Agro-climatic update of favourable areas to Robusta and Arabusta coffee growing in Ivory Coast

ABSTRACT

Following a drastic fall in coffee production, Côte d'Ivoire has made it a priority to revive its coffee-growing industry. This requires the development of regionalized technical itineraries adapted to climate change. To this end, agro-climatic analyzes were carried out using data from 55 rain gauge stations covering the period from 1985 to 2019. This involved cross-referencing the climatic parameters calculated, taking into account the climatic requirements of coffee trees (Robusta and Arabusta) to define homogeneous agro-climatic zones in the forest and pre-forest zones bounded by the 8th parallel north. The results show that 70.47% of the area is suitable for growing Robusta coffee, compared with 11.37% for Arabusta. The mountainous west remains generally favorable to growing both varieties of coffee. The study also updated information on the agro-climatic suitability of coffee-growing areas.

Keywords: Robusta and Arabusta coffee; Agro-climatic zoning; GIS mapping; Ivory Coast.

1. INTRODUCTION

In Côte d'Ivoire, coffee is one of the main agricultural products exported and employs nearly 400,000 farmers, mainly made up of small producers whose farm size rarely exceeds 2 ha [1] [2]. Thus, coffee presents an important economic issue for producing countries such as Côte d'Ivoire [3]. Unfortunately, the sustainability of this crop and the volume of exports are today compromised by the degradation of natural production factors (pedoclimatic conditions) and also accentuated by the aging of the orchards. Formerly the leading producer (with a production of 300,000 tons in 1970), the country fell to 3rd place among African producing countries and 15th place among world producing countries, in 2019, with a production of around 108,000 tons [4] [5]. Average yields are low with 325 kg/ha/year while the productive potential varies from 2.5 to 3 t/ha/year for Robusta coffee and from 1 to 1.5 t/ha/year for Arabusta coffee [1] [6]. The current production environment for Robusta and Arabusta coffee trees in Ivory Coast is characterized by a reduction in annual rainfall amounts and a shortening of the length of growing seasons [7] [8] [9]. This drop in rainfall is remarkable, even in areas with high rainfall (more than 1800 mm/year), more particularly in the mountainous west [10] [11] [12] [13]. This situation leads certain authors [14] to assert that climate change has created limiting conditions for the cultivation of coffee in certain regions of Côte d'Ivoire. These observed climatic variations have repercussions on the production of coffee orchards by causing a considerable reduction in agricultural production [15] [16]. If technical itineraries, through technical sheets [6], are put in place to improve production, climate variability being in perpetual evolution, there is therefore a need to update the agro-climatic mapping of Ivorian coffee-growing zones in this current context of climatic disturbances.

Then, the objective of this research is to contribute to improving the sustainable productivity of the coffee tree based on the updating of agro-climatic zones favorable to the cultivation of coffee trees.

2. MATERIAL AND METHODS

2.1 Study Area

The study area covers the southern half of Côte d'Ivoire (57.4% of the territory) below the 8th parallel. Two rainfall regimes (unimodal and bimodal) are observed in this area (Fig. 1).
The study area covers 19 square degrees (cartographical division of Côte d'Ivoire). It extends over the entire forest zone in the South and part of the transitional forest zone in the North. Average annual rainfall amounts vary between 1,000 mm in the East and 2,600 mm in the West. Analysis of the 1971-2000 normal compared to that of 1961-1990 shows an average reduction in rainfall amounts of 6% across the entire Ivorian territory with remarkable drops of 13% in Sassandra and 11% in Adiaké, two localities located on the Ivorian coast respectively in the South-West and the South-East [7]. Average annual temperatures vary between 25 and 29° C with thermal amplitudes of -0.5 to 2° C. The distribution of climatic parameters (water deficits, crop water satisfaction index, thermal amplitudes, duration of dry seasons, etc.) gives the study environment five (05) distinct agro-ecological zones: the dense humid forest zones of the South and the West, the dense humid semi-deciduous forest zone in the East, the semi-mountainous forest zone of the West and the transitional forest zone in the North.

