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Climate Change

Aptitude of Coffee (*COFFEA ARABICA L.*) and Cacao (*THEOBROMA CACAO L.*) crops considering climate change

Aptitud de los cultivos de café (*COFFEA ARABICA L.*) y cacao (*THEOBROMA CACAO L.*) considerando escenarios de cambio climático

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Abstract

The areas of current and future aptitude for cocoa (*Theobroma cacao L.*) and coffee (*Coffea arabica L.*) crops were evaluated, in climate change scenarios in the Soconusco region, Chiapas, Mexico and the areas where the aptitude of the land increased or decreased were defined. The above provides information to recommend its management and conservation. Two methodologies were used: weighting of factors and limiting factors; both based on the optimal and extreme tolerance values of each crop for each edaphoclimatic requirement. First one, for the determination of potential areas for the establishment of crops; the second one, for differentiation of the combinations of environmental variables that took place within the study area. Climate change scenarios were evaluated and the distribution and aptitude areas were determined. Also, a comparison was made between current and future suitability for both crops to quantify the impact of climate change. The results indicate that the future aptitude of the land will have a decrease in the potential areas for the establishment of both crops that range between 4.5 and 4.8 % for coffee and from 7.2 to 9.3 % for cocoa.

Keywords: Biodiversity, Chiapas, Socunusco, Agroforestry systems, Sustainability.

Resumen

Se evaluaron las zonas de aptitud actual y futura para los cultivos de cacao (*Theobroma cacao L.*) y café (*Coffea arabica L.*), en escenarios de cambio climático en la región del Soconusco, Chiapas, México y se definieron las áreas donde aumentó o disminuyó la aptitud de la tierra. Lo anterior permite tener información para recomendar su manejo y conservación. Se emplearon dos metodologías: ponderación de factores y factores limitantes; ambas con base en los valores óptimos y extremos de tolerancia de cada cultivo para cada requerimiento edafoclimático. Con la primera, se determinaron las áreas potenciales para el establecimiento de los cultivos; con la segunda, se diferenciaron las combinaciones de las variables ambientales que tuvieron lugar dentro del área de estudio. Se evaluaron escenarios de cambio climático y se determinó la distribución y superficies de aptitud. Además, se realizó una comparación entre aptitud actual y futura de ambos cultivos para cuantificar el impacto del cambio climático. Los resultados indican que la aptitud futura de la tierra tendrá una disminución de las áreas potenciales para el establecimiento de ambos cultivos de entre 4,5 y 4,8 % para café y de 7,2 a 9,3 % para cacao.

Palabras clave: Biodiversidad, Chiapas, Socunusco, sistemas agroforestales, sustentabilidad.

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1 Introduction

The Mexican tropics have agro-ecological conditions which are suitable to have perennial crops, such as cocoa (*Theobroma cacao L.*) and coffee (*Coffea arabica L.*), which are species that are naturally distributed in the middle strata of humid warm forests; however, the situation in the world's forests is worrying and difficult, due to many factors such as uncontrolled deforestation, the increase in the agricultural frontier, extensive livestock, climatic changes that affect the increase in the number of forest fires, increase of pests and diseases, floods and population growth, among others (Roa-Romero et al., 2009).

Climate change is the result of meteorological events that influence the functioning of natural systems, observed in alterations in the biodiversity of ecosystems, in productivity and food sources and, consequently, in the life of humans. There is a growing interest in understanding the processes that make up climate change and their influence on the dynamics of the carbon cycle in natural ecosystems, since plants are essential to the global balance of this gas due to their ability to absorb CO_2 through photosynthesis, storing it as cellulose or transforming it into another type of organic compound (Yepes and Buckeridge, 2011; Fatichi et al., 2016; Baumgartner et al., 2018; Beaumont et al., 2019; Guisan et al., 2014).

