International Journal of Recent Research and Review, Vol. IX, Issue 2, June 2016
ISSN 2277 – 8322

Environments Suitable for the Species of the *Coffea*genus in Martinique
(The case of *Coffea Arabica Typica Variety*)

J.P. CLAUDE
UMR ESPACE DEV-BIORECA, University of the French West Indies, Martinique
Email: claudejeanphilippe1@gmail.com

***Abstract* -A geographic information system (GIS) was developed in Martinique, to perform soil zoning for the revival of the production of *Coffea arabica var. typica*. Pioneer in the cultivation of coffee in the Caribbean since 1720, today Martinique plays no role in the coffee industry. In addition, due to its rarity on the island, the edapho-climatic requirements of *Coffea arabica* had to be defined based on the world literature. The digital data (isohyets, isotherm, geomorphology) was obtained from Martinique's institutions with expertise in the production of environmental data (IRD, IGN, Météo-France, DEAL Martinique, CTM)[1]. These data have been processed with a SIG software: QGIS version 2.8.1. During the investigations, the rainfall represented a factor limiting any possibility of production of *Coffea arabica var. typica* in the future. By removing the pluviometry from the set of parameters, we can visualize the areas that might be acceptable to this culture. With the forecast of the National Meteorological services for the 2071-2100 period under the new climate requirements, we carried out an agro-climatic zoning which also showed us the impossibility of producing this coffee in the future.**

***Keywords* - *Martinique, Coffea arabica var. typica, edapho-climatic requirements, GIS, soil zoning, agro-climatic zoning, climate change*.**

I. INTRODUCTION

From the point of view of its geomorphology, Martinique offers a diversity of biotopes favouring the implementation of very varied ecosystems with numerous life forms, including the useful plants. They could help the economic development of the territory: it is the case of the coffee species. Among these, a variety of the most cultivated species in the world: the *Coffea arabica var. typica* [1-5], was introduced nearly 300 years ago on the island (Fig.1) and had been cultivated here before it was abandoned in the nineteenth century [6].

To revive this culture, it was necessary to identify suitable zones[2]. Therefore, soil zoning was carried out based on the edapho-climatic requirements of *Coffea arabica* as defined in the world literature [1-3], [7-18]. There are several definitions regarding crop zoning on the basis of the objectives [19]. We can summarize zoning by the delimitation of the agricultural characteristics of the regions depending on the climate, the types of soils and geomorphology to which we can add the socio-economic context. Globally, there are several types of zoning for crops. This type of study can have several objectives: launching the production of a crop in a given region based on its ecological requirements [7], [8], [11], [20-22], planning the crops and increasing the yields [23], [24] or assessing the likely effects of climate changes on these crops and their yields [14], [25-29]. However, these zonings are often approximated and in general the microclimates are not taken into account [19]. In any case, zoning requires several steps [7], [8], [19], [22], [30]: defining the ecological requirements of the species on the basis of the main physical factors; then defining the zoning database, in other words establishing the criteria for a classification of the study area in several areas ranging

[1]IRD: Institute of research for development (France) / IGN: National Geographic Institute (France) / Météo-France: French Meteorology Agency / DEAL: Directorate of planning and housing environment / CTM: the Territorial Community of Martinique.

[2] Because today there are no more coffee plantations on the island.

from optimal to unsuitable. Criteria such as the heat amplitude and rainfall as well as the soil type form the basis of zoning, as they are seen as determining zoning factors according to the world scientific literature [7], [9-11], [19], [22], [28], [29], [31]. These criteria result from the overlay of the mono-factorial extracted maps at 1: 500 000 (Temperature, rainfall, soil) [19], [22] using a GIS (geographical information system).

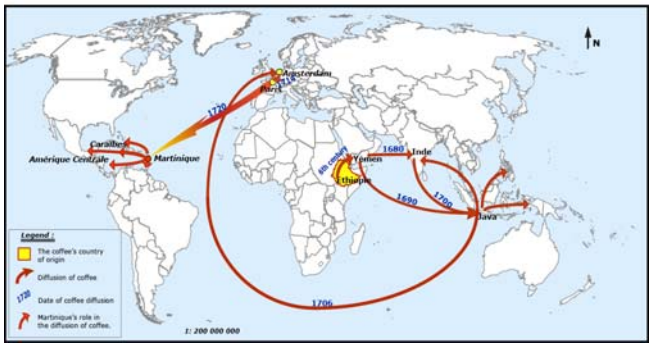

Fig.1 Dissemination of coffee Arabica from Ethiopia to Martinique.

II. MATERIALS

Coffea arabica var. typica is native to Ethiopia [32], its grains were brought to Europe, to Amsterdam by the Governor of Java in 1706, and then to Paris circa 1714. It was not until 1720 that they are introduced in Martinique by Gabriel De Clieu (1688-1774), an infantry captain, Knight and Lord of the Kingdom of France [6], [12], [17], [33].For half of the XVIIth century and in the nineteenth century, the *Arabica Var. Typica* coffeeseems to have been grown intensely in Martinique resulting in the famous "Martinique coffee" [6]. From its plantations, Martinique was also one of the redistribution places of the *ArabicaVar. Typica* coffeein the Caribbean [1], [2], [34-37] and till the 1750sit remained France's leading West Indian supplier [6]. Introduced for agricultural purposes in the past, this species is currently very rare in Martinique. As a result, its ecological profile has been described using the world's scientific literature [1-3], [7-18].

Martinique is a mountainous island with a 1128 km^{2}surface (70 km long, 30 km wide) located in the archipelago of the Lesser Antilles in the Caribbean, at 14° 40' North latitude and 61° West longitude. It is located between Dominique to the North and St. Lucie in the South and is bordered to the East by the Atlantic Ocean and to the West by the Caribbean Sea. The climate is tropical, with an annual average temperature of 26° C. This island is regularly swept by trade winds from the East. The inter-seasonal temperature variations vary by 3° C [38]. There are two main seasons: from February to March (the dry season called lent) and from July to October (the rainy season called winter). These two seasons are accompanied by shorter transitional periods with less pronounced features. The wide variety of geological formations as well as the contrasting space distribution of rainfall result in great soil diversity.

III. METHODS

A world science literature search was carried out to establish the ecological profile of *Coffea arabica*. The ecological determining factors and the selected values are presented in table I [1-3], [7-18]. Eco-climatic data which can be used in a GIS were provided by Martinique'sinstitutions competent in the production of environmental data: average minimal and maximal temperatures, annual rainfall, soils and altimetry. For example, Météo-France provided climate data for 2015 and the forecasts for 2071-2100[3][39,40] (Fig.2). The average annual temperatures are not available in the form of maps to be used in a GIS, so we used digital data of average annual minimal and maximal temperatures. Martinique's soil maps, in the form of GIS data named: "pedo_IRD_2006" were received from the IRD. DEAL and the territorial community of Martinique supplied us with orographic and administrative GIS data as well as place names. The IGN database was used for altimetry (BDALTI 25 metres from IGN, BD ORTHO® Version 2 of the IGN; 2010 ortho-photos).On the basis of these elements, we were able to set criteria to obtain a basis for zoning from optimal to unsuitable on the basis of the Arabica coffee requirements. The Qgis version

[3]Meteorological simulations named "ALADIN-CLIMAT" for the Lesser Antilles with a 10 km resolution (rainfall, maximal and minimal annual mean temperatures) and a 1km resolution for Martinique's territory.

