Climate and agriculture in Côte d'Ivoire: Perception and quantification of the impact of climate change on cocoa production by 2050

Abstract

Cocoa contributes 7.5% of Côte d'Ivoire's Gross Domestic Product (GDP) and is an important cash crop for the rural population in the country's forest areas. Cocoa, like the crops of West Africa, is deeply affected by the consequences of climate change. The objective of this research is to predict the impact of climate change on cocoa production in the main producing regions of Côte d'Ivoire and to analyze farmers' perceptions of climate change. The soil data were those of the World Harmonized Database version 1.2 of the FAO and allowed the spatio-temporal analysis of the useful reserve of water in the soil. The socio-economic data used integrated in the production forecasting model were taken from the report of the Census of Farmers and Farms 2015/2016. The temperature and precipitation series over the period 1981-2016 served as a climatic reference. The RCP 4.5 and RCP 8.5 scenarios were used for climate projections by 2050. The results showed a temperature increase of around +1°C to +1.5°C by 2050 ; and a decrease in rainfall over the entire Ivorian territory. According to the developed model, national cocoa production is expected to fall by around 17% and 23% respectively under the RCP 4.5 and 8.5 scenarios. Moreover, some current cocoa production areas will become unsuitable (Lagunes and Sud-Comoe in Côte d'Ivoire) due to the new pedoclimatic conditions. The results obtained also highlighted a relatively low level of knowledge of cocoa producers regarding the effects of climate on well-being.

Key words

Cocoa, climate change, horizon 2050, RCP 4.5 and RCP 8.5 scenarios, Côte d'Ivoire

Introduction

The uncontrolled growth of greenhouse gas emissions is warming the planet, with the consequences of changes in rainfall, the multiplication of extreme meteorological phenomena, shifts in the seasons and soil impoverishment. Accelerating climate change, coupled with global population and income growth, is threatening the livelihoods of rural people everywhere. The World Bank estimates that the countries of sub-Saharan Africa are the country's most widely affected by this phenomenon due to the weakness of their production systems based essentially on subsistence agriculture (Hallegatte et al., 2016, Baarsch et al., 2020). This is dependent on climatic vagaries, low yields and the absence of adequate adaptation strategies (Mouleye et al., 2019). Higher temperatures decrease the yields of useful crops. Changing rainfall patterns increase the likelihood of short-term crop failures and long-term production declines (Boualem et al., 2021).

Côte d'Ivoire is no exception to this situation. In this country, the harmful effects of climate change have been highlighted in numerous studies. From this work, it appears that Côte d'Ivoire is experiencing a succession of dry and rainy climatic episodes punctuated by periods of drought whose intensity and spatial extension have become exceptional since 1970 (Kouassi et al., 2017). Other work has shown that the country recorded rainfall ruptures which were reported between 1966 and 2000 and which generated deficits of around 21% with a temperature rise of between +1 and +1.6°C. globally over the period 1960-2010 (Goula et al., 2012, Kouakou et al., 2012).The emerging general consensus is that changes in future temperature and rainfall will cause crop yields to decline.(Dibi Kangah Agoh and Mian 2016, Ochou and Ouattara 2020).

Cocoa (*Theobroma cacao*) production is expected to be adversely affected by these changes in temperature and rainfall. Indeed, Côte d'Ivoire is one of the world's leading cocoa producers. This speculation contributes to 7.5% of the Gross Domestic Product (GDP) of Côte d'Ivoire (Läderach et al., 2013). Several previous works have documented the effects of the observed decline in rainfall on cocoa in Côte d'Ivoire (Ochou 2018, Yoroba et al., 2019, Guy and Tia 2021). If gradual climate change were to affect the climate suitability of cocoa in West Africa, it would have implications for global cocoa production as well as national economies and farmer livelihoods, with potential repercussions for forests. and natural habitat as cocoa growing regions expand, shrink or shift (Läderach et al., 2013). Cocoa has played a key role in the conservation of forests and their biodiversity, both negatively and positively. On the one hand, cocoa has been an important factor in the conversion of forests for agriculture (Ruf and Schroth 2004). On the other hand, the shade cocoa tree can provide valuable secondary habitat for forest fauna and flora in agricultural landscapes (Ruf and Schroth 2004). The cocoa area under soft shade is estimated at 50% in Ghana and Côte d'Ivoire, while about 10% and 35% are managed without shade in Ghana and Côte d'Ivoire, respectively. Overall, the past few decades have seen a decline in the use of shade in cocoa in West Africa (Ruf and Schroth 2004, Ruf 2011, Läderach et al., 2013). The objective of this research is to predict the impact of climate change on cocoa production in main Ivorian producing regions.

PRESENTATION OF THE STUDY AREA

The study concerns the entire cocoa growing area on Ivorian territory (figure 1). The climate is humid tropical, with average annual rainfall varying between 1200 and 1400 mm.(Brou et al., 2005). Average annual temperatures vary between 24 and 32° C (Kassin et al., 2008). The sunshine duration is more than 1,800 hours per year (Eldin 1971). The vegetation is made up of a mosaic of degraded forests and dense semi-deciduous forests in the Centre-West and the East. In the South, South-West and West, it is characterized by dense evergreen humid forests (Bourlière 1972). Mountain forests are the vegetation of the western areas and mangrove forests cover the coast (Bourlière 1972). The soils of the South-West and South-East are hyperdystric Ferralsols (pH greater than 5.5). As for the soils of the eastern, central-western and western zones, they are made up of dystric and eutric ferralsols, with a pH oscillating between 4.5 and 6.5. (Perraud 1971). The chemical fertility of the soils is low to average, with deficiencies in phosphorus and potassium, with regard to the requirements of the cocoa tree (Assiri et al., 2016).

figure1: Geographical location of Côte d'Ivoire

MATERIAL AND METHODS

Source of data

The information required for the study is essentially of a soil, climatic and socio-demographic nature. The soil data are those of the World Harmonized Database version 1.2 of the FAO (https://www.fao.org/soils-portal/soil-survey/cartes-histoires-et-bases-de-donnees-des-sols/base-harmonisee-mondiale-de-donnees-sur-les-sols- version-12/en). The socio-economic data used for the drafting of this document come from the report of the Census of Farmers and Farms 2015/2016 of the Ministry of State Ministry of Agriculture and Rural Development (MEMINADER). Climate projections for 2050 for the selected indicators will be collected through the following sources:

- https://climateknowledgeportal.worldbank.org/;
- https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/#nodes/observed-cmip5?folder_id=33&extent=100135;
- http://iridl.ldeo.columbia.edu/

Description of variables

- **Soil variables**

The pedological variables used are those which are of interest on the one hand for the estimation of the useful water reserve and on the other hand for the growth of the plants. The variables needed to calculate the useful water reserve are: the apparent density of the soil (Da), the percentage of coarse elements (Eg), the root depth (RAC), the field capacity (Hsc) and the point of wilting (Hpf).