Regarding Chiapas, the cocoa cultivated area is 18 426 ha, with a production of 9 869 t with an average yield of 535,6 $kg \cdot ha^{-1}$ (SIAP, 2018). According to Avendaño et al. (2011) it represents an important source of income with 33.0% of national production, so that 11 069 producers in Chiapas depend economically on this crop. In most cases, cacao farmers cultivate cacao with experience and knowledge of traditional agriculture and do so with a peasant economy approach (Nájera, 2012), even though Avendaño et al. (2013) indicate that cocoa plantations have economic, social, cultural and environmental value. These assessments are corroborated with the results obtained by Hernández et al. (2015), who point out that cocoa production in Chiapas is managed by small producers, with plots smaller than 2 ha (58.7%) and 41.3% with larger plots. Most of the producers are male (80%) and 19.3% female, who are also housewives and take care of their children, tripling their working days.

Cocoa crop faces a crisis due to environmental, technological, economic, social and phytosanitary factors (Díaz et al., 2013; Hernández et al., 2015; Suárez-Venero et al., 2019); however, it presents encouraging future, since there is a national and international potential market that reports a demand growth of 2.5% per year, led by the consumption of cocoa that is related to industrial demand to produce mainly chocolates (ICI, 2013). There are agroclimatic conditions in Chiapas to increase production, which implies increasing the cultivated area. For this reason, it is necessary to identify areas with high productive and economic potential by generating information that becomes a necessary element for decision-making (Espinosa-García et al., 2015).

Coffee cultivation was introduced in Mexico in 1796, and consolidated as an important crop in the economic, environmental and social context that is part of the agro-productive culture of subtropical and tropical regions. Chiapas is the main coffee producer (var. robusta and arabiga), with a sown area equivalent to 252.743,77 ha, with approximately 180 856 coffee producers and 367.874,15 t of production in 2019 (SIAP, 2018). The coffee areas in Chiapas are characterized by their environmental, technical, economic and sociocultural differences, which influence grain production (Medina-Meléndez et al., 2016). Coffee is currently produced in 11 states of the Republic. Chiapas, Veracruz, Puebla and Oaxaca account for 89.7% of total national production in 85% of the total area sown, with 83% of national producers (SIAP, 2018). Internationally, Mexico is the eighth coffee largest producer (Organización Internacional del Café, 2018).

Hence the importance of generating climate change scenarios that represent thermal variation in the study region. Regional vulnerability reveals the differential effects of climate on society and its productive activities; for this reason, it is necessary to study the causes and distribution of the impacts of climate change on agro-productive systems based on the complex interaction of environmental, social, economic and political factors involved in each region or geographic area (Torres et al., 2011).

Studies based on the increase in temperature due to the effect of climate change show that coffee cultivation will suffer a significant geographical redistribution in Mexico and other producing countries (Paes, 2010; Haggar and Schepp, 2012; Ovalle-Rivera et al., 2015); in this sense, there are few studies on cocoa farms; however, the scenario is not different. Regarding factors and limiting factors for agricultural production, agro-ecological zoning is a practical tool that defines areas by combining similar characteristics of climate, soil and biophysical potential for agricultural production. This combination is observed in areas with limitations and potentialities, which allows it to be a reference to improve the existing situation, increasing production or the area of the crop, or limiting the degradation of natural resources (Suárez-Venero et al., 2019).

Climate variability is the main factor responsible for annual fluctuations in crop production (Comisión Económica para América Latina y el Caribe, 2010). Therefore, the purpose of this research is to evaluate the current and future suitable areas (2018-2040) for cocoa (*Theobroma cacao L.*) and coffee (Coffea arabica L.) crops in climate change scenarios in the Soconusco region, Chiapas, Mexico and define the regions where availability to have information to recommend their management and conservation increases or decreases.