2.2 Meteorological and Agro-Climatic Data

The meteorological data used, covering the period from 1985 to 2019, come from fifty-five (55) meteorological stations distributed throughout the study area (Fig. 1). The climatic parameters used in this study are essentially rainfall, temperature (minimum and maximum) and potential evapotranspiration (ETP).

In terms of agro-climatic data, the climatic requirements of the coffee tree relating to rainfall (annual quantity, tolerable drought duration, dry sequences), temperature (minimum, optimal, maximum), relative humidity and duration of sunshine were taken into account.

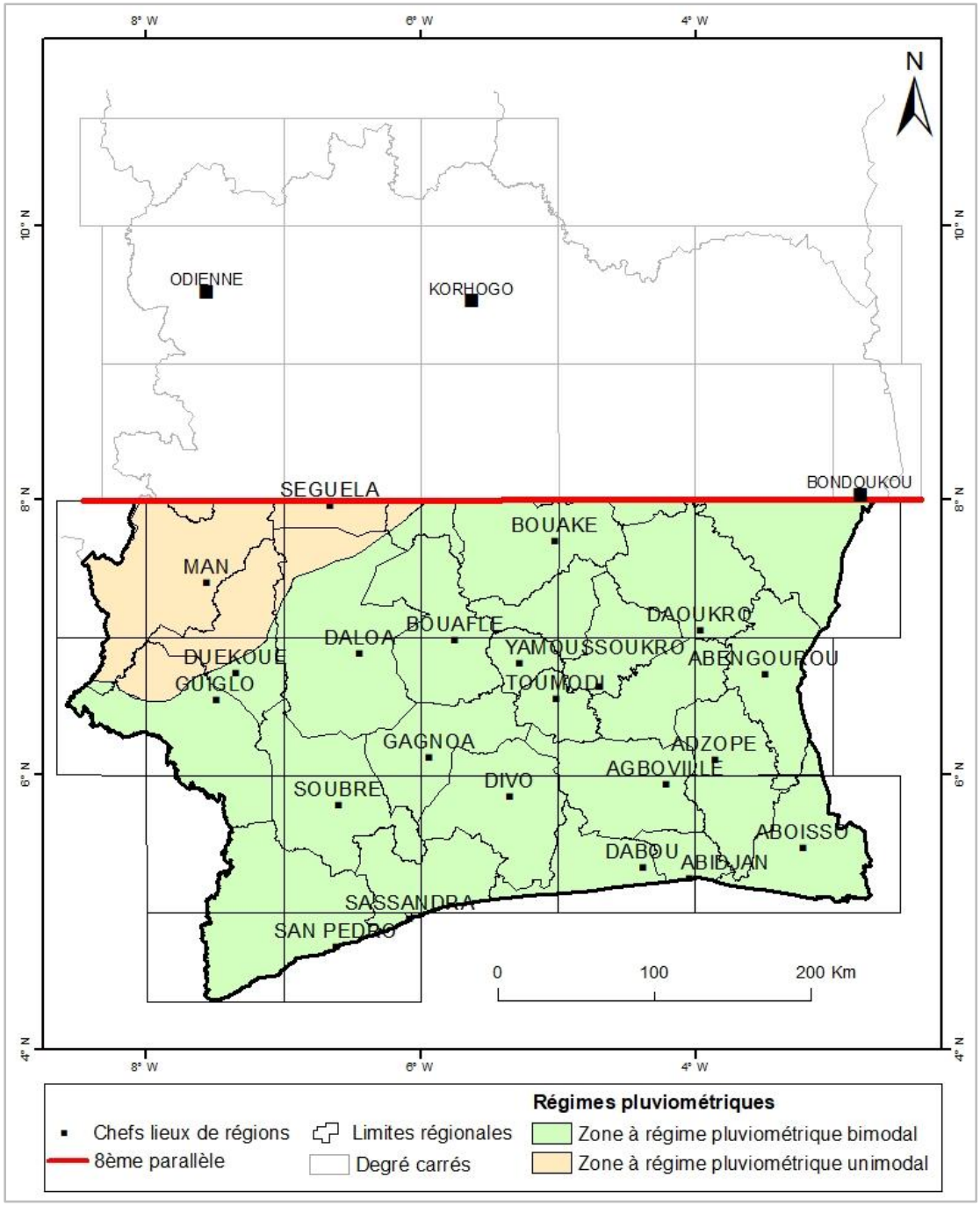

Fig. 1. Presentation of the study area according to the cartographic division into square degrees and regional boundaries

The climatic requirements of the coffee tree often vary depending on function of the authors. However, a synthesis of the information made it possible to define the limits in terms of the climatic requirements of the crop.