The parameters of interest for plant growth are: pH (H2O), organic carbon ((CO)(%)), cation exchange capacity (CEC (cmol/kg)) and salinity ((ECe) (dS/m)).

- **Socio-demographic variables**

The socio-demographic variables used in this study are the rural population density (DPR), the percentage of male household heads by locality (SEXE), the average land area owned by households by locality (SUP_POS), the average family labor force per locality (MOF) and the average yield of the cocoa grove (RVC) per region.

- **Climatic variables**

Temperatures (T) and precipitation (P) are the climate variables used to assess the impact of climate change. The climatic data considered in this study are those of the rainy seasons (average temperatures and average annual precipitation). The reference period covers the period 1981-2016.

METHODS

Evaluation of the water reserve

The useful water reserve or useful reserve of the soil and is defined as the quantity of water retained by a certain volume of soil between its limiting characteristic humidity values corresponding to its states of "field capacity (pF ≈ 2.5)" and "withering point (pF ≈ 4.2)"(Baize 2000). To facilitate its integration into the estimation of a water balance, the useful reserve is expressed in millimetres, just like precipitation and evapotranspiration. It must therefore be perceived as a layer of water for a given soil thickness and its calculation generally follows the formulation presented in equations 1 and 2 (Baize 2000, Quentin et al., 2001):

$$RU_{sol} = \sum_{i=1}^{n} RU_{horizon\ (i)} \quad (1)$$

$$RU_{sol} = (Hcc - Hpf) * Da * Ep * (1 - Eg) \quad (2)$$

ù RU is the useful reserve (mm), Hcc and Hpf the weight humidity at the field capacity and at the wilting point (g.(100.g)-1), Ep the thickness of the horizon considered (dm) , Da the apparent density (g.cm-3) and Tc the coarse element loading rate (%).

- **Choice of scenarios for climate modeling**

For future climate simulations by 2050, there are several scenarios from the special report of the Intergovernmental Panel on Climate Change (IPCC). The Representative Concentration Pathways radiative scenarios version 4.5 (RCP 4.5) and 8.5 (RCP 8.5) have been retained to estimate future precipitation and temperatures, in particular the 2050 horizon, for comparison purposes.

- **Design of the annual production prediction model**

Multiple regression models were used to determine agricultural production to 2050. Indeed, these multiple linear regressions are used to determine the most satisfactory linear relationship to predict the dependent value that produces the least standard error big (Kouassi et al., 2017). In such a model, each independent variable is weighted so that the value of the regression coefficients maximizes the influence of each variable in the final equation. Multiple regression is a variant of the simple regression method that can help deal with collinearity by iteratively choosing the variables with the greatest explanatory value(Kouassi et al., 2017). In a multiple linear regression, the equation is of the following form:

$$Y = C_1X_1 + C_2X_2 + C_3X_3 + \cdots + C_NX_N + C_0 \quad (3)$$

Y: explained variable;
Xi: explanatory variable;
C0: constant; Ci (1≤i≤N): weighting coefficients of the explanatory variable Xi
In other words, Y is a vector of observed values of the production of the crop considered, Xi is a matrix of independent or explanatory variables (hazard, exposure, and vulnerability), Ci is a vector of parameters or regression coefficients to estimate, and C0 is a vector of residuals or random perturbations. Linear regression estimates the vector Ci as the least squares solution:

$$C_i = \left(X_i^T X_i\right)^{-1} X_i^T Y \quad (4)$$

with XT the transpose of X.

- **Wedging of the different models**

The calibration of the models was based on the principle of the "split-sample test" which consists of calibration on two-thirds (2/3) of the sample of available data and validation on the third (1/3) remaining. Thus, the calibration of the models was carried out on a sample of 21 regions and the validation on a sample of 11 regions. The calibration was carried out automatically with the XLSTAT 2015.4.01 software. The estimation of the weighting coefficients of the selected variables was carried out by automatic calibration with the XLSTAT 2015.4.01 software. It consisted in adjusting the numerical values attributed to the parameters of the models to best reproduce the response observed.

In the presentation of the calibration results, it is important to associate each of the regression coefficients with the associated standard error, which is an indicator that can be likened to the standard deviation. Indeed, the standard error is to the regression coefficient what the standard deviation is to the mean of a variable. It therefore consists of a measure of the variability of the regression coefficient. Thus, if several regressions were carried out on as many sub-samples drawn from the same main sample, the value of the regression parameters thus obtained would differ from one time to another. The robustness of a given coefficient will be all the greater when its variation around the most probable value, ie the coefficient itself, is small. This is precisely what the standard error of the coefficient measures.