2 Materials and methods

2.1 Area of study

The socio-economic region of Soconusco has an area of approximately 4.605,4 km^2, equivalent to 6.28% of the state territory and is composed of 16 municipalities: Acacoyagua, Acapetahua, Cacahoatan, Escuintla, Frontera Hidalgo, Huehuetan, Huixtla, Mapastepec, Mazatan, Metapa, Suchiate, Tapachula, Tuxtla Chico, Tuzantan, Union Juarez and Villa Comaltitlan. According to the Population and Housing Census (INEGI, 2010), this region had a population of 664,437 inhabitants, which represented 16.9% of the state total.

2.2 Crop requirements

The edapho-climatic requirements involved in the development and productivity of each crop were defined with the aim of assigning levels of importance to each of the variables to be considered. A table was created for each crop with their corresponding requirements and were classified into different proficiency levels: very suitable, marginally suitable and unsuitable, using as a reference the lower and upper ranges of each of the requirements tolerated by each crop (Table 1 and 2).

Mapping was handled and generated using ArcGIS 9.3 software. The layers used for the classification of proficiency levels according to Tables 1 and 2 were obtained from the following sources. 1) The precipitation and temperature maps were obtained from the UNAM Center for Atmospheric Sciences (Gómez et al., 2008). 2) Terrain elevation and slope maps were generated using ArcGIS 3D Analysis and Spatial Analyts tools based on INEGI (1994) 1:50.000 scale digital elevation models, available online on the official website. 3) The soil map was classified from the dominant soil map of INEGI (1994) scale 1:1.000.000.

Table 1. Environmental requirements for *Coffea arabica L.* and fitness levels with respect to environmental variables.

	Fitness level				
Requirement (variable)	Not suitable	Marginally suitable	Very suitable	Marginally suitable	Not suitable
Average annual precipitation (mm)	<750	750-1400	1400-2200	2200-4200	>4200
Average annual temperature (°C)	<10	10-14	14-28	28-34	>34
Height (masl)	<1000	1000-1200	1200-1700	1700-2800	>2800
Slope terrain (%)			<30	30-40	>40
Soils (texture)	Light (sandy)		Loams (medium)		Heavy (clay)

Source: Adapted from INIFAP (2018); Pérez-Portilla and Geissert-Kientz (2006).

Table 2. Environmental requirements for *Theobroma cacao L.* and fitness levels with respect to environmental variables.

	Fitness level				
Requirement (variable)	Not suitable	Marginally suitable	Very suitable	Marginally suitable	Not suitable
Average annual precipitation (mm)	<1000	1000-1500	1500-2500	2500-3000	>3000
Average annual temperature (°C)	<18	18-22	22-28	28-32	>32
Height (masl)	<5		5-400	401-601	>601
Slope terrain(%)			0-15	15-30	>30
Soils (texture)	sandy		alluvial		Clayey, burdensome

Source: Adapted from INIFAP (2018); SIAP-SAGARPA (2019).

2.3 Zoning by weight

From the above requirement matrices, current aptitude maps were generated by requirement for both crops, assigning the following weight to each of the variables: precipitation= 0.4, temperature= 0.2, height= 0.2, slope= 0.1, and soils= 0.1. Then, new weighted values were assigned to each proficiency level for each variable or map: 4, 2, and 0 for very suitable, over positioned and algebra were used in maps to obtain the current potentiality ranges. Maps were classified into three equal intervals and were again assigned the key nomenclature very suitable, marginally suitable, and not suitable (Figure 1).

2.3.1 Crop zoning by limiting factors

Zoning by limiting factors was performed using a layer overlay with the Geoprocessing tool. Maps were reclassified according to the tables of crop requirements at their different suitable levels. For this, it was necessary to assign keys to each suitable level and generate a nomenclature that allowed to know the incidence of each factor when superimposing the maps (Table 3).

Using the assigned keys, layer overpositioning was performed in order to obtain a single map that showed all possible combinations (agro-ecological cells) between proficiency levels of each of the indicators studied as shown in Figure 2.

