Available online at http://www.ifgdg.org

Int. J. Biol. Chem. Sci. 16(6): 2516-2535, December 2022

ISSN 1997-342X (Online), ISSN 1991-8631 (Print)

International Journal of Biological and Chemical Sciences

Original Paper http://ajol.info/index.php/ijbcs http://indexmedicus.afro.who.int

Adaptation strategies for the adverse effects of climate disruptions on coffee and cocoa trees productivity in Cameroon

Omer Gatien MALEDY[1], Raymond ADENGOYO [1], Michel NDOUMBÈ NKENG[2] and Joseph Aubert MOUEN BEDIMO[2*]

[1] Cocoa and Coffee Interprofessional Council (CCIC), PO. Box: 3928, Bonanjo Douala, Cameroon.
[2] Consulting firm in Agricultural Research and Advice (CERCA), PO. Box: 6202, Yaoundé, Cameroon.
[*] Corresponding author; E-mail: josephmouen@yahoo.fr; phone +237 699 55 87 76.

ACKNOWLEDGEMENTS

Authors acknowledge the financial support of, CICC, International Trade Center (ITC) and the Ministry of Commerce in Cameroon.

Received: 09-10-2022 Accepted: 20-12-2022 Published: 31-12-2022

ABSTRACT

The decline of Cameroon cocoa and coffee productions are increasingly designated as one of the negative consequences of climate change on plants development. The purpose of this study was to contribute to improving the productivity of cocoa and coffee trees, in their production areas, in Cameroon. Thus, 280 plots, located in three different agro-ecological zones, were monitored for five consecutive years (2014-2018). Meteorological data were also systematically collected at each site. Data analysis highlighted three classes of unstable meteorological profiles that reflect the non-recurrence of climatic events on the study sites. Multiple logistic regression analysis showed that the incidence of cocoa black pod disease and that of Arabica coffee berry disease increases with the quantity of rainfall and the number of rainy days. This increase rather induces a decrease in the attack rate of berry borer on the Robusta coffee trees. The results obtained made it possible to identify, by elucidating their respective roles, the climatic variables which have an effect on the productivity of cocoa and coffee trees. They have also led, for the first time, to the conceptualization of innovative technical processes, which can reduce the harmful effects of climatic disturbances on cocoa and coffee crops.

Keywords: Climate change, meteorological profiles, cocoa, coffee.

INTRODUCTION

The Intergovernmental Panel on Climate Change (Pachauri et al., 2008) predicted a global average temperature increase from 1.4°C to 5.8°C by the end of the 21st century (Houghton et al., 2001). For Africa, the future annual warming should vary between 0.2°C and more than 0.5°C per decade (Hulme et al., 2001). However, predictions of changes in average seasonal rainfall in Africa are less well defined, although there are models that generally predict that some locations of equatorial Africa will experience a likely increase in rainfall, from 5 to 20% between the months of December to February and a 5-10% reduction between June and August before

 9233-IJBC
DOI : https://dx.doi.org/10.4314/ijbcs.v16i6.5

2050 (Hulme et al., 2001). Such events can therefore negatively impact the availability of water resources, the dynamics of cultivated plants, the status of diseases and pests of agricultural interest and possibly lead to a significant reduction in crop yields. This situation can be particularly damaging for cocoa and coffee productions, the marketing of which is negatively impacted by high price volatility on the market (Rosenzweig et al., 2001).

Coffee and cocoa crops are among Cameroon's strategic agricultural strategic crops. The resulting coffee orchards are made up of Robusta coffee trees (*Coffea canephora* Pierre), grown mainly in the low-altitude in forest and coastal regions of the Southern part of the country (alt.≤1000 meters) and Arabica coffee trees (*Coffea arabica* L.), planted in the Western Highlands region (alt.>1000 meters). The cocoa orchards (*Theobroma cacao* L.) are cultivated in the same agro-ecological area as the Robusta coffee trees. These products still occupy a key position in the national trade balance and they represent about 30% of non-oil exports. The last two decades have been marked by a considerable increase in areas dedicated to cocoa and coffee plantations that reached approximately 230,000 ha of coffee orchard and 400,000 ha of cocoa orchard, with nearly 600,000 producers involved. The 2020/2021 national marketed cocoa production was 292,471 tons while that of coffee during the same period was around 12,157 tons. Despite the increase in cultivated areas, trends in cocoa and coffee yields remain fluctuating, even downward. Coffee production fell by about half, from 2019-2020 to 2020-2021 farming seasons. The main constraints mentioned among others are: the aging of plantations and producers, the high incidence of diseases and pests, inappropriate agricultural practices and probably climatic variations.

The potential impact of climate variations on cocoa and coffee ecosystems appears to be a real concern for the various actors in these agricultural sectors. Thus, the understanding of relationships between these new climatic phenomena and the expression of the ontological development of these plants *in situ*, could lead to resilient solutions, favoring an optimal and sustainable functioning of these ecosystems (Gay et al., 2006; Läderach et al., 2017). This study is part of this innovative dynamic. Its general objective is to contribute to the improvement of cocoa and coffee productivity in Cameroon. Specifically, the first objective will be to identify climatic variables affecting the productivity; then the second will be to suggest alternative technical processes to mitigate the harmful effects of climatic variations. It could also help to elucidate the involvement of some meteorological variables such as level of rainfall, average temperatures and number of rainy days in the occurrence or not of cocoa pod rot, Arabica coffee berry disease or the Robusta coffee berries attacks by insects. In the short term, it could be envisaged putting forward innovative measures to mitigate the adverse effects of climatic variations on cocoa and coffee productions. This study was carried out during five consecutive years, from 2014 to 2018.

MATERIALS AND METHODS

Experimental sites

Depending on the target crop, the experiments were carried out at different sites in three (03) agro-ecological zones (AEZ) (Figure 1). These sites remain representative of each of the agro-ecological zones selected for the study; namely:

The Western Highlands Zone (Zone 3)

Conducive for the cultivation of Arabica coffee trees, this agro-ecological zone lies between 4°54'-6°36' North latitude and 9°18'-11°24' East longitude. It covers the West and North-West administrative regions of Cameroon, with a great diversity of reliefs, and altitude extending from 1100 to 2740 meters above the sea level. Its climate is characterized by two seasons of unequal length: a dry season, which theoretically extends from mid-November to mid-March, and a rainy season which lasts from mid-March to mid-November. Average temperatures are low (19°C) and heavy rains (1500 - 2000 mm) fall in a monomodal pattern. This area also has a diversity of soil types: poorly evolved soils (Inceptisoils) on steep slopes, highly desaturated ferralitic soils (Oxisoils) in the old plateaus, ferralitic soils more or less enriched in clay (Ultisoils/Ferralsoils) in closed depressions, and the ferralitic soils with ash coverings in the plateaus, and the andosoils. These are generally acidic soils (pH 3.8 to 5.6), but very fertile overall.

This agro-ecological zone was chosen for Arabica coffee trees. The experiments were set up in Santa (altitude 1800 m) and Dschang (altitude 1398 m). However, an experiment on Robusta coffee trees was established in a plain at Dschang locality.

The rainforest zone with a monomodal rainfall pattern (Zone 4)

Favorable to cocoa and Robusta coffee crops, zone 4 lies 2°6'- 6°12' North latitude and 8°48'-10°30' East longitude. It includes the administrative region of Littoral and the coastal edge of the Southern part of the country. The zone is characterized by an equatorial climate, with rainfall ranging between 2500 and 4000 mm per annum and a very mild dry season. Temperatures vary between 22 and 29°C and air humidity, between 85 and 90%. The soils are mostly ferralitic, yellow, leached, not very fertile, with an acid pH (3.8 to 4.8), on metamorphic or sedimentary rocks. In some places, they often develop aluminum toxicity. However, in the banana-growing areas, the soils are rather very fertile because they are browned and stand on volcanic ash or on basalt.

This agro-ecological zone was selected for experiments on cocoa trees and Robusta coffee trees. They were established at Melong (altitude 790 m). However, the locality of Tombel (altitude 460 m) exclusively hosted the cocoa trees experiments.

The humid forest zone with a bimodal rainfall regime (Zone 5)

Situated between 2°6' to 4°54'/5°48' North latitude and 10°30' to 16°12' East longitude, Zone 5 extends over most of the southern Cameroon plateau, with altitudes varying between 500 to 1000 meters above the see level. It’s hot and humid climate is said to be of "Guinean" type, with annual average temperatures of 25° C. Its rainfall of 1500-2000 mm per year describing a bimodal rainfall pattern is divided into two distinct wet seasons that allow two cycles of crops. Low insolation and constantly high air humidity favor the development of crop diseases and do not always facilitate the traditional drying and storage of crops. The soils are mainly ferralitic, yellow, ocher or red depending on the bedrock and their location in the landscape. They are acidic (pH 4-5.5), clayey, with a low cationic exchange capacity (i.e. a low capacity for storing/retaining nutrients).

