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Full Length Research Paper

Impact of pollution by the hydrocarbons on the biological activity of soils in Ouagadougou, Burkina Faso

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The microbial activity estimated by respirometry test method made it possible to measure the quantity of CO_2 produced per day, from four soils polluted at different degrees by hydrocarbons. These samples have been wet to 2/3 of their maximal capacity of retention and incubated at 30°C for 30 days. The quantity of CO_2 released and measured shows a high value (83.97 mg/100 g of soils against 36.05 mg/100 g of soils) in soils highly polluted by hydrocarbons treated without cow dung. We get higher values (148.98 mg/100 g of polluted soils against 66.52 mg/100 g of not contaminated soils) when the cow dung is used as a ferment. The total aerobic mesophilic flora in the samples of soils has been counted on the nutritive agar. The result is that the total aerobic mesophilic flora varied from 1×10^4 Colony Forming Unit (CFU) to 50×10^4 CFU before treatment and from 5×10^4 CFU to 420×10^4 CFU after 30 days of treatment. During the treatment of the soils, the bacteria and molds microflora increases with time while yeasts disappear progressively.

Key words: Respirometry, microorganisms, contaminated soils, hydrocarbons.

INTRODUCTION

The use of fossil fuels such as hydrocarbons has increased for fifty years. As it is the case in most of the African countries, the main energy sources used in Burkina Faso for the production and distribution of electricity are hydrocarbons (Ouédraogo and Sodré, 2006; Tetteh, 2015). Their use engender the liquid and gas waste like polycyclic aromatic hydrocarbons, oxide of carbon, oxide of azote, etc., which are sources of

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pollution and greenhouse gas. Therefore, these pollutants have many consequences for the people and their environment (Cerniglia, 1992; Morelli et al., 2005; Ouédraogo and Sodré, 2006; Pinheiro et al., 2013; Jacob and Irshaid, 2015; Sawadogo et al., 2015; Tetteh, 2015; Sawadogo, 2016). The action of pollutants on men is a direct or indirect contact with these hydrocarbons that can sometime be mutagenic or carcinogenic (Pinheiro et al., 2013; Jacob and Irshaid, 2015).

In addition to the pollution of the atmosphere of the water, one of the most worrying forms of pollution is that of the soils on which hydrocarbons are spilled (Colin, 2000; Vandermeer and Daugulis, 2007; Pinheiro et al., 2013). The toxicity of these hydrocarbons varies according to several factors like their nature, composition, concentration, biodegradability, etc (Lecomte, 1998; Vanishree et al., 2014; Wuana et al., 2014). The effect of soils pollution is to question their biological activity which can affect the ecological balance of the ecosystem (Peressutti et al., 2003; Pinheiro et al., 2013; Tetteh, 2015).

This study analyses, the impact of pollution by hydrocarbons on the biological activity of soils. It is specifically about testing the respirometry of microorganisms of four soils from an industrial site, polluted at different degrees by total hydrocarbons. The process passes by a counting of the microorganisms and the introduction of cow dung in the different samples of polluted soils in order to study their biological activity.

MATERIALS AND METHODS

Study site

These studies have been realized in the area of the electric power plant Ouaga 1 of SONABEL (Burkinabé National Electricity Society), in Ouagadougou, capital city of Burkina Faso. For Garmin GPSMAP 62s, the site's altitude is 300.53 m; its position is N12°23.031' and W1°30.927'. In a Soudano-Sahelian climate with a leached tropical ironed soil, Ouagadougou has four big power plants (Ouaga I, Ouaga II, Kossodo, Komsilga), the oldest and most polluted of which is Ouaga I, the site of the present study. Being the first power plant in Burkina Faso, its generating set consume heavy fuel (HFO), some distillated diesel oil DDO, some oils and some water for them to work (SONABEL, 2005). The oldness of the site (1954), the complexity and the diversity of the industrial effluents (gas, liquid and solid) ejects make it impossible to measure exactly the extent of pollution on the site.

Soil sampling and measurements

On a square meter (1 m^2) soil, five samples have been collected up to 20 cm of depth, mixed, dried in the shade at open air then sieved at 2 mm of meshing. The samplings are done considering the distance of the power plant's site as well. Apart from the soil « A » that has been sampled at 100 m out of the site, the other three (« B », « C », « D ») have been sampled, respectively at 50, 25 and 5 m from the dump in the site where the power plant is. The physical and chemical characteristics of these soils are shown in Table 1.

The total hydrocarbons in the soils have been dosed from an analyzer «PetroFLAG» coming from Dexsil Corporation order N° NA, 1996. The method has been the turbidimetry and the results are shown in Table 1.

Organic substrate

The cow dung has been used as a source of nutritive elements and as a source of microorganisms. Its use would be profitable in relation to the chemical products. It contains ten times more organic substances, total carbon and total nitrogen than the studied polluted soils and a good relation of ideal C/N (15). It is a good ferment for the bio-depollution of hydrocarbons (Table 2).

Setting of the microcosm

Follow-up of the microbial activity by the cumulated evolution of the CO_2 released by the soils according to time, the tenor in hydrocarbons and the quantity of the organic substrate

The experimental units composed of 1 L bottles tightly closed. In each bottle are set a 100 g of the soil wet up to two thirds (2/3) of its maximal capacity of retention, a Borel bottle containing 20 ml of soda (NaOH; 0.1N) and another Borel bottle containing 20 ml of distilled water. The first bottle is used to capture the carbonic gas (CO_2) released by the soil's microorganisms (this bottle is replaced every 24 h during the first 15 days and every 48 h during the last 15 days) and the second bottle is used to maintain the soil humidity in the bottle.

The same process has been repeated adding 1% to the samples of soil and 0.1% of the cow dung to stimulate the biological activity of the polluted soils. This experiment is repeated three times for each type of soil. The appliance is incubated at 30°C in a steam room for 30 days (Figure 1).

The CO_2 released during the study and trapped by the soda is precipitated in a sodium carbonate by the barium chloride (3%). The exceeded soda is going to be neutralized by hydrochloric acid (HCl, 0.1 N) with phenolphthalein as a colored indicator. The quantity of the daily CO_2 obtained by the Dommergues formula (1960) is expressed in mg/100 g of dry soil:

$$Q \text{ (mg/100 g of soil)} = [V_{HCl} \text{ (white)} - V_{HCl} \text{ (treatment)}] \times 0.6$$

where V_{HCl} = volume of hydrochloric acid (HCl).

The experimental control has been the empty bottle in which the two flasks containing, respectively soda and distilled water have been placed.

Microbiological analysis

Counting of microorganisms in the polluted soils

The counting of total mesophylic aerobic flora, fungus and yeasts has been done, respectively with Plate Count Agar (PCA) and Yeast Glucose Chloramphenicol (YGC) after 48 h and 5 days of incubation.

Table 1. The physical and chemical parameters of the soil (Kaboré-Ouédraogo et al., 2010).

Hydrocarbons content	Type of soil			
	A	**B**	**C**	**D**
Rate of hydrocarbons (g/kg of soil)	9.83±1.21	19.23±0.38	41.97±0.59	136.13±1.39
Maximal capacity of retention	45.0±2.5	34.0±1.0	27.0±2.0	6.0±0.2
Texture (%)				
Clay	17.65	23.53	33.33	11.76
Total silt	25.49	23.53	25.49	21.57
Total sands	56.86	52.94	41.18	66.67
Organic substance (%)				
Total organic substance	2.638	3.569	4.189	4.948
Total carbon	1.53	2.07	2.43	2.87
Total nitrogen	0.172	0.12	0.104	0.074

A: Less polluted, B: moderately polluted, C: much polluted, D: extremely polluted.