2.8.1 software (GIS software) allowed us to process the collected data (Geographic reference: WGS_1984_UTM_20N) and to draw up thematic 1: 500, 000 maps.

TABLE I
Ecological requirements of *Coffea Arabica*

	Edapho-climatic requirements of*Coffea arabica*
Average annual temperatures	16° to 25° C with an optimal temperature of 18° to 22° C
Annual rainfall	1200 to 2400/3000 mm with an optimal quantity of 1800 to 2400 mm
Soil types	Ferrisols, Andosols, alluvial soils, Brown-rusty to Halloysite soils, Fersiallitic soils

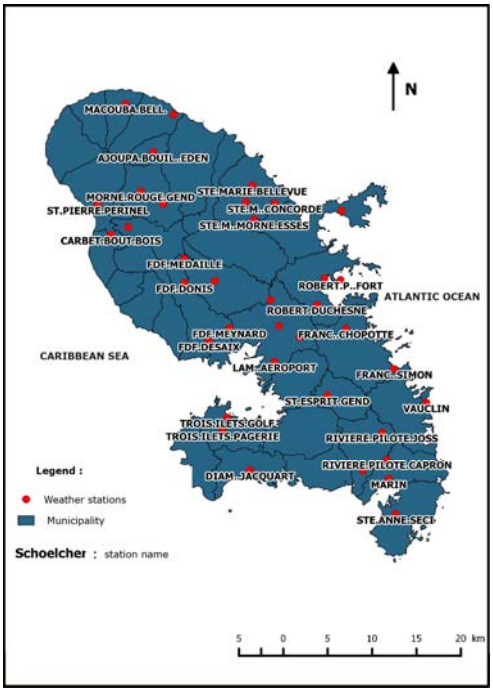

Fig.2 Weather stations in Martinique.

IV. RESULTS

A. SOIL ZONING FOR COFFEA ARABICA VAR. TYPICA (1971-2000 CLIMATE DATA AND 2006 SOIL DATA)

A1. Temperatures

In the literature, the temperatures suitable for *Coffea arabica*are average annual temperatures ranging between 16 and 25° C, therefore we had to determine the minimal and maximal annual average temperatures suitable for the biology of *Coffea arabica* (Fig. 3 &4). In reality, only the maximal temperatures have been considered since they represent the limiting factor (Fig.4). We found that the areas with average temperatures ranging between 16 °C and 25 °C [1-3], [7-18], exhibit maximal average annual temperatures reaching 28 °C. 28 °C were therefore chosen as the only criterion for zoning. Thus, several stations in the North of the Island correspond to the above mentioned elements like Fonds-Saint-Denis and Ajoupa-Bouillon (Fig.4). In these areas suitable for the *Coffea Arabica,* although the average annual temperatures range between 22 and 25 °C, the maximal average annual temperatures can reach 28/29 °C (Fig. 5 & 6). They are in fact acceptable areas for growing the Arabica. However, they are not optimal under the *Coffea Arabica* climate requirements defined in the literature [1-3], [7-18].

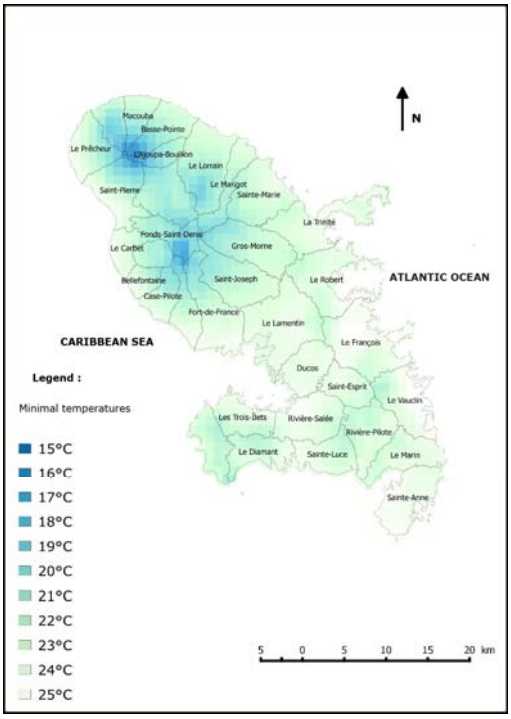

Fig.3 Average annual minimal temperatures (1971-2000normal). (Source: Météo-France)

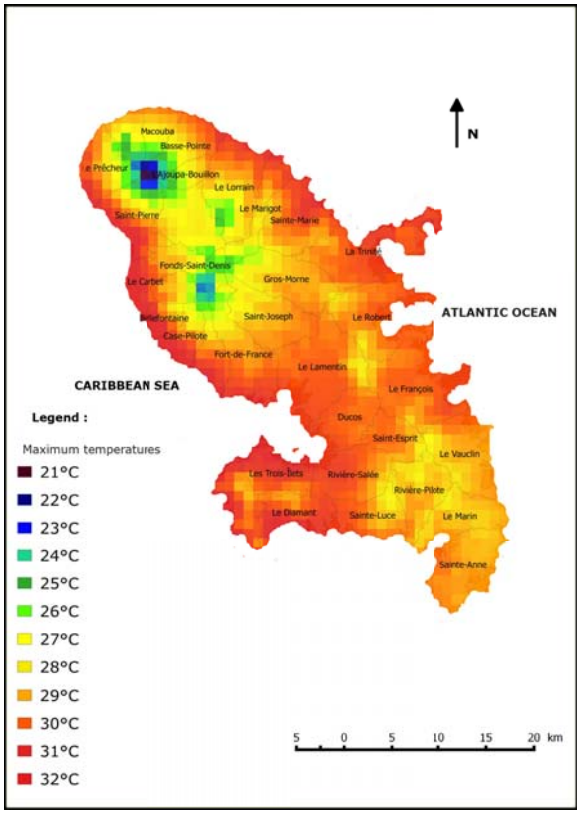

Fig.4Average annual maximal temperatures (1971-2000 normal). (Source: Météo-France)

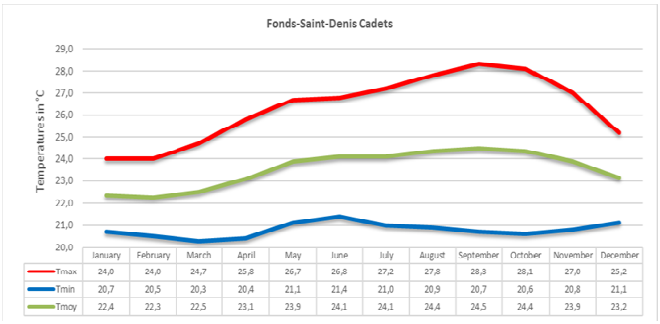

Fig.5 Annual temperatures in Fonds-Saint-Denis (normal 1971-2000). (Source: Météo-France)