- **Assessment of the quality of the various models developed**

The performance of the models was evaluated using numerical and graphical criteria. The analysis of the simulation results is focused on the performance of the models in the calibration phase and in validation. Indeed, the calibration performances are less revealing of the real simulation capacities of the models (Kouassi et al., 2017). These are best expressed by validation. To evaluate the performance of the models developed in this study, the criteria used are the correlation coefficient and the Nash criterion (Nash and Sutcliffe 1970). The expression for the correlation coefficient is as follows:

$$R = \frac{\sum_i (P_i - \overline{P}) * (P'_i - \overline{P'})}{\sqrt{\sum_i (P_i - \overline{P})^2 * \sum_i (P'_i - \overline{P'})^2}} \quad (5)$$

with :
Pi: Measured production (ton);
P'i: Simulated production (ton);
$\overline{P}$: Average production measured (tonne)
$\overline{P'}$: Average of simulated productions (ton)

To determine the quality of any model, Nash-Sutcliffe (1970) proposed a criterion:

$$\text{Nash} - \text{Sutcliffe} = 100 \times \left(1 - \frac{\sum_{i=1}^{n}(P_i - P'_i)^2}{\sum_{i=1}^{n}\left(P_i - \overline{P}\right)^2}\right) \quad (6)$$

Pi: Measured production (ton);
P'i: Simulated production (ton);
$\overline{P}$: Average production measured (tonne)
The Nash-Sutcliffe criterion measures the performance of the model relative to a model that would use the mean value as the simulated value. The Nash-Sutcliffe criterion varies between -∞ and 100%. The model is considered efficient when the estimated productions are close to 100%.
To assess the quality of the simulation, Kachroo (Kachroo 1986, Perrin et al., 2003) gave the following scale for the values taken by the Nash criterion:

- Nash-Sutcliffe,≥90%, the model is excellent;
- Nash-Sutcliffe between 80% and 90%, the model is very good;
- Nash-Sutcliffe between 60% and 80%, the model is good;
- Nash-Sutcliffe < 60%, the model is bad.

- **Robustness of the different models**

In this study, the robustness is evaluated by making the difference between the Nash values obtained in calibration and in validation (Klemeš 1986):

$$R' = R_{validation} - R_{calage} \quad (7)$$

The model is considered robust if the value of the robustness criterion varies between -10 and +10% (Kouassi 2016).

- **Sociological data**

The sociological aspect considered in the context of this study is that related to the analysis of perceptions (behavior, attitude, and practice). If we start on the basis that the individual or community actions taken around a phenomenon reflect the meaning that we give to this thing, it is necessary to understand the meaning that the actors have of climate change even before to determine the link they make with their production or other indicators of social well-being.

- **Statistical analysis**

The Ascending Hierarchical Classification (AHC) made it possible to group together administrative regions with a profile of similar soil physical characteristics. This operation, carried out using the XLSTAT 2015.4.01 software, made it possible to link each region to a segment. This analysis was supplemented by the parallel coordinate graph in order to calculate the descriptive statistics for each segment, again using the XLSTAT 2015.4.01 software.

- **Regional spatialization of water reserves and yields**

The spatialization was carried out using kriging which is a geostatistical modeling technique allowing, from scattered data, to obtain a homogeneous representation of the information studied (Hennequi 2010). In soil, demographic, climatic and yield analysis, the data available is limited and the number of measurement points is reduced. Kriging will therefore make it possible, using the observed values, to generate the values outside the observation point. It will then be possible to create a map extending the surveys to any part of the Ivorian territory. Other geostatistical techniques allow this work to be carried out, but kriging has the advantage of taking into account the distances between the data (ie the measurement points), the distances between the data and the target, i.e. the point for which the measure will be estimated and the spatial structure thanks to the cartographic analysis (Hennequi 2010). The main tool allowing this analysis is the semi-variogram which describes the evolution of the semi-variance as a function of the distance between the measurements and thus makes it possible to study the spatial link between the data. It is defined as follows:

$$\gamma(h) = \frac{1}{2}Var[Z(s+h) - Z(s)] \quad \forall s \in D$$

In this formula, Z(.) is the regionalized variable studied, s designates the vector of coordinates, h the distance vector and D indicates the geographical domain considered. To apply this type of kriging interpolation, ESRI©'s ArcGIS© 9.2 software was used.

RESULTS

- **Spatio-temporal evolution of the average temperature**

The mapping of the average temperature over the period 1981-2016 shows a West-East gradient, with minima (24.96 to 25.48°C) along the Guinean mountain ridge and maxima (26.91 to 27. 44° C) on the entire eastern facade. The observation of the projections for the 2050 horizon is interesting because it provides visual proof of a net increase in temperature over the whole territory. The West-East gradient is no longer marked and tends to move in the North-South direction.). Compared to the reference period (1981-2016), the maximum values of average daily temperatures could increase by +0.5 to +1°C and by +0.5 to +1.5°C respectively according to the RCP 4.5 scenarios and CIMP5 Ensemble Modeling RCP 8.5. The temperature difference between the RCP4.5 and RCP8 scenarios. 5 is quite clear because the values obtained by the rcp8.5 scenario are greater than those resulting from the RCP 4.5. This difference is of the order of 0.5°C.