Table 2. The physical and chemical parameters of the cow dung (Kaboré-Ouédraogo et al., 2010).

Parameter	Results
Total organic substance (%)	43.871
Total carbon (%)	25.447
Total nitrogen (%)	1.69
C/N	15
Assimilable phosphor (ppm)	0.519

Figure 1. Setting of the microcosm in the incubator.

Data analysis

The data have been typed with the Excel software, treated with XLSTAT-Pro 7.5. ANOVA with a probability point p=5%.

RESULTS

Evolution of the CO_2 production by soil according to time and the tenor in hydrocarbons

During the 30 days of incubation, it was noticed that the CO_2 quantity, for all the types of soil, increases with the pollution degree. Similar results are also obtained in stimulating the process by the cow dung (Figure 2). Moreover, no significant difference of CO_2 production in the less polluted soils (curves (A), (B), (C)) was observed. Yet, curve (D), from the most polluted soil, shows a production twice higher of CO_2 than the other curves.

Thus, at the end of 30 days of treatment, the cumulated amounts of CO_2 produced from the soils « D », « C », « B » and « A » are, respectively:

(i) 83.97 mg/100 g of soil; 46.37 mg/100 g of soil; 43.35 mg/100 g of soil and 36.05 mg/100 g of soil for the biodegradation of samples not containing the cow dung (Figure 2A);
(ii) 96.94 mg/100 g of soil; 61.43 mg/100 g of soil; 56.95

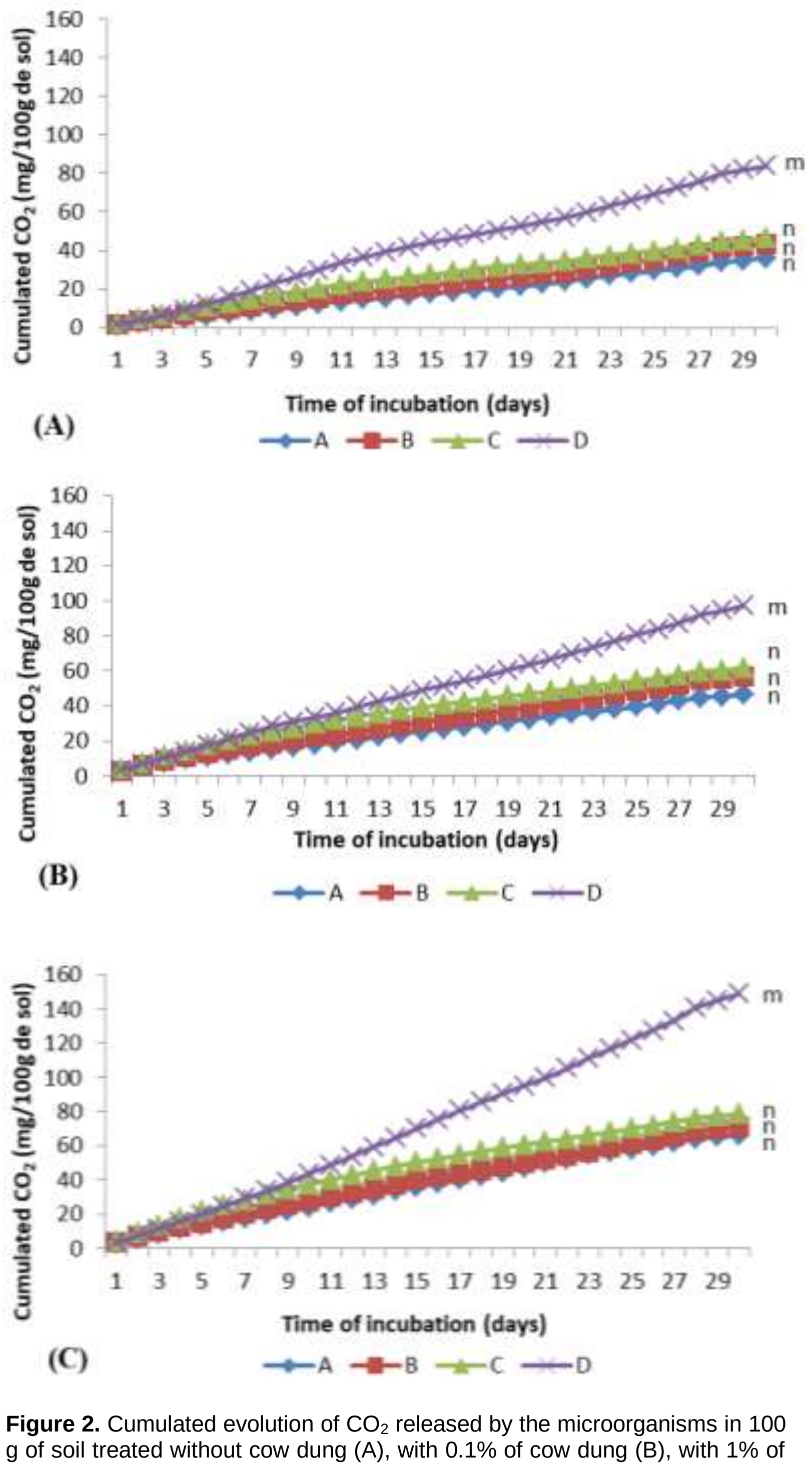

Figure 2. Cumulated evolution of CO_2 released by the microorganisms in 100 g of soil treated without cow dung (A), with 0.1% of cow dung (B), with 1% of cow dung (C) as regards to time (days) and the tenor in hydrocarbon [different letters indicate significant differences ($p<0.05$)]. A: Less polluted soil, B: moderately polluted soil, C: much polluted soil, D: extremely polluted soil.

mg/100 g of soil and 46.35 mg/100 g of soil for the biodegradation of samples containing 0.1% of cow dung

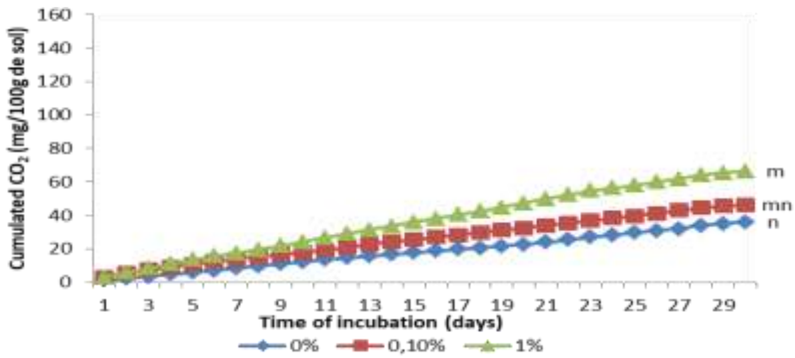

Figure 3. Cumulated evolution of CO_2 released by the microorganisms in 100 g of less polluted soils (A) regarding time (days) and the treatment with cow dung [different letters indicate significant differences ($p<0.05$)].

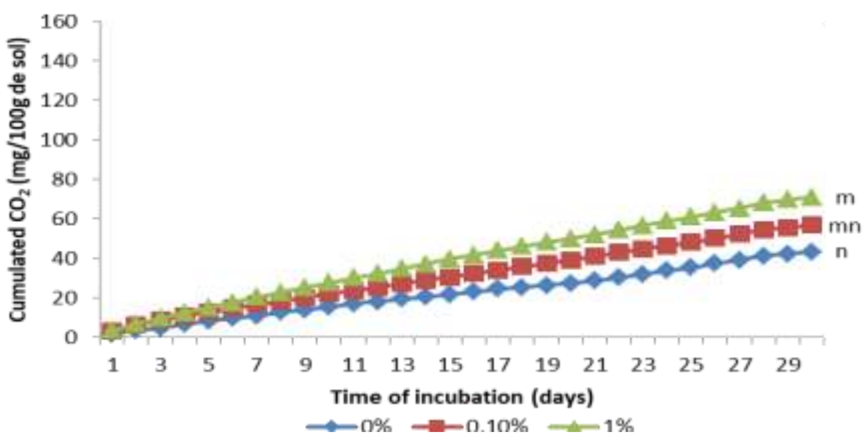

Figure 4. Cumulated evolution of CO_2 released by the microorganisms in 100 g of moderately polluted soil (B) regarding time (days) and the treatment with cow dung [different letters indicate significant differences ($p<0.05$)].