2.3.2 Climate change scenarios

Temperature and precipitation, and in general, the water cycle were the variables through which climate change was evident. Thus, the output data of atmospheric-oceanic general circulation models (GCMs) of these two parameters were necessary for developing a future crop fitness scenario, considering such a change. The output data from two GCMs, HadleyCM3 and GFDLR30, were used to map climate change. Climate change models were obtained from the UNAM Center for Atmospheric Sciences for scenario A2 and B2 at the time horizon of 2030 (Gómez et al., 2008). The same steps, nomenclature and criteria used in determining the current (base scenario) fitness by weight and constraints were used for preparing future fitness maps with climate change. Whenever the temperature and precipitation variables were modified, the tables of climatic requirements were applied again to obtain possible future scenarios. Figure 3 describes the general process of this study.

3 Results and discussion

3.1 Current fitness by weight for the two crops

Once the algebra of maps was done, the ground surfaces of the different fitness levels for coffee were 37.8% for very suitable, 61.0% for marginally suitable and 1.1% for not suitable. On the other hand, the different fitness levels for cacao were: 59.2; 24.3 and 16.5% very suitable, marginally suitable and unfit; respectively (Figure 4).

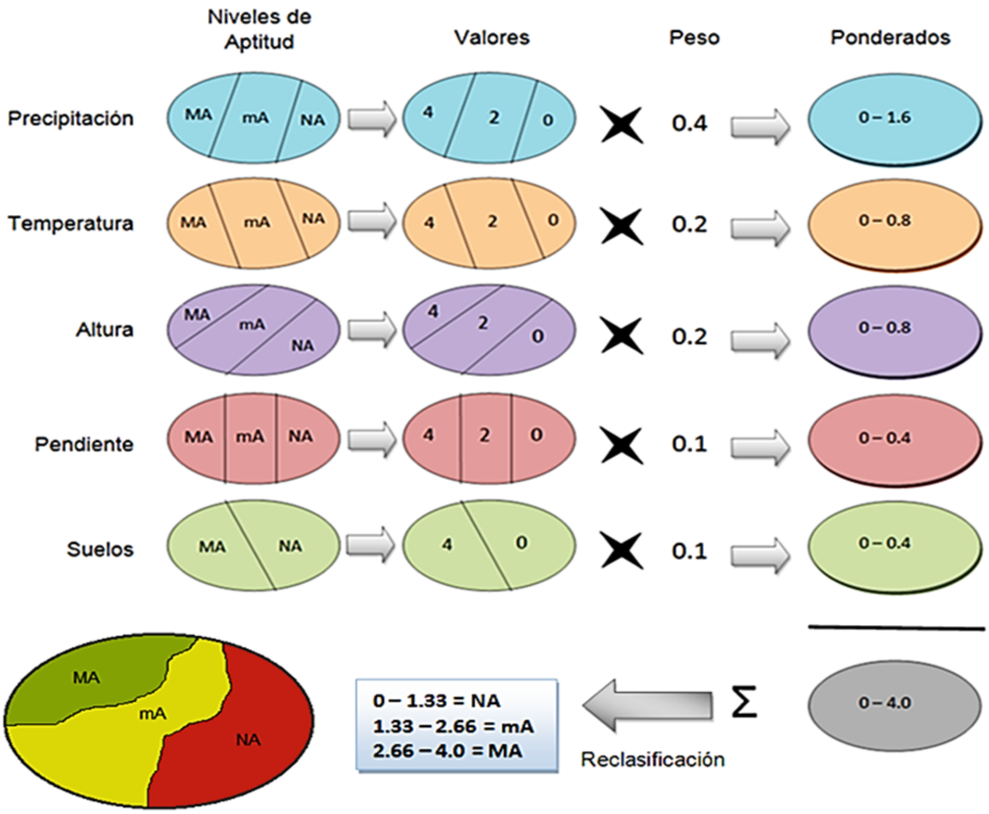

Figure 1. Factor weighting method with nomenclature and assigned values.

