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Stability of productivity parameters of six cocoa clones [*Theobroma cacao* (Malvaceae)] during the main production season in Côte d'Ivoire

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The strong climatic fluctuation observed during the major cocoa production period with reductions in rainfall and rising temperatures lead to a low graining index. This climatic situation makes cocoa marketing difficult for producers. The stability of quantitative productivity parameters in six cacao clones on farm was analyzed during the main production season. Flowering, average pod weight, number of beans per pod, average bean weight, bean size, and pod index were analyzed. The results obtained showed that the flowering intensity of the clones was high in September (49.07). The average weight of pods decreased from 511.38 g in September to 433.53 g in January. The average weight of a bean and the weight of 100 beans, respectively of 1.3 g and 125.62 g at the beginning of the season dropped in January to 1.13 g and 94.03 g. Clones C8 and C15 showed more stable agronomic characteristics, notably average pod weight, average bean weight, bean size, and pod index during the major production phase. These two promising clones could be used in the rehabilitation phase of degraded cacao plantation, given the stability of their agronomic characteristics.

Key words: Cocoa, flowering, pod index, yield.

INTRODUCTION

Cacao (*Theobroma cacao* L.) produces a valuable commodity for many producing and processing countries (Lahive et al., 2018; World Bank, 2019). However, these two decades, cocoa sector is faced with economic However, over the last two decades, the cocoa sector has faced economic constraints, with a need to increase the proportion of total added value generated in the global value chain; environmental constraints (Traore,

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2018), with an obligation to halt deforestation associated with cacao farming through responsible intensification; and social constraints (Konaté et al., 2015), with an urgent need to improve producer income and living conditions.

The disturbance of the cacao-forest balance is the cause of the deterioration of the cacao landscape leading to a modification of the climatic factors (Brou, 2010; Läderach et al., 2013). This change is reflected, among other things, in a decrease in annual rainfall since 1970 in the south forest region (Tanina et al., 2011), which is considered favorable for cacao production. The rainfall is the most significant factor in cacao farming, as a prolonged lack of water during the flowering phase can lead to a drop in cacao production for both production seasons September - January and April - July. Temperature in cocoa growing areas usually lies between a minimum of 18-21°C and a maximum of 30-32°C.

When, the mean annual rainfall drops below 1000 mm, moisture loss from evapotranspiration is likely to exceed precipitation and may intensify and prolong drought at the critical stage of cacao crop‟s life. Other factors of climate (humidity, solar radiation) as well as ecological, biological and physical factors can also have a significant influence on the phenology of the cocoa tree and its yield. Cacao is an understory tree, which requires specific climatic conditions for its development. annual rainfall between 1300 and 2000 mm with a limited number of dry days (less than 3 months), an average daily temperature between 24 and 28°C, a relative humidity between 80 and 90%, with a daily sunshine duration more than four hours. It is important to consider not only cacao responses to individual climate variables but also how the interactions of these variables influence growth and productivity of cacao. In cacao, very limited research has been performed. To date, research on the interactions of climate change variables on cacao has been limited, and much of the available data is based on seedling studies. Genotypic differences in productivity, net photosynthesis, canopy architecture, and biomass partitioning have been identified (M'bo et al., 2016), as well as differential effects of temperature on fruit development, and bean quality (Daymond and Hadley, 2008). So far, investigation of clone in field condition is very limited in cacao.

The aging of cacao plantation (Assiri et al., 2012), the low productivity of farm (Van Vliet et al., 2021), and the degradation and decline of soil fertility (Koko et al., 2009), have forced the Ivorian government to adopt new programs to improve the productivity of cacao farm than the full sun farming system adopted by cocoa farmers with unimproved planting material. However, weather parameters continue to affect cacao growth, as well as flowering, fruit development, and technological characteristics which causes high depreciation of the marketable bean (Kanohin et al., 2012).

