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RESEARCH PAPER

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Determination of the optimum date for planting cocoa hybrids in the Divo region (Côte d'Ivoire)

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Abstract

The cocoa tree, a crop highly prized in the world for its beans, is one of pillars of the Ivorian economy. However, it is confronted with numerous constraints including climatic disturbances which disturb the cropping calendar. The aim of this work is to determine an optimal planting date allowing a good establishment in the cocoa field. Thus, six-month-old plants were planted on different dates, in particular in March, April, May and June 2015. The parameters studied were the annual rainfall, the monthly distribution of the rains, the growing seasons of Divo, the mortality rate of the plants, the vegetative growth and the production. The results showed that cocoa trees planted in June expressed the highest survival rate (87.9%), followed by that of April (84.96%). The best increases in diameter and height were observed with the March and April plants. Regarding production parameters, the results showed that the March and April plants recorded the highest crowning rates with 66.3 and 57.8% respectively. The same was true of flowering where their rates were 35.4 and 30.3%. Production of cherries was higher in March (25.2%) and April (21.1%) plants. Ultimately the study shows that an early planting of cocoa trees is possible in the Divo region, at least, from the 3rd decade of March.

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Introduction

Côte d'Ivoire has been the world's largest producer of cocoa for four decades. Over an estimated area of over 2,000,000 ha, more than 2,010,000 tonnes of cocoa are produced annually (ICCO, 2017). For the 2016-2017 season, this production represented more than 42.77% of the world supply (ICCO, 2017). Cocoa, which makes a fundamental contribution to economic prosperity, is a strategic product for Côte d'Ivoire. In fact, cocoa provides around 40% of export earnings and contributes more than 15% to Gross Domestic Product (GDP) (Dufumier, 2016). Despite all these performances, the sustainability of cocoa farming and export volumes are threatened by many constraints, including the low level of use of improved plant material (Tahi *et al.,* 2011), aging of the orchard and high parasite pressure due, among others, to certain pests such as mirids (N'Guessan and Coulibaly, 2000) and certain diseases such as brown pod rot. In addition to those mentioned above, the most important production constraint at the moment remains climatic disturbances. These result in a drastic decrease in rainfall, poor distribution of rainfall and the appearance of longer and more severe droughts (Brou *et al*, 2005).The consequences of this change are, among others, the decrease in the amount of rains as well as the shortening of the rainy season. This situation changes the traditional cropping calendars used for decades to the extent that these irregular rains threaten agriculture with the onset of droughts that they are likely to engender. To maintain the competitiveness of cocoa farming in the face of climatic disturbances, it is necessary to take adaptation measures aimed at reducing its water deficiency because the cocoa tree is sensitive to lack of water (Mossu, 1990). One of these is weather forecasts, but they are inaccessible to all farmers.

On the other hand, agroforestry and/or the adaptation of cropping calendars can constitute an adequate response to these climatic disturbances. Indeed, agroforestry can help both mitigate warming and restore soil because planted trees decrease the overall concentration of CO_2 and increase soil stability and fertility. In addition, adapting cropping calendars to climate change can help maintain agricultural yields at a high level. This assertion was confirmed by Brown and Walsh (2016) who showed that a good planting period guarantees the establishment of the plant stand and, therefore, is one of the most important factors affecting crop yield. This study was therefore conducted in the context of adapting cropping calendars to climate change. Specifically, it aims to find an optimal period for planting cocoa trees that will reduce planting failures.

Material and methods

Plant material

The material used in this study consisted of hybrids developed by the National Centre for Agronomic Research (CNRA) of Côte d'Ivoire. The popularization of these hybrids3 has been carried out since 1995. They come from the crosses IMC 67 x IFC1, T85/799 x IFC 15 and UPA 409 x C 412. These hybrids are characterized by strong vigor, early pod production (2 years alternative planting) and high productivity in beans (2.5 to 3 t/year/ha).

Methods

Creation of a nursery and obtaining plants

The nursery was established using nursery bags with dimensions of 20cm x 15cm. Each bag was filled with 2kg of arable forest soil. In each bag, a bean was sown flat, 1cm deep. The establishment of the nursery took place from October to January 2014. To do this, from October, a sowing was carried out each month, from a mixture of beans from the pods of the three types of hybrids. At the end of the process, for each planting period (March, April, May and June), seedlings aged 6 months in the nursery were obtained.