This agro-ecological zone was also selected for experiments on cocoa trees and Robusta coffee trees. These were conducted in the localities of Meyomessala (altitude 620 m), Nkoemvone (altitude 560 m), Ngat (altitude 760 m) and Nguélémendouka (altitude 690 m), with regard to cocoa trees. Those on Robusta coffee trees were carried out in Ngat and Nguélémendouka.

Planting materials

At each site, this study was conducted in plots within plantations producing cocoa trees or coffee trees (Arabica and Robusta), in a minimum area of one hectare. The varieties available in the said plantations are essentially the *amelonado* for the cocoa trees, the *java* for the Arabica coffee trees and the “*Tout-venant*” for the Robusta coffee trees.

Experimental design and observations

Each plot contained twenty (20) trees arranged in contiguous blocks. Each tree studied was marked with a specific number to allow its precise identification each year, throughout the experimental period. Regarding coffee trees, observations were made on three plagiotropic branches, located at their upper, middle and lower parts. These branches were marked each year at the second week after fruit set. On the other hand, concerning cocoa trees, observations were made on two compartments of the tree, namely, at the heights of 0-0.5 m and 0.5-2 m.

The study was conducted in 10 sites. In each site, for each of the crops concerned, two (02) experimental fields were implemented. In some sites, the experiment was carried out on two crops. This is the case of Nguelemendouka (Cocoa tree and Robusta coffee tree), Ngat (Cocoa tree and Robusta coffee tree), Melong (Cocoa tree and Robusta coffee tree), Dschang (Arabica coffee tree and Robusta coffee tree). Each of the plots included twenty (20) contiguous trees used for recording and arranged in a block.

In total, 280 cocoa trees, 80 Arabica coffee trees and 200 Robusta coffee trees were observed during the present study.

Variables measured

Climatic variables were recorded daily. These were the height of the rains (mm), the minimum and maximum temperatures (°C). Primary meteorological data were collected as part of the OC4 project (*Observatory of the influence of Climate Change on the Cocoa and Coffee productivity*), of the Cocoa and Coffee Interprofessional Council (CICC). In addition, secondary data sets were obtained from the meteorological stations of the National Directorate of Meteorology of the Ministry of Transport and from small weather stations of the Institute of Agricultural Research for Development (IRAD).

Biological variables were measured weekly at tree level. **On cocoa trees**, they concerned the number of open flowers, number of *cherelles* (fruits of 4 cm long or under), number of young pods, number of ripe pods, number of harvested pods, number of beans per pod, weight of beans, rotten fruits (affected by the *Phytophthora megakarya*), or that bitten by mirids (*Sahlbergella singularis*). **On the coffee trees**, a count was made on the number of berries at the "pinhead" stage, young berries, ripen berries, healthy harvested berries and those on affected by disease (*Colletotrichum kahawae* on Arabica coffee trees) or bitten by borers (*Hypothenemus hampei* on Robusta coffee trees).

Statistical analysis

Other variables computed from the field data include the rate of infection of fruit by cocoa black pod disease, Arabica coffee berry disease (CBD) and insects' bites on Robusta coffee berries. In addition to exploratory data analysis, hierarchical ascending classification of meteorological profiles and binary logistic regressions were carried out. A multiple logistic regression analysis was carried out to derive the best-fitting and biologically reasonable model to describe the relationship between an outcome and covariates (Dobson, 2001; Hardin et al, 2001). The outcome was coded as 0 or 1, where 1 indicates that the outcome (*Phytophthora* pod disease, CBD or berry bites by insects) of interest is present, and 0 indicates that the outcome of interest is absent. The multiple logistic model equation was as follows:

$$E(Y_i) = p_i = \frac{\exp(\beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_p X_{ip})}{1 + \exp(\beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_p X_{ip})}$$

Where:

$\hat{p}_i$ represents the expected probability that the outcome is present;

X_{in} represents the selected covariates (Annual rainfall (mm), Annual number of rainy days, Average annual temperature (°C))

β_0, β_1, β_2, …, β_p are multiple regression coefficients

MS EXCEL software was used for data formatting. The actual statistical analyzes were carried out with SAS (SAS Institute Inc. 2013) and R (R Core Team, 2022) software.

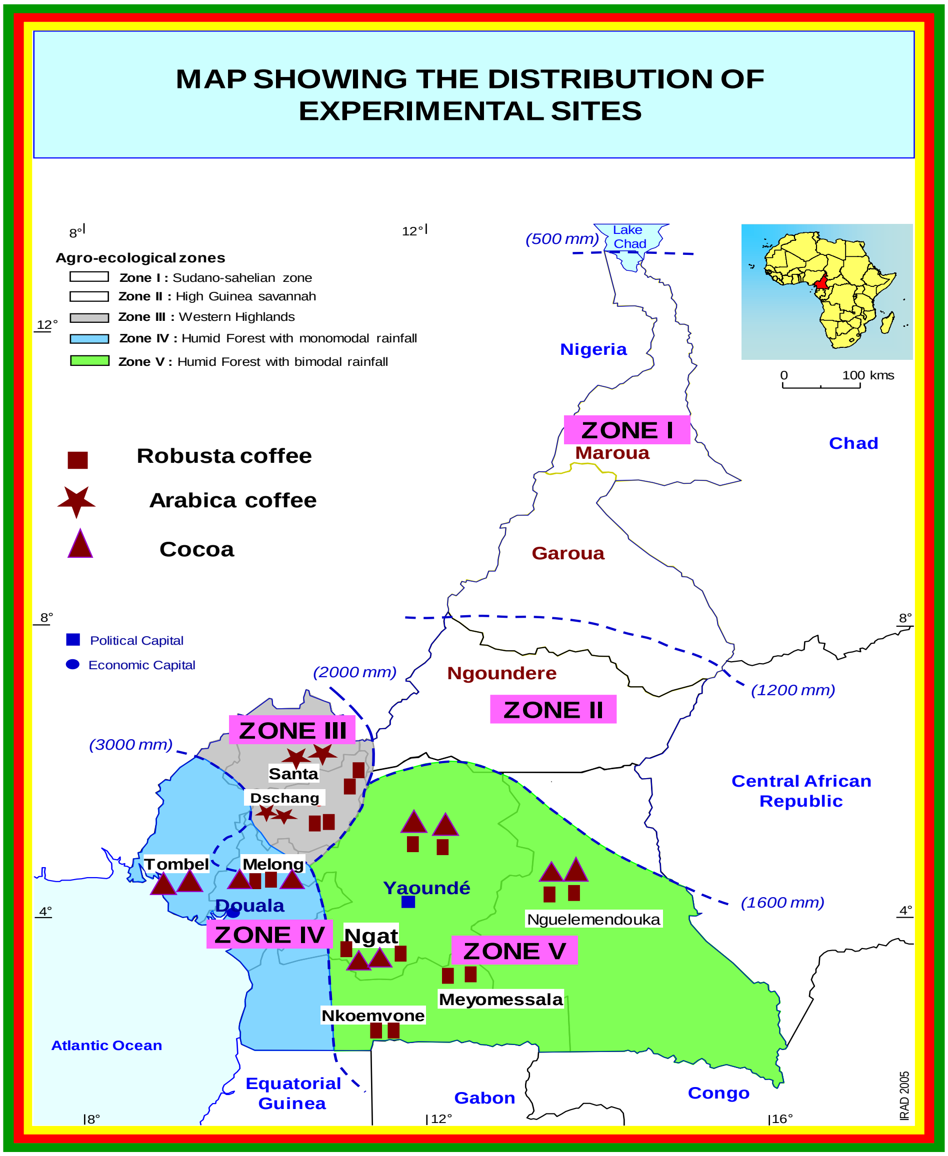

Figure 1: Geographical distribution of observation points.

RESULTS

Typology of meteorological profiles

The scree plot of eigenvalues (Figure 2a) shows that from k = 3 classes, the addition of another group does not significantly increase the share of inertia explained by the partition. The dendrogram (Figure 2b) has therefore been divided into three (03) classes: (1) – a first of seven (07) elements (29%) representing the meteorological profile of the AEZ5; (2) – a second of seven (07) elements (29%) that can allow the specification of the meteorological profile of the AEZ3 and (3) – a third of 10 elements (42%) whose meteorological profiles belong to the three AEZs studied (AEZ3, AEZ4, AEZ5), despite a slight domination of AEZ4. This last class remains quite heterogeneous because it is not very specific to a particular AEZ. In addition, 2014-2018 data analysis revealed that it comprises meteorological profiles belonging to the three AEZs. The dendrogram and Table 1 clearly indicate that during the 70s, 80s and 90s, meteorological profiles were always classified in their specific agro-ecological zones. The results obtained with the observations made during the period 2014 – 2018 did not lead to compliance with this typology. A profile of AEZ3 was found into class 1 which is dominated by the profiles of AEZ5. Similarly, a AEZ5 profile was found into class 2 which is dominated by the AEZ3 profiles. Into class 3, slightly dominated by the profiles of AEZ4, the confusion is greater with the presence of profiles, both of AEZ3 and those of AEZ5. This pattern of variation does not repeat itself in the same way every year.