Indeed, Robusta is cultivated in the plains, at an altitude less than 800 meters lower than Arabusta, in a hot climate with temperatures between 24 and 30°C, annual rainfall amounts

varying from 1200 to 2000 mm and a dry season lasting 2 to 3 months [17]. As for Arabusta, it is a plant from high altitudes (1300 to 1800 m) which thrives in regions where annual precipitation is between 1500 and 1800 mm. Below 1000 mm of rainfall, even well distributed, the cultivation of Arabusta becomes uncertain and productivity fluctuates. It supports a dry season of 4 to 5 consecutive months. Average temperatures should be around 20 to 25°C with minimums between 4 and 5°C and maximums around 30 to 31°C, but favorable temperatures are between 22 and 26°C. C without very marked differences [18].

These climatic requirements of coffee trees made it possible to define classes of homogeneous agro-climatic zones for Robusta coffee growing and Arabusta coffee growing.

2.3 Method of Zoning and Agro-Climatic Mapping

2.3.1 Zoning method

The methodological approach to agro-climatic zoning consisted of daily collecting data from the 55 meteorological stations located throughout the study area. From these data, climatic parameters were calculated then cross-referenced with the climatic requirements of the different crops (Table 1 and 2) to define homogeneous agro-climatic zones.

Table 1. Criteria for classifying the agroclimatic potential of areas favorable to Robusta coffee growing

areas	Annual rain (P)	Dry Season Duration (DS)	Temperature	Relative humidity (RH)	Probability of Dry Sequence greater than 20 days from April to July (Prob (SS))
Very favorable	D ≥ 1500 mm	DS ≤ 3 consecutive months	24 ≤ Tavg< 30 Tmin> 10 TMax<35	RH ≥ 80%	Prob (SS) ≤0.4
Favorable	1200 ≤ D < 1500 mm	DS ≤ 3 consecutive months	24 ≤ Tavg< 30 Tmin> 10 TMax<35	HR >75%	Prob (SS) ≤ 0.4
Unfavorable	1000 ≤ P < 1200 mm	DS ≤ 4 consecutive months	24 ≤ Tavg< 30 Tmin> 10 TMax<35	HR >70%	Prob (SS) ≤ 0.4
Not favorable	The set of zones that do not obey the very favorable, favorable and unfavorable zone conditions.				

* Tmoy: Average temperature, Tmin: Minimum temperature, TMax: Maximum temperature (Source: Cambrony, 1987; Petithuguenin, 1998; FAO, 2011; Daniel, 2013)

Table 2. Criteria for classification of the agroclimatic potential of areas favorable to Arabusta coffee growing

Areas	Annual rain (P)	Dry Season Duration (DS)	Temperature	Relative humidity (RH)
Very favorable	D ≥ 1300 mm	DS ≤ 4 consecutive months	18 ≤ Tmean< 22 Tmin> 5 TMax< 30	70% < RH ≤ 80%
Favorable	D ≥ 1200 mm	DS ≤ 4 consecutive months	20°C ≤ Tmean ≤ 25°C Tmin> 5°C TMax ≤ 31°C	70% < RH ≤ 80%
Unfavorable	D ≥ 1000 mm	DS ≤ 4 consecutive months	25 <Tmean ≤ 28°C Tmin> 5°C 31 <TMax ≤ 34°C	70% < RH ≤ 80%
Not favorable	The set of zones that do not obey the very favorable, favorable and unfavorable zone conditions.			