Supplying farmers with cacao varieties that are tolerant and adapted to the climatic context is one of the conditions for sustainable production. Vulgarized plant material, characterized by its early production (N'Goran and Eskes, 2006; Lachenaud, 2010; Tahi et al., 2012, 2019), should present a stability of these agronomic characteristics, such as flowering intensity, average weight of pod, number of beans per pod, weight of marketable bean, graining and pod index. However, despite the efforts made, the Ivorian cacao crops are still aging. Faced with such challenge, Côte d'Ivoire must explore other production models in order to ensure the sustainability of its production. The holistic approach to increasing cacao farm productivity by establishing effective environmental management has been implemented in the Vision for Change (V4C) project in Soubré. This approach includes the use of high yielding cloned whose agronomic behavior in the field in face to climatic drivers remains poorly understood. However, local rainfall and temperature pattern influence the agronomic parameters of cacao. To understand the behavior of trees during the main production period (September-January), an analysis of the agronomic characteristics of the clones was conducted in the farm. This study was conducted under the hypothesis that the agronomic parameters of cacao clones are stable during the harvest period. The objective is to analyze the stability of productivity parameters in cacao a clones in the farm.

MATERIALS AND METHODS

Environmental conditions and climate variable of study zone

The study was conducted in Guéyo in the southwest of Côte d'Ivoire in the Nawa region between latitudes 5°41" 18" N and longitudes 6° 4" 16" W. The climate of the region is humid tropical and characterized by two rainy seasons, April-June and September-November, and two dry seasons, July-August and December-March. The average annual rainfall and temperature are respectively 1503 mm and 28°C. With its hot and humid environment, Soubré region provides more than 30% of the cocoa production and is the first production area. The metrological parameters recorded during the study period are shown in Figures 1 and 2.

Plant material

The plant material is constituted of six (6) cacao clones provided to ICRAF by the National Agricultural Research Center (CNRA). These are clones C1, C8, C9, C14, C15 and C17.

Experimental design

The study was conducted in cacao plots of 0.5 ha. These homogeneous cacao farms are at least seven years old. In each of the plots, clones C1, C8, C9, C14, C15, and C17 are represented by 60 individuals. The clones were grafted onto cacao 3 m apart on the baseline and 2.5 m apart on the planting line. The plots are constituted of randomized lines of clone.

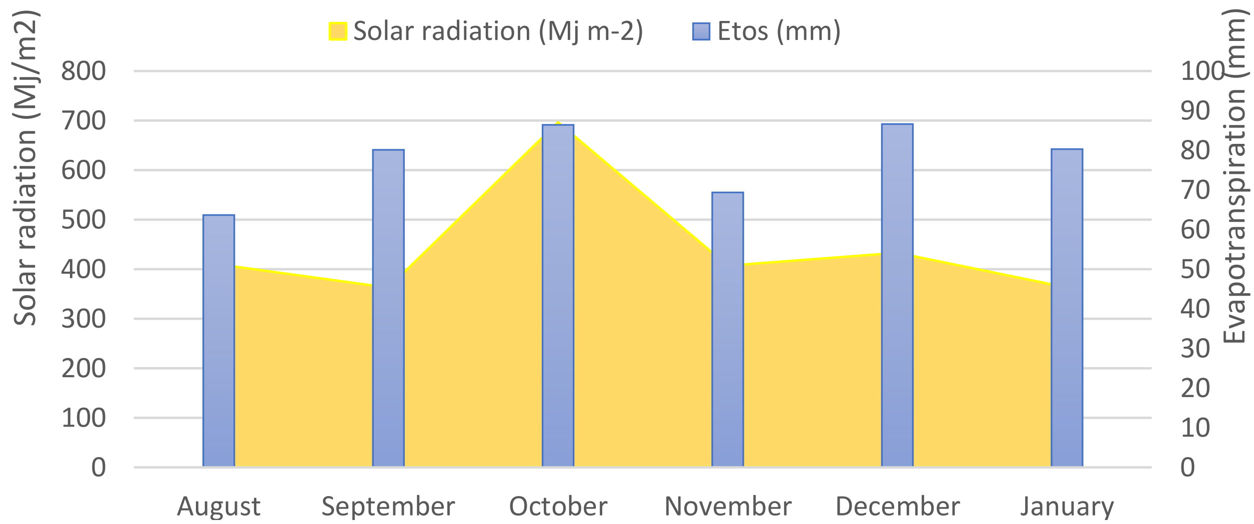

Figure 1. Monthly solar radiation and evapotranspiration in study area.
Source: Authors