(Figure 2B);
(iii) 148.98 mg/100 g of soil; 78.81 mg/100 g of soil; 71.13 mg/100 g of soil and 66.52 mg/100 g of soil for the biodegradation of samples containing 1% of cow dung (Figure 2C).

Evolution of CO_2 production by the soil regarding time and the treatment with the cow dung

The intensity of the cumulated releases of CO_2 increases with the addition of the cow dung in the same type of soil. In other words, the soil treated without cow dung releases less CO_2 than the one treated with 0.1 or 1% of cow dung; the sample containing 1% of cow dung being the one that releases more CO_2. In Figures 3, 4, 5 and 6, a significant difference was noticed between the soils treated without the cow dung and those having 1% of the cow dung. The concentration of 0.1% of cow dung has no significant influence on the release of CO_2 in these figures.

The cumulated amounts of CO_2 of the soils containing 0, 0.1 and 1% of cow dung can reach respectively:

(i) 36.05 mg/100 g of soil; 46.35 mg/100 g of soil; 66.52 mg/100 g of soil in the less polluted soil « A » (Figure 3);
(ii) 43.35 mg/100 g of soil; 56.95 mg/100 g of soil; 71.13 mg/100 g of soil in the moderately polluted soil « B » (Figure 4);
(iii) 46.37 mg/100 g of soil; 61.43 mg/100 g of soil; 78.81 mg/100 g of soil in the much polluted soil « C » (Figure 5);

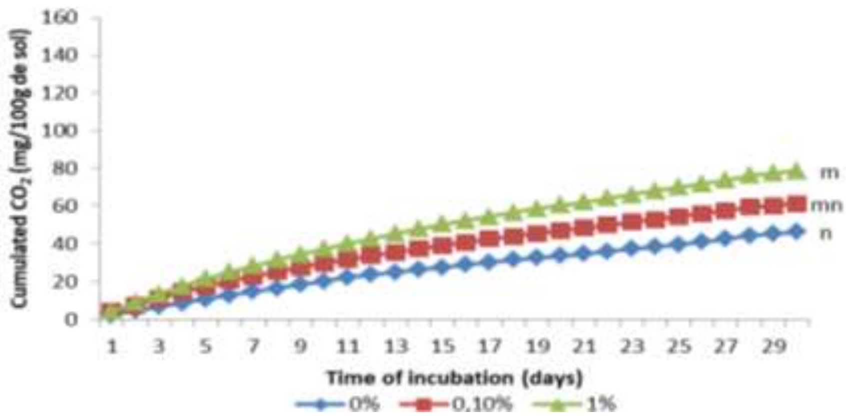

Figure 5. Cumulated evolution of CO_2 released by the microorganisms in 100 g of much polluted soil (C) regarding time (days) and the treatment with cow dung [different letters indicate significant differences ($p<0.05$)].

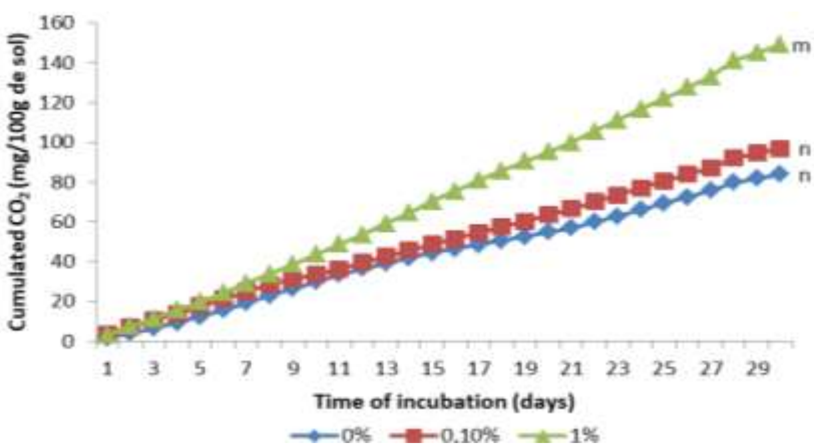

Figure 6. Cumulated evolution of CO_2 released by the microorganisms in 100 g of extremely polluted soil (D) regarding time (days) and the treatment with cow dung [different letters indicate significant differences ($p<0.05$)].

(iv) 83.87 mg/100 g of soil; 96.94 mg/100 g of soil; 148.98 mg/100 g of soil in the extremely polluted soil « D » (Figure 6).

The slightest pick in each figure results from the soils treated without cow dung (0% of cow dung). The strong release of CO_2 is noticed in the soils treated with 1% of the cow dung.

Microbiological analysis

Counting of microorganisms in the polluted soils

The microbiological analysis showed the cultivable mesophilic aerobic microorganisms on a solid ground. The counting of total microflora, molds and yeasts has been done (Table 3). The total microflora, present in all the samples of soil, varies from 1×10^4 to 50×10^4 CFU before treatment and from 5×10^4 to 420×10^4 CFU after 30 days of treatment. The molds are absent only in the soil « C » treated without substrate. In the other soils, their number varies from 1.5 to 33 CFU before treatment and from 2 to 200 CFU after 30 days of treatment. The yeasts are in soils « C » and « D » (6.5 to 10 CFU before treatment and 00 CFU after treatment), but absent in the samples « A » and « B » before as well as after treatment of the soil.

The counting of these microorganisms often varies regarding the degree of pollution, the addition of the

Table 3. Counting of microorganisms (total microflora, molds, yeasts) in the polluted soils (CFU/g).

Type of soil	Quantity of cow dung (%)	Before treatment (CFU)			Thirty (30) days after treatment (CFU)		
		Molds	Yeasts	Micro. (×10^4)	Molds	Yeasts	Micro. (×10^4)
A	0	10.5±0.5	-	6±1	33±1	-	140±10
	0.1	23±2.0	-	8.5±0.5	43±1	-	40±10
	1	33±1.73	-	9.9±1.1	23±1	-	72±11
B	0	1.5±0.5	-	1±1	2±1	-	5±5
	0.1	7±1	-	1.2±0.1	31±1	-	12±0
	1	14.5±3.5	-	15±5	35±2	-	22±2
C	0	-	10±0	10±0	-	-	196±34
	0.1	2±1	8±1	19±1	-	-	200±0
	1	4±0	9.5±0.5	40±10	8±2	-	225±5
D	0	3.5±1.5	8±1	25.8±4.2	9±0	-	240±10
	0.1	5±0	6.5±0.5	32±2	39±3	-	390±20
	1	15±1	7±2	50±10	200±4.36	-	420±26.46
Dung	-	4000±1000	-	340±98.5	-	-	-

Micro.: Total microflora, A: less polluted soil, B: moderately polluted soil, C: much polluted soil, D: extremely polluted soil.

substrate (cow dung) and time. If the addition of the substrate increases the number of the total microflora and the molds, it has no influence on the yeasts. Also, while the biomass of the total microflora and that of the molds increase with time, the yeasts disappear.