* Tmoy: Average temperature, Tmin: Minimum temperature, TMax: Maximum temperature (Source: Cambrony, 1987; Sivakumar, 1988; Petithuguenin, 1998; Daniel, 2013)

2.3.2 Agro-climatic mapping method

The mapping of agro-climatic zones was carried out from the processing and analysis of the calculated climatic parameters and the climatic requirements of each crop. Particular attention was paid to the period from April to July, because this period corresponds to the rainy season when coffee trees are particularly sensitive to water deficit. The processing and analysis of the data made it possible to obtain the following parameters at the different measuring stations:

- the length of the dry season;
- the average annual rainfall for the period considered;
- the average rainfall totals from April to July of the period considered;
- the average, minimum and maximum temperatures of the period considered;
- the average humidity of the period considered;
- the average daily and annual insolation durations for the period considered;
- the probabilities of dry sequences greater than 20 days from April to July over the period considered.

The different agro-climatic parameters were spatialized over the entire study area. Subsequently, the different layers of spatial information were crossed for the classification of areas according to the criteria defined for each culture. Thus, for each crop, four zones have been defined. These are:

- **very favorable areas:** these are the parts of the study area in which the climatic conditions are optimal to ensure better development of coffee growing.

The climatic requirements of the coffee tree are met by the existing climatic conditions;

- **favorable areas:** These are the parts of the study space in which the climatic conditions, although not optimal, allow good development of coffee growing. The climatic requirements of the coffee tree are almost met by the climatic conditions with satisfactory production;

- **unfavorable areas:** theytake into account the parts of the study area in which the climatic conditions do not allow good development of coffee growing. Production there is uncertain because certain climatic requirements of the crops are not met;

- **unfavorable areas:** These are parts of the territory of Côte d'Ivoire in which climatic conditions do not allow the development of coffee cultivation. Most of the climatic requirements of the coffee tree are not met. This is the set of zones that do not obey the very favorable, favorable and unfavorable zone conditions.

2.4 Method for Determining Dry Months

To characterize the drought status of an area over a given period, several indices established from different methods (Gaussen, Thorntwaite and the Forest-Weather Index) can be used. Gaussen's was used in this study. The Gaussen method uses a graphical procedure (ombrothermal diagram) to define dry periods and wet periods, exploiting the relationship P = 2T [19]. This diagram allows you to distinguish between dry and wet months. A month is considered dry if the temperature curve is higher than the precipitation histogram. Conversely, a month will be said to be humid if the temperature curve is lower than the bar representing a month's precipitation.

2.5 Determination of Maximum Dry Sequences and Their Probabilities of Appearance

A dry sequence is a succession of consecutive days during which rainfall is less than a threshold p (p = 5 mm in this study). The longest dry sequences occurring in the different rainy seasons were calculated per year for each of the 55 rainfall stations. The average value of maximum dry sequences and the probability of occurrence of dry sequences greater than or equal to 20 days were subsequently calculated per observation post.

Data processing and analysis were carried out using Excel, INSTAT+ V3.37 software while the various maps were developed using Surfer, ARGIS and QGIS software.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Agro-climatic zones favorable to the cultivation of Robusta

The analysis of the climatic requirements of the Robusta coffee tree and the climatic conditions of the Ivorian coffee production zone (limited to the North by the 8th parallel) over the period from 1985 to 2019 made it possible to identify very favorable, favorable, unfavorable zones. and not favorable for growing Robusta coffee trees (Fig. 2).