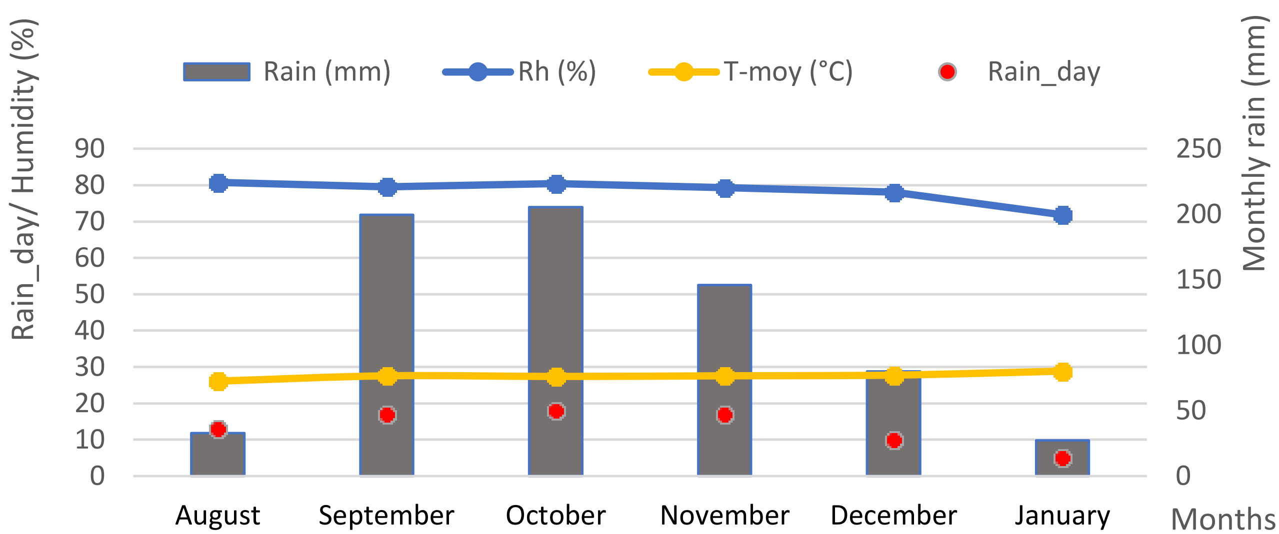

Figure 2. Monthly rain parameters, relative humidity, and temperature of study area.
Source: Authors

Data collection

The agronomic data were collected from September to January on 6 trees per clone and per plot according to the plantation lines on which the clones were grafted.

Assessment of flowering intensity (FI)

Flowering intensity was determined by counting the number of flowers appearing on the cacao branches from the graft insertion point to 2 m above.

Determination of pod weight and number of beans per pod

At the tree base of per cacao clone, 10 healthy and mature pods were harvested per month using secateurs. The average weight of the pods was determined directly by weighing the pods from the clones studied using a precision electronic scale (0.01; Satoruis, Germany). After dehusking, the number of normal beans and flat beans for each clone was counted**.**

Determination of the average weight of a bean, the graining and the pod index (PI)

Fresh beans were placed in labeled tissue and covered for seven (7) days by plantain leaves. After fermentation, the beans of each clone were dried separately in the sun for seven days.

The average weight of a dry bean or seed index, which reflects the unit weight of a fermented dry bean was determined by weighing 50 selected normal beans using a precision (0.01) Statorius electronic balance. Graininess (bean size) was determined by the average weight of samples of 100 selected and separately weighed beans using a precision Statorius electronic scale (0.01). The pod index (PI), which corresponds to the number of pods needed to obtain 1 kg of marketable cocoa, was calculated by the following formula:

PI = (1000 g x 100) / (weight of 100 beans x Number of beans per pod), Equation 01; Vera, 1969; Duval et al., 2017).