Characterization of meteorological profiles classes

Table 1 shows that classes 1, 2 and 3 are dominated by the meteorological profiles of AEZs 5, 3 and 4 respectively. These classes were essentially being made on the basis of rainfall parameters, that is: the rainfall quantity (mm) and the number of rainy days. A day has been considered as rainy if the height of the rainfall was greater than 1 mm. AEZ3 is characterized by a mild climate with average temperatures of 19°C and abundant monomodal rainfall of 2149 mm, spread over 186 days. However, our results revealed that in 2016, the climate of this AEZ was very hot with average temperatures of 29°C. It was also wetter due to the abundant rainfall estimated at 2839 mm and spread over 211 days. This is the typical climate of AEZ4, which in 2017, corresponded to the climate of AEZ3. Moreover, in 2018, the same AEZ3 presented a climate that mimics that of AEZ5, namely: high average temperatures (25°C) and less rainfall in AEZ5 of 1723 mm, spread over only 82 days.

The Hierarchical Ascending Classification (HAC) revealed that the rainfall and the number of rainy days are major climatic parameters, which permit to perform an objective discrimination between classes of meteorological profiles. However, from 2014 to 2018, there was an apparently illogical positioning of some profiles in fairly homogeneous classes. These were AEZ3_2018 and AEZ3_2016 in classes 1 and 3, respectively. The attachment of AEZ4_2017 element to class 2 indicates that cocoa and Robusta coffee trees plots found themselves in 2017, in the climatic conditions of the Western Highlands zone. During the same year, the presence of AEZ5_2017 element into class 3 indicates that these two crops, which are planted in the humid forest zone with a bimodal rainfall pattern, suffered the climatic conditions of the zone of humid forest with monomodal rainfall pattern. Thus, cocoa and Robusta coffee trees, which initiated two flowerings and implicitly two main fruit development cycles, had been reduced to producing a single fruiting cycle, under the climatic conditions of 2017.

Modeling of damage due to pests and diseases according to climatic variables

Black pod disease of cocoa trees

Logistic regression model equation (cocoa tree)

$$\hat{p}_i = \frac{\exp(0.083 + 0.102 * Pluvio_i + 0.161 * \text{NJP} - 0.009 * \text{Temp})}{1 + [\exp(0.083 + 0.102 * Pluvio_i + 0.161 * \text{NJP} - 0.009 * \text{Temp})]}$$

(1)

Where:

$\hat{p}_i$ represents the probability of a fruit to be attacked by brown rot

Pluvio= Annual rainfall (mm);

NJP= Annual number of rainy days;

Temp= Average annual temperature (°C)

The regression analysis between the rate of black pod disease on cocoa trees and the meteorological parameters (Table 2) shows that data fit the logistic model well, with an adjustment coefficient (adjusted R^2) of 0.81 at Pr > Chi-2 = 0.1123. It also indicates that the infection rate is very strongly linked to the annual number of rainy days ($p<0.001$). This disease rate is highly dependent on rainfall ($p<0.01$). But, it is not significantly dependent on average temperatures. The correct prediction rate of the black pod disease rate according to climatic variables is 78%. Odds ratios show that for one-unit increase in rainfall, there are about 11% chances that the fruit will be infected. These chances will be around 17%, for an increase of one unit in the number of rainy days. Equation (1) predicts the probability of a fruit to be infected, depending on the meteorological variables recorded during this study. Thus, for the cocoa tree, the number of rainy days and the amount of rains have a major impact on the level of infected pods The damage caused by this disease is all the more important as the quantity of the rains is high. They are more so with the increase in the number of rainy days.

Arabica coffee berries disease

Logistic regression model equation (Arabica coffee tree)

$$\hat{p}_i = \frac{\exp(0.069 + 0.087 * Pluvio_i + 0.153 * \text{NJI}}{1 + [\exp(0.069 + 0.087 * Pluvio_i + 0.153 * \text{N}}$$

(2)

Where:

$\hat{p}_i$ represents the probability of a berry to be attacked by CBD

Pluvio= Annual rainfall (mm);

NJP= Annual number of rainy days;

Temp= Average annual temperature (°C)

Table 3 shows that the Arabica coffee berry disease rate and the meteorological parameters fit the logistic regression model, with an adjustment coefficient (adjusted R^2) of 0.78 at Pr > Chi-2 = 0.0963. It is highly dependent on the annual number of rainy days and average temperatures ($p<0.01$). There is also a significant dependence between this infection rate and the amount of rainfall ($p<0.05$). This dependence is positive with rainfall variables but negative with average temperatures. The correct prediction rate of the level of infection according to climatic variables is 69%. Odds ratios show that for one-unit increase in the amount of rainfall, there are about 9% chances that a berry will be infected. These chances increase to 16%, for one-unit increase in the number of rainy days. Equation (2) predicts the probability that a berry will be infected, depending on the meteorological variables studied.

Bites of Robusta coffee tree berries by borers

Logistic regression model equation (Robusta coffee tree)

$$\hat{p}_i = \frac{\exp(0.296 - 0.131 * Pluvio_i + 0.099 * \text{NJP} + 0.196 * \text{Temp})}{1 + [\exp(0.296 - 0.131 * Pluvio_i + 0.099 * \text{NJP} + 0.196 * \text{Temp})]}$$

(3)

Where:

$\hat{p}_i$ represents the probability of a cherry to be bitten by the borer

Pluvio= Annual rainfall (mm);

NJP= Annual number of rainy days;

Temp= Average annual temperature (°C)

In Table 4, it is indicated that the rate of berries bitten by borers on Robusta coffee trees and the meteorological parameters fit the logistic regression model, with an adjustment coefficient (adjusted R^2) of 0.73 at Pr > Chi- 2 = 0.0826. It is highly dependent on average temperatures ($p<0.001$) and rainfall ($p<0.01$). There is also a significant dependence between the rate of bitten berries and the number of rainy days ($p<0.05$). The dependence is positive between the rate of bitten berries with the average temperatures. But it is negative with the number of rainy days. The rate of correct prediction of the level of infection according to climatic variables is 73%. Odds ratios show that for one-unit increase in average temperature, there are about 18% chances that borers will bite a berry. These chances fall to 10%, for an increase of one unit in the number of rainy days. Equation (3) predicts the probability that borers, depending on the meteorological variables studied, will bite a berry.

Temporal dynamics of flowering in the different agro-ecological zones

The main periodic events that mark the seasonal development of cocoa and coffee trees are: leafing (budburst), leaf coloration, flowering, fruiting and senescence. Specific monitoring of cocoa tree flowering and coffee tree fruiting ("pinhead" stage) led to a better understanding of the dynamics of the fruit development cycle for three consecutive years (2014-2016). Figures 3b indicate that cocoa trees bear flowers almost all year round. However, they have flowering peaks that vary from one AEZ to another, depending on annual climatic variations. In 2014, while this peak was observed at the end of June in AEZ4, flowering had already begun its residual phase in AEZ5. The early arrival of the rains and their sudden stop a few days later often triggered premature and massive flowering which consequently led to significant flowers run-out. This phenomenon was observed in 2015 in AEZ4 and in 2016 in AEZ5 as shown in Figures 3b.

Berries at the "pinhead" stage appeared in April-May in 2014, in February-April in 2015 and in April-May in 2016. A residual berries occurrence at this juvenile stage of their development was observed in June 2016 (Figure 3a). The grouped fruiting pattern thus highlighted results from the synchronous flowering, usually observed in Arabica coffee plantations. The presence of the berries on the trees from February 2015 revealed that the flowering of the year in question took place very early, compared to the years 2014 and 2016. This early flowering exposes the resulting cherries to adverse conditions for their growth. These could be imposed by dry spells which sometimes occur during the rainy seasons and which cause significant reductions in yields. In AEZ3 and 4, the main flowering from March to April was also observed on the Robusta coffee trees. On the other hand, there are two flowerings in AEZ5, corresponding overall to the short rainy season from March-April and the long one from July to August (Figures 4). Cherries from the second bloom reach their ripening stage in the middle of the dry season; that is to say when they are at a growth stage that predisposes them to infestations of borers, which may be present in large numbers in the plantations.