DISCUSSION

Evolution of the CO_2 quantity released by the soil regarding time and the tenor in hydrocarbons

One notice that the microbial activity increases with the degree of pollution of soils. The soil « D », containing the highest hydrocarbon rate and therefore having more fermentable organic substances, induces a strong microbial activity in relation to the other three soils. The slightest productions of CO_2 obtained with soil « A » are the result of a microbial activity from less polluted soil, than containing less organic substances.

The release of CO_2 shows a real daily biological activity in each soil. The microbial activity results from the fermentation of the organic substance in the different grounds (Dommergues, 1962). The daily release of CO_2 shows the mineralization of the pollutants. More the quantity of hydrocarbons in a soil is great, more the mineralization's level of its organic substance is high. This results in a stronger CO_2 rejection by the microorganisms which are in this soil. The easily biodegradable products (light hydrocarbons, micro-organisms dead during the desiccation stage, protein substances, sugar, etc.) are the first elements used by the microorganisms (Chaineau et al., 1995; Aichberger et al., 2005; Zombré, 2006); then the most resistant substances such as the heavy hydrocarbons (aromatic polyclinic hydrocarbons) or lignin are decomposed (Chaineau et al., 1995; Aichberger et al., 2005).

Cumulated evolution of CO_2 released by the soil regarding time and the treatment with the cow dung

The slightest quantities of CO_2 got came from the soils treated without cow dung (0% of cow dung). The highest quantities are obtained in the soils treated with 1% of the cow dung. The cow dung has therefore a stimulating effect on the biological activity in the treated samples. It brings to the soil not only an additional ferment, but also some chemical elements like carbon, nitrogen and phosphor. The ferment degrades the organic substances of the soils and the chemical elements stimulate the metabolism of the microorganisms and therefore their growth (Chaineau et al., 1995; Aichberger et al., 2005; Adekunle and Adeniyi, 2015; Jacob and Irshaid, 2015). The cow dung has, at a certain concentration (1%), a positive influence on the biological activity like the mineralization of the pollutants in all the soils after 30 days of treatment.

Microbiological analysis

Counting of microorganisms in the polluted soils

Bacteria are present in all the studied samples of soils. Their number increases regarding the pollution of the ground (their tenor in hydrocarbons) and the quantity of cow dung. During the treatment of different soils, their number increases progressively from simple to double in all samples. They would be able to use the hydrocarbons in their growths (Dash et al., 2013; Sawadogo et al., 2014; Vanishree et al., 2014; Adekunle and Adeniyi, 2015; Jacob and Irshaid, 2015; Sawadogo et al., 2015; Sawadogo, 2016).

The number of molds also increased with the addition of the cow dung but is not influenced by the tenor of the soil in total hydrocarbons. They would actively participate in the biodegradation of hydrocarbons in the soil (Okerentugba and Ezronye, 2003; Zhang et al., 2006; Damisa et al., 2013). Many researches confirm that fungi have been capable of biodegrading the hydrocarbons (Vanishree et al., 2014; Adekunle and Adeniyi, 2015).

The yeasts, only present in the soils « C » and « D » disappear after the 30 days of incubation. The high concentration of hydrocarbons would inhibit their biodegradation and would limit the use of oxygen (Adenipekun and Fasidi, 2005; Vanishree et al., 2014). However, much research has shown that they can degrade hydrocarbons (Zhang et al., 2006; Vanishree et al., 2014).

Generally, for their metabolism and reproduction, all living being previously seen use hydrocarbons as source of carbon. Various microorganisms have the capacity to use hydrocarbons as their source of carbon and energy (Adekunle and Adeniyi, 2015). They also need nitrogen and phosphor that also could be found in the cow dung.

These microorganisms would be able to degrade hydrocarbons in the soil (Lecomte, 1998; Okerentugba and Ezronye, 2003; Zhang et al., 2006; Adekunle and Adeniyi, 2015). They would probably make it possible to bio-decontaminate the soil of pollutants such as petroleum hydrocarbons; hence, their decrease (at least 10.64% of abatement after 30 days) more or less considerable at the end of the study (Kaboré-Ouédraogo et al., 2010).

Conclusions

This study made it possible to see the impact of total hydrocarbons on the microbial activity in four soils polluted at different degrees. Thus, the biological activity of the soils has been measured, thanks to the CO_2 released daily by the microorganisms. It is shown that released CO_2 is very important in soils with a high tenor in hydrocarbons, therefore a high quantity of organic substances. It is once more important after an addition of cow dung to the soils. The measured CO_2 results essentially from a mineralization of the organic substances by the microorganisms.

The presence of hydrocarbons in the soils in this study shows that these fossilized organic substances play an important role in the microbial activity of the ground. Their use by the microorganisms of the soil would involve their biodegradability that could make a depollution of contaminated grounds by the organic substances.

The microbiological analysis made it possible to have a high microbiological diversity in the samples of soil. It made it possible to note an increase of the microbial biomass regarding the increase of the tenor in hydrocarbon, the bringing of cow dung and the time. This microbial biomass plays a role more or less important in the degradation of hydrocarbons. A molecular isolation and characterization of efficient microorganisms in the biodegradation of the hydrocarbons would be performed in subsequent studies.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Prospects for sustainable cocoa farming from the rainfall balance in the last thirty years at Lôh-Djiboua and Gôh post-pioneer regions, Côte d'Ivoire

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The rainfall disturbances observed in the recent decades in Côte d'Ivoire constitute a constraint for sustainable cocoa production, the mainstay of the Ivorian economy. These disturbances constitute, in addition to the losses of production and those from the quality of the cocoa beans, one of the causes of the high cocoa mortality at the recovery stage in all cocoa production area. The present study, carried out in the Goh and Lôh Djiboua, post-pioneer regions, is a contribution for the searching of solutions to the continuity challenge of the Ivorian cocoa farming in front of the climate change. It aims to analyze not only the evolution and distribution of rainfall, but also to identify the rainfall constraints related to cocoa farming, and to propose possible solutions to ensure the sustainability of cocoa farming in these two regions. The analysis covered the three decades of the period from 1986 to 2015. The rainfall data were collected at the weather stations of the CNRA (Centre National de Recherche Agronomique) based both on Divo and Gagnoa. The study of the two rainfall data series using the rainfall index showed that the current climate of the two regions is characterized by a predominance of dry periods at Divo and the wet one in Gagnoa. Also, 40 to 90% of the 30-years recorded less than 700 mm of rain during the main rainy season both in the two regions. In addition the beginning of the rainy season in the two regions is between the 1st and 2nd 10 days of March in both regions, while in practice the planting of cacao is usually made in May or June. To note this variability, the technical itineraries for all regions must to be regionalized to enable cocoa to exhibit its potentialities in its new production environment.

Key words: Rainfall assessment, Lôh-Djiboua and Goh regions, sustainable cocoa farming.

INTRODUCTION

Cocoa bean is the most important export product of Côte d'Ivoire. Its contribution to the total export incomes is estimated at 40%, which corresponds to 15% of the gross domestic product (GDP). It is also the main

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Table 1. Environment characteristics and cocoa production in Lôh Djiboua and Gôh.