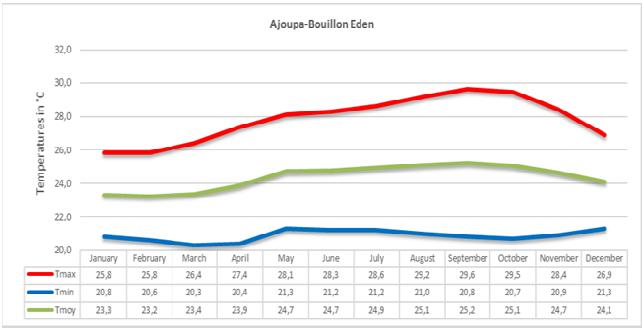

Fig.6 Annual temperatures in Ajoupa-Bouillon (normal 1971-2000). (Source: Météo-France)

A2. Rainfall and soils

The rainfall data is for 1971-2000 normal temperatures. The rainfall gradient ranging from 1200 mm to 6000 mm of water per year seems to result in more suitable areas for the Arabica coffee (Fig.7). Figure 8 shows the main types of soils in Martinique, where several seem compatible with the cultivation of Arabica coffee [7-9], [12-41].

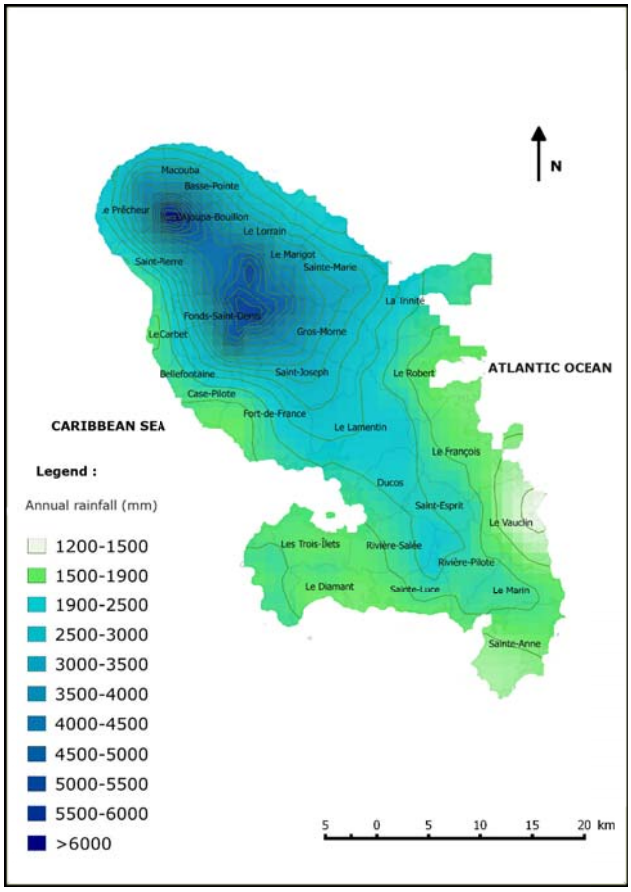

Fig.7 The rainfall canvas in Martinique. (Source: Météo-France)

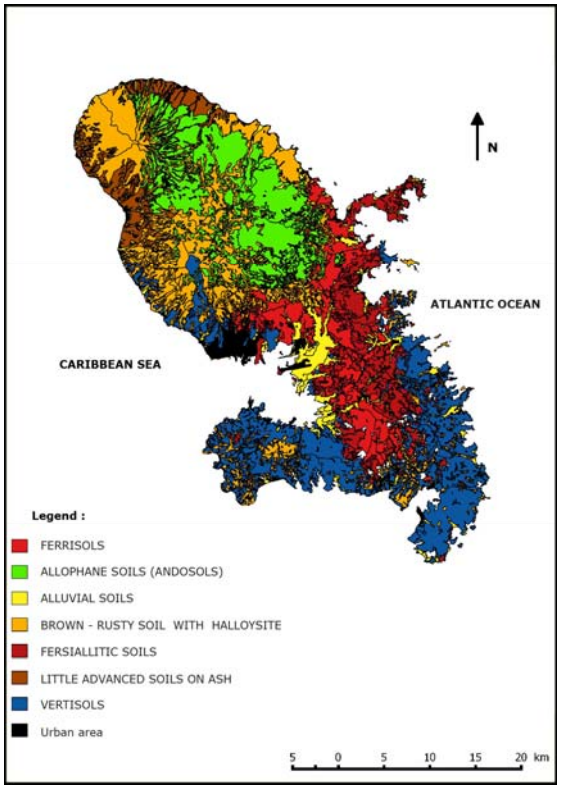

Fig.8 Map of Martinique soils. (Source: IRD).

A3. The zoning

With regard to data from the international literature, we were able to carry out the zoning by considering the following three key factors: namely, temperatures, rainfall and soils [7], [9-11], [19], [22], [28], [29], [31], (Tables 2 & 3).

TABLE II
Requirements of *Coffea arabica* in the world scientific literature

	Acceptable	**Unsuitable**
Average annual temperatures	16 ° to 25 °C with an optimum at 18 ° to 22 °C	<16 ° and >25 °C
Annual rainfall	1200 to 2400/3000 mm with an optimum of 1800 to 2400 mm	>2400/3000
Soil types	Ferrisols, Andosols, alluvium, soil brown-rust to Halloysite soils Fersiallitic soils	Little developed soils on ash, Vertisols, urban areas

TABLE III

Soil zoning database for *Coffea arabica*, according to our own criteria

	Acceptable	**Unsuitable**
Average annual maximum temperatures	<28 °C	>28 °C
Annual rainfall	1200 to 3000 mm	>3000 mm
Soil types	Ferrisols, Andosols, alluvial soils, brown-rust to Halloysite soils Fersiallitic soils	Little developed soils on ash, Vertisols, urban areas

Searches were carried out using the raster option calculator in the QGIS software [30]. To obtain the zoning we formulated the search as follows: [maximal temperatures] < 28 + [annual rainfall] < = 3000 + [soil] = 1. The soil map was the subject of a selection allowing us to retain those considered suitable soils [7-9], [12], [41]. This gave us a simplified map with two identifiers: 0 corresponding to unsuitable soil and 1 for soil suitable for cultivation, this principle facilitated the previous zoning search. Using this search we created a map which showed there is no area favourable for the cultivation of*Coffea arabica* (Figure 9). Unlike the temperature and soil, the rainfall is a very binding parameter because the rainfall quantities are too large. We wanted to achieve a zoning without precipitation to visualize any suitable areas since the drainage technologies allow us to limit the water over-saturation of damageable soils for this type of culture [18], [42]. In this case we obtain a more favourable zoning (Fig. 10 to 13).