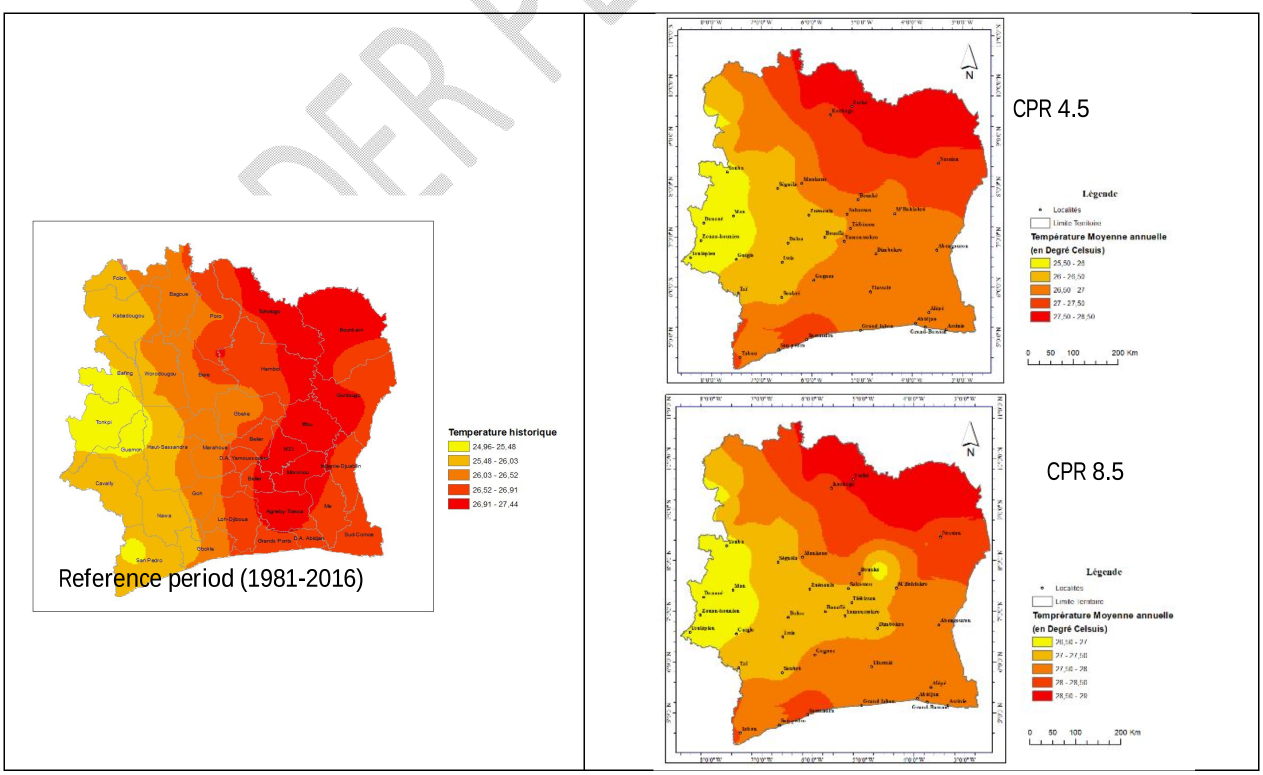

figure2: Average temperatures, during the period 1981-2016 and by 2050

- **Spatio-temporal evolution of average annual rainfall**

Figure 3 spatializes average annual rainfall. The period 1981-2016 is marked by an annual rainfall between 1050 and 2205 mm following a North-East / South-West gradient. The average annual precipitation volume is therefore everywhere greater than 1,000 mm, with even much higher average annual maxima (> 2,000 mm) along the Guinean mountainous ridge and near the coast, particularly in the San-Pedro region.

This situation contrasts considerably with what is observed later on the 2050 horizon where most stations record lower levels of precipitation. Indeed, initially confined to the northeast quarter, the precipitation zone below 1100 mm now reaches certain areas of the coast, in particular the strip from Aboisso to Sassandra. All of the stations in the Centre, including the stations of Bouaflé, Séguela, Gagnoa, Yamoussoukro, Tiassalé, Dimbokro, Bouaké, Abengourou will be immersed in the precipitation zone of around 1200 mm/year. It's around along the Guinean mountainous ridge that the situation is the most analgesic because henceforth, the annual rains there generally remain between 1390 and 1570 mm/year.

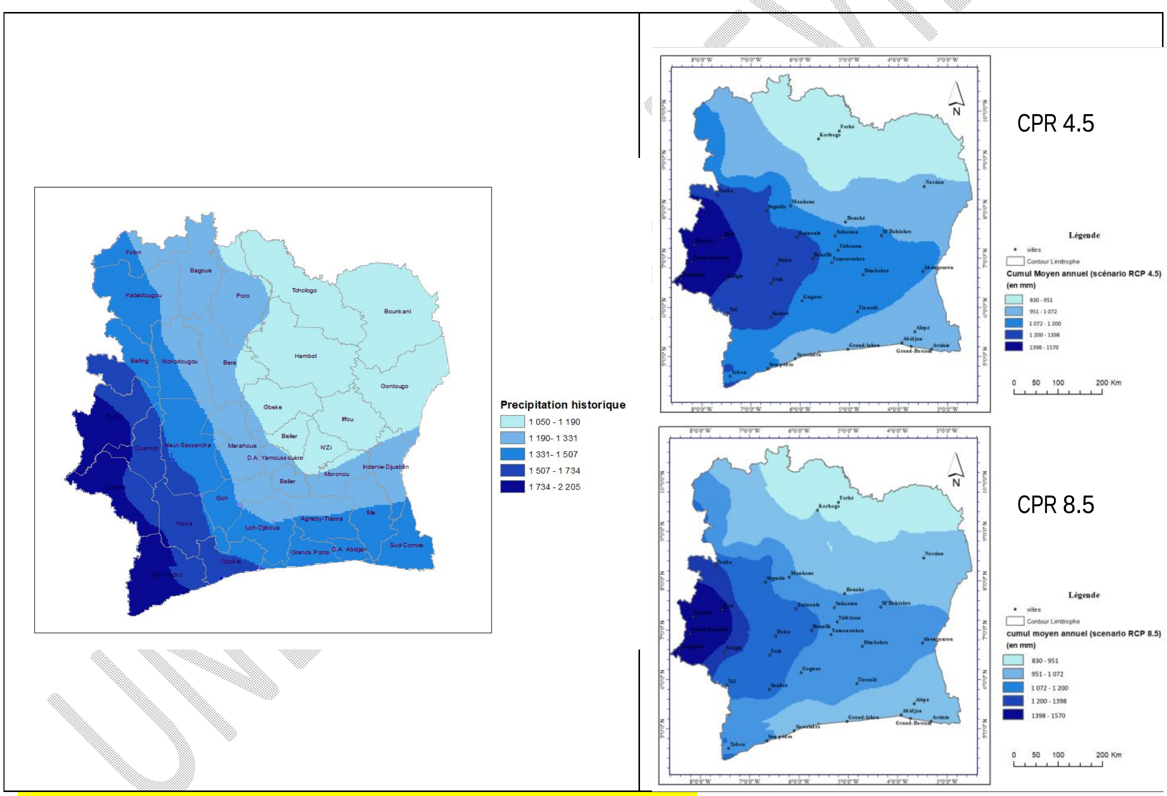

figure3: Average annual rainfall, during the period 1981-2016 and by 2050

- **Spatialization of the water reserve**

The analysis of the physical parameters reveals three classes of soil which refer to different textures (figure 4). Class 1 brings together nineteen regions, i.e. 58% of the soils studied. It includes the following regions: Agneby-Tiassa, Bafing, Béré, Bounkani, Cavally, DaAbidjan, Folon, Gbêkê, Gontougo, Hambol, Haut-Sassandra, Iffou, Kabadougou, Lôh-Djiboua, Mé, Moronou, Nawa, N'zi, Sud-Comoé. The third class includes 27% of the regions: Belier, DAYamoussoukro, Gboklé, Gôh, Grands-Ponts, Guémon, Indenié-Djuablin, San-Pedro and Tonkpi. The second class brings together the five remaining regions, i.e. 15%: Bagoué, Marahoué, Poro, Tchologo and Worodougou.