Parameter	Lôh Djiboua Divo/Divo	Gôh /Gagnoa
Climate	Tropical humid	Tropical humid
Rainfall avairage (mm)	1223	1333
Temperature (°C)	21-35	19-33
Humidity (%)		85
Soil type	Ferralsol pH: 6.09 C: 1.7 N:0.15 Pavail.:23.86 K: 0.33	Ferralsol pH: 6.1 C: 1.7 N:0.2 Pavail.:23.9 K: 0.3
Cacao surface (ha)	170 605	105 605
Yield (T/ha)	0.58	0.79
Production (T)	92 766	78 270

source of income for more than 500 000 producers and their families. The cocoa production system is extensive and itinerant on forest clearings (Coulibaly et al., 2002). This system is subject to climate constraints. It has been practiced successfully since 1920, when cocoa was introduced in Côte d'Ivoire until the 1990s because of favorable growing conditions (Assiri, 2007). This ensured a continuous renewal of the cocoa farms on the pioneer front from the East (1920 to 1960), to the Centre-West (1960 to 1980) and the Southwest and West, in the 1980s (Ruf, 1991; Ruf et al., 2015). Such an increase in the cultivation surface allowed the maintaining or increasing of the yielding of cocoa beans in Côte d'Ivoire. Today, the cocoa farms are aging in all cocoa growing area (Aguilar et al., 2003; Assiri, 2007; Deheuvels, 2007) and more particularly in the post pioneer regions like Lôh Djiboua and Goh in the Central West part of the country zones. It is therefore necessary to replant it, due to the economic importance of cocoa for Côte d'Ivoire and for the many smallholder farmers. However, in recent decades, several authors (Freud et al., 2000; Jarrige and Ruf, 1990; Ruf, 1995; Bari et al., 2016) report a general decrease in rainfall and a modification in the rainfall distribution during the year in both Côte d'Ivoire and the world. According to these authors, the evolution of the climate led to the appearance of ecological "limits" conditions of cocoa growing in some cultivation zones in Côte d'Ivoire. The rainfall decline is estimated between 20 and 25% as a function of regions (Coulibaly et al., 2009). In addition, observations made during the last decades in the farms reveal a high mortality of seedlings transplanted in June in accordance with the current practices and a reduced size of pods and beans during the main cocoa harvest season. Such a situation shows that Côte d'Ivoire is likely faced with the challenge of the sustainability of cocoa farming caused by climate change. If no sustainable solution is found, actual disturbances of rainfall might reduce the cultivated surfaces as well as cocoa production in the long term. This study aims to analyze the evolution and distribution of rainfall, identify the rainfall constraints related to cocoa farming, and to make suggestion to ensure the sustainability of cocoa farming in Côte d'Ivoire and particularly in these two regions.

MATERIALS ET METHODS

Study area

The study was conducted at Lôh Djiboua and Gôh in Centre-West, Côte d'Ivoire. The main environmental characteristics are shown in Table 1. The two regions are composed of Gôh-Loh-Djiboua district (Figure 1). This district is a post-pioneer zone with an orchard of 22 years old (Deheuvels, 2007). These regions are under the influence of tropical humid climate with four-season, including two dry seasons and two rainy seasons. Since the late 1970s, the decline in annual rainfall amounts in the West African sub-region, particularly in Côte d'Ivoire, also affected this area (Brou et al., 2005; Kassin et al., 2008). The average humidity of 85% has a strong seasonal variation. The minima are obtained between November and March. The average temperature is 27°C and varies annually between 19 and 33°C.

METHODS

The rainfall data analyzed were collected at the meteorological stations of CNRA both based on Divo and Gagnoa. These data covered a period of 30 years, namely from 1986 to 2015. The two-rainfall series was complete. The methodology used for the analysis of the data consisted of first studying the evolution and distribution of rainfall over the whole period per decade. Then some rainfall parameters, such as annual rainfall heights and cumulative rainfall of a rainy season were calculated and compared to the thresholds required for cocoa (Mian, 2007).

Evolution of annual rainfall

The study of the variation of annual rainfall was done by calculating the rainfall index (Equation 1), which allows the determining of the excessive and deficit years relatively to each meteorological station (Servat et al., 1998). Thereafter, the frequency of years with annual rainfall less than 1200 mm, the

Figure 1. Map of Lôh-Djiboua and Gôh region (Distric of Gôh-Djiboua) https://fr.wikipedia.org/wiki/L%C3%B4h-Djiboua, 2018.

minimum threshold required for cacao tree was determined.

Rain index $(Ii) = \frac{xi-\bar{x}}{s}$ (1)

Where, x_i = quantity of rainfall during year I; $\bar{x}$= Average annual rainfall over the study period; S = standard deviation of the annual rainfall amounts during this period

A year is humid, when the rainfall index is positive; otherwise it is dried when this one is negative (Soro et al., 2011). Thereafter, the proportion of years with annual rainfall less than 1200 mm, the minimum threshold required for cacao was determined.

The rainfall index was then ranked according to the range of values (Table 1) to allow an assessment of the extent of drought or moisture for each year of the rainfall series (Wu et al., 2005).

Monthly rainfall distribution

The study of the monthly rainfall distribution was based on rainfall quantity criteria (IFCC, 1978). Thus, a month is dry when it records less than 50 mm of rain; a month is considered as deficit when it records a rainfall amount between 50 and 100 mm; a month is wet when it records a rainfall greater than 100 mm.

The occurrence probability of humid, deficit and dry months per year led to determine the wettest and driest months over the observation period.

Climatic characterization of rainy season

The characterization of the growing seasons consisted of determining the beginning and end of the rainy seasons by the rainfall balance method (Cocheme et Franquin, 1976). According to this method, the rainy period is defined by the position of the 10 days rainfall curve above the 10 days ETP curve of the latest normal (1971 to 2000). The beginning and the end of the rainy season are thus at dates corresponding to the intersections of the two curves. Subsequently, the probability of rainy seasons was calculated by 10 days by comparing the rainfall totals of the major rainy seasons per year at the threshold of 700 mm required for cocoa farming.

RESULTS

Variation of annual rainfall

The study showed a secession of wet and dry periods (Figures 2 and 3) in the two stations. At Divo, the three decades were moderately dry ranging from 60 to 80% of years characterized by rainfall deficits (Table 2). The extreme dry and wet years were almost non-existent in this station.

At Gagnoa, the decade (1986-1995) was moderately dry with 60% years characterized by a rainfall deficit (Table 3). On the other hand, the decades of 1996 to 2005 and 2006 to 2015 were moderately humid from 60 to 80% of the years having recorded rainfall surpluses. Only 10% of the years were extremely wet in this station. Furthermore, taking into account the minimum threshold of 1200 mm of annual rains, required for cocoa farming, over the three decades 50 to 60% of the

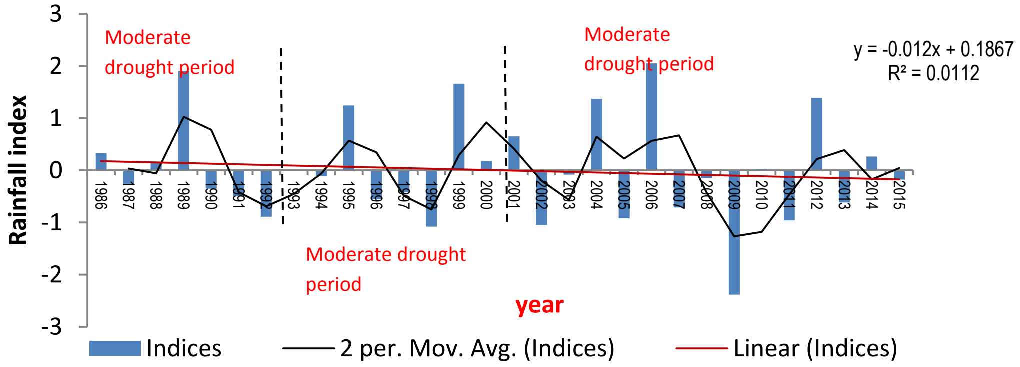

Figure 2. Variation of rainfall index at Divo from 1986 to 2015.