Experimental set-up and plantation

A Fisher block experimental set-up with 3 replicates was used. Each block was made up of 12 rows of 12 cocoa trees including three rows per month of planting or treatment. The total area of the trial was 0.30 ha. For setting up the trials, six-month-old cocoa trees were used. The planting was carried out during the rainy season of 2015, during the months of March (Tms), April (Tav), May (Tmi) and June (Tju). The month of June, traditionally used as a period of cocoa planting in Côte d'Ivoire, was taken as a witness. Plant spacing was 3 m between rows and 2.5 m between plants.

Measurement of agro-morphological parameters

The first measurements of the height of the plants, of the diameter at the crown and the determination of the number of living and dead plants were carried out one month after each planting, that is to say after the time taken for the resumption of the plants. Subsequently, the number of living and dead plants was determined by counting every 3 months, for 15 months. It was the same for the total height of the plants and the diameter at the crown which was measured 6 and 12 months after the resumption.

Obtaining and analyzing rainfall data

The rainfall data was provided by the agro-climatic stations of the station of the National Agronomic Research Center (CNRA) of Divo. They cover 30 years, i.e. from 1988 to 2017, which includes the period of this study. The methodology adopted for the analysis of these data consisted of determining the annual rainfall amounts, the monthly rainfall distribution, the characteristics of the Divo rainfall and the evolution of the growing seasons.

Monitoring of the monthly rainfall distribution

The study of the monthly rainfall distribution was carried out using the rainfall quantity criteria according to IFCC (1978). Thus, the calculation of the probability of occurrence of wet, deficit and dry months per year made it possible to determine the rainiest and driest months over the observation period.

Statistical analysis

All the analyzes carried out on the cocoa trees data were carried out using the XLSTAT 7.5.3 software. For this purpose, the mortality, crowning, flowering and fruiting rates of the plants were compared by chi-square tests. Growth data such as root collar diameter and plant height were subjected to a one-way analysis of variance. The Newman-Keuls tests made it possible to compare the means of the increases in height and diameter at the crown of the plants. The rainfall curves were produced using the EXCEL 2016 spreadsheet.

Results

Table 1 presents the probability of occurrence of wet periods, deficit and dry periods at the Divo experimental site over a period of 30 years. Analysis of the results relating to the distribution of rainfall showed that during the 30 years of observations, the months of March, April, May, June and October were the wettest, with the probability of occurrence of wet periods greater than 50%, that is to say with rainfall levels greater than 100mm. During these three decades, all the months of June showed a rainfall greater than 100mm. On the other hand, the months of January and December were the driest while the months of September and November with probabilities of occurrence of wet periods equal to 43% can be considered as moderately humid (Table 1). Table 2 presents the characteristics of the rainfall of Divo over the three decades (1988-2017). Analysis of the average values per decade showed that the rainfall of the first two decades was greater than 1200mm while that of the third decade (2008-2017) was less than 1200mm or 1161mm. The highest maximum rainfall was observed in the second decade (1998-2007) with 3027mm and the lowest minimum rainfall in the third decade (738mm).

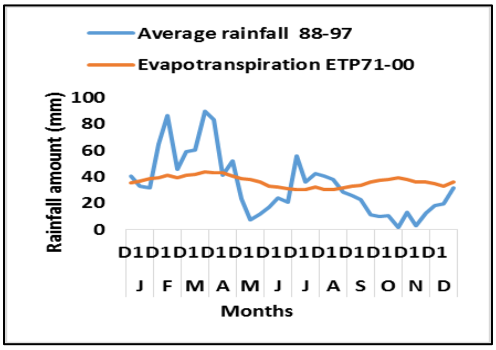
Table 1. Semi-annual and annual increases in diameters and heights of cocoa trees according to the date of planting.