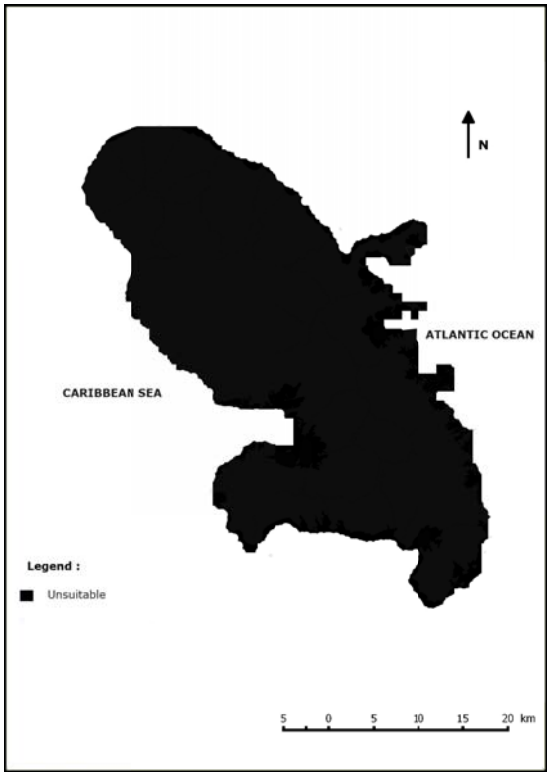

Fig.9 Soil-climate zoning [if the rainfall criterion is taken into account]

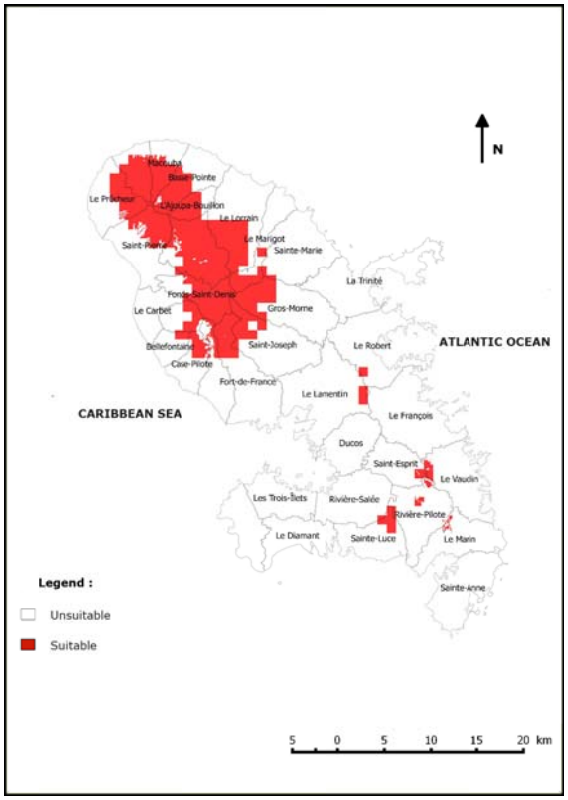

Fig.10 Soil- thermic zoning based on the maximal temperatures and soil.

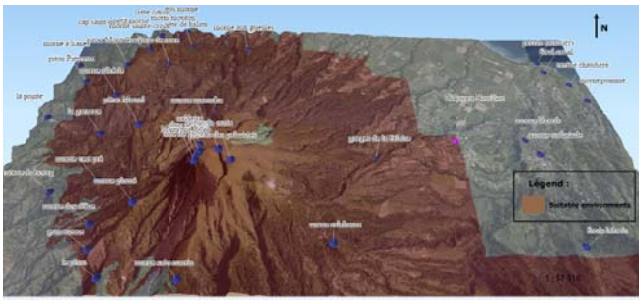

Fig.11 Model of suitable environments in the North of the island: the Pelée mountain (obtained using "Qgis2threejs" and the Ortho-photos from IGN).

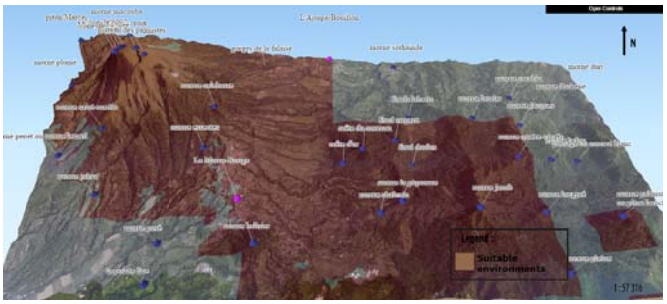

Fig.12 Model of suitable environments in the North of the island: the commune of Morne Rouge (obtained using "Qgis2threejs" and the Ortho-photos from IGN).

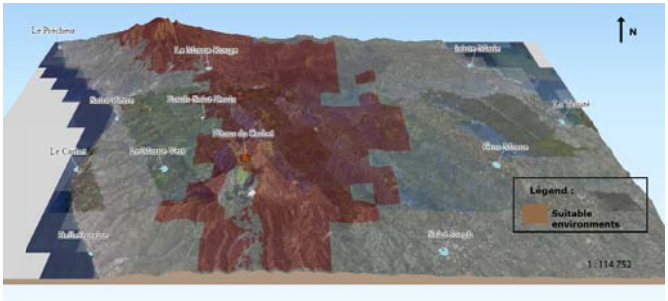

Fig.13 Model of suitable environments in the North of the island: the Pitons du Carbet (obtained using "Qgis2threejs" and the orthophotos of the IGN).

B. AGRO-CLIMATIC ZONING FOR COFFEA ARABICA IN THE 2071-2100 PERIOD

B1. Temperatures

In the absence of a map of mean annual temperatures usable in the GIS, we used only the maps for minimal

and maximal average annual temperatures (Fig. 14 &15). The requirements of Coffee arabica do not change, it was therefore necessary to determine the limits of the maximal and minimal temperatures for this zoning.