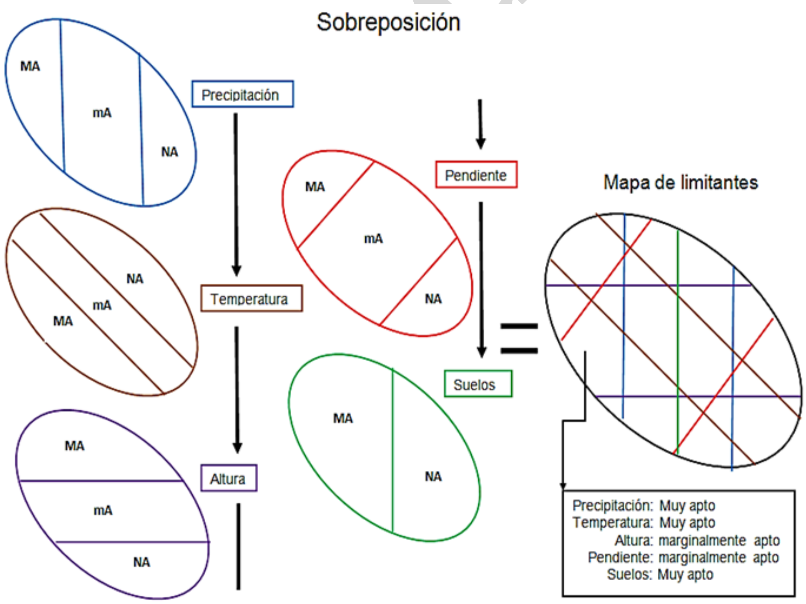

Figure 2. Limitation method with nomenclature and description of agro-ecological cells.

Figure 4 is interpreted as a distribution of areas: (1) where it is advisable to establish crops (highly suitable); (2) in appropriate areas but which require more management for their development (marginally suitable); and finally, (3) where it is not recommended to establish crops because the land does not have the necessary potential for its production.

3.2 Current suitability for coffee and cocoa crop constraints

Constraint maps for both crops showed the variability of different units, perfectly identifiable by the environmental conditions that occurred in each of them, so the color schemes used were neither hierarchical nor exclusive. Likewise, each unit was described by a unique formula. In the case of the current suitability for growing coffee, 24 different units were presented, although the first seven covered more than 75% of the area of the region. On the other hand, the current suitability for cacao presented 36 different classes, of which the first six covered more than 50% of the total area (Figure 5).

The suitability by constraints is totally qualitative and represents a complement to what was obtained during weighting, because it allows to identify the incidence of each of the variables considered in the agro-ecological zoning. It can be seen in Figures 5a and 5b that the red colored areas are limited by a greater number of variables and can be identified using the nomenclature described in Table 3.

Table 3. Nomenclature used for determining formulas.

Variable	Very suitable	Marginally suitable	Not suitable
Precipitation	P_{MA}	P_{mA}	P_{NA}
Temperature	T_{MA}	T_{mA}	T_{NA}
Height	A_{MA}	A_{mA}	A_{NA}
Slope	Pe_{MA}	Pe_{mA}	Pe_{NA}
Soil	S_{MA}	S_{mA}	S_{NA}