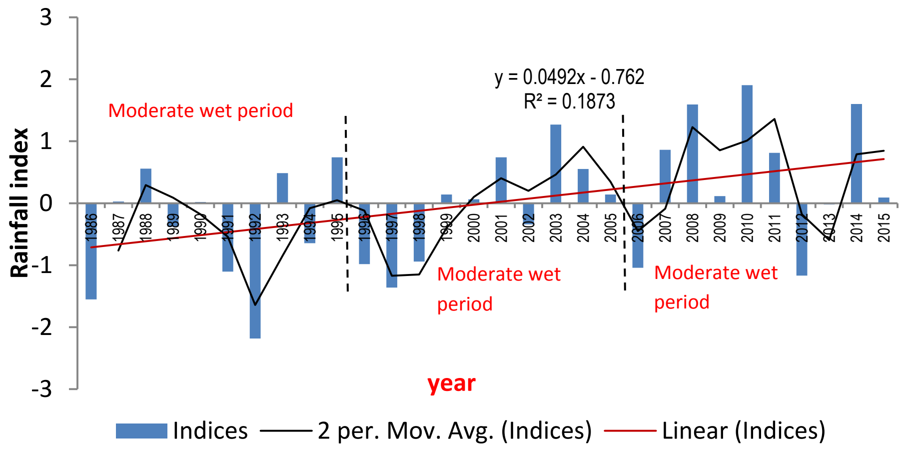

Figure 3. Variation rainfall index at Gagnoa from 1986 to 2015.

years at Divo and 20 to 30% at Gagnoa were deficient (Table 4).

Monthly rain distribution

During 30 years of observations, March, April, May, June, September and October were the rainiest months, with probabilities of occurrence of events P> 100 mm greater than 50%, on one hand (Table 5). On the other hand, January and December were the driest months.

Evolution on the beginning and the end of the rainy seasons

Divo station at the Lôh Djiboua region

Figure 4 indicated that the beginning of the rainy seasons varied between the 1st 10 days of January (1996 to 2005) and the 2nd 10 days of March (2006 to 2015) with the frequency of the events P> ETP of 50 and 40% (Table 6). However, over the 30 years of observations (1986-2015), the rainy season started at the 1st 10 days of March with a probability of P> ETP of 50%. Over the past three decades, the beginning of rainy seasons varied between 30 and 70 days with early rains during the 1996 to 2005 decade.

The end of the rainy seasons also fluctuated from the 1st 10 days of May (1986-2006) to the 2nd 10 days of July (2006-2015), that is, an offset of 10 to 50 days with P> ETP event probabilities of 0% at the 2nd 10 days of May and 10% at the 3rd 10 days of July. Nevertheless, over all the 30 years, the rainy seasons ended from the 2nd 10 days of July with a probability of the P> ETP event of 43% in the 3rd 10 days of July (Table 7). So the length of the rainy seasons was thus 70 days during the decade (1986-1995) and 130 days during the decades 1996-2005 and 2006-2015. As a result, the duration of the rainy season was increased with 60-days from 1986-1995 to 1996-2005 and 2006-2015.

Moreover, in the past 30 years, 90% of the years (1986-1995); and 40% during the decades 1996 to

Table 2. Different ranks of the values range of Li and their meaning.

Ranks of pluviometric indexes	Meaning
Ii>2	Extreme humidity
1<Ii<2	Strong humidity
0<Ii<1	Moderate humidity
-1<Ii<0	Moderate drought
-2<Ii<-1	Strong drought
Ii<-2	Extreme drought

Table 3. Frequencies (%) of wet and dry year per decade at Divo.

Decades	Extreme drought (%)	Strong drought (%)	Moderate drought (%)	Moderate humidity(%)	Strong humidity (%)	Extreme humidity (%)
1986-1995	0	0	80	20	0	0
1996-2005	0	0	60	30	0	10
2006-2015	0	10	70	10	10	0

Table 4. Frequencies (%) of wet and dry year per decade at Gagnoa.

Decades	Extreme drought (%)	Strong drought (%)	Moderate drought (%)	Moderate humidity (%)	Strong humidity (%)	Extreme humidity (%)
1986-1995	0	30	30	40	0	0
1996-2005	0	0	20	60	20	0
2006-2015	0	20	10	40	20	10

Table 5. Characteristics of rainfall in Divo and Gagnoa from 1986 to 2015.

Parameter	Divo			Gagnoa		
Decade	**1986-1995**	**1996-2005**	**2006-2015**	**1986-1995**	**1996-2005**	**2006-2015**
Average	1229.9	1401.8	1184.6	1333	1392	1392
Max	1570.9	3027.3	1688.9	1570	1640	1640
Min	1027.9	991.1	738	1042	1157	1157
Standard deviation	162.6	597.1	257.5	182.3	164.4	164.4
CV	13.2	42.6	21.7	13.7	11.8	11.8
% rainfall<1200	60	50	60	30	20	20
% rainfall <700m during the rainy season	90	40	70	90	40	40

2005 and 70% in the decade 2006-2015 recorded cumulative rainfall less than 700 mm, the minimum required for the cacao cultivation during the great rainy season.

Gagnoa Station in the Gôh region

The beginning of the rainy seasons in Gagnoa fluctuated between the 2nd 10 days of March (1986 to 1995, 1996 to 2005) and the 3rd 10 days of February (2006-2015) during the three decades (Figure 5). However, the probability of occurrence of the P> ETP events (Table 8) was higher (60%) in the 3rd 10 days of March than in the 2nd 10 days (50%) during the decade (1986 to 1995). The beginning of the rainy season therefore varied between 10 and 20 days from decade to decade. In addition, over the 30 years, the probability of rains settling during the 3rd 10 days of March was greater (60%) than that of the 2nd 10 days (47%).

The end of the main rainy season also fluctuated between the 1st 10 days (1986 to 1995 and 2006 to 2015) and the 2nd 10 days of July (1996-2005), an average offset of 10 days from decade to decade. The

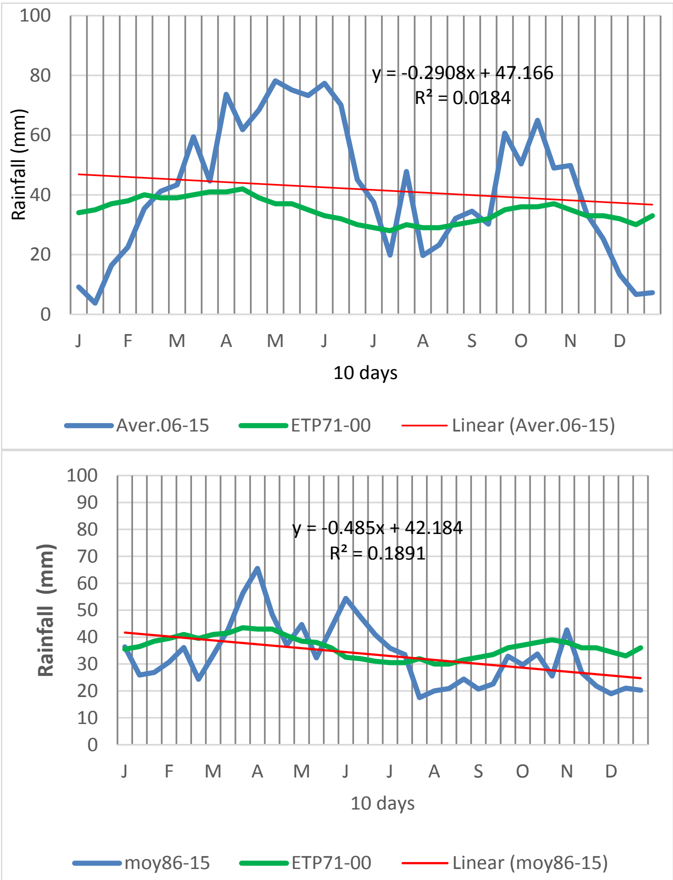

Figure 4. Evolution of 10 days rainfall and 10 days ETP over the decades 1986-1995, 1996-2005, 2006-2015 and 1985-2015 at Divo.

probability to have P> ETP events after these rainy decades is respectively 40 (1986 to 1995), 30 (1996 to 2005) and 20% (2006 to 2015). Moreover, over the thirty years of observations, the end of the main rainy season was at the 1st 10 days of July with a probability of the P> ETP event in the next decade of 47% (Table 8). Thus, the duration of the rainy season was 110 days (1986-1995), 130 days (1996-2005), 140 days (2006-2015) during the three decades. The duration of the rainy season thus varied from decade to decade between 10 and 20 days.