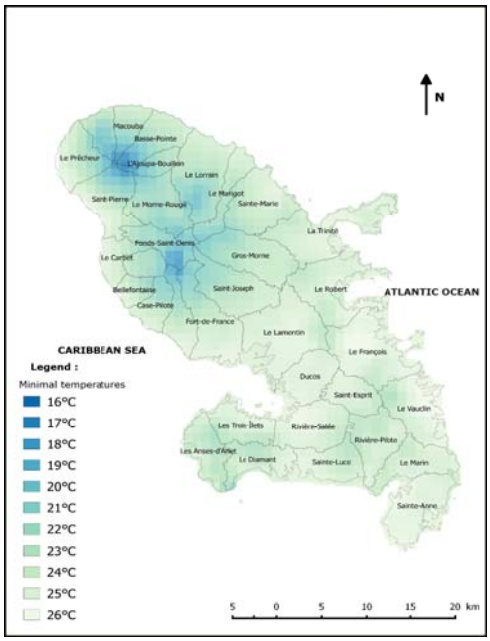

Fig.14 Average annual minimal temperatures (scenario RCP 4.5, 2071-2100). (Source: Météo-France)

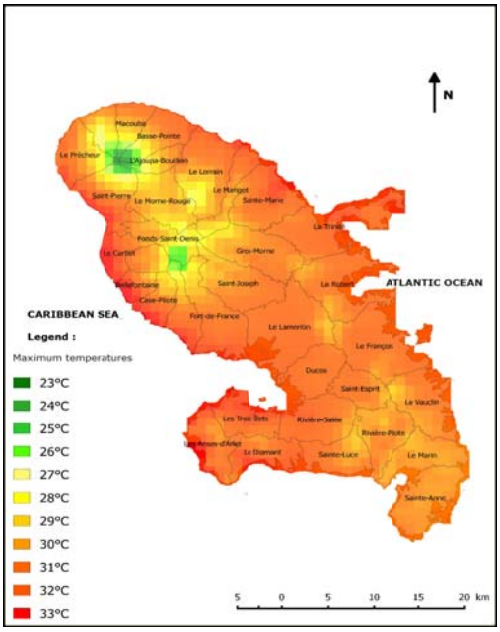

Fig.15 Annual average maximal temperatures (scenario RCP 4.5, 2071-2100). (Source: Météo -France)

According to the forecasts for 2071-2100 (Fig.15), the highest altitude areas in the north will be the only ones exhibiting maximal temperatures not exceeding 28 °C. The rest of the territory will be beyond this limit. Using the average temperatures we were able to show that the current stations suitable for coffee crops will no longer be suitable at the end of the century. This is the case of Fonds-Saint-Denis and Ajoupa-Bouillon, which will exhibit minimal and maximal temperatures up to respectively 21°C and 32°C and average temperatures between 24°C and 27 °C, which will no longer be suitable for the production of Arabica coffee (Fig. 16 & 17).

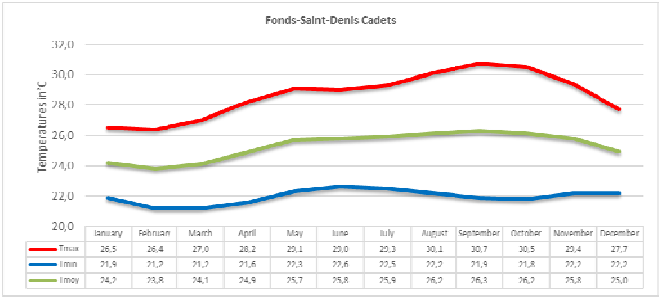

Fig.16Annual temperatures in Fonds-Saint-Denis (screenplay RCP4.5, 2071-2100). (Source: Météo-France)

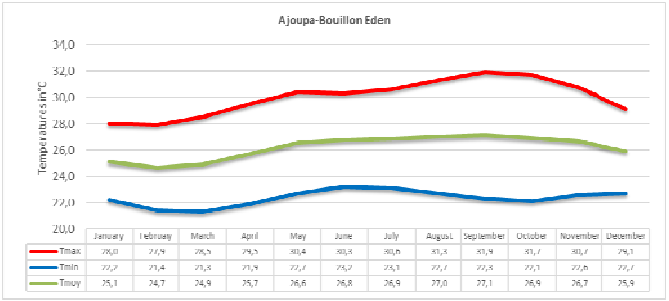

Fig.17 Annual temperatures in Ajoupa-Bouillon (scenario RCP4.5, 2071-2100). (Source: Météo-France).

The effects of climate changes which modify the boundaries of the bioclimatic floors will change the understanding of the *Coffea arabica* species. The suitable areas will be located on the island's high peaks where the maximal temperature may sometimes reach 28 °C, however the annual average temperatures would be lower. Thus, the limit of 28 °C for maximum temperatures has therefore been considered a reliable and justified limit for this agro-climatic zoning.

However, the minimal temperatures are not determinative, since there will range between 16 °C and 26 °C (Fig.14), [1-3], [7-18]. Essentially only the maximal annual average temperatures are discriminatory.

B2. The rainfall

The forecasts for the 2071-2100 rainfall indicate an annual precipitation gradient from the coast to the highest peaks ranging from 1500 mm to more than 5000mm. This future forecast rainfall range appears to create sufficient suitable areas for the Arabica coffee (Fig.18).

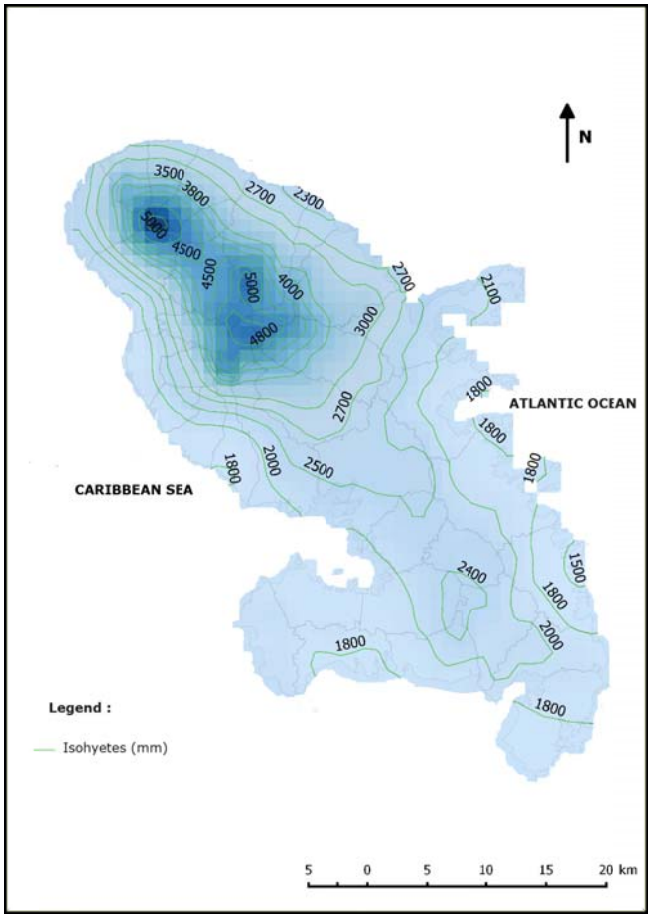

Fig.18 Annual rainfall (scenario RCP 4.5, 2071-2100). (Source: Météo-France).

B3. The zoning

Taking into account the same requirements set out in the literature for the Arabica, we established the basis of our agro-climatic zoning (Table IV) using the maximal average annual temperatures and the rainfall.