Conceptualization of new technical processes

The heterogeneity of meteorological profile groups constitutes additional proof of the climate change described by many authors in recent years (Cilas et al., 2020; Davis et al, 2012). They affect the current practice of cocoa and coffee trees growing and above all, complicates the implementation of scheduled technical processes. The distinction between seasons becomes less easy for farmers, due to climatic instability, from one year to another. Consequently, it will seem almost impossible to them to correctly apply the technical recommendations of the specialized official services, for the management of their farms. Agricultural operations applicable in this uncertain climatic context should therefore be implemented according to a new, simple and effective approach, which would be free from the agricultural calendar. Results obtained in this study clearly demonstrate the direct effect that variations, in the amount of rainfall, the number of rainy days and average temperatures, have on the phenological cycles of cocoa and coffee trees. It would also be globally the same, in all ecosystems within which they develop. Successive agricultural operations should therefore be carried out, not on the basis of a pre-established calendar, but following precise observations of the different phases of phenological cycles of cocoa and coffee trees. A detailed knowledge of the morphological changes of these plants and their biological interactions with their pests would lead to decide for effective technical actions to be undertaken, at each phase of a phenological cycle. Thus, management guides for cocoa (Figure 5), Arabica and Robusta coffee (Figure 6) trees farms have been conceptualized, to optimize these crops productions. They are based on a principle requiring that each agricultural operation implemented in a farm must always be preceded and motivated by an excellent observation of the change of plants state. In order to free farmers from agricultural calendars, these guides detail at each phenological phase of each of the plants: (1) the morpho-physiological signals observed, (2) – the favorable technical actions to be undertaken and (3) – the adverse productive agricultural operations to avoid.

Technical itinerary of the cocoa plantation

The phenological cycle of the cocoa tree could be subdivided into five main phases of vegetative development (Figure 5), namely:

The post-production phase during which healthy residual pods from the end of the campaign, mummified pods and aging of the leaves are observed. It therefore becomes essential to carry out agronomic operations such as sanitary harvesting, maintenance pruning and shade adjustment (50 to 60%). These operations are carried out to prepare the trees to initiate new leaves and fruiting branches, and then to eliminate or reduce the primary sources of disease. It is especially recommended to avoid leaving rotten or mummified pods lying around in the field and to prune the trees when the foliage is renewed and the flowers appear.

The leaf renewal or flushing phase characterized by the fall of old leaves and the appearance of new leaves. This observation must necessarily trigger the application of a systemic insecticide, preferably with an atomizer, to control the capsids. It is also necessary to apply a nitrogenous foliar fertilizer or a bio-stimulant. It is strongly recommended to avoid pruning cocoa trees during this phase of its development.

The flowering and fruit setting phase during which we observe flower buds, flowers, a smell of perfume emanating from the flowers and a strong presence of pollinating insects. It then becomes necessary to systematically apply a bio-stimulant by spraying the leaves in order to prevent excessive flower drop. During this phase, it is absolutely recommended to avoid all operations likely to keep pollinating insects away. Insecticide treatments are strictly prohibited.

The phase of appearance of the cherelles during which, it is observed that many young pods are formed, the perfume smell of the flowers fades, the number of pollinating insects decreases and the first attacks of capsids occur. As soon as these signals are observed, it is necessary to apply a contact insecticide to fight against the capsids. A bio-stimulant must also be applied to the trees to fight against the yellowing of cherelles. Pruning cocoa trees should be avoided.

The pod maturation phase during which we observe the presence of pods at different stages of their development (young, adult, ripe) and that of diseased fruits (mainly brown rot). This is the time to apply alternately, a systemic fungicide, then contact on the pods. It is also essential to systematically remove diseased fruits from trees and bury them outside the fields. Gradual harvesting of three-quarters ripe fruit should be carried out. During this phase, it is essential to avoid any phytosanitary treatment 14 days before any harvest, the destruction of the floral cushions of the cocoa trees during the harvest and the over-ripening of the pods on the trees.

Technical itinerary of the coffee plantation

The technical itinerary of coffee plantation includes the following five phases (Figure 6):

The leaf renewal phase during which the fall of senescent leaves and numerous leaf flushes occur. The coffee tree “rebuilds” its assimilating system with a view to its survival and the subsequent production of fruit. All the agricultural operations to be undertaken during this phase must contribute to new leaves emergence, their good development and their protection against insects and diseases. In this case, it is a question of: aerating the trees by removing non-productive branches and those which intersect, carrying out the removal of orthotropic branches and the sanitary harvest, applying bio-stimulants rich in nitrogen and insecticides for protecting leaves and branches against pests and for mulching coffee trees. It is important to avoid leaving the ground bare because coffee trees are very susceptible to erosion and weeds.

The fruit initiation phase in which flowering occurs after a rainy episode of more than 10mm of water, with a strong smell of perfume (jasmine) in the field. The drying of the flower petals (fruit set) takes place one week after flowering and young fruits appear in the form of "pinheads" at about ten days after fruit set. It is then recommended to apply complex fertilizer (N-P-K) at doses depending on the general aspect of the plantation. Fertilizer quantities applied must nevertheless be adjusted according to fertility pockets that may be identified in the plantations. Insecticide treatments and any phytosanitary products having an insecticidal effect must be avoided.

The fruit expansion phase which is characterized by the growth of green fruits until they reach their final size. Fruits nevertheless remain supple, milky and vulnerable to anthracnose as far as the Arabica coffee tree is concerned. Insecticide treatments against pests on Robusta coffee trees and fungicide treatments against anthracnose on Arabica coffee trees are strongly recommended. The use of non-homologated phytosanitary products should be avoided.

The hardening phase of the endocarp. Green fruits become hard on finger pressure due to lignification of the endocarp (parchment). It is recommended to carry out agricultural operations that enable coffee trees to withstand adverse conditions during the dry season, namely: nitrogen fertilization, application of foliar fertilizers or bio-stimulants, preparation of "plates" for mulching in the dry season and the use of bio-insecticides against ants. Avoid any phytosanitary treatment that may have a residual effect on the coffee beans.

Fruit ripening phase. Green berries gradually turn red. It is the harvest period which consists in practicing selective picking. Ripe cherries are harvested one by one. Any application of pesticides should be strictly avoided.

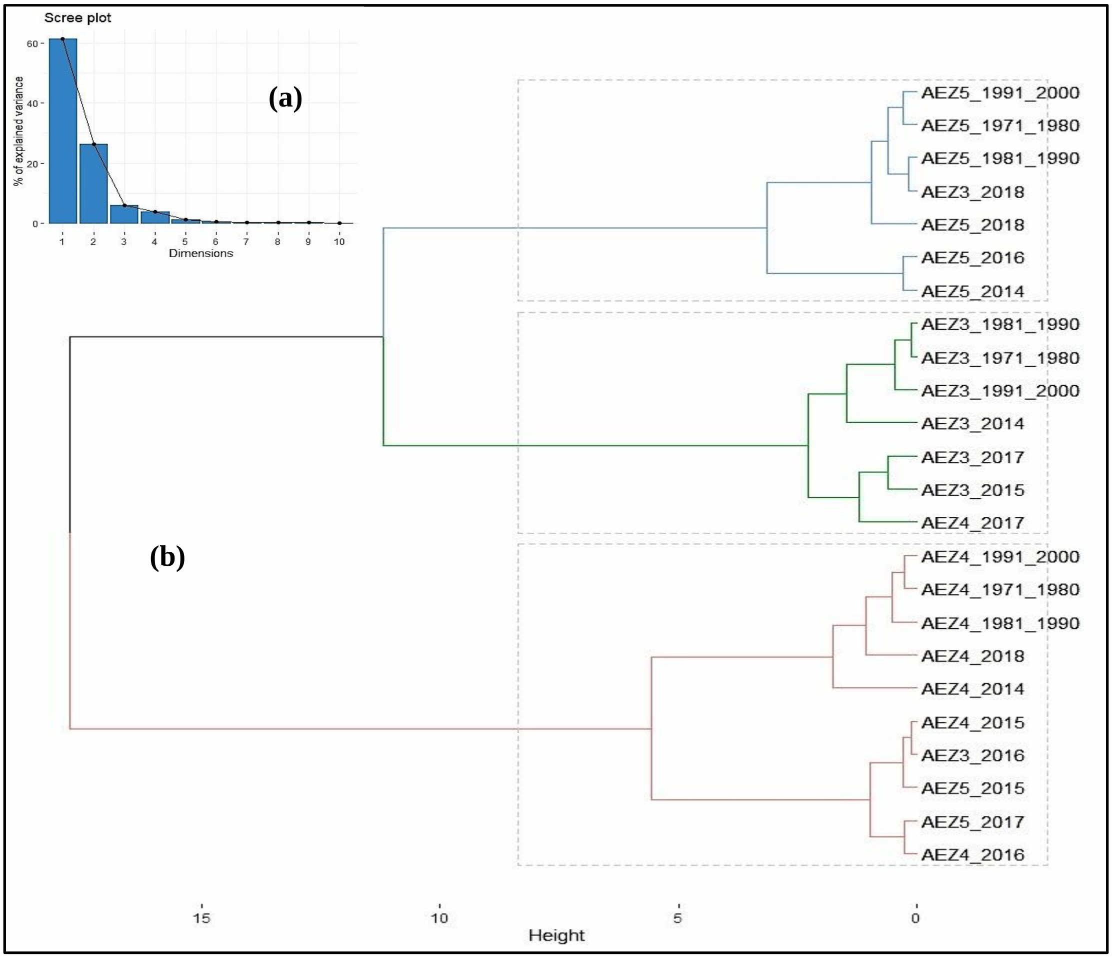

Figure 2: Clustering of meteorological profiles (a: scree plot of eigenvalues; b: dendogram).