Data analysis

The collected data were formatted in Excel files. Excel files were validated with SAS Insight and outliers were corrected.

The general linear model (GLM) analysis of variance in SAS software 9.4 (2013) was used to compare clones according to the LSD test at the 5% threshold.

RESULTS

Flowering intensity (FI)

The analysis of flowering intensity (FI) of cacao clones by months showed a significant effect of January (p≤0.0012) and October (p ≤0.00410) on flowering intensity. However, no significant difference was revealed for flowering intensity of clones for the month of December (p ≥ 0.3418), November (p ≥ 0.8133), and September (p ≥ 0.1280) (Table 1). For all clones, January month (FI 23.08) was marked by a low intensity of flowering. However, the strong flowering of cocoa trees was observed in September (FI 49.07). A clonal variation in the number of flowers was observed from September to January. However, for September, November and December, the flowering intensity of the clones did not reveal any difference. In October and November, clone C8 (FI 74.56) and C17 (FI 72.67) recorded the highest flowering rates.

Average pod weight (Pw) and number of beans per pod (Nb)

The average weight of a pod (Pw) per cacao clone is affected by monthly climatic parameters (Table 2). The months of September (P ≤ 0.0128), October (P ≤ 0.0001), November (P ≤ 0.0001), December (P ≤ 0.6612) and January (P ≤ 0.0001) significantly influenced the pod weight of cocoa clones (Table 2). Depending on the month, the lowest average pod weight of clones was observed in January (Pw 433.53 g) and the highest in September (Pw 511.38 g). From September to January clone C8 presented a high pod weight with an overall average of (Pw 661.67 g). It is followed by clone C15 with an average pod weight (Pw 531.952 g).

Analysis of the effect of month on number of beans revealed a significant monthly effect for the months of September (P ≤ 0.0413), October (P ≤ 0.0001), November (P ≤ 0.0001), December (P ≤ 0.0001), and January (P ≤ 0.0001) (Table 3).

September (Nb 33.22) had the lowest number of beans per pod. Genotypic variation was observed for number of beans. Comparison of clones indicates that the highest values were observed with C14 (Nb 41.38 beans) and C8 (Nb 38.87 beans) and the lowest with clone C1 (Nb 28.56).

Weight of a bean (Wb)

Over the study period, the months of October (P ≤ 0.0401), November (P ≤ 0.0145), December (P ≤ 0.0431), and January (P ≤ 0.0441) significantly affected the mean bean weight (Wb) of cacao clones (Table 4). The average weight of a dry bean per month showed variation with the lowest average in January (Wb 1.13 g) and the highest value in November (Wb 1.30 g). The average weight of a dry bean showed a variation from one clone to another. Except for clone C14 which had an average of (Wb 0.95 g), the average value of the average bean weight among the clones was above 1 g.

Weight of 100 beans (W100)

In the studied cacao clones, the weight of 100 beans was significantly affected by the months of December (P ≤ 0.0223), November (P ≤ 0.0132), and October (P ≤ 0.0229) with the exception of January where all clones were statistically identical (P ≥ 0.4335) (Table 5). The month of December (W100 94.03 g) recorded the lowest value of 100 bean weight while the highest value was observed in October (W100 125.62 g). The weight of 100 beans showed a genotypic difference from October to January. Clone C8 with (W100 209.75 g) in October showed the highest 100 bean weight. Clone C14 is less interesting for this trait over the whole study period with the lowest average value of (W100 76.20 g) shown in January.

Pod Index (PI)

The results of the pod index (PI) indicate that in the cacao clones studied, in the months of October (P ≤ 0.0207), November (P ≤ 0.0434) and December (P≤ 0.0106) showed a significant month effect. In contrast, in January (P ≤ 0.2157), no difference was noted (Table 6). In general, the pod index varied with the lowest value in October (PI 25.12) and the highest values observed in December (PI 28.56) and January (PI 28.15) between clones, a variation was noted. Clone C1 with an average (PI 36.93) and values (PI 38.74) in December and (PI 38.75) in November showed the highest pod indices. Clone C8 with average value (PI 14.03) and value (PI 11.60) in October showed the lowest pod index.