TABLE IV
Agro-climatic zoning database

	Acceptable	**Unsuitable**
Maximum annual average temperatures	<28 ° C	>28 ° C
Annual rainfall	1200 to 3000 mm	>3000 mm

To perform the agro-climatic zoning with the QGIS 2.8.1 we used the "raster Calculator" function again for the search. In order to obtain the zoning database the search was formulated as follows: [maximal temperatures] <28 + [annual rainfall] ≤ 3000. We obtain figure 19 which demonstrates that in the 2071-2100 period, there will be no areas suitable for the cultivation of Arabica coffee.

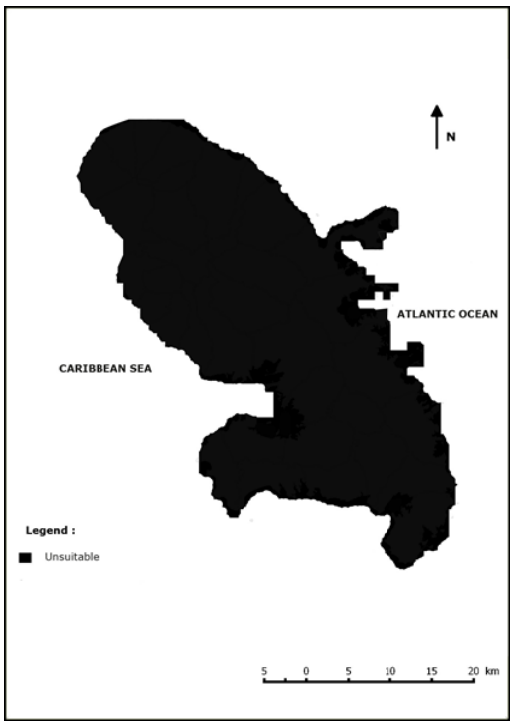

Fig.19 Agro-climatic zoning

However, we can also avoid the problems created by the rainfall by using agricultural drainage techniques in areas where the temperatures will be acceptable (Fig.20). These areas correspond to the island's

highest peaks which are classified as "protected areas".

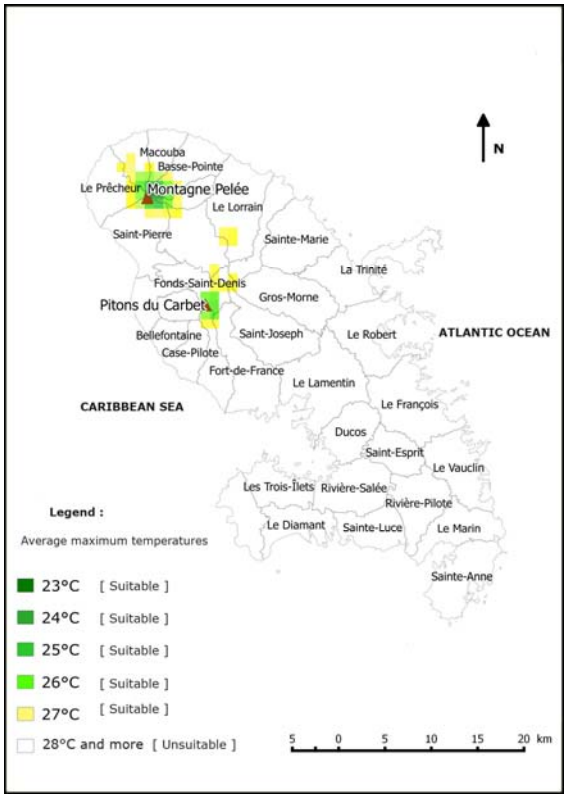

Fig.20 Areas suitable for Arabica in the 2071-2100 period based on maximal temperatures (RCP 4.5 scenario). (Source: Météo-France).

V. DISCUSSION

We had to perform a bibliographic search to establish the ecological profile of *Coffea arabica*. In fact, this allochthon species is rare on the island and the few found specimens can be seen in people's gardens: this does not actually establish its ecological profile. This is quite surprising because the historical sources tell us of an important coffee growing activity using this species, which reportedly took place in the XVIIIth century and XIXth century.

However, the results clearly demonstrate that the possibilities are limited for this coffee. Figure 21 reinforces this observation starting with the altitude. In fact the highest peak of the island does not exceed 1400 metres and our proximity to the Ecuador (14 ° North latitude) rob us of biotopes comprising the temperatures suitable for the production of *Coffea arabica.*

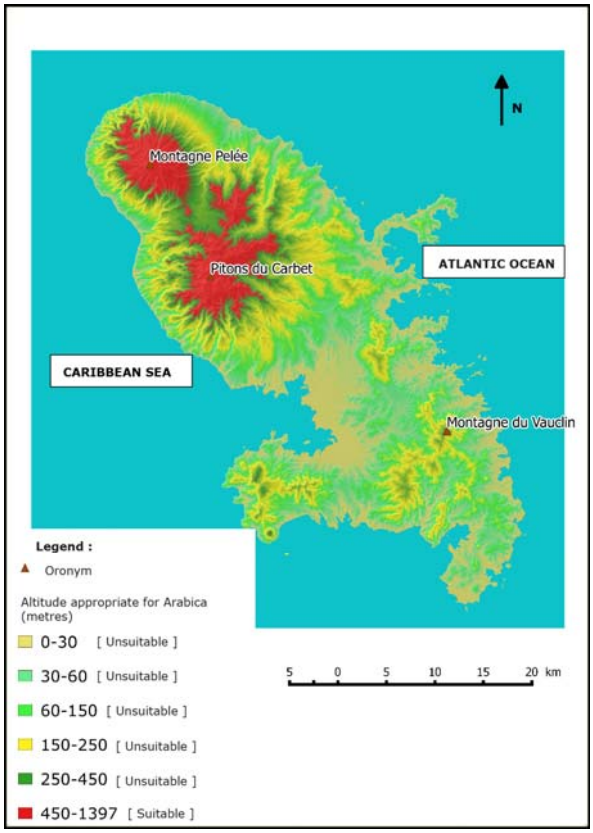

Fig.21 Altitudinal zoning for the *Coffea arabica* (Source: IGN).

The minimal temperatures range between 15ºC and 25°C and do not exhibit strong requirements (Fig.3). With regard to the maximal temperatures (Fig.4), the variations lie between 21° and 32 °C. However, much of the territory exhibits maximal temperatures in excess of 28 °C during the year: which is excessive for the cultivation of Arabica coffee. The acceptable areas whose maximal average temperatures would not exceed 25°C are mainly located in the North. It should be noted that there are areas in the highest summits whose maximal annual average temperature is less than 25°C. The above mentioned features indicate that the environmentally acceptable areas for the production of Arabica coffee in Martinique are therefore very limited.