Table 1: Characteristics of meteorological profiles classes in the study area.

Classes	Meteorological variables		
	Rainfall (mm)	**Number of rainy days**	**Average temperature (°C)**
1 (AEZ5_1971_1980, AEZ5_1981_1990, AEZ5_1991_2000, AEZ3_2018, AEZ5_2018, ZAE5_2016, ZAE5_2014)	1723 (211)	82 (13)	25 (3)
2 (AEZ3_1971_1980, AEZ3_1981_1990, AEZ3_1991_2000, AEZ3_2014, AEZ3_2017, AEZ3_2015, AEZ4_2017)	2149 (396)	186 (10)	19 (2)
3 (AEZ4_1971_1980, AEZ4_1981_1990, AEZ4_1991_2000, AEZ4_2018, AEZ4_2014, AEZ4_2015, AEZ3_2016; AEZ5_2015, AEZ5_2017, AEZ4_2016)	2839 (419)	211 (11)	29 (3)
Proportion of variance explained	**89%**	**94%**	**57%**

(Values represent means and standard deviations in parentheses)

Table 2: Modeling of the rotting rate of cocoa tree fruits according to some meteorological variables.

Independent Variables	Coefficients	Standard error	Estimated odds ratios (OR)		
			Estimated value	95% Wald CI	
Constant	0.083*	0.007			
Pluvio	0.102**	0.023	1.1074	1.0586	1.1584
NJP	0.161***	0.041	1.1747	1.0840	1.2730
Temp	-0.009^{ns}	0.006	0.9910	0.9795	1.0028

Model performance:

- Number of cases (N): 832
- Nagelkerke adjusted R^2 : 0.81
- Hosmer and Lemeshow Test: Pr > Chi-2 = 0.1123
- Correct predictions: 78%

Pluvio= Annual Pluviometry (mm); NJP= Annual number of rainy days; Temp= Annual mean temperature (°C)
Ns : not significant; * significant (p<0.05 ; two-tailed test) ; **highly significant (p<0.01 ; two-tailed test) ; *****very highly significant (p<0.001 ; two-tailed test)

Table 3: Modeling of the anthracnose rate of Arabica coffee tree berries (CBD) according to some meteorological variables.

Independent Variables	Coefficients	Standard error	Estimated odds ratios (OR)		
			Estimated value	95% Wald CI	
Constant	0.069*	0.013			
Pluvio	0.087*	0.044	1.0909	1.0008	1.1892
NJP	0.153**	0.081	1.1653	1.9943	1.3658
Temp	-0.148**	0.052	0.8624	0.7789	0.9550

Model performance:

- Number of cases (N): 453
- Nagelkerke adjusted R^2 : 0.78
- Hosmer and Lemeshow Test: Pr > Chi-2 = 0.0963
- Correct predictions: 69%

Pluvio= Annual Pluviometry (mm); NJP= Annual number of rainy days; Temp= Annual mean temperature (°C)
Ns: not significant; * significant (p<0.05; two-tailed test); ** highly significant (p<0.01; two-tailed test); ***** very highly significant (p<0.001; two-tailed test).

Table 4: Modeling of the rate of biting of cherries by insects (borers) in the Robusta coffee plant according to some meteorological variables

Independent Variables	Coefficients	Standard error	Estimated odds ratios (OR)		
			Estimated value	95% Wald CI	
Constant	0.296***	0.091			
Pluvio	-0.131**	0.038	0.8772	0.8143	0.9450
NJP	0.099*	0.017	1.1041	1.0679	1.1415
Temp	0.169***	0.046	1.1841	1.0820	1.2958

Model performance:

- Number of cases (N): 580
- Nagelkerke adjusted R^2 : 0.73
- Hosmer and Lemeshow Test: Pr > Chi-2 = 0.0826
- Correct predictions: 73%

Pluvio= Annual Pluviometry (mm); NJP= Annual number of rainy days; Temp= Annual mean temperature (°C)
Ns: not significant; * significant (p<0.05; two-tailed test); ** highly significant (p<0.01; two-tailed test); ***** very highly significant (p<0.001; two-tailed test)

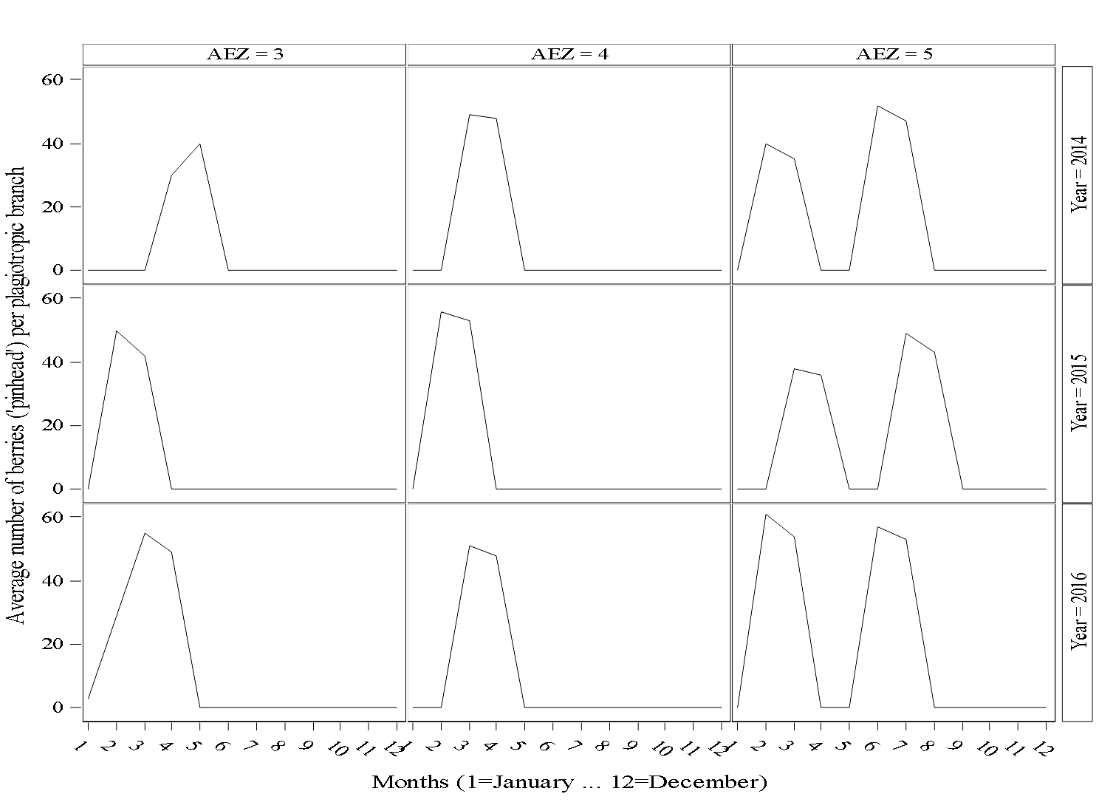

Figure 3: Dynamics of the flowering cycle in trees per AEZ: (a) on Arabica coffee trees; (b) on cocoa trees.