Table 1. Flowering intensity (FI) of cacao clones.

Clone	Number of flowers (FI)					Means
	September	October	November	December	January	
C1	45.56^{a}	17.00^{b}	28.90^{a}	42.36^{a}	17.88^{b}	30.34^{bc}
C8	71.75^{a}	74.56^{a}	64.90^{a}	37.50^{a}	16.75^{b}	53.09a
C9	43.67^{a}	34.57^{b}	45.07^{a}	36.60^{a}	22.86^{ab}	36.55^{b}
C14	40.50^{a}	8.20^{b}	39.33^{a}	12.00^{a}	21.00^{ab}	24.20^{c}
C15	51.78^{a}	23.00^{b}	19.92^{a}	8.50^{a}	19.67^{ab}	24.57^{c}
C17	41.20^{a}	28.38^{b}	72.67^{a}	54.53^{a}	41.67^{a}	47.69a
Means	49.07^{a}	30.95^{ab}	45.13^{a}	31.88^{ab}	23.08^{b}	
LSD(p≤0.05)	0.128	0.0041	0.8133	0.3418	0.0012	

In each column, means followed by the same letter are statistically identical at the 5% level (LSD), LSD (p ≤ 0.05), Probability LSD.
Source: Authors

Table 2. Average pod weight of cacao clones.

Clone	Pod weight (Pw)					Means
	September	October	November	December	January	
C1	498^{ab}	503.48^{bc}	470.45^{bc}	486.8^{ab}	378.20^{cd}	467.29^{bc}
C8	-	771.83^{a}	656.94^{a}	603.00^{a}	614.94^{a}	661.67^{a}
C9	555.46^{ab}	457.15^{cd}	444.42^{c}	425.9^{ab}	371.45^{cd}	450.87^{c}
C14	407.17^{b}	405.75^{d}	296.48^{d}	338.00^{b}	323.00^{d}	354.08^{d}
C15	633.80^{a}	544.03^{b}	510.55^{b}	493.3^{ab}	478.08^{b}	531.95^{b}
C17	462.50^{b}	419.68^{d}	461.02^{bc}	459.7^{ab}	435.56^{bc}	447.69^{c}
Means	511.38^{a}	516.38^{a}	473.31^{b}	467.78^{b}	433.53^{c}	
LSD (p≤0.05)	0.0128	0.0001	0.0001	0.6612	0.0001	

In each column, means followed by the same letter are statistically identical at the 5% level (LSD), LSD (p ≤ 0.05): Probability LSD.
Source: Authors

Table 3. Number of beans (Nb) per pod.

Clone	Number of beans per pod (Nb)					Means
	September	October	November	December	January	
C1	28.50^{b}	28.7^{b}	28.31^{b}	29.75^{b}	27.51^{a}	28.56d
C8	-	41.33^{a}	37.51^{a}	38.54^{a}	38.14^{a}	38.87^{b}
C9	31.38^{ab}	32.95^{ab}	31.04^{b}	28.57^{b}	37.20^{a}	35.16^{c}
C14	38.83^{a}	41.25^{a}	37.05^{a}	43.25^{a}	44.00^{a}	41.38^{a}
C15	34.60^{ab}	38.57^{a}	37.65^{a}	39.30^{a}	33.67^{a}	37.29^{ab}
C17	27.87^{b}	33.64^{ab}	38.17^{a}	37.94^{a}	37.91^{a}	36.91^{ab}
Mean	33.22^{b}	36.07^{b}	34.95^{b}	36.22^{a}	36.4^{a}	
LSD:(p≤0.05)	0.0413	0.1842	0.0058	0.0277	0.5461	

In each column, means followed by the same letter are statistically identical at the 5% level (LSD), LSD (p ≤ 0.05): Probability LSD.
Source: Authors

DISCUSSION

This study revealed the instability in production parameters in cacao clones during the peak productivity period of July to January. Because of the fluctuation of climatic parameters and the appearance of short dry

Table 4. Dry bean weight of cacao clones.