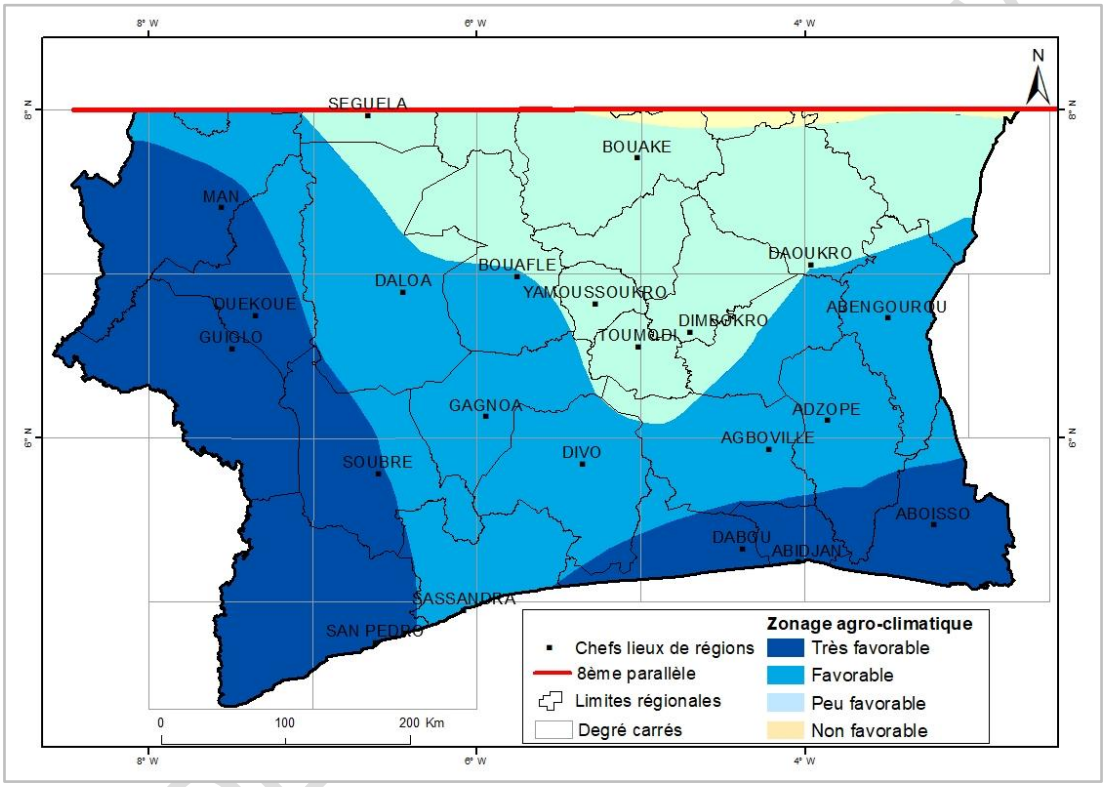

Fig. 2.Agro-climatic zoning for Robusta coffee growing in the Ivorian coffee production zone according to the cartographic division in square degrees and regional boundaries

Source: Mapping based on climate data from 1985-2019

3.1.2 Agro-climatic zones favorable to the cultivation of Robusta

The analysis of the climatic requirements of the Robusta coffee tree and the climatic conditions of the Ivorian coffee production zone (limited to the North by the 8th parallel) over the period from 1985 to 2019 made it possible to identify favorable, unfavorable and unfavorable zones. to Arabusta coffee cultivation (Fig. 3).

3.1.2 Areas and proportions occupied by agro-climatic zone classes for the cultivation of Robusta and Arabustacoffee trees during the period 1985 – 2019

Table 3 presents the areas and proportions occupied by the classes of agro-climatic zones for the cultivation of Robusta and Arabusta coffee trees during the period 1985 - 2019 of the coffee production zone in Côte d'Ivoire.