These areas suitable for the *Coffea arabica*, according to the mean annual maximal temperature

are found primarily in the North at altitudes above 450 metres (Fig. 4 & 21). However, the annual rainfall in these areas is too important because it exceeds the water requirements of Arabica coffee. While not allowing the production of excellent coffee, the agronomic drainage techniques are likely to solve this problem. With regard to world literature and soil data (IRD GIS), the soils suitable for the culture of *Coffea Arabica* are: Ferrisols, Andosols, the alluvial soils, the brown-rust to Halloysite soils and the Fersiallitic soils (Fig.8), [7-9], [12], [41]. When the rainfall is not taken into account in searches using the QGIS (GIS software) software, we obtain a new map for the areas allowing the culture of *Coffea arabica* (Fig.10): all the lots cover an area of 16567 hectares. However, the latter will require appropriate agricultural techniques to reduce the soil's water load.

Taking into account the same data for the ecological requirements for *Coffea arabica var. typica*, and taking into account only the climatic data (temperatures and annual rainfall), we can carry out the zoning for the cultivation of this coffee for the 2071 to 2100 period: using the effects of the climate change. This agro-climatic zoning is carried out using the first scenario named RCP 4.5 one of two Aladin-Climat simulations for the Lesser Antilles (Météo-France) at a 10km resolution [39], [40].

According to this simulation (Fig.14, 15 & 18) Martinique will exhibit increased temperatures. First, the maximal average temperatures for the entire island will increase from 21° to 32 °C at 23° to 33 °C. At the level of the island's highest peaks the rising temperatures will result in a decrease of humidity. Therefore the highest altitude areas in the north will be the only ones exhibiting maximal temperatures not exceeding 28 °C considered acceptable for the Arabica coffee. These more suitable areas located on the island's peaks are also steep, inaccessible and classified as protected natural areas.

Like the maximal average annual temperatures, the minimal average annual temperatures will also increase and range between 16 ° and 26 °C in the 2071-2100 period (Fig.14). Unlike the maximal temperature, the values of the minimal temperature (16 ° to 26 °C), do not restrict the possibilities for the cultivation of coffee Arabica. In spite of a decrease in rainfall on the high peaks which are favourable for the coffee from the temperature's point of view, it (the rainfall) will still remain too important: up to 5000 mm of water per year (Fig.18). That is why, limited by rainfall, with the maximal average temperatures and the steep peaks where some areas are protected, Martinique has no real possibilities for the culture of *Coffea arabica var. typica*by for the 2071-2100 period.

VI. CONCLUSION

This study was carried out using eco-climatic data collected from Martinique's institutions competent in the production of environmental data usable in a GIS (Q-GIS) software. Nevertheless several data are not available: namely the map of the mean annual temperature for soil zoning and the agro-climatic zoning as well as a more accurate map of the soils specifying their characteristics. However, the map for the average minimal and maximal annual temperatures allowed us to characterize the best environments based on extreme values. The map of the major soil types allowed us to include the necessary soil component for this type of study in our zoning. Anyway, in the scientific literature, the limits of this type of studies were given: namely the approximation or the fact of not taking into account the microclimates [19].

We can draw several conclusions regarding the study. First if we consider just the edaphic-climatic requirements of the Arabica coffee (temperature, rainfall, and soil) for good vegetative growth and the good production of coffee and Martinique's simple environmental conditions, there are no optimal environments. In fact, if in the North of the island we note acceptable temperatures and suitable soils, however the rainfall is not suitable for the culture of this coffee. Despite adapted agricultural techniques such as regular and limiting soildrainage, the opportunities for the culture of Arabica coffee are very limited. Several eco-climatic factors mustalso be checked later to complement our zoning such as: exposure to winds, cloudiness and the presence of moderate slopes to facilitate the crops. Secondly, this study also showed, based among others, on the

climate projection model that there will be no suitable area on the island for the cultivation of this coffee by 2071-2100 due to the effects of climate changes. The project for the revival of this culture in Martinique seems very difficult or even impossible.

VII. ACKNOWLEDGEMENT

We were able to carry out this study thanks to the BIORECA laboratory (University of the French West Indies) and the data supplied by Météo-France, the Martinique DEAL, the territorial community of Martinique, the IRD and the IGN. Our sincere thanks to the University Professor and Director of the BIORECA laboratory, Mr. Philippe JOSEPH for reading the text and his numerous corrections.

VIII. REFERENCES

[1] BAREL, Michel. Café: de la cerise à la tasse. Ed. Techniques Ingénieur, 2008.

[2] PINARD, Fabrice. Sur les chemins des caféiers. Etudes rurales, 2008, no 2, p. 15-34.

[3] DAMATTA, Fábio M., RONCHI, Cláudio P., MAESTRI, Moacyr, et al. Ecophysiology of coffee growth and production. Brazilian Journal of Plant Physiology, 2007, vol. 19, no 4, p. 485-510.

[4] Gomez, Céline. Etude de l'hybridation inter-spécifique entre espèces du genre Coffea en Nouvelle-Calédonie: distribution des niches favorables et structuration de la diversité. Diss. Université de la Nouvelle-Calédonie, 2009.

[5] Lamah, Daniel. L'insertion de la caféiculture dans les structures de production en Guinée forestière. Diss. Université Toulouse le Mirail-Toulouse II, 2013.

[6] Hardy, Marie. Le monde du café à la Martinique du début du XVIIIe siècle aux années 1860. Diss. Antilles-Guyane, 2014.

[7] SOTO, F. La zonificación agroecológica del Coffea arabica L. en Cuba. Macizo montañoso sagua-nipe-baracoa. Cultivos Tropicales, 2013, vol. 22, no 3, p. 27-51.

[8] SOTO, F. La zonificación agroecológica del Coffea arabica L. en Cuba. Macizos montañosos Sierra Maestra y Guamuhaya. Cultivos Tropicales, 2013, vol. 23, no 1, p. 35-44.

[9] SOTO, F. Zonificación agroecológica de la cordillera de Guaniguanico. Cultivos tropicales, 2013, vol. 28, no 1, p. 41-55.

[10] BARROS, Marco Aurélio, MOREIRA, Maurício Alves, et RUDORFF, Bernardo Friedrich Theodor. Geotecnologias como contribuição ao estudo do Agroecossistema cafeeiro de Minas Gerais em nível municipal. Geotecnologias como contribuição ao estudo do Agroecossistema cafeeiro de Minas Gerais em nível municipal, 2006.

[11] MEIRELES, E., VOLPATO, M., ALVES, H., et al. Zoneamento agroclimático: Um estudo de caso para o café. Informe Agropecuário, Belo Horizonte, 2007, vol. 28, no 241, p. 50-57.

[12] ELZEBROEK, A. Ton G. Guide to cultivated plants. CABI, 2008.

[13] SOLÓRZANO, Néstor et QUERALES, Daniel. Crecimiento y desarrollo del café (Coffea arabica) bajo la sombra de cinco especies arbóreas. Revista Forestal Latinoamericana, 2010, vol. 25, no 1, p. 61-80.

[14] ZULLO JR, Jurandir, PINTO, Hilton Silveira, ASSAD, Eduardo Delgado, et al. Potential for growing Arabica coffee in the extreme south of Brazil in a warmer world. Climatic Change, 2011, vol. 109, no 3-4, p. 535-548.

