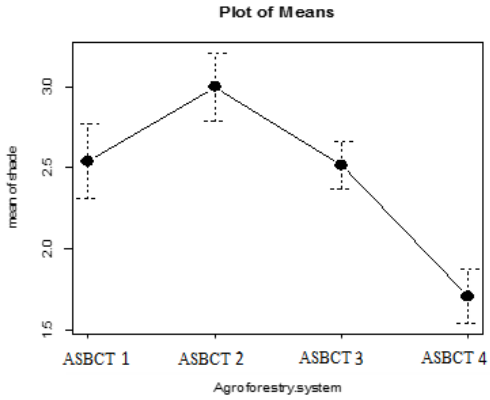


**Figure 5**: The figure presents the shade level in the ASBCT studied.

## 3.4. Correlation between percentage of forest trees and shading level

The percentage of forest trees and the shading rate are correlated with a positive slope (Figure 6). The correlation coefficient is high (r = 0.94) so the correlation is perfect and positive, which means that the shading level increases proportionally with the percentage of forest trees and the equation linking these two parameters is y = 0.33x + 2.13 (coefficient of Bravcus Pearson)

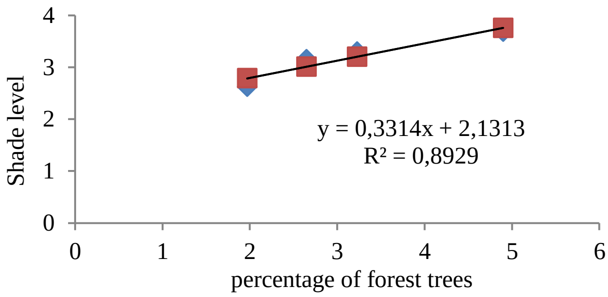


**Figure 6**: Regression line between the percentage of forest tree and the level of shading.

## 3.5. Incidence of black pod disease in agroforestry systems

The incidences ranged from 9 % to 26.08 % in ASBCT (Table 3). They are distributed heterogeneously among the different ASBCT in the study site. ASBCT 2 and 3 had the highest incidences (16.40 ± 4.10 and 26.08 ± 16.53 % respectively) compared with the others where incidence is below 10 %.

**Table 3**: The table presents the incidence of black pod disease in the different cocoa ASBCT studied.

| Agroforestry systems | Shading level | Incidence (%) |
|---|---|---|
| **ASBCT 1** | AS | 9.00 ± 4.91a |
| **ASBCT 2** | DS | 16.40 ± 4.10ab |
| **ASBCT 3** | AS | 26.08 ± 16.53b |
| **ASBCT 4** | LS | 8.39 ± 5.17a |

The averages followed by the same letter in the same column are not significantly different at the 5 % threshold according to the Turkeys test. **LS** = light shading; **AS** = average shading and **DS** = dense shading; **ASBCT: Agroforestry Systems Based on Cocoa Trees**.

## 2.6. Severity of black pod disease

The intensity of infection (severity) of the disease on the pods for each plot was determined. Significant differences were observed between the different ASBCT studied according to the turkey's test at the 5 % threshold (Figure 7). ASBCT 2 has the highest severity compared to the others (ASBCT 1, 3 and 4) which show no significant difference between them and therefore the severity is less than 60 %.

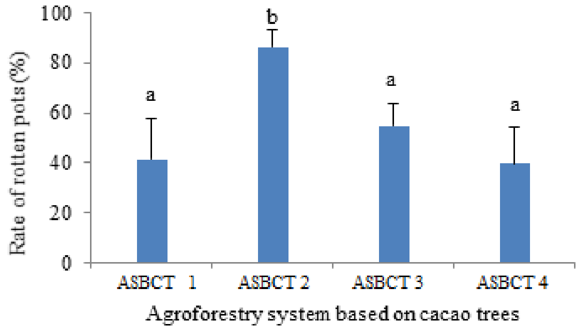


**Figure 7**: Severity of black pod in different ASBCT.

## 3.7. Correlation between severity and shading level

The severity and shade level correlate with a positive slope (Fig. 8). The correlation coefficient r = 0.8 shows that the correlation is perfect, meaning that the severity increases proportionally as the shading becomes more and more dense.