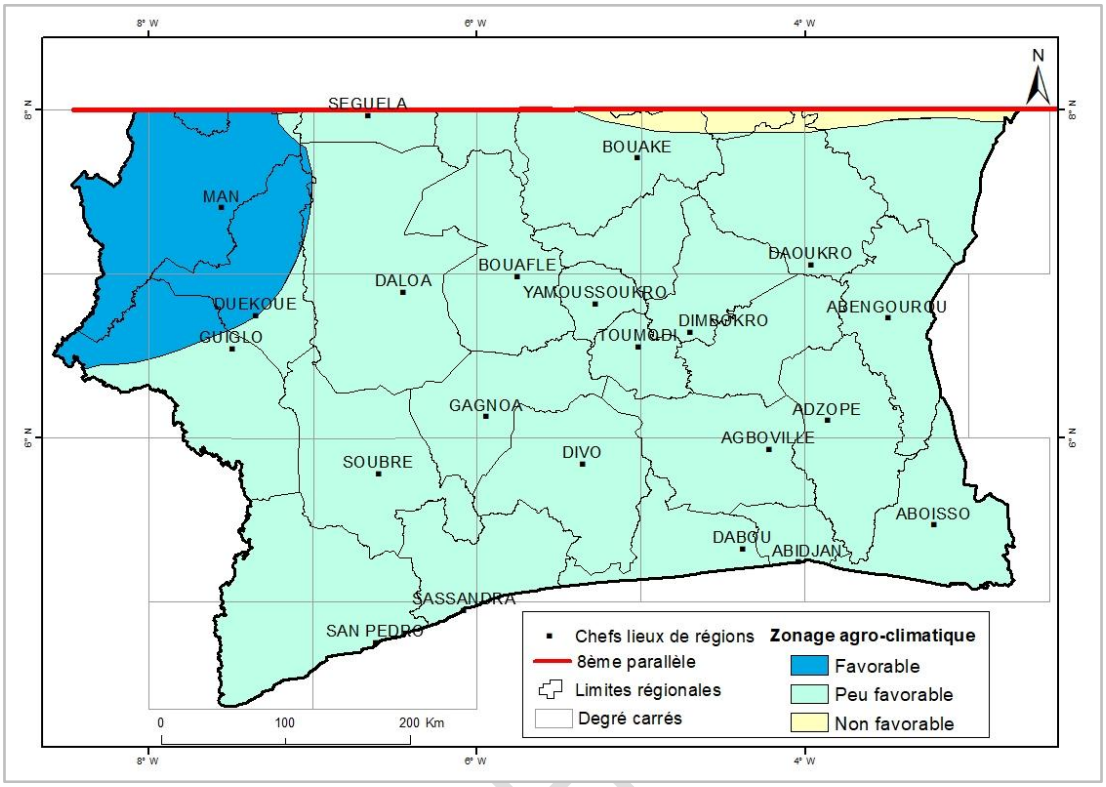

Fig. 3.Agro-climatic zoning for Arabusta coffee growing in the Ivorian coffee production zone according to the cartographic division in square degrees and regional boundaries

Source: Mapping based on climate data from 1985-2019

Table 3.Areas and proportions occupied by agro-climatic zone classes for Robusta and Arabusta coffee crops during the period 1985 – 2019 in the Ivorian coffee production zone

Class	Description	Robusta coffee growing		Arabusta coffee growing	
		Area (km2)	Proportion (%)	Area (km2)	Proportion (%)
1	Very favorable	58345.21	31.54	0	0
2	Favorable	72015.48	38.93	21029.71	11.37
3	Unfavorable	52109.29	28.17	160568.38	86.81
4	Not favorable	2503.15	1.35	3375.04	1.82
Total		184973.13	100	184973.13	100

Source: Statistics based on agro-climatic mapping from 1985-2019

The analysis of these data (Table 3) allows us to say that in general the agro-climatic parameters of the zone located below the 8th parallel are favorable to Robusta coffee

growing ((70.47% of the areas) and not very favorable to Arabusta coffee growing (86.81% of areas).

3.1.2 Description of the main climatic zones

The most favorable zones for coffee growing were determined based on the main climatic parameters: temperature (T), rainfall (P), length of the dry season (DS) and relative air humidity (RH)). These areas are presented in Fig. 4 and 5.