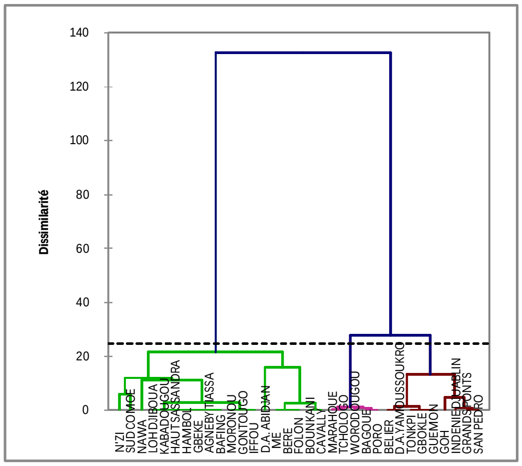

figure4: Dendrogram for soil classification

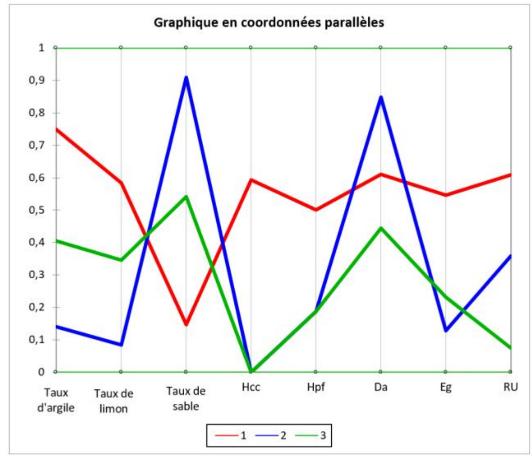

Figure 5: Graph in parallel coordinates associated with the dendrogram

Classes 2 and 3 are quite close in the graph in parallel coordinates (figure 5) and in fact, they contain clay, sand and silt rates on the one hand and field capacity values (Hsc) and wilting point (Hpf) relatively similar. These two classes belong to the “Sandy-Clay-Silty” soil category because they contain a high level of sand which varies between 48% and 68%. The Hcc and Hpf are very low and are respectively at 27% and 17%. What distinguishes these two classes are the rate of silt, the apparent density (Da) and the rate of coarse elements (Eg). The silt content of class 2 is between 9% and 12% against 9% and 24% for class 3. The apparent density is set between 1.48 kg/dm3 and 1.60 kg/dm3 for class 2 against 1.3 kg/dm3 and 1.4 kg/dm3 for class 3. The rate of coarse elements is between 4% and 10% for class 2 and between 5% and 19% for class 3. The first class has the particularity of being rich in clay (between 21% and 41%), rich in silt (between 20% and 35%) and relatively poor in sand (between 36% and 41%). These proportions of clay, silt and sand make it possible to classify it in the group of clay-loam soil. Its Hsc and Hpf are very high and its average respectively between 36% and 41% and between 14% and 22%. of silt and sand make it possible to classify it in the clay-loamy soil group. Its Hsc and Hpf are very high and its average respectively between 36% and 41% and between 14% and 22%. of silt and sand make it possible to classify it in the clay-loamy soil group. Its Hsc and Hpf are very high and its average respectively between 36% and 41% and between 14% and 22%.

The results of the spatialization of the water reserve of the Main Soil Types highlight five major regional trends (figure 7). Categories A and B include areas with a RU between 125 mm and 154 mm. It concerns the following regions: Agneby-Tiassa, Bafing, Béré, Bounkani, Cavally, Da Abidjan, Folon, Gbêkê, Gontougo, Hambol, Haut-Sassandra, Iffou, worodougou, Lôh-Djiboua, Mé, Moronou. Regions belonging to category C contain soils with a RU of between 108 mm and 125 mm. These are the regions of Bagoué, Marahoué, Poro, Tchologo, N'Zi Coméo and Sud-Comoé. Category Dregisters people on soils with low RU (less than 108 mm). It includes regions such as Belier, DA Yamoussoukro, Gboklé, Gôh, San-Pedron, Indénie-Djuablin and Tonkpi.

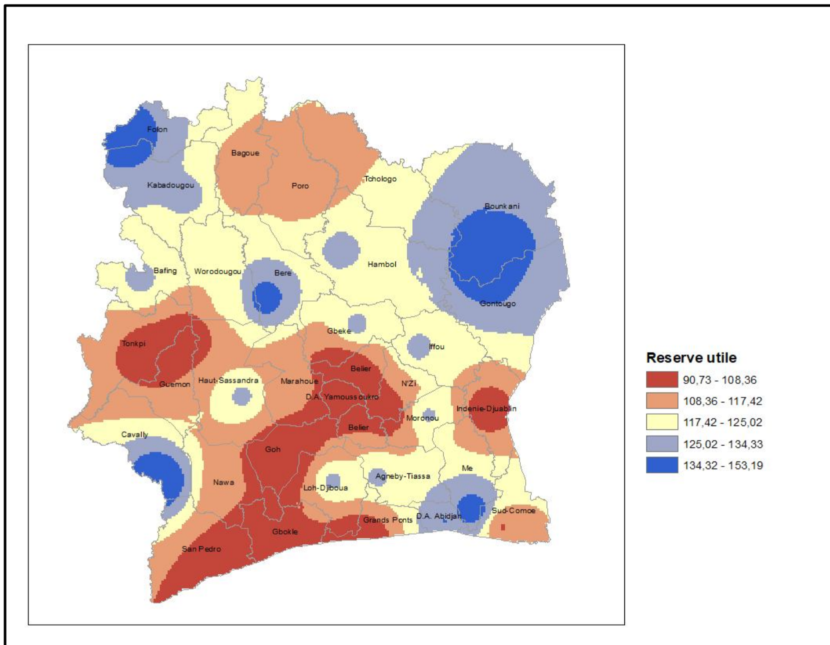

Figure6: Spatial distribution of the Useful Water Reserve (RU)