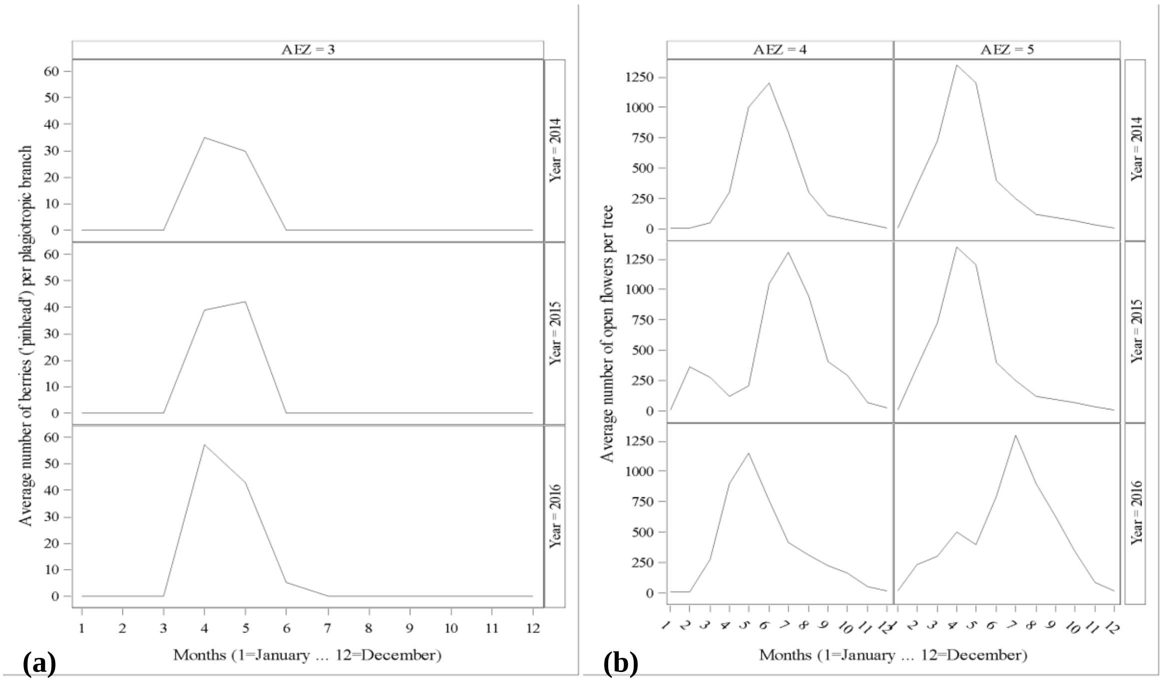

Figure 4: Dynamics of the flowering cycle in the Robusta coffee tree per AEZ.

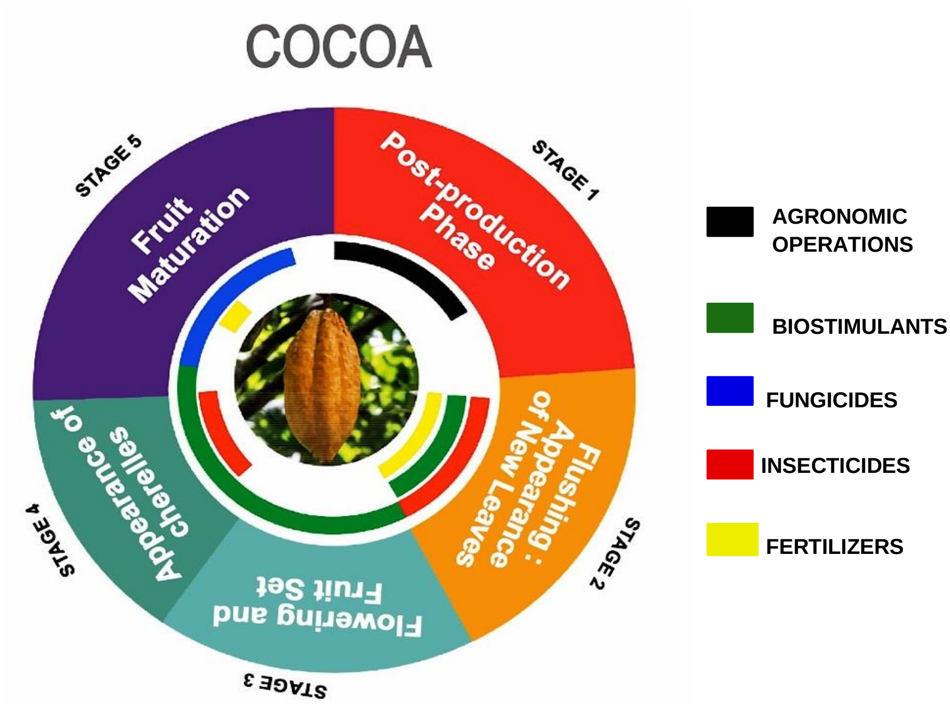

Figure 5: Technical itinerary on cocoa trees farms.

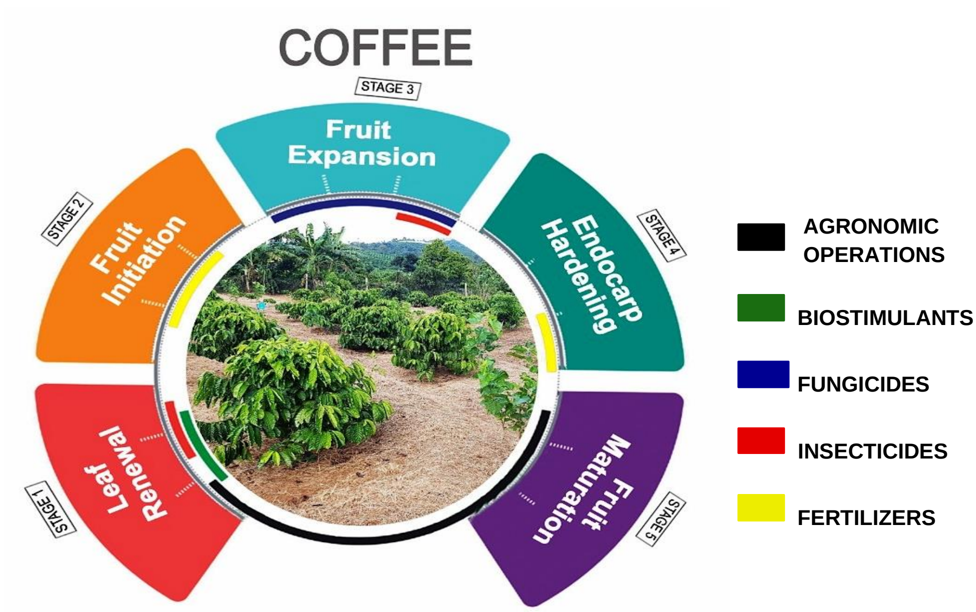

Figure 6: Technical itinerary on coffee trees farms.

DISCUSSION

The results about the typology of meteorological profiles reflect the non-recurring nature of the climatic variation observed *in situ*, particularly in the cocoa-coffee production areas, over the past five (05) years. They referred to real climatic disturbances that cannot allow a smooth implementation of the cultural calendar by farmers, who no longer easily make distinctions between seasons. Like all perennial plants, coffee and cocoa trees have a phenological cycle that is entirely dependent to seasonal climate variations (Bunn et al., 2015). They are therefore annually subjected to completely unpredictable climatic disturbances (DaMatta et al., 2010). These have a direct impact on the physiology and intrinsic growth of the plant, and indirectly on the development of pests and diseases (Agostini et al., 2003; DaMatta et al., 2019; Cilas et al., 2020). From 2014 to 2018, the instability of the meteorological profiles observed in class 3 and the intrusion of those of AEZ3 and 4, respectively in the unrelated classes 1 and 3, suggest that the development cycles of the plants studied are also fluctuating from year to year. It therefore becomes necessary to adopt a flexible way of farm management to circumvent some of the unfavorable effects of this climate change. For example, on rubber trees, the increase in atmospheric carbon dioxide (CO_2) stimulates photosynthesis, in times of higher temperatures (Kositsup et al., 2009). This CO_2 increase should lead to implement agricultural operations, likely to promote the development and preservation of the assimilatory system of coffee and cocoa trees (leaf growth, leaves and young green branches). In addition, our study corroborates that of Ngomeni et al. (2021) who highlighted the contribution of Robusta coffee-based agroforests in the mechanisms for mitigating the effects of climate change.

In regard with the characterization of meteorological profiles classes, results obtained revealed that in 2018, the Arabica coffee trees, whose biotope is in the mountainous zone, suffered the consequences of the climate of the humid forest zone, with a bimodal rainfall pattern. Moreover, in 2016, these same coffee trees found themselves in the climatic conditions of the humid forest zone, with a monomodal rainfall pattern. In both cases, these coffee trees had a growth pattern adapted to each of these new environmental conditions; which are completely different from those of their natural development areas. In Cameroon, Arabica coffee trees are planted in regions of altitude varying between 1100 and 2000 meters (Muller et al., 2004; Manga et al., 2013), where the rainy season is spread over 7 to 8 months following a monomodal rainfall pattern. The particular climatic characteristics of these regions favor a synchronous flowering of the coffee trees, triggered by the first rainfall with a minimum quantity of 10 mm (Muller et al., 2004). In principle, fruit development takes place over a period of 6 to 7 months from plants flowering (Muller et al., 2004). These favorable climatic conditions for the production of Arabica coffee did not occur in 2016 and 2018. During these two years, the berries development cycle was probably greatly disrupted by the new climatic realities. It is not excluded that this disruption will be exacerbated in 2018 due to a bimodal rainfall pattern. This type of rainfall distribution suggests the occurrence of two flowering peaks leading to the coexistence of two berry development cycles that moreover, would have overlapped. This new environment would contribute to making the cultivation of the Arabica coffee trees more complex, in terms of the management of epidemic cycles which would be juxtaposed and/or which would overlap. It would be the same for the harvest and postharvest management of the berries, whose ripening would occur according to the aforementioned scheme.