The equation linking these two parameters is y = 0.01x + 2.29 (coefficient of BRAVCUS PEARSON):

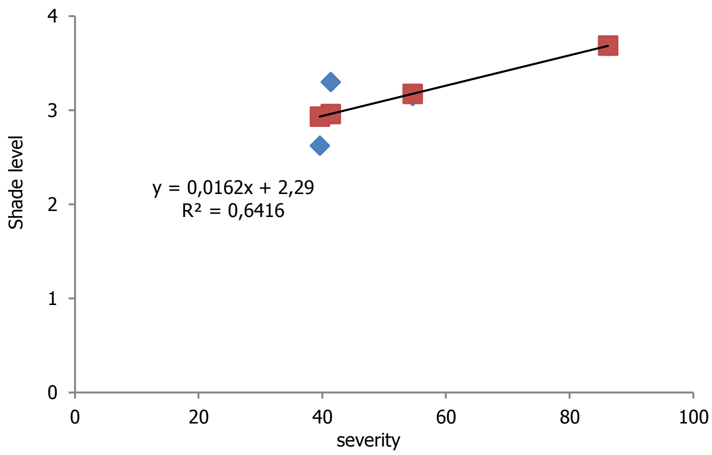


**Figure 8**: Regression line between severity and shade level.

## 3.8. Production in pods in different agroforestry systems

Healthy cocoa pods production is heterogeneous. It varies from about 10 to 25 pods per cocoa tree. The analysis of the results showed that there are significant differences between the different ASBCT studied according to the student's test at the 5 % threshold (Fig. 9). ASBCT 4 has the highest production (25.35 ± 4.48) followed by ASBCT 1 and 2. ASBCT 3 has the lowest production (9.93 ± 3.09).

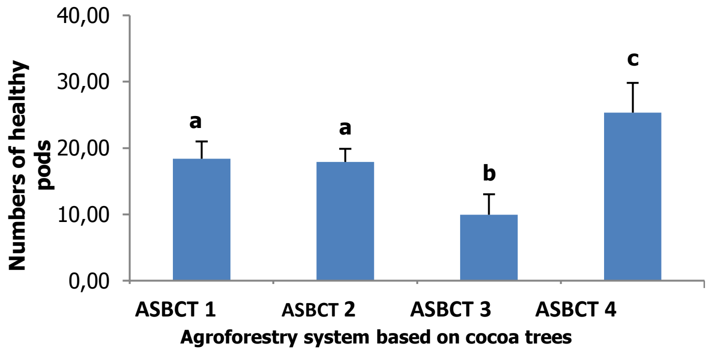


**Figure 9**: The figure presents the production in healthy pods by cocoa trees in the different ASBCT studied.

## 3.9. Correlation between parasite incidence and production in healthy pods

The Bravcus coefficient close to 1 ($R^2$ = 0.81) reflects the very close relationship between production and incidence (Fig. 10). The slope with equation y = -1.17 + 36.02 is negative. This demonstrates that production is high in ASBCT where the incidence is low and conversely.