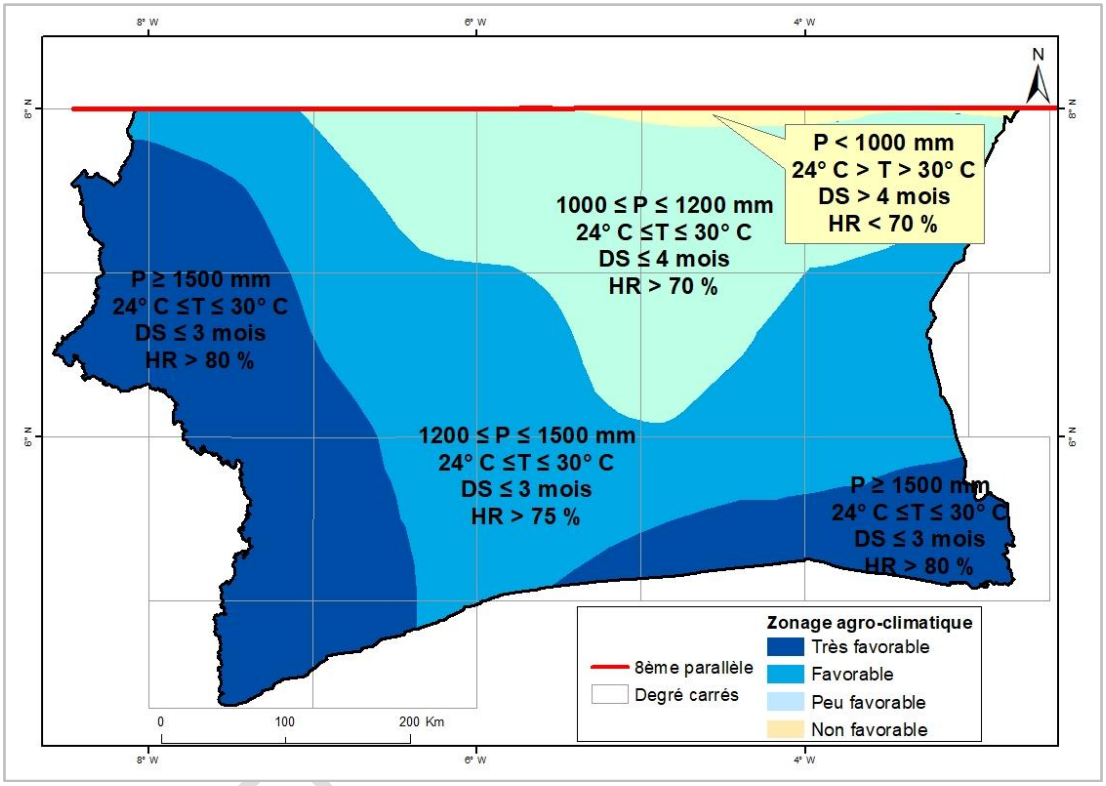

Fig. 4.Characteristics of climatic zones favorable to the cultivation of Robusta coffee trees in Ivory Coast

The study area is more favorable to Robusta coffee cultivation compared to Arabusta coffee cultivation. The areas favorable to Robusta are generally located in the south of Côte d'Ivoire with annual rainfall amounts greater than or equal to 1200 mm, temperatures varying between 24 and 30° C, dry season durations less than or equal to 3 months and relative air humidity values strictly above 75%. As for Arabusta, the favorable area for its cultivation is essentially located in the mountainous West. In this area, the average annual rainfall amounts are greater than or equal to 1200 mm, the average annual temperatures vary between 20 and 25° C with dry season durations less than or equal to 4 months and relative humidity values of the air between 70 and 80%.

The combination of the long dry season (4 months on average) and the low relative humidity of the air (< 70%), with its impact on the length of dry sequences and their probabilities of occurrence, constitute the main limiting factor for Robusta and Arabusta coffee crops. The favorable areas for the cultivation of Robusta are limited to the North by the pre-forest zone and those of Arabusta are limited to the West of the country.