Concerning cocoa trees development, the ecological conditions of AEZ5 induce two or more annual fruiting cycles of trees. The management of the constraints related to this type of cocoa production is mainly oriented towards the control of black pod disease and the deployment of functional cropping systems. It has been demonstrated that the systematic practice of sanitary harvesting reduces, very significantly, this infection on cocoa trees (Ndoumbé Nkeng et al., 2009). It is the same for an optimal adjustment of the shading, concerning mirids attacks of cocoa pods (Babin et al., 2010; Babin et al, 2011; Mahop et al., 2018). The intercropping farming practice of cocoa trees with shade trees of economic interest and non-competing food crops helps to ensure the diversification of income sources for farmers. This might contribute to a proper functioning of the farming systems (Jagoret et al., 2011). Controlling the production constraints mentioned above could necessarily lead to a significant increase in the productivity of cocoa and Robusta coffee trees established in that agro-ecological zone (AEZ5). The climate of the AEZ4, which induces grouped flowering, could greatly reduce this increase in plant productivity, despite the lifting of production constraints as described above.

Rainfall and the number of rainy days appeared to be the most important climatic variables that explained the disease development on trees. Cocoa trees are generally cultivated in hot and humid regions where rains are abundant. However, if the ecologies of these regions are suitable for their good development, they could disturb equilibrium needed for the efficiency of biological control against pests damages such as that epiphytic that of parasite plants belonging to LORANTHACEAE's family (Ladoh and Yemeda, 2013). These suitable ecologies could also be favorable for the development of black pods disease epidemics on cocoa trees. They start as soon as the pathogen (*Phytophthora sp*.) encounters vulnerable host tissues during the rainy season. The dispersal power of rain, by the pathogen propagules *splashing* (Lovell et al., 2002) likely to contaminate healthy tissues, depends on the essential rains quantity constituents that are: their intensity, their duration and the kinetic energy of their drops (Pietravall et al, 2001; Lovell et al., 2002; Ji et al., 2021). However, contamination of healthy fruits is only a prerequisite for the initiation of the infectious process. It begins with the penetration of the pathogen into the susceptible host tissues, when the humidity of the environment tends towards saturation, in order to be able to maintain a sufficient degree of wetting of the fruits (Chen et al., 2017). The distribution of rainfall during the rainy season therefore appears to be a key variable for the development of an epidemic cycle. This is how a large number of rainy days can presume a shortening of the time interval between rainy days. In this case, the fruits would remain at a level of humidity favorable to triggering the infectious process. Conversely, a small number of rainy days would lengthen these periods and favor the rapid drying of the fruits; which would greatly disrupt the continuation of the infectious process.

The disease rate of Arabica coffee berries due to *Colletotrichum kahawae* increases significantly according to the amount of rain. This increase becomes more significant as the number of rainy days increases. In general, the rainfall variables have a similar effect on the epidemic dynamics and the course of the infectious process of mycosis, as mentioned above, for the black pod disease of cocoa trees. In the specific case of coffee berry disease, it has been demonstrated that there is no infection on fruits completely protected from the rain; which remains the major parameter in conidia dispersal of the pathogen (Mouen Bedimo et al., 2010).

This study also indicates that any increase in average temperatures leads to a significant decrease in the infection rate of the berries. The same phenomenon was highlighted by the analysis of cross-correlations between the disease rate and the minimum and maximum temperatures (Mouen Bedimo et al., 2012). The *Coffea Arabica / Colletotrichum kahawae* pathosystem remains functional in biotopes where temperatures vary between 18°C and 22°C. Below or above these thresholds, the system equilibrium may likely be broken, due to environmental conditions that alter the growth of the pathogenic fungus and/or, that induce changes in the biochemical state of the host organ. In addition to saturating humidity (Chen et al., 2017; Estrada et al., 2000), conidia germination of *C. kahawae* has been reported to occur at optimum temperatures of 20-22°C (Phiri et al, 2001). The indications provided by meteorological profiles classes (Figure 2) as well as their characteristics (Table 1), indicate that these temperatures were sometimes greatly exceeded in groups 4 and 5 in which the plots of Arabica coffee trees were found, in 2016 and 2018. Moreover, the conidia germination is triggered only if there is compatibility between the parasite and the cells of the host organ concerned by the infection. It has also been reported that conidia germination can be induced by the waxy layer of the fruit pericarp. It is possible that temperatures outside the limits of those favorable to the disease development have effects inducing an incompatibility between the parasite and the coffee tree cherries.

The rate of damage due to borers on the Robusta coffee tree increases very strongly according to the average temperatures; but it decreases very significantly with increasing rainfall. Borers hardly attack young berries because of their milky state and the very wet environment in which they are located. In general, they settle in the fruits at the beginning of their hardening until their complete ripening. Before reaching maturity, coffee tree cherries develop into “pinheads” and then undergo expansion (Wintgens, 2004). These are the fruit growth stages that occur in the midst of the rainy season. At this time precisely, berries from the main flowering remain virtually unscathed from borers’ attacks. Borers will bite only mature ones from an early marginal bloom. On the other hand, during their hardening and ripening, which occur respectively at the end of the rainy season and in the middle of the dry season, the fruits become very vulnerable to attacks by borers. These stages of their development coincide with the increasingly hot periods in the Robusta coffee production areas.

Conclusion

Heterogeneity as well as instability of the classes of meteorological profiles were observed annually during this study. They provided some concrete clues on the effectiveness of the phenomenon of climate change observed in the cocoa and coffee production areas of Cameroon. The rainfall variables allow identifying three distinct classes of meteorological profiles. However, the presence of most of the profiles obtained from 2014 to 2016, in unrelated classes, no longer allows a definition of typical climatic parameters by agro-ecological zone. These vary each year within an AEZ, thus impacting the fruit development cycles and, by extension, the productivity of the plants. Moreover, regardless of these variations, the incidence of black pod disease in cocoa trees and that of coffee berry disease in Arabica coffee trees increases with rainfall (mm) and the number of rainy days. On the contrary, the attack rate of borers on Robusta coffee trees berries decreases when the level of these rainfall parameters increases. But, the infestation of these insects increases according to the average temperatures. Climate change causes an almost recurrent annual modification of the phenological cycles of plants as well as that of their biotic and abiotic environments. In this context, it becomes very difficult to anticipate, from flowering to ripening, the key stages of fruit growth. Consequently, it will be the same for the implementation of the cultural calendar, because of their inadequacy with the phenological cycles concerned. These new constraints imposed by climate change have led to the conceptualization of innovative technical processes. They are based on close observation of the main phases of plant development. The successive agricultural operations carried out in the plantations must be motivated and triggered by the occurrence of precise morpho-physiological signals observed on the plants. These technical processes, recorded in the cocoa and coffee trees farms management guides, constitute an important technical tool for mitigating the harmful consequences of climate change on these crops.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

MOG: formulation of the problem; monitoring and evaluation; Interpretation of results; AR: monitoring and evaluation; data collection; results Interpretation; NNM: experimentation layout; data collection; data analyses; results interpretation; MBJA: experimentation layout; data collection; results interpretation; corresponding author; writing the first draft of the manuscript. All authors commented on previous versions of the manuscript. They read and approved the final version.

ACKNOWLEDGEMENTS

This study was carried out within the framework of the activities of the Cocoa and Coffee Interprofessional Council (CICC) of Cameroon. The authors extend their sincere thanks to Mr. ESSONO MESSANGA Sylvestre, Mr. ABISSI Yves, Mr. BASSANAGA Simon, Dr. MANGA ESSOUMA François and Dr. BEGOUDE Didier for their technical support in carrying out this work.

REFERENCES

Agostini JP, Bushong PM, Bhatia A, Timmer LW. 2003. Influence of environmental factors on severity of citrus scab and melanose. *Plant Dis.*, **87**:1102-1106. DOI: 10.1094/PDIS.2003.87.9.1102 .

Babin R, Ten Hoopen GM, Cilas C, Enjalric F, Yédé, Gendre P, Lumaret JP**.** 2010. Impact of shade on the spatial distribution of *Sahlbergella singularis* in traditional cocoa agroforests. *Agricultural and Forest Entomology*, **12**(1): 69-79. DOI: 10.1111/j.1461-9563.2009.00453.x

Babin R, Anikwe JC, Dibog L, Lumaret JP. 2011. Effects of cocoa tree phenology and canopy microclimate on the performance of the mirid bug *Sahlbergella singularis*. *Entomologia Experimentalis et Applicata*, **141**(1): 25-34. DOI: 10.1111/j.1570-7458.2011.01164.x.

Bunn C, Läderach P, Ovalle Rivera O, Kirschke D. 2015. A bitter cup: climate change profile of global production of Arabica and Robusta coffee. *Climatic Change*, **129** : 89–101. DOI : https://doi.org/10.1007/s10584-014-1306-x.