Moreover, in the past 30 years, 90% of the years (1986-1995) and 40% during the decades 1996 to 2005 and 2006 to 2015 recorded cumulative rainfall less than 700 mm, the minimum required for the cacao cultivation during the great rainy season.

DISCUSSION

Evolution of annual rainfall

The study showed a fluctuation of the annual rainfall during the decades over the 30 years (1986-2015) in the two regions. The average annual rainfall calculated over this period is between 1200 and 1400 mm, instead of 1500 and 1700 mm, during the period 1951-1960 (Dabin, 1973). This downward trend in rainfall was already highlighted by several other authors (Servat et al., 1995; Brou et al., 1998; Bari and al., 2016). However, the inter-annual average rainfall recorded remains above 1200 mm, the minimum required for cocoa farming, on one hand. On the other hand, at the level of each weather station, the study showed the existence of years with a rainfall of less than 1200 mm. This average is 56% at Divo and 23% at Gagnoa. This reflects a gradual drying up of the climate in the study area and especially at Divo; where the three decades (1986-1995, 1996-2005 and 2006-2015) were moderately dry. The existence of these drier years with a rainfall of less than 1200 mm is a constraint for cocoa farming.

Rainfall distribution

The study of rainfall distribution revealed that the rainfall regime at the two stations was bimodal. The rainiest months are March, April, May and June for the great rainy season and September and October for the

Table 6. Probability (%) of onset of wet, deficit and dry periods in Divo and Gagnoa during the months of 1986 to 2015.

Month	Divo			Gagnoa		
	P>100 mm	**50<P< 100 mm**	**P<50 mm**	**P>100 mm**	**50<P< 100 mm**	**P<50 mm**
January	0	13	**87**	7	10	**83**
February	17	50	33	20	37	43
March	**63**	30	7	**57**	40	3
April	**87**	10	3	**93**	7	0
May	**87**	13	0	**97**	3	0
June	**100**	0	0	**87**	13	0
Jully	33	30	37	40	27	33
August	13	34	**53**	20	37	43
September	**43**	37	20	**67**	16	17
October	**73**	21	6	**87**	13	0
November	43	37	20	40	37	23
December	10	0	**90**	17	10	**73**

Table 7. Frequencies (%) of P> ETP events during the 1986-1995, 1996-2005 and 2006-2015 decades at Divo.

Decades	January			February			March			April			May			Jun			July		
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
1986-1995			20	60	70	50	50	80	90	70	20										
1996-2005	50	50	60	70	40	50	60	60	80	90	50	40	50	0							
2006-2015				20	40	20	30	40	60										50	50	10
1986-2015						30	43	47	60										63	63	43

short season. However, the beginning and the end of the seasons fluctuated from decade to decade. The shift of the beginning of the seasons from decade to decade at Divo is between 30 and 70 days and in Gagnoa between 10 to 20 days with a high probability of installation of the rains from the 2nd 10 days of March in the two stations. The study also revealed an increase in the rainy seasons during the last two decades, namely 1996-2005 and 2006-2015 for the two stations. However, this development has not affected much rainfall, especially at the Divo station since more than 70% of the years during the decade 2006-2015 recorded less than 700 mm of rain required for cocoa farming. Rainfall deficit recorded during this period exposes cocoa trees to water deficit.

The water deficit is a constraint for all crops and more particularly for the cocoa tree, a very sensitive plant. Several studies indeed showed the negative influence of the water deficit on the establishment of a young cacao and on the productivity and sustainability of a mature cacao. Indeed, for a cocoa seedling in the establishment phase some authors (Boyer, 1973; Freud et al., 2000; Petithuguenin, 1995) showed that the water deficit stops the growth, then leads to the death of young cocoa trees with a high mortality rate during the extremely dry years. For example, the mortality rate observed in Togo fluctuates from 15 to 53% depending on the type of soil (Jagoret and Jadin, 1993). In Côte d'Ivoire; the mortality rate observed in a sample of 50 plots in the East is 39% (Petithuguenin, 1995). The water deficit also delays the development and entry into production of young cocoa trees. This study confirms that, in West Africa, the survival of young cocoa trees, with a shallow root system, is particularly conditioned by a good distribution of rains, on one hand. On the other hand, adult cocoa trees can withstand periods of water deficit greater than 3 months, due to their deep root system; but, their production potential is affected in different ways. When the water deficit occurs a few weeks before flowering, it leads to an increase in the final yield by stimulating flowering. A few weeks after fruit set, the same deficiency causes wilting of the young fruits. If it occurs 3 to 4 months after setting, it causes the reduction of the size of the cocoa beans. This explains the small size of the cocoa beans during the intermediate harvest in West Africa. Similarly, the size of the beans in the main crop is decreasing more and more. Such a phenomenon is linked to the water deficit recorded during the great rainy season (Brou et al., 2003). When the water deficit occurs over several months and is repeated from year to year, it weakens and reduces the longevity of the cocoa trees. This explains the shortenedness of the mature phase and the lateness of the senescent one (Petithuguenin, 1995)