Production forecasting model

According to the descriptive analysis, all the parameters studied are homogeneous, except production and population. Indeed, according to Table 1, the administrative regions have cocoa production values that fluctuate between 5854 and 198945 tons with an average of 70198 ± 68144 tons. The yield varies between 0.30 And 0.75 t/ha with an average of 0.61 t/ha. Average annual rainfall is between1065 And 1779 mm with an average of1389mm. The useful water reserve is between90.72And149.52with an average of113.11mm. The soils are acidic with pH values ranging from4.80To5.70and an average of4.99±0.21. This demonstrates the acidity of the soils studied.

The coefficient of variation (CV) of the dependent variable (production) is 97.08%, which reflects a large dispersion of values around the mean. Moreover, the coefficients of variation of the explanatory variables are greater than 10%, in the sense of temperature and pH, whose CVs are respectively 3.85% and 4.26% (Table 1). It therefore emerges that the series of data concerning the temperature and the pH are homogeneous and the other series are heterogeneous.

Table 1: Descriptive statistics of the variables

Variable	Minimum	Maximum	Mean	Standard deviation	resume
Yield (t)	585	198945	70198	68144	97.07
Average precipitation (mm)	1065	1779	1389	221	15.88
Temperature (°C)	27,569	32,207	30,446	1,171	3.85
RU (mm)	90.72	149.52	113.11	17.04	15.06
pH	4.80	5.70	4.99	0.21	4.26
Organic Carbon	0.11	0.41	0.35	0.07	19.84
CEC	2.00	8.00	5.33	1.20	22.57
Rural population	7720	122692	53621	31120	58.04
Access to Crédit Agricole (%)	0.04	0.27	0.19	0.06	29.80
Cooperative and Informal Grouping	0.14	0.61	0.39	0.13	33.88
Household Size	5.00	10.40	6.76	1.02	15.02

Access to improved seeds	0.08	0.53	0.25		0.08	33.48

The production prediction model is significant at the 0.0001 level (Table 2). The values of the normalized coefficients make it possible to compare the relative weight of the variables that make up the model: 31% of production is explained by the cation exchange capacity (CEC), 19% by the pH, 9% for access to seeds improved and the constant, 8% for organic carbon, 7% for useful water reserve, 6% for household size and 4% for precipitation. The remaining variables have minor weights that are less than or equal to 2% (Table 2). The coefficient of variation of the model is 96.83%. The equation obtained from the regression coefficients is as follows:

$$Prod = 544620 + 76{,}15817 * \mathrm{PM} - 6100 * \mathrm{TM} - 194{,}55452 * \mathrm{RU} - 52496 * \mathrm{pH} - 684448 * \mathrm{C.Org} + 12770 * \mathrm{CEC} + 1{,}95065 * \mathrm{Pop} - 59878 * \mathrm{TCA} - 13047 * \mathrm{CGI} + 2477 * \mathrm{TMen} - 123603 * \mathrm{AS}$$

With :

P. Avg. (Average annual precipitation in mm); TM (Average temperature in °C); RU (useful reserve in mm); pH (Hydrogen potential); C.Org (Organic Carbon); CEC (Cation Exchange Capacity); Pop (rural population); TCA (Rate of farmers with access to agricultural credit); CGI (Rate of farmers belonging to a cooperative or an informal group); TMen (average household size); AS (Rate of farmers with access to improved seeds).

Table 2: Model parameters

Explanatory variables	Regression coefficient	Standard deviation	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)	Normality coefficient	standard error
Constant	544620	550360	0.990	0.368	-870126.13	1959365.85	0.256	0.213
Average precipitation (mm)	76	63	1,204	0.283	-86.51	238.82	-0.109	0.272
Temperature (°C)	-6100	15262	-0.400	0.706	-45332.29	33133.18	-0.057	0.248
RU (mm)	-195	849	-0.229	0.828	-2375.76	1986.65	-0.187	0.382
pH	-52496	106972	-0.491	0.644	-327477.06	222484.70	-0.525	0.403
Organic Carbon	-684448	525030	-1.304	0.249	-2034082.14	665185.26	0.230	0.259
CEC	12770	14359	0.889	0.415	-24140.36	49679.62	0.844	0.154
Rural population	2	0	5,473	0.003	1.03	2.87	-0.046	0.189
Access to Crédit Agricole (%)	-59878	249345	-0.240	0.820	-700839.19	581083.21	-0.026	0.160
Cooperative and Informal Grouping	-13047	80758	-0.162	0.878	-220642.48	194548.07	0.042	0.204
Household Size	2477	12163	0.204	0.847	-28787.97	33742.45	-0.167	0.317
Access to improved seeds	-123603	235200	-0.526	0.622	-728204.90	480999.02	0.256	0.213

- **Performance of the annual agricultural production simulation model**

The analysis of the performance results obtained (Table 3) shows that in calibration, the models recorded very high performance rates at the level of the two criteria. Indeed, the correlation coefficients between the observed annual production values and those simulated oscillate between90.04% and 97.00%. As for the Nash-Sutcliffe criteria, they are excellent with values between81.17% and 86.64%. In validation, the performances recorded show correlation coefficients varying from84.11% to 89.49%and a Nash-Sutcliffe swinging between80.75% and 90.04%. Thus, the values of the robustness criterion evaluated (Table 3) fall within the interval [-4.94%; 8.24%°] with the correlation coefficient and [-5.59%; 0.81%] with the Nash-Sutcliffe. These different results obtained indicate the performance and robustness of the model.