[15] BART, François. Café des montagnes, café des plaines. Études rurales, 2008, no 2, p. 35-48.

[16] POHLAN, Hermann A. Jürgen et JANSSENS, Marc JJ. Growth and production of coffee. Soils, Plant Growth and Crop Production-Volume III, 2010, p. 101.

[17] JEANGUYOT, Michelle, SÉGUIER-GUIS, Martine, et DURIS, Daniel. Terres de café. Editions Quae, 2003.

[18] RUTUNGA, V., KAVAMAHANGAT, F., et NSENGIMANA, C. Synthèse des résultats de recherche sur l'agronomie du caféier arabica (Coffea arabica L.) au Rwanda. DGGI, 1994, p. 130.

[19] WOLLMANN, Cássio Arthur et GALVANI, Emerson. Zoneamento agroclimático: linhas de pesquisa e caracterização teórica-conceitual. Revista Sociedade & Natureza, Uberlândia, 2013, vol. 25, no 1.

[20] DE MEDEIROS, Raimundo Mainar, DE AZEVEDO, Pedro Vieira, SABOYA, Luciano Marcelo Falle, et al. Classificação climática e zoneamento agroclimático Para o município de Amarante–PI-DOI: 10.7127/rbai. v7n200011. REVISTA BRASILEIRA DE AGRICULTURA IRRIGADA-RBAI, 2013, vol. 7, no 2, p. 170-180.

[21] NUNES, E. L., AMORIM, RCF de, SOUZA, WG de, et al. Zoneamento agroclimático da cultura do

café para a bacia do Rio Doce. Revista Brasileira de Meteorologia, 2007, vol. 22, no 03, p. 297-302.

[22] SOTO, F. Metodología para la zonificación agroecológica del Coffea arabica L. en Cuba. Cultivos Tropicales, 2013, vol. 22, no 4, p. 51-53.

[23] ROSA, VGC. Modelo agrometeorológico-espectral para monitoramento e estimativa da produtividade do café na Região Sul/Sudoeste do Estado de Minas Gerais. Modelo agrometeorológico-espectral para monitoramento e estimativa da produtividade do café na Região Sul/Sudoeste do Estado de Minas Gerais, 2007.

[24] PETEK, Marcos Rafael, SERA, Tumoru, et FONSECA, IC de B. Exigências climáticas para o desenvolvimento e maturação dos frutos de cultivares de Coffea arabica. Bragantia, 2009, vol. 68, no 1, p. 169-181.

[25] ANDRADE, Giselly Aparecida, DA SILVA RICCE, Wilian, CARAMORI, Paulo Henrique, et al. Zoneamento agroclimático de café robusta no Estado do Paraná e impactos das mudanças climáticas. Semina: Ciências Agrárias, 2012, vol. 33, no 4, p. 1381-1390.

[26] CARAMORI, Paulo Henrique, CAVIGLIONE, João Henrique, WREGE, Marcos Silveira, et al. Zoneamento de riscos climáticos para a cultura de café (Coffea arabica L.) no Estado do Paraná. Revista Brasileira de Agrometeorologia, 2001, vol. 9, no 03, p. 486-494.

[27] CHEMURA, Abel, KUTYWAYO, Dumisani, CHIDOKO, Pardon, et al. Bioclimatic modelling of current and projected climatic suitability of coffee (Coffea arabica) production in Zimbabwe. Regional Environmental Change, 2015, p. 1-13.

[28] DE CARVALHO ALVES, Marcelo, DA SILVA, Fábio Moreira, SANCHES, Luciana, et al. Geospatial analysis of ecological vulnerability of coffee agroecosystems in Brazil. Applied Geomatics, 2013, vol. 5, no 2, p. 87-97.

[29] PINTO, Hilton Silveira, ZULLO JUNIOR, J., ASSAD, Eduardo Delgado, et al. Zoneamento de riscos climáticos para a cafeicultura do Estado de São Paulo. Revista Brasileira de Agrometeorologia, 2001, vol. 9, no 03, p. 495-500.

[30] SANTOS, Lexa Dayana Pineda et HERNÁNDEZ, Jorge Eduardo Suárez. Elaboración de un SIG orientado a la zonificación agroecológica de los cultivos.

[31] EVANGELISTA, Adão WP, CARVALHO, LG de, et SEDIYAMA, Gilberto C. Zoneamento climático associado ao potencial produtivo da cultura do café no Estado de Minas Gerais. Revista Brasileira de Engenharia Agrícola e Ambiental, 2002, vol. 6, no 3, p. 445-452.

[32] GOLE, T. W. M., DEMEL, T., DENICH, Manfred, et al. Diversity of traditional coffee production systems in Ethiopia and their contribution to conservation of genetic diversity. In : Conference on International Agricultural Research for Development, Bonn, Germany. 2001.

[33] DU BOIS, Louis (1855). Notice sur le chevalier De Clieu et bibliographie du café. Caen : Librairie normande de E. Le Gost-clérisse, 26, rue écuyère-17p. ;22cm.-(Bibliographie normande).[Online]. Available: http://www.bmlisieux.com/normandie/clieu.htm

[34] G.-E. Coubard d'Aulnay (1832). Monographie du café, ou Manuel de l'amateur de café. Paris, Chez Delaunay, au Palais Royal. Bibliothèque nationale de France. [Online]. Available: gallica.bnf.fr

[35] DULCIRE, Michel. Une culture patrimoniale du mythe à la renaissance, le café “bonifieur” de Guadeloupe. Anthropology of food, 2005, no 4.

[36] GELETU, Kassahun Tesfaye. Genetic diversity of wild Coffea arabica populations in Ethiopia as a contribution to conservation and use planning. Cuvillier Verlag, 2006.

[37] TRAN, Thi Minh Hue. Genetic variation in cultivated coffee (Coffea arabica L.) accessions in northern New South Wales, Australia. 2005.

[38] ALBERT, Philippe et SPIESER, Julien. Atlas climatique de la Martinique: le temps à la Martinique. Météo-France, Direction interrégionale Antilles-Guyanne, 1999.

[39] CANTET, Philippe, DÉQUÉ, Michel, PALANY, Philippe, et al. The importance of using a high-resolution model to study the climate change on small islands: the Lesser Antilles case. Tellus A, 2014, vol. 66.

[40] Météo-France Antilles Guyane, D. M. Projection Climatique régionalisée en Martinique. Rapport disponible à la demande. 2012.

[41] Venkatapen, Corinne. Étude des déterminants géographiques et spatialisation des stocks de carbone des sols de la Martinique. Diss. Antilles-Guyane, 2012.

[42] CHEMURA, Abel. The growth response of coffee (Coffea arabica L) plants to organic manure, inorganic fertilizers and integrated soil fertility management under different irrigation water supply

levels. International Journal of Recycling of Organic Waste in Agriculture, 2014, vol. 3, no 2, p. 1-9.