Chen C, Nunes MA, Silva MC, Rodrigues Jr CJ. 2017. Appressorium turgor pressure of *Colletotrichum kahawae* might have a role in coffee cuticle penetration. *Mycologia*, **96**(6): 1189-1209. DOI: https://doi.org/10.1080/15572536.2005.11832868

Cilas C, Bastide P. 2020. Challenges to cocoa Production in the Face of climate change and the spread of pests and diseases. *Agronomy*, **10**(9): 1232. DOI : https://doi.org/10.3390/agronomy10091232.

DaMatta FM, Grandis A, Arenque BC, Marcos S, Buckeridge MC. 2010. Impacts of climate changes on crop physiology and food quality. *Food Res. Int*., **43**(7): 1814-1823. DOI: 10.1016/j.foodres.2009.11.001.

DaMatta FM, Rahn E, Läderach P, Ghini R, Ramalho JC. 2019. Why could the coffee crop endure climate change and global warming to a greater extent than previously estimated? *Climatic Change*, **152:**167–178. DOI: https://doi.org/10.1007/s10584-018-2346-4.

Davis AP, Gole TW, Baena S, Moat J. 2012. The Impact of Climate Change on Indigenous Arabica Coffee (*Coffea arabica*): Predicting Future Trends and Identifying Priorities. *PLoS ONE* **7**(11): e47981. DOI: https://doi.org/10.1371/journal.pone.0047981

Dobson, AJ. 2001. *An Introduction to Generalized Linear Models*. Chapman and Hall, second edition: London.

Estrada AB, Dodd JC, Jeffries P. 2000. Effect of humidity and temperature on conidial germination and appressorium development of two Philippines isolates of the mango anthracnose pathogen *Colletotrichum gloeosporioides*. *Plant Pathology*, **49**: 608-618. DOI: https://doi.org/10.1046/j.1365-3059.2000.00492.x.

Gay C, Estrada F, Conde C, Eakin H, Villers L. 2006. Potential impacts of climate change on agriculture: a case of study of coffee production in Veracruz, Mexico. *Climatic Change,* **79:** 259–288. DOI: 10.1007/s10584-006-9066-x

Hardin J, Hilbe J. 2001. *Generalized Linear Models and Extensions*. Stata Press: USA, South Carolina.

Houghton JET, Ding Y, Griggs D, Noguer M, Van der Linden P, Dai X, Maskell M, Johnson C. 2001. *Climate Change: The Scientific Basis*. Cambridge University Press: United Kingdom, pp.881.

Hulme M, Doherty RM, Ngara T, New MG, Lister D. 2001. African climate change: 1900-2100. *Climate Research*, **17**: 145-168. DOI : http://dx.doi.org/10.3354/cr017145.

Jagoret P, Michel-Dounias I, Malézieux E. 2011. Long-term dynamics of cocoa agroforests: A case study in central Cameroon. *Agroforestry Systems*, **81**(3): 267-278. DOI: 10.1007/s10457-010-9368-x

Ji T, Salotti I, Dong C, Li M, Rossi V. 2021. Modeling the Effects of the Environment and the Host Planton the Ripe Rot of Grapes, Caused by the *Colletotrichum* Species. *Plants*, **10**(11): 2288. DOI: https://doi.org/10.3390/plants10112288

Kositsup B, Montpied P, Kasemsap P, Thaler PP, Ameglio T, Dreyer EE. 2009. Photosynthetic capacity and temperature responses of photosynthesis of rubber trees (*Hevea brasiliensis* Müll. Arg.) acclimate to changes in ambient temperatures. *Trees*, **23**: 357–365. DOI : 10.1007/s00468-008-0284-x**.**

Läderach P, Ramirez–Villegas J, Navarro-Racines C, Zelaya C, Martinez–Valle A, Jarvis A. 2017. Climate change adaptation of coffee production in space and time. *Climatic Change,* **141:**47–62. DOI: https://doi.org/10.1007/s10584-016-1788-9

Ladoh Yemeda CF, Mony R, Tchatat M, Dibong S. 2013. Contribution des fourmis à la lutte biologique contre les Loranthaceae. *J. Biol. Chem. Sci*., **7**(3): 924-937. DOI: http://dx.doi.org/10.4314/ijbcs.v7i3.4

Lovell DJ, Parker SR, Van Peteghem P, Webb DA, Welham SJ. 2002. Quantification of raindrop kinetic energy for improved prediction of splash-dispersed pathogens. *Phytopathology,* **92**: 497–503. DOI: DOI: 10.1094/PHYTO.2002.92.5.497

Mahob RJ**,** Etam PBSN, Dibog L**,** Babin R**,** Voula AV**,** Begoude D**,** Toguem YGF**,** Baleba L**,** Ndongo PAO**,** Bilong CFB**.** 2018. Assessment of the effect of cocoa mosquito mirid true bug, *Helopeltis* spp. (Hemiptera: Miridae) on the cocoa (*Theobroma cacao* L.) production in Cameroon (Central Africa). *International Journal of Biological and Chemical Sciences*, **12**(4): 1865-1875. DOI : https://doi.org/10.4314/ijbcs.v12i4.27

Manga MA, Akoa A, Abolo D, Mbang AA, Bedimo JAM, Nomo LEB, Akume ND. 2013. Structure et composition floristiques des agroforêts à base de caféiers arabica (*Coffea arabica* L.) dans les hauts plateaux de l'Ouest du Cameroun. *J. Biol. Chem. Sci*., **7**(4): 1474-1489, DOI: http://dx.doi.org/10.4314/ijbcs.v7i4.5

Mouen Bedimo JA, Bieysse D, Notteghem JL, Cilas C. 2010. Role of rainfall in the development of coffee berry disease in *Coffea arabica* caused by *Colletotrichum kahawae*, in Cameroon. *Plant Pathology*, **59:** 324-329. DOI: 10.1111/j.1365-3059.2009.02214.x.

Mouen Bedimo JA, Cilas C, Notteghem JL, Bieysse D. 2012. Effect of temperatures and rainfall on the development of coffee berry disease caused by *Colletotrichum kahawae*. *Crop Protection*, **31 :** 125-131. DOI: 10.1016/j.cropro.2011.09.010.

Muller RA, Berry D, Avelino J, Bieysse D. 2004. Coffee diseases. In: *Coffee: Growing, Processing, Sustainable production: A guidebook for growers, processors, traders, and researchers*, Wintgens JN (edn). WILEY-VCH Verlag GmbH and Co. KGaA, Weinheim: Germany, 491-545. DOI: 10.1002/9783527619627.

Ndoumbé Nkeng M, Efombagn MIB, Nyasse S, Nyemb E, Sache IC, Cilas C. 2009. Relationships between cocoa *Phytophthora* pod rot disease and climatic variables in Cameroon. *Can. J. Plant Pathol.*, **31**(3): 309-320. DOI: 10.1080/07060660909507605.

Ngomeni AF, Bidzanga ELN, Avana ML, Tchamba MN, Chimi CD. 2021. Potentiel de séquestration du carbone des agroforêts à base de caféier robusta (*Coffea canephora* var. robusta) dans les bassins de production du Cameroun. *J. Biol. Chem. Sci.*, **15**(6): 2652-2664. DOI: https://dx.doi.org/10.4314/ijbcs.v15i6.31

R Core Team (2022). R: *A language and environment for statistical computing*. R Foundation for Statistical Computing: Vienna, Austria. URL https://www.R-project.org/

Pachauri RK, Reisinger A. 2008. Climate change: Synthesis report. Contribution of Working Groups I, II and III to the fourth assessment report. Switzerland: N. p. Web. DOI: http://www.ipcc.ch/ipccreports/ar4-syr.htm.

Pietravall S, van den Bosch F, Welham SJ, Parker SR, Lovell DJ. 2001. Modelling of rain splash trajectories and prediction of rain splash height. *Agric. For. Meteorol.*, **109:**171-185. DOI: https://doi.org/10.1016/S0168-1923(01)00267-2

Phiri NA, Hillocks RJ, Jeffries P. 2001. Incidence and severity of coffee disease in smallholder plantations in Northern Malawi. *Crop Protection*, **20** : 325–332. DOI: https://doi.org/10.1016/S0261-2194(00)00161-7

Rosenzweig C, Iglesias A, Yang XB, Epstein PR, Chivian E. 2001. Climate change and extreme weather events: Implications for food production, plant diseases, and pests. *Glob. Change Human Health*, 2: 90-104. DOI : https://doi.org/10.1023/A:1015086831467.

SAS Institute Inc. 2013. SAS/ACCESS® 9.4 Interface to ADABAS: Reference. Cary, NC, SAS Institute Inc.: USA

Wintgens, J. N. 2004. The Coffee Plant In: *Coffee: Growing, Processing, Sustainable production: A guidebook for growers, processors, traders, and researchers*, Wintgens JN (edn). WILEY-VCH Verlag GmbH and Co. KGaA, Weinheim: Germany: 1-24. DOI: 10.1002/9783527619627.