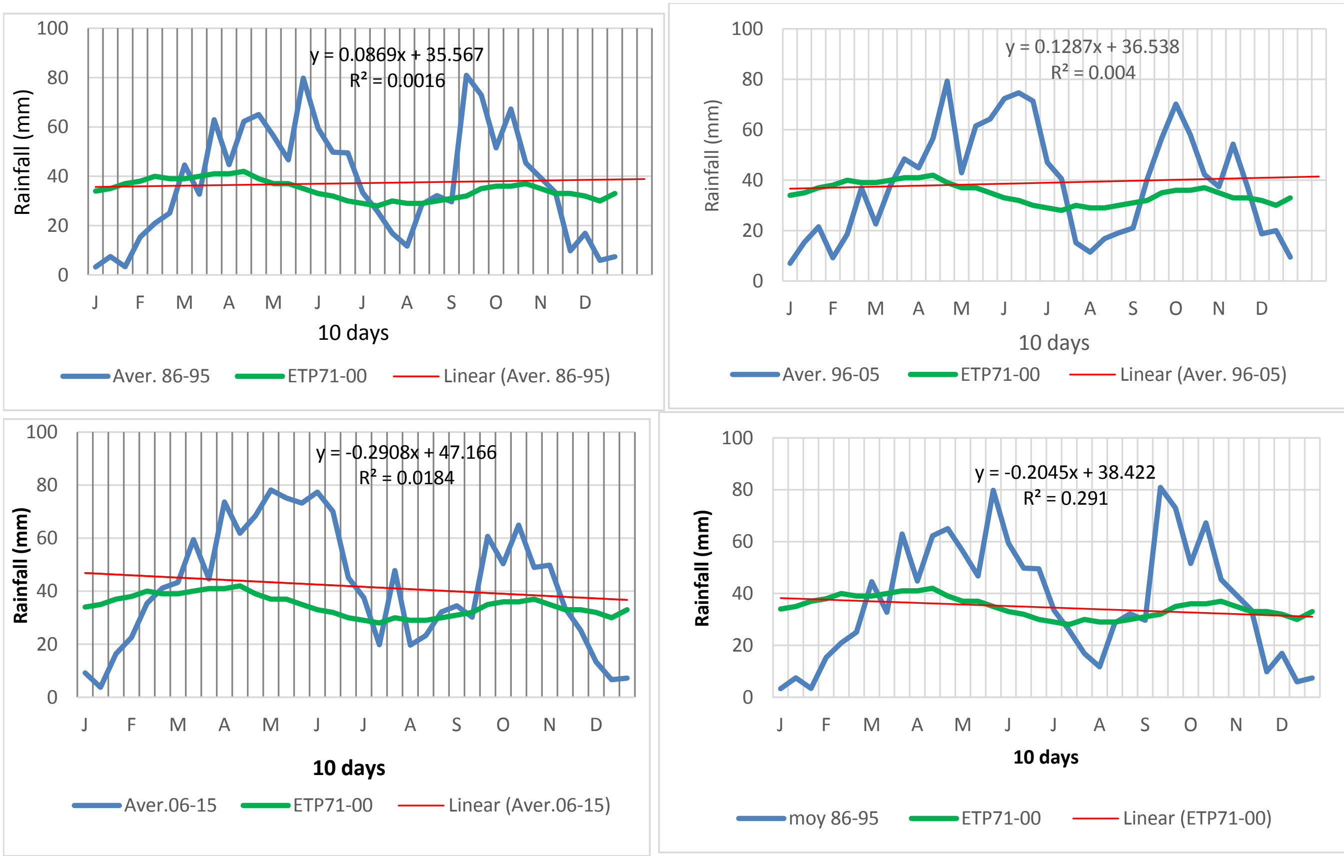

Figure 5. Evolution of 10 days rainfall and 10 days ETP over the decades 1986-1995, 1996-2005 and 2006-2015 at Gagnoa.

Impact of disturbance of the rainy seasons on cocoa farming

The study of the distribution of rainfall between 1986-1995, 1996-2005 and 2006-2015 revealed a shift in the dates of the beginning and end of the growing seasons. The time lag is about 30 days between the was observed between the 1986-1995 decade and the decade 1986-1995 and the decade 1996-2005 and 70 days between the decade 1996 to 2005 and the decade 2006 to 20015.However, at Gagnoa, the lag is less pronounced. It is 30 days between the decade 1996-2005 and the decade 2006-20015. Any time lag1996-2005 decade. But, generally, over the period (1986 to 20015), the main rainy season was established at Divo from the 1st 10 days of March to the 2nd 10 days of July and at Gagnoa from the 3rd 10 days of March to the 1st 10 days of July, while in

Table 8. Frequencies (%) of P> ETP events in the 1986-1995, 1996-2005 and 2006-2015 decades in Gagnoa.

Decades	J			F			M			A			M			J			J		
	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
1986-1995					20	20	60	40	60									50	40	40	20
1996-2005						20	20	60	60										60	80	30
2006-2015			20	30	40	50	50										80	70	60	20	20
1986-2015				17	17	30	43	47	60							83	80	67	53	47	23

practice the planting of cacao is usually made in May or June. That could partly explain the high mortality of seedlings or even the failure of replanting during the first two years of replantation. Climate change not only affects the agricultural calendar, but also the cacao growth and production cycle. In fact, at eastern Côte d'Ivoire, the first cocoa production zone, the main harvest is shifted from October to December (Brou et al., 2003). Many other studies have revealed that cacao productivity, development and quality are strongly affected by the amount, distribution and duration of rainfall (Almeida and Valle, 2007; Balasimha and Bhat, 1991; Moser et al., 2010). Consequently, cacao is not generally considered resilient in the face of extreme weather conditions, particularly during prolonged periods of drought (Alvim and Kozlowski, 1977; Almeida and Valle, 2007). Cacao's noted low tolerance to prolonged water limitation is concerning given that climate models predict reduced rainfall, and increased temperatures will become significant limitations to production in the near future, with some areas of West Africa already being affected (Agbongiarhuoyi et al., 2013; Bari et al., 2016; Hutchins et al., 2015).

Solutions for sustainable cocoa production in the two regions

The study revealed a variation in rainfall over the years causing the shifts of the beginning and the end of the main rainy season in the two regions. Under these conditions, producers no longer know when to plant cocoa and associated food crops. This situation increases the vulnerability of rural populations in these two regions to face the adverse effect of climate change. Although the study showed a high probability to have the beginning of the main rainy season by the 2nd 10 days of March in both regions, it would be advantageous to make rainfall predictions and make these information available to farmers on time to help them install their crops at the good time. Similar studies have been done elsewhere (Cetin, 2015a; Cetin et al., 2018; Cetin et al., 2010; Cetin and al., 2016). In addition, the use of climate prediction models in combination with GIS will help define areas suitable for cocoa farming both regionally and nationally (Cetin, 2015b;Cetin,2015c;Kaya et al.,2018;Cetin et al., 2018b; Cetin et al., 2018c). In addition to deforestation, current cocoa full sun production systems have led to land degradation (Tondo et al., 2015; N'guessan et al., 2017; Kone et al., 2012).The promotion of agroforestry systems based on cocoa could not only contribute to restoring soil fertility but also diversify the income sources of cocoa farmers to make them less dependent on cocoa and vulnerable (Koko et al., 2013).

This system also provides stress alleviating services (Jacobi et al., 2015; Verchot et al., 2007; Tscharntke et al., 2010; Beer et al., 1998). In coffee, shade trees protect the plants from drought by reducing the evaporative transpiration demand, and increasing the infiltration capacity of the soil (Lin, 2007). Shade can affect cacao stomatal conductance, ameliorating the effects of drought especially during seedling establishment. Such interaction was observed by Frimpong et al. (1999). Currently, chocolate makers have initiated in several countries the promotion of agroforestry in cocoa farming through numerous projects including REDD+. Drought-resistant plant material for cocoa could also be used in replantation or rehabilitation of farms (Medina and Laliberte, 2017; Smith, 2014). A review was done on the effects of drought and temperature stress and increased CO2 in Theobroma cacao Costa Rica: Bioversity International) and short cycle varieties for associated food crops. However, based on the concept that a healthy cacao tree under balanced nutrition is more likely to be resilient to abiotic stresses, potassium amendment was highlighted for its potential to mitigate the effect of drought in cacao orchards. Interactions between potassium nutrition and drought stress have been observed in other crops – e.g. sorghum (Asgharipour and Heidari, 2011); cassava (Ezui et al., 2017); olive (Erel et al., 2014); and highland banana (Taulya, 2013) – and could be a management opportunity towards drought resilience adaptability in cacao. Aside from depending on potassium to regulate intrinsic osmotic functions, cacao has a specifically high demand for potassium, particularly for pod structure, and so it could benefit from supplemental potassium. Therefore, the best period to apply potassium is thought to be during pod set and development (Almeida and Valle, 2007). Irrigation can also be adopted as a solution to provide cacao with additional water they need to express their potential.

Conclusion

The current evolution and distribution of the rains show a preponderance of moderately dry years in the Lôh Djiboua region and moderately humid in the Gôh region during the three decades studied. In addition, the study showed that the beginning of the main rainy season is between the 1st and 2nd 10 days of March in both regions. However, a high probability of rainfall deficit during rainy seasons, unfavorable to cacao was also revealed. So at the short term planting in both areas could be done earlier in March at the beginning of the rainy season to allow the young plants to benefit from all the rains so as to reduce their mortality rate. But tests will have to be carried out in real environment to confirm these periods. Agroforestry could also be a solution to mitigate the negative effects of climate on cocoa farming. Special attention should also be given to the choice of the soils. These soils should have a good water retention capacity in order to compensate for the rainfall deficit during the rainy seasons.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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