Table 3: Performance and robustness of the electrical conductivity model

Crops	Criteria	wedging	Validation	Robustness criterion (%)
Cocoa	Correlation (%)	97.00%	90.04%	-2.01%
	Nash–Sutcliffe (%)	86.64%	81.17%	-5.47%

Spatio-temporal evolution of production

Table 2 shows that the sign of the relative change in production between the present and the future is in most cases negative with a decline in production nationwide in the range of 12-18% from the present. . These figures are nevertheless subject to considerable uncertainty, since the production distributions are very spread out and vary from -40% to +80% depending on the case. In effect, current cocoa production is estimated at around 1,700,000tons. The main production areas are located in the South-West regions: Nawa (198,945 tons), Haut Sassandra (196,542 tons), Guemon (166,620 tons), San-pedro (153,606 tons), Marahoué (147,005 tons), Tonkpi (138,017 tons), Goh (134,497 tons), Me (111,238 tons), Cavally (102,174 tons) (figure 6). The RCP 4.5 and RCP 8.5 scenarios foresee respective productionsof1377563 tons and1498015 tonsby 2050. The areas of high future production will be the following regions: Nawa, Haut Sassandra, Guemon, San Pedro, Marahoué, Tonkpi, Goh, Mé and Cavally. The regions of Gbokle, Indenie djuablin, Agneby tiassa, Loh djiboua, Moronou and Sud Comoé and the Grands Ponts would become marginal.

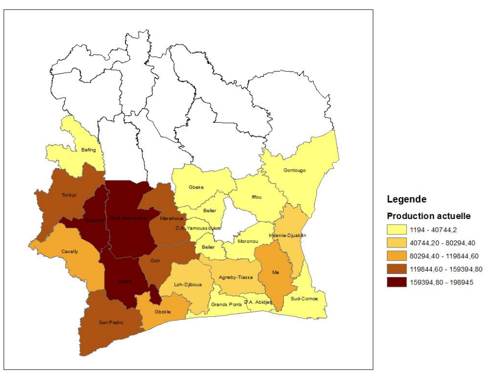

Figure7: Spatial distribution of cocoa production in 2016

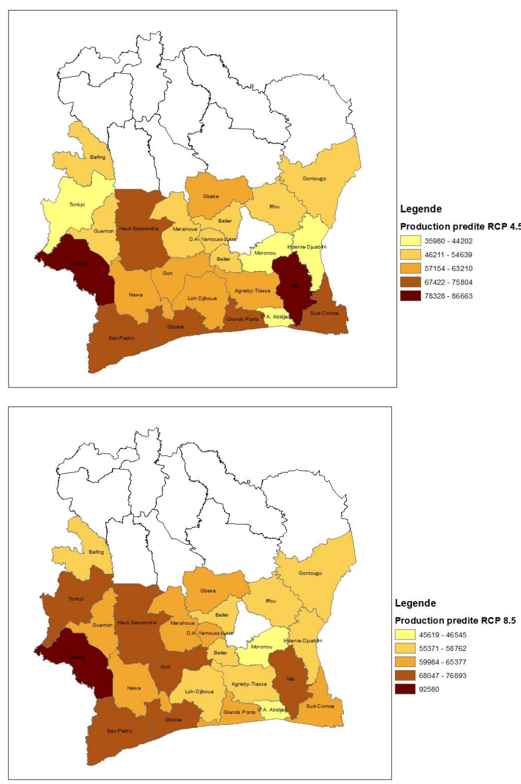

Figure8: Spatial distribution of cocoa production by 2050

DISCUSSION

- **Spatio-temporal trends in precipitation and temperature**

The results of the present study predict a decrease in rainfall in most regions of Côte d'Ivoire by 2050. This observation is consistent with the values found by Djè (Ministère de l'Environnement de la Salubrité Urbaine et du Développement Durable 2014), showing an 8% daily decrease in rainfall during the April to July season for the next hundred years. However, the projections made by P. Roudier (Roudier 2012), IPCC (GIEC 2013)and Panthou (Panthou 2013)in West Africa sustain increasing rainfall trends over the 2031-2050 periods. This is proof that there is no scientific consensus. However, it should be remembered that these discrepancies could find their explanations in the models used. However, some recent studies (Biasutti and Sobel 2009, Patricola and Cook 2010, Monerie et al., 2012, Biasutti 2013)found a robust signal between the different models of CMIP3 and CMIP5 which attests to a delay in the monsoon west of the Sahel. This opposition in terms of the evolution of rainfall is not found for temperatures. Indeed, the trend of the evolution of the temperature observed in Côte d'Ivoire revealed by our results, gives an increase of +1°C and +1.5°C by 2050, respectively according to the RCP 4.5 scenarios and CIMP5 Ensemble Modeling RCP 8.5. These results support previous work (Roudier 2012, Danumah 2016, Yapi et al., 2020, Kpan et al., 2021). Indeed, the use of LARS-WG also allowed OGA et al (2016) and DANUMAH (2016) to predict respectively a temperature rise of 0.32 to 1.36°C around 2050 in the Southeast coast of Ivory Coast. However, our results are slightly weak compared to the overall context of global climate predictions (OECD, 2008; IPCC, 2013). The increase of +1 to +1.5°C in temperature in Côte d'Ivoire by 2050 is included in the range of temperature increases (1.7-2.4°C) determined by the Organization for Economic Co-operation and Development (OECD, 2008). It is almost similar to the thermal increase (1.1°C) by 2050 predicted in Benin (Boko et al., 2012).