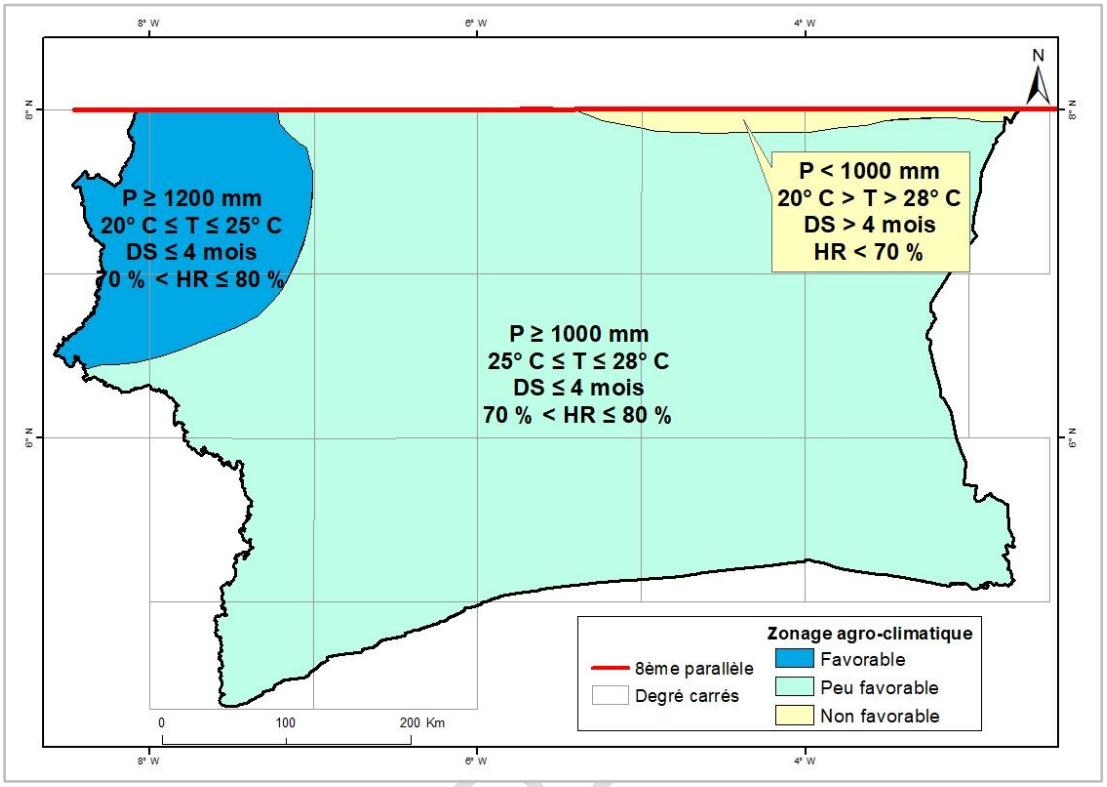

Fig. 5.Characteristics of climatic zones favorable to the cultivation of the Arabusta coffee tree in Ivory Coast

3.1 Discussion

Agro-climatic Analyzes made it possible to map the current agro-climatic zones favorable to coffee growing. They revealed areas still favorable to the two varieties of coffee trees, but those favorable for Arabusta coffee growing remain limited to the western Ivorian regions. Indeed, studies on the evolution of climatic parameters have revealed a drop in annual rainfall amounts and a shortening of the length of cropping seasons [7] [15] [16]. This development has led certain authors [14] [20] to assert that the evolution of the climate has generated limit conditions for the cultivation of coffee in certain regions of Côte d'Ivoire.

The work thus highlighted a strong agro-climatic suitability for the Robusta coffee tree (70.47% of very favorable to favorable zones) and a marginal suitability for the Arabusta coffee tree (11.37% of favorable zones). These results corroborate those of [5] in the mountainous west. For them, Robusta coffee (*Coffea canephora)* was for many years the main cash crop in Côte d'Ivoire and it continues to be the variety grown in the semi-mountainous west. It is therefore right that [2] stipulated that in Côte d'Ivoire only the Robusta variety of the C. *canephora* species is cultivated. All these observations confirm the results obtained by [19] [21] [22]. For [20], to the question of whether it was possible to improve Ivory Coast coffee by growing the high-altitude coffee tree *Coffea Arabica* L., hybrid Arabusta is not satisfactory for cultivation but it nevertheless offers the advantage of being vigorous, therefore of serving as good rootstocks for Arabica.

As research aimed at updating climatic zones favorable to coffee growing throughout the Ivorian production zone has not yet been carried out, the results obtained on agro-climatic zoning for coffee growing constitute a first in this direction. They should serve as a guide for the regionalization of technical routes adapted to said culture.

4. CONCLUSION

Analyzes based on climatic and agroclimatic parameters, including statistics and GIS, made it possible to map the agroclimatic capabilities of Ivorian coffee production areas. They show the existence of areas favorable to the cultivation of the two varieties of coffee trees grown in Côte d'Ivoire despite the climatic changes observed in recent years. In fact, 70.47% of the areas are favorable for Robusta coffee growing compared to 11.37% for Arabusta coffee growing. Favorable areas for Arabusta coffee growing are mainly located in the mountainous West.

In terms of research perspective, this study will make it possible to: (i) develop technical itineraries adapted to different agro-climatic zones; (ii) select the best trial sites and validate resistant varieties intended for areas with deficit rainfall (unfavorable areas). Also, the agro-climatic database should be updated every 10 years.

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