Clone	Average weight of dry bean (Wb)				
	October	November	December	January	Mean
C1	1.10^{ab}	1.10^{b}	0.94^{b}	0.96^{b}	1.05^{c}
C8	1.91^{a}	2.14^{a}	1.99^{a}	1.95^{a}	1.99^{a}
C9	1.19^{ab}	1.10^{b}	1.10^{b}	1.03^{b}	1.1^{bc}
C14	0.91^{b}	1.04^{b}	0.87^{b}	0.88^{b}	0.95d
C15	1.33^{ab}	1.22^{b}	1.10^{b}	1.12^{b}	1.19^{b}
C17	1.09^{ab}	1.23^{b}	0.97^{b}	0.86^{b}	1.03^{c}
Means	1.25^{a}	1.3^{a}	1.16^{b}	1.13^{b}	
LSD(p≤0.05)	0.0401	0.0145	0.0431	0.0441	

In each column, means followed by the same letter are statistically identical at the 5% level (LSD), LSD (p ≤ 0.05): Probability LSD.
Source: Authors

Table 5. Weight of 100 dry beans of cacao clones.

Clone	Weight of 100 dry beans or grains (W100)				
	October	November	December	January	Means
C1	105.65^{b}	102.41^{b}	88.01^{b}	93.86^{a}	97.48^{c}
C8	209.75^{a}	192.54^{a}	166.89^{a}	177.19^{a}	186.59^{a}
C9	112.67^{b}	110.25^{b}	102.25^{b}	101.57^{a}	106.66^{b}
C14	89.80^{b}	88.20^{b}	83.90^{b}	76.20^{a}	84.52d
C15	117.33^{b}	112.15^{b}	100.84^{b}	107.54^{a}	109.46^{b}
C17	110.49^{b}	101.68^{b}	95.19^{b}	92.32^{a}	99.92^{bc}
Means	125.62^{a}	117.87^{b}	94.03^{c}	108.11d	
LSD(p≤0.05)	0.0229	0.0132	0.0223	0.4335	

In each column, means followed by the same letter are statistically identical at the 5% level (LSD), LSD (p ≤ 0.05): Probability LSD.
Source: Authors

Table 6. Pod index of cacao clones.

Clone	Pod index (IC)				
	October	November	December	January	Means
C1	35.57^{a}	34.66^{a}	38.74^{a}	38.75^{a}	36.93^{a}
C8	11,60^{c}	13.84^{c}	15.64^{b}	15.04^{a}	14.03d
C9	27.16^{b}	29.39^{ab}	36.25^{a}	33.04^{a}	31.46^{ab}
C14	26.99^{b}	30.60^{ab}	27.55^{ab}	29.49^{a}	28.65^{b}
C15	22.37^{b}	24.00^{b}	25.37^{ab}	23.46^{a}	23.8^{c}
C17	27.06^{b}	25.90^{ab}	27.83^{ab}	29.13^{a}	27.48^{b}
Means	25.12^{b}	26.39^{b}	28.56^{a}	28.15^{a}	
LSD(p≤0.05)	0.0207	0.0434	0.0106	0.2157	

In each column, means followed by the same letter are statistically identical at the 5% level (LSD), LSD (p ≤ 0.05): Probability LSD.
Source: Authors

sequences during the production period, cacao trees lose their production capacity in this period. The characters of flowering intensity, average weight of a pod, number of beans per pod, weight of a market bean, graining and pod indices were analyzed.