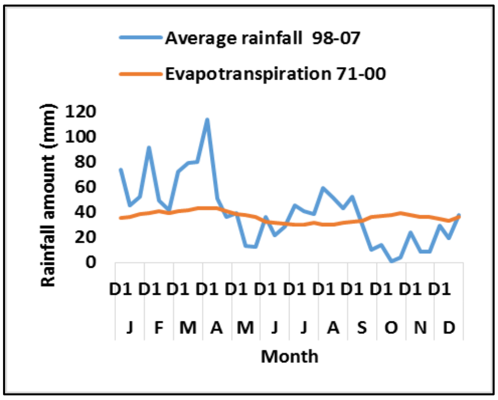
Planting month	Half-yearly increase (cm)		Annual increase (cm)	
	Diameter at collar	heigth	Diameter at collar	Heigtht
March	0,63±0,31 ab	30,18±11,09 a	1,31 ± 0,583 a	66,27 ± 28,95 a
April	0,77 ± 0,28 a	27,45 ±12,18 ab	1,47 ± 0,51 a	55,20 27,31 ab
May	0,63±0,29 ab	20,03 ± 12,22 b	1,05 ± 0,53 ab	45,33 ± 26,89 b
*June	0,56 ± 0,22 b	21,38 ± 13,07 b	0,96 ± 0,50 b	48,03 ± 26,67 b
P	0,05	0,02	<0,0001	0,03
Cv (%)	42	50	44	49

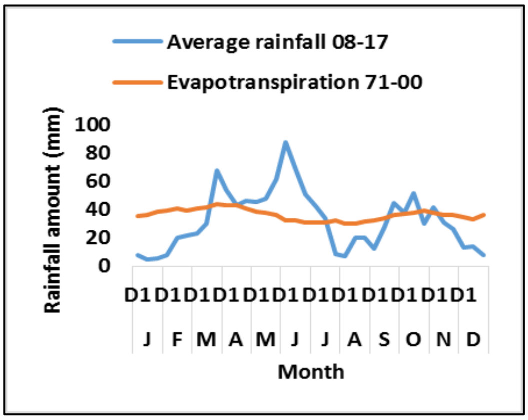
The means followed by the same letter in the same column are statically identical (Newman-Keuls test, P = 5%); * June: month recommended for planting cocoa trees in Ivory Coast and taken as a witness.

Characterization of cropping seasons over the decades 1988-1997, 1998-2007 and 2008-2017

Fig. 1 shows the evolution of the ten-day rainfall and potential evapotranspiration of Divo over the 30 years from 1988 to 2017. Analysis of this Fig. generally shows a fluctuation in the start and end of the rainy seasons. In fact, at the level of the 1st decade (1988-1997) and the 2nd decade (1998-2007), the rains started from the 1st decade of January and ended in the 1st decade of May. However, for the 3rd decade (2008-2017), the rains started in the 2nd decade of March and ended in the 2nd decade of July. The start of the rainy seasons therefore fluctuated between the 1st decade of January (1998-2007) and the 2nd decade of March (2008-2017). However, over all thirty (30) years of observation (1988-2017), the rainy season started from the first ten days of March. During the three decades, the onset of the rainy seasons varied between 30 and 70 days with early rains during the decade 1998-2007. The end of the rainy seasons also fluctuated between the 1st decade of May (1988-1997; 1998-2007) to the 2nd decade of July (2008-2017), i.e. a lag of 50 days. Concerning the year 2015 during which the test was carried out, the rains started after the 2nd decade of March and ended at the beginning of the 3rd decade of July (Fig. 2).







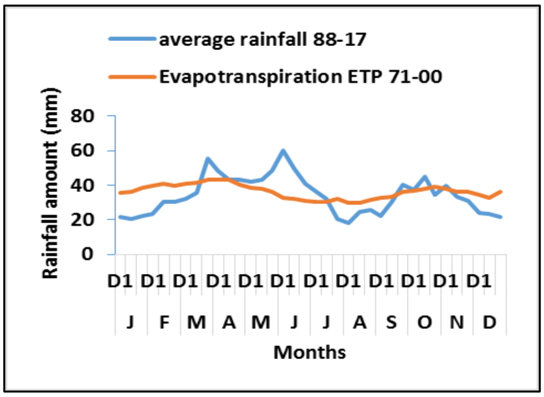


Fig. 1. Evolution of ten-day rainfall and potential evapotranspiration over the decades 1988-1997, 1998-2007, 2008-2017 and 1988-2017.