- **Advantages of the spatialization of the water reserve**

This study has highlighted a high spatial variability of soil water available to plants, called "useful reserve" (RU). On the scale of the administrative regions, the lowest value of the RU obtained of 91 mm/m and the highest of 150 mm/m. Two fundamental factors explain these differences. The first parameter influencing RU is soil texture. Indeed, at equal thickness, silty soils will present the highest water reserves and the weakest sandy soils (Vauthier 2011). The RU of a clay soil horizon is around 1.7 mm/cm of soil, that of a clay-loam soil horizon is around 2 mm/cm of soil and that of a sandy soil of the order of 0.7 mm/cm of soil (Chambre d'Agriculture 2017). The results of the particle size analysis show that on the Ivorian territory, the soils with the highest RU values (150 mm/m) have a clayey-loamy texture. These soils are particularly present in the North/East quarter, the North/West, a few localities in the Centre, the Cavally region and the strip extending from the District of Abidjan to the Mé. The second factor explaining this variability of the RU is the quantity and the nature of the coarse elements present in the soil. the percentage of coarse elements must be deducted from the RU because they do not store water (Chambre d'Agriculture 2017). This can be observed particularly well on the entire west-mountainous facade where the soils have a clayey-sandy texture and low RUs due to the presence of numerous fragments of altered rock (Dabin et al., 1960). The third factor influencing the RU is the thickness of the soils (Ridremont et al., 2012). This influence of soil depth is observed in the corridor going from San-Pedro to Yamoussoukro passing through the regions of Gboklé, Nawa, Goh, Belier and Marahoué. In these localities, the O horizon at 25 cm is sandy-loamy, slightly gravelly (ferruginous gravel). Beyond 25 cm, brown, silty-clayey horizon is rich in ferruginous gravel and some quartz grains. However, the thickness of the soil very reduced, between 70 and 90 cm and the granite very weathered, but forms a compact mass, difficult to penetrate to the roots, begins at 90 cm deep (Aubert and Moullnler 1954). The observed taproots are clearly stopped between 90 and 95 cm (Aubert and Moullnler 1954). The information revealed by the present spatialization of the reserve of useful water in the soil should lead to a better perception of the vulnerability of cocoa farming to water stress and to more precise management recommendations regarding the choice of crop establishment sites.

- **Spatio-temporal evolution of production**

Production modeling based on the physical characteristics of the soil, climatic and demographic data was carried out. The analysis of the input and output parameters of the model showed that there is a good correlation (0.90-0.97) between the production and the parameters studied. However, the main results showed that the input parameters are not correlated with each other, which would therefore avoid the collinearity effect (Kouassi et al., 2012). The values of the regression coefficients of the variables are homogeneous. These results obtained reflect close relationships between the explained variable (production) and the explanatory variables (Precipitation, temperature, RU, pH, organic carbon, CEC, population size, Access to Agricultural Credit, membership of the farmer in a cooperative and a group Informal, average household size and access to seeds improved).

In validation, the performances recorded were greater than 80%. Thus, the values of the robustness criterion evaluated are -2.01% with the correlation coefficient and -5.47% with the Nash-Sutcliffe. In calibration as in validation, the two criteria recorded performances beyond the defined thresholds (60%). Thus, the Nash-Sutcliffe criterion, which reflects a rapprochement between the observed values and the simulated values, confirms the results of the correlation coefficient which does not always reflect a rapprochement between the observed values and the simulated values but the existence of a certain proportionality between the two series (Kouassi et al., 2017). These observations lead to the conclusion that the model developed and evaluated is efficient and robust. It is therefore able to simulate cocoa production in the Ivorian context with good reliability from the explanatory parameters retained in this study.

By analyzing the spatio-temporal evolution of cocoa production in Côte d'Ivoire, the objective was to document the situation of cocoa farming with regard to the evolution of climate change. The results have shed light on areas that may be unfavorable to cocoa production due to climate change. Indeed, by 2050, the production context should be increasingly hostile and local climatic conditions will cause production drops in several administrative regions. The main current production areas will pay the heaviest price with falls of around -40% compared to the 2016 campaign. This result is generally in line with previous agronomic studies. Previous studies (Djako 2014, Ochou 2018, Yoroba et al., 2019, Guy and Tia 2021, Kouadio et al., 2021) argue that cocoa production is harmed by climate change. The effects of soils on agricultural production are negative in all models. The general characteristics of Ivorian soils which are acidic and have a low water retention capacity aggravate this situation.

Furthermore, it would also be very important to adapt a participatory approach to involve the various actors in the management of the effects incurred. It goes without saying that to achieve this, a transdisciplinary approach must be taken. The adaptation of the communication system around the phenomenon will contribute to an effective awareness of the populations for a better adaptation. Men acting with regard to things according to the meaning they have for them (De Queiroz and Marek Ziolkovski (1994), that their behavior is therefore a function of the image they have of this And, since these meanings are changing over time, the process of interpretation involved in processing information on climate change will be both manipulated and modified according to the affiliations and beliefs of the moment.

Conclusion

This study provides an estimate of cocoa production in Côte d'Ivoire by 2050 according to the RCP 4.5 and RCP 8.5 climate scenarios. Using climatic, socio-economic and soil data, a regional production forecasting model was developed. Interestingly, the correlation coefficient analysis and the Nash criterion showed that the model is efficient and robust, therefore suitable for use in the Ivorian context. The application of the model to the two scenarios shows that in some current cocoa production areas will become unsuitable (Lagunes and Sud-Comoe in Côte d'Ivoire) due to new pedoclimatic conditions. The fall in production could be aggravated in the old cocoa loop, moreover.

This study can constitute a basis for reflection aimed at preparing emergency plans/responses specific to an administrative region to combat the drop in cocoa production associated with the change. These responses could take the form of the implementation of a precipitation forecasting system in combination with the dissemination that underlies these forecasts. The deployment of climate-smart agriculture (AIC) techniques whose adaptation potential can help increase agricultural production. Other intervention strategies such as access to agricultural credit and improved seeds, encouraging farmers to join cooperatives could also be implemented at the local level.

Strengthening existing central and state government programs through mechanisms such as diversifying off-farm activities and creating alternative and sustainable livelihood options in rural areas can also be fundamental to reducing the land pressure inherent in agriculture. current production system. In doing so, it will also address socio-economic and environmental issues that threaten the lives of people living in climate-sensitive areas and drive distress migration in response to climatic events.

Disclaimer

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