The flowering of the cacao follows a seasonal rhythm depending on climatic parameters. In wet periods during the peak of production, the flowering intensity is important and becomes weak in dry period. Studies by Lachenaud (1991) concluded that intense flowering during rainy months is due to good water availability, optimal temperature and high relative humidity. Dry sequences of more than 20 days would be a limiting factor for cacao flowering (Mian, 2007). The weak flowering of January clones would be linked to the decrease in rainfall and the increase in temperature during the dry period. Monthly fluctuations in average pod weight were recorded for clones in the field. The authors’ results are in accordance with those of Boyer (1970). Indeed, the development of a pod includes two phases, the first, marked by the growth of the volume at the beginning of the development by an enrichment of the pod in water and the second manifesting itself by a strong increase of the dry matter. The long rainy season from April to June at the beginning of the development of the pods as well as the short rainy season from September to November at the stage of maturation favored both good growth in volume of the pods at the beginning of their development and an increase in dry matter at the last stage of maturation. The lack of water during the short dry season from July to August at the beginning of pod development and during the long dry season in January at the last stage of pod maturation could explain the low pod weights observed in January. However, clones C8 and C15 showed excellent average pod weights compared to the other clones. The number of beans per pod varied from 41.38 (C8) to 28.53 (C1) between clones. This variation indicates a genotypic factor (Fabien et al., 2020). Indeed, such variations were observed by Youbi et al. (2018) in clones Bat1 (30.24) and SNK413 (35.51). According to Mossu (1990), pod filling is attributable to the pollination process, the average number of ovules contained in the ovaries and the minimum number of seeds for a cherelle not to wilt. A monthly variation in the number of beans is observed and is in agreement with the results of Lachenaud (1991) who observed a decrease in the number of beans per pod in the dry season. The author attributes this to the worsening of the water deficit during the long dry season, which would cause a nutritional imbalance due to the hydromineral deficit.

The average weight of a bean, the weight of 100 beans and the pod index or yield of marketable cocoa underwent a clonal and monthly variation. This variability would be related to monthly climatic disturbances (Zuidema et al., 2005; Towaha and Wardiana, 2015). The average weight of a dry bean for the clones studied was above 1 g and the average weight of 100 dry beans was above 100 g except for clone C14 with an average bean weight of 0.95 g and a weight of 100 beans of 84.5 g. In the rainy season (October-November), the average bean weight and weight of 100 high beans decreased in the dry season (December-January). The authors’ results confirm those of Lachenaud (1991) in Côte d'Ivoire, who highlighted seasonal variations in the average weight of fresh beans and those of Youbi et al. (2018) who found a decrease in the average weight of a bean by 42% during the harvest period. Furthermore, results showed that in the rainy season (October-November), the pod index is low but increases in the dry season (December-January). These results are also in accordance with Edwards (1972) who mentions that the pod index increases from August to January depending on the planting material. For Boyer (1970), the hydric and thermal conditions are the drivers governing the weight of beans per cocoa pod. Indeed, the water requirement of the cacao tree estimated to 70 mm per month is likely to increase the size of beans (Kassin et al., 2008). According to Bastide et al. (2008), abundant and well distributed rainfall increases the yield of cocoa marketable beans. The high rainfall could therefore account for the increase in average bean weight, bean size and the increase in marketable cocoa yield in October and November. Daymond and Hadley (2008) showed that excessive temperatures during the ripening season are likely to reduce bean size. For Petithuguennin (1998), the water deficit favors the production of small beans, less rich in butter and consequently a decrease in the yield of marketable cocoa. The drop in rainfall and the increase in temperature would therefore be the cause of the decrease in average pod weight, bean size and the decrease in marketable cocoa yield during the dry season (December-January).

Conclusion

The authors work was based on the analysis of the stability of the yield parameters of cacao clones during the main harvest period. The clones studied showed stable agronomic traits in abundant rainfall and a decrease in the quantitative values of these parameters in dry periods. However, some clones studied showed stable agronomic traits due to their ability to tolerate the effects of climatic disturbances as much as possible. Some clones such as C8 is interesting for its flowering characteristics, average bean weight, graining and yield of marketable cocoa. It is followed by C15. The C14, although it produces more beans, is not very good for the other agronomic characteristics. It seems to be poorly adapted compared to the other clones. This study is a contribution to a better knowledge of the stability of agronomic traits in cacao clones used in the rehabilitation of degraded orchards. Clones C8, C15, and C14 with stable agronomic characteristics are promising for the rehabilitation of ageing and non-productive crops.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

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