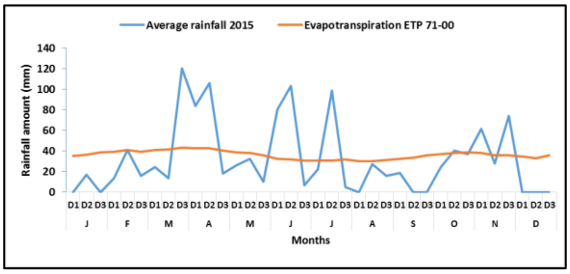


Fig. 2. Ten-day annual rainfall in Divo in 2015.

Effect of the date of planting on the mortality rate of cocoa hybrids

The evolution of the mortality rate of cocoa trees according to the dates of planting is presented in Fig. 3. Cocoa trees planted in March (Tms) had a mortality rate of 10.63%. Throughout the survey period, these mortality rates steadily increased. In fact,15 months later, the plants transferred to the field in May (Tmi) had the high mortality rate (29.3%) while the low rate was recorded among those planted in June (Tju) (12, 1%). The mortality rates observed in cocoa trees planted in March (Tms) and April (Tav) were 19.30% and 15.04%. Statistical analyzes carried out for each period revealed a significant difference (p<5%) for all the dates of planting.

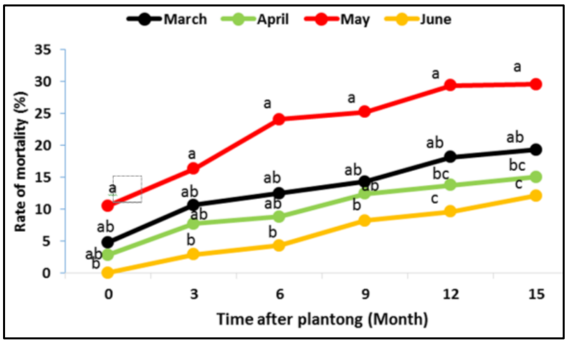


Fig. 3. Evolution of the mortality rate of cocoa trees according to the date of planting in Divo in 2015.

The rates followed by the same letter for the same time after planting are statically identical (Chi-square tt, P = 5%). March: cocoa trees planted in March; April: cocoa trees planted in April; May: cocoa trees planted in May; *June: cocoa trees planted in June, the month recommended for planting cocoa trees in Ivory Coast and taken as a witness.

Effect of planting date on the growth of cocoa hybrids

The results of the semi-annual and annual diametrical growth reported in Table 3 showed that the cocoa trees planted in April (Tav) had statistically greater increases than the other plants (0.77cm). Cocoa trees planted in March and May had intermediate but statistically identical values (0.63cm). The smallest increase was observed with plants transferred to the field during the month of June (0.56cm). In height growth, the greatest increases were obtained in cocoa trees planted in March and April. The smallest height increases were observed in cocoa trees planted in May and June (Table 3).

Effect of planting date on crowning of cocoa hybrids

Fig. 4 shows the evolution of the crowning rate of cocoa trees planted at different dates. The results obtained showed those 12 months after planting, the cocoa trees of all the treatments started their crowning with very low rates (3.8%) but statistically identical between them. Thirty (30) months after planting, the crowning rates of plants transferred to the field in May (45.6%) and June (49.9%) remained below 50%. But those planted in March (57.8%) and April (66.3%) had high crowning rates.

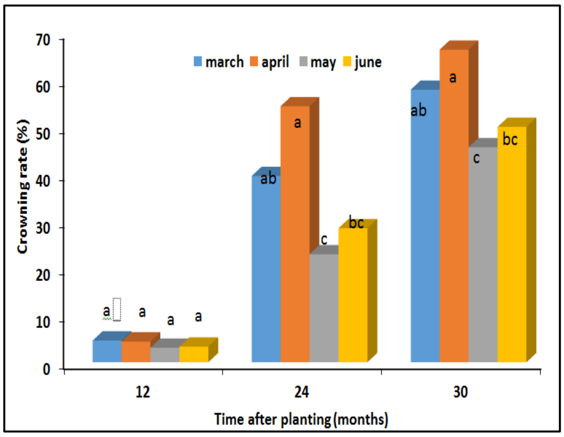


Fig. 4. Evolution of the crowning rate of cocoa trees according to the date of planting in Divo in 2015.