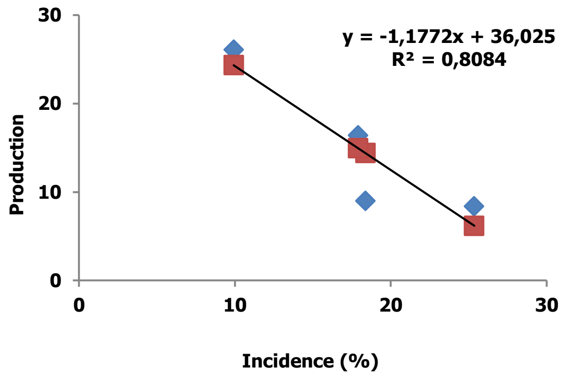


**Figure 10**: The figure presents the regression line between incidence and production.

## 4. DISCUSSION

A diversity of other tree species than cocoa trees and even annual and/or biennial crops has been identified in the different ASBCT studied. These species occupy four strata as described by Schroth et *al.* (2004) and Deheuvels et *al.* (2012) [16, 17]. Forest and fruit trees have a relatively balanced proportion in old plantations (ASBCT 1 and 2) while in young orchards (ASBCT 3 and 4) the proportion of fruit trees is much higher than forest trees. Young cocoa farmers explain this by the need to increase not only the production of non-timber forest products but also the diversification of the resource. However, these allow appreciating the specific diversity which attests the complexity of ASBCT as emphasized by Sonwa *et al.* (2007) [18]. This specific diversity also causes a diversity of spatial structure that can be adopted by the plant population. Analysis of the horizontal structure of ASBCT confirms the intermediate situation of agroforests, located between managed agroecosystems and natural ecosystems as described by Gidoin *et al.* (2013) [19].

There is a diversity of horizontal structures depending on the plant population studied and the plots considered. Although forest and fruit trees have a diversity of horizontal structure that varies from random structures to aggregated structures while cocoa trees are regularly distributed in almost all of the plots studied, thus corroborating the results obtained by Gidoin *et al.* 2013) in similar research on the relationships between plant stand structure and pests in agroforests based on cacao trees [19]. The random structures observed could be explained by farmer's desire to achieve a uniform shade of cocoa in the plots [20]. Thus, depending on the distribution of pre-existing forest trees in the plot, the fruit trees will preferably be planted where the forest trees produce little (or no) shade with the advantage of maximizing the production. Fruit trees themselves while creating shade for the culture of interest reduces some diseases such as Black pod disease [21]. Aggregated structures could be due to the natural regeneration of trees. In other cases, the planter could introduce fruit trees where the cacao has not been successful. The level of shading increases progressively with the proportion of forest trees thus corroborating the results of Babin (2009) in similar research on the influence of agroecological factors on the dynamics of mirid populations in cocoa [12]. The ASBCT 2 with the highest shading rate is due to the presence of a high proportion of forest trees (4.9 %), whereas ASBCT 4 has the lowest level of shading with low proportion forest trees (1.97 %). These results showed that all ASBCT studied had plots infested with *Phytophthora megakarya.* Significant differences are observed between the ASBCT studied. ASBCT 2 and 3 have the highest incidences, contrary to ASBCT 1 and 4. This result would certainly be related to the high density of trees in the plantation, creating dense shading and subsequently permanent moisture, favorable to the development of the disease as demonstrated by Touani (2014) in similar research on, the influence of the association of plant species in the control of cocoa diseases. The severity rates were very high in ASBCT [22]. They ranged from 39.61 % to 86.21 %. This high rate is explained by the aggregate spatial structure of the associated tree species in the different ASBCT as Gidoin et *al.* (2013) also showed in similar research on the influence of plant population structure on the development of black pod disease in the central region [19]. Severity and shading levels were correlated with a positive slope (r = 0.8). This explains the high severity recorded in ASBCT 2, which had the highest level of shading (dense shading) compared to the others. ASBCT 4 (light shading) has the highest production, which is explained by the low incidence recorded in this ASBCT compared to the others. The Bravcus coefficient close to 1 ($R^2$ = 0.81) reflects the very close relationship between production and incidence. This demonstrates that production is high in ASBCT where the incidence is low and conversely. Overall, cocoa pod production is low in the study site, which would certainly be related to the shade in the plots which is relatively dense. In fact, shading and the use of hybrid varieties are determining factors of production in a traditional agroforestry system based on cocoa trees as demonstrated by Babin and al., (2011) [23].

## 5. CONCLUSION

Traditional agroforestry systems based on cocoa trees were characterized in central region of Cameroon with the aim of determining their impact on the control of black pod disease caused by *Phytophthora megakarya*. The aggregated structures of the associated trees create a disproportion of the microclimate and consequently a highly heterogeneous distribution of the severity of the disease in the same ASBCT. The incidence and severity of the disease decrease proportionally with shade level, tree density, different pod maturity stages, and the horizontal spatial structure of ASBCT. Those agro-ecosystems are complex and the management of the farmer is associated with the complexity of the natural forests in which they are installed to lead to various vegetation structures. The research of an ideal ecological environment where cocoa trees could best express its potential is remaining and therefore represents a serious challenge for researchers as for producers. However, this needs to be assessed and adopted as part of an integrated approach.

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