The histograms followed by the same letter for the same time after planting are statically identical (Chi-square test, P = 5%). March: cocoa trees planted in March; April: cocoa trees planted in April; May: cocoa trees planted in May; *June: cocoa trees planted in June, the month recommended for planting cocoa trees in Ivory Coast and taken as a witness.

Effect of planting date on flowering and fruiting of cocoa hybrids

The results presented in Fig. 5 showed that the flowering rates of cocoa trees planted in March and April were higher (9.3 and 9.8%) than those of May and June (5.3 and 3.5%). After 18 months of planting. These rates evolved in the same direction during the experiment. After 30 months of planting, the highest flowering rates were recorded in cocoa trees planted in March (35.4%) and April (30.3%).

The lowest rates were observed among those buried in May (20.2%) and June (23.6%). Examination of Fig. 6 showed that the fruiting rates of cocoa trees planted in May (23.2%) and June (22.4%) remained low compared to those planted in March (32.6%) and April (28.3%) after 30 months of planting. These low rates did not show any significant difference between them for each survey period considered (p< 5%).

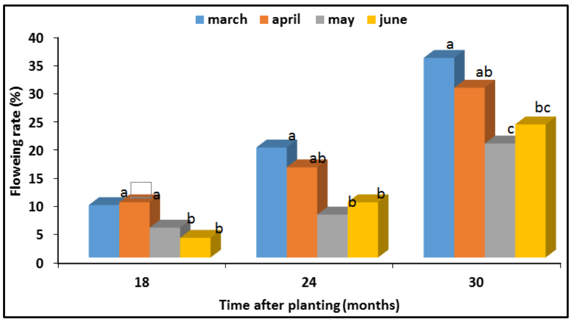


Fig. 5. Evolution of the flowering rate of cocoa trees according to the date of planting in Divo in 2015.

The histograms followed by the same letter for the same time after planting are statically identical (Chi-square test, P = 5%). March: cocoa trees planted in March; April: cocoa trees planted in April; May: cocoa trees planted in May; *June: cocoa trees planted in June, the month recommended for planting cocoa trees in Ivory Coast and taken as a witness.

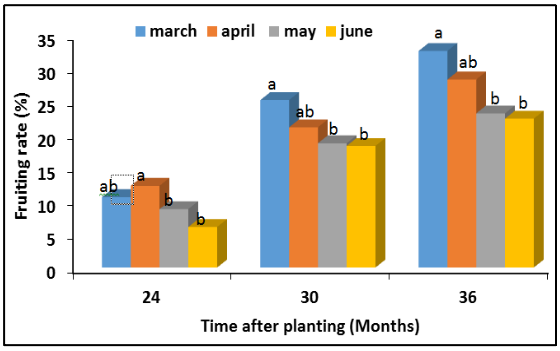


Fig. 6. Evolution of the fruiting rate (%) of second wave cocoa trees according to planting in Divo in 2015.

The histograms followed by the same letter for the same time after planting are statically identical (Chi-square test, P = 5%). march: cocoa trees planted in March; april: cocoa trees planted in April; may: cocoa trees planted in May; june: cocoa trees planted in June, the month recommended for planting cocoa trees in Ivory Coast and taken as a witness.

Discussion

Rainfall analysis of the study site

Analysis of rainfall data collected over three decades (1980-2017) at the Divo station generally revealed a tendency for the climate to dry up over the years. This drying up is manifested by a decrease in rainfall characterized by the decrease in annual rainfall levels, the monthly distribution and the seasonal and / or monthly duration of the rains. Regarding the evolution of rainfall amounts, a variation characterized by the reduction in their rainfall was observed. Even if the average rainfall was between 1161 and 1455mm, in Divo , 70% of the rains recorded respectively, had heights less than 1200mm. This decrease in rainfall heights was very marked for the decade 2008-2017 with 70 of the rains whose heights were below 700mm respectively in Divo. His rainfall recession is believed to be due to the drop in total annual rainfall. In fact, the annual rainfall averages noted by Dabin (1973) from 1951 to 1960 fluctuated between 1500 and 1700mm. This tendency to dry out has been observed by Balliet *et al.* (2016) in the Gôh region, an area very close to the experimental sites of this study. This observation had been made previously by several authors, in particular Paturel *et al.*, (1995), Servat *et al.*, (1997) and Brou *et al.*, (2005). These authors noted that in Côte d'Ivoire, like all the countries of West and Central Africa, has experienced an increase in climate variability since the end of the 1960s. This decrease in precipitation, which began in the late 1960s, intensified during the 1980s and 1990s (Paturel *et al.*, 1995; Brou *et al.*, 1999) before experiencing a slight remission in the 2000s. This phenomenon of climatic variability could be explained according to some authors (Péné and Assa, 2003; Assémian *et al.*, 2013) by climatic deregulation linked to the unfavorable influence of certain synoptic and / or environmental factors on the mechanism of Intertropical Front migration (ITF). This determines the climate in West Africa. Another essential cause of climate variability is the “El Niño” phenomenon born off the coast of Peru in the Pacific, in Latin America and which is developing in the intertropical zone (Nicholls, 1988; Orstom, 1996; Péné and Assa, 2003).

In addition to these aforementioned phenomena, the drop in rainfall observed in the areas of this study could be explained, among other things, by deforestation. Indeed, studies carried out in Côte d'Ivoire on plant cover have shown significant deforestation. They indicate that the area of dense forest in Côte d'Ivoire has increased from 13 million hectares since colonial times to 1.385 million hectares in 2000 (Koné *et al.*, 2014). It also appears from studies carried out by other authors that this trend towards climate drying is on a planetary scale (Merle, 1995; IPCC, 2007; Assemian *et al.*, 2013). The variation in the distribution of rainy months from decade to decade and/or the probability of occurrence of rain events could be a consequence of the rainfall disturbance. Indeed, during the first two decades in Divo (1988-1997 and 1998-2007), the four rainy months detected were January, February, March and April, while for the decade 2008-2017, they were the months of March, April, May and June, two months apart.

Effect of the date of planting on the mortality rate of cocoa

The rainfall fluctuations observed over the years could affect agriculture by disrupting the different phenological stages of plants. Also, the recovery of young cocoa trees transplanted in the field varied according to the planting period. In fact, the high mortality rate obtained in cocoa trees planted in May (29.30%) is thought to be due to the water deficit in the soil when the young cocoa trees are transferred. Indeed, the results obtained on the study of rainfall in 2015 revealed that the month of May suffered a rainfall deficit over 3 decades compared to normal. The cocoa trees thus planted received an insufficient amount of water at the time of planting. In addition, after planting, the young plants only received 4 decades of excess rainfall (2 decades in June and 2 decades in July) before entering the dry season of August 2015 which was completely in deficit. This lack of water delayed the establishment of adaptation mechanisms to the new living environment, which increased the rate of plant mortality (Durand, 2005). As a result, the survival and establishment of young plants was compromised. The intermediate mortality rates observed in cocoa trees planted in March (19.30%) could be explained by an alternation of excess and deficit rains occurring during the planting of these cocoa trees. Indeed, these cocoa trees established in fairly rainy decades (from the 3rd decade of March to the 2nd decade of April) suffered from the sudden deficit of rain that occurred in May. On the other hand, the low mortality rates recorded in cocoa trees planted in April and June (15.04 and 12,1%) could be due to a fairly high rainfall during and after planting. However, the decade in deficit after the planting did not allow a 100% recovery to be achieved. Overall, the weather conditions at the time of planting had a profound influence on the survival of these cocoa trees (Akinnuoye-Adelabu and Modi, 2016).

Effect of planting date on cocoa tree growth

Vegetative growth assessed through crown diameter and cocoa tree height varied according to the periods of transfer to the field. Indeed, after one year, the increases in diameter at the crown and in height were statistically greater in cocoa trees planted early, i.e. in March (1.31cm and 66.27cm) and April (1.47 and 55.20cm). The diametrical growth and elongation of the stems result from the resumption of metabolism manifested by increased mitotic activity of the meristems. The activation of the metabolism was made possible by water and nutrients from the soil.

The results obtained from rainfall data had shown that the rainiest months were March, April, May and June (Eldin, 1971; FAO, 2005). During this period, there was an increase in the level of precipitation and an increase in the number of rainy days. These plants therefore benefited from a long period of rain before the onset of the dry season in December, January and February. This sufficient distribution of precipitation improved stomatal conductivity, favored the diffusion of CO_2 into the leaf and increased the rate of photosynthesis necessary for growth and development. Similar results have been obtained by several authors who have indicated the crucial role of water in the growth and development of plants (Anonymous, 2007;; Ahmad *et al.,* 2011; Akinnuoye-Adelabu and Modi, 2016). Cocoa trees planted in May (1.09cm and 52.24cm) and June (1.02cm and 50.23cm) which had only a short duration of rain, recorded weak growth. Similar results were obtained by Khan *et al.* (2008) and Ismail *et al.* (2013) who showed that vegetative growth is influenced by the planting period. Indeed, it is characterized by environmental factors such as temperature, light intensity, photoperiod and soil moisture which have an impact on the physiology of the plant (Akinnuoye-Adelabula and Mobi, 2016). According to Garcia (1973), environmental factors exert an influence of about 70% on the development of the cocoa tree in the juvenile stage. Among the environmental stresses to which plants are constantly exposed (Zhu, 2002). Drought is the stress that most limits plant growth. During the establishment phase, the water deficit leads to the stopping of growth and then to the death of young cocoa trees with a high mortality rate (Boyer, 1973; Petithuguenin, 1995; Freud *et al.*, 2000). This assertion has been verified in cocoa trees planted in May and June which suffered a short period of rain.

Effect of the date of planting on the crown of cocoa trees

The crowning is an important phase in the young cocoa tree. It determines its aptitude for production and intervenes when the cocoa plant has reached about 1 m in height. During this period, orthotropic growth ceases and the plant emits three to five plagiotropic branches which form the crown (Cuatrecasas, 1964; Garcia and Nicolella, 1985). This explains why the low crowning rate after 12 months of planting, increased with the age of cocoa trees.

These branches, after reaching a certain length, branch out in their turn. Thus, the crowning rate increases as the cocoa tree grows. Also, the crowning rate was higher (66%) in cocoa trees, 30 months after transplanting in the field. Thus, the high crowning rates recorded in cocoa trees planted in March (57.8%) and April (66.3%) could be explained by their strong growth. As all plants developed under the same climatic conditions, reduced plant growth resulted in a low crowning rate. These results are in agreement with those of Akinnuoye-Adelabu and Modi (2016) who showed that environmental conditions in particular planting dates influenced the phenological stages of corn plants.

Effect of planting date on production

The cocoa tree hybrids used in this study acquired flowering maturity 18 months after transfer to the field. This ability would not depend on the date of planting but would rather be linked to the crowning of the plant which is a function of the state of development of the cocoa tree. According to the results obtained during their study, Alkurdi *et al.* (2015) also indicated that there was no significant difference between planting dates and flowering time in *Matthiola incana*. However, the flowering rate was correlated with the crowning rate. Indeed, abundant flowering was observed in cocoa trees planted in March and April, which showed a high crowning rate.

The fruiting evaluated by the production of cherelles/ pods on the plot installed in Divo in 2015 was correlated with flowering. Indeed, the fruiting rate was important where the flowering rate was high.

Thus, the high fruiting rates obtained in cocoa trees planted in March (32.6%) and April (28.3%) could be explained by the high flowering rates observed in the latter. In addition, the many leaves carried by their twigs have certainly contributed, through their photosynthetic capacity, to the mobilization of carbohydrate nutrients, necessary for fruit growth. The low fruiting rates recorded in cocoa trees planted in May (20.2%) and June (22.4%) are thought to be due to the low flowering rates.

Conclusion

Rainfall analysis over the past three decades (1988-1997, 1998-2007, 2008-2017) in Côte d'Ivoire has shown a drying trend with a shift in the rainy months which are the months of March, April, May and June for the decade 2008-2017. This drying out contributed to the reduction in rainfall levels, 70% of which were less than 1200mm in divo.

But in general, the rainfall averages obtained during these decades correspond to the minimum required for cocoa farming. In Divo in 2015, a high death rate was recorded in May (29.57%) while a low rate was observed in June. Apart from the death rate, all the growth and production parameters evaluated were better in plants transferred to the field in March, April and May. This study therefore shows that an early planting of cocoa trees is possible in the Divo region, from the 3rd decade of March.

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