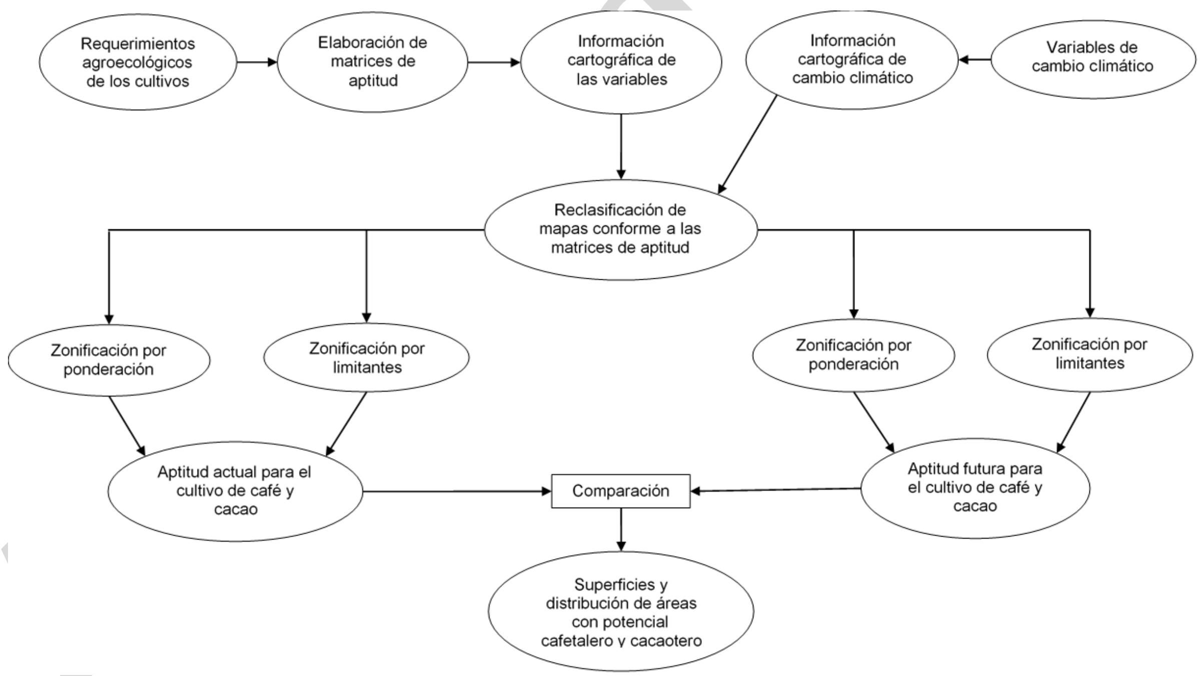

Figure 3. General diagram of the employed method.

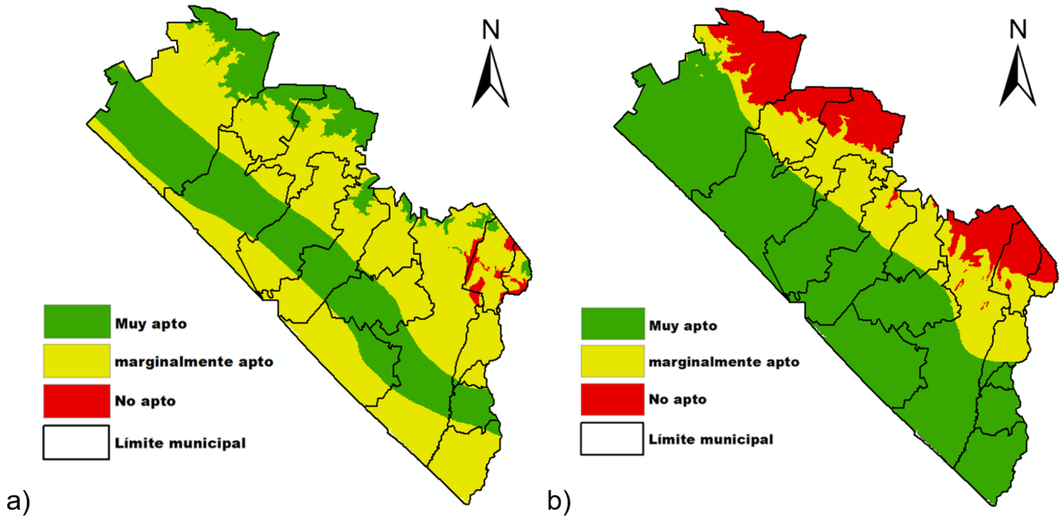

Figure 4. Current land fitness with the weighting method for coffee (a) and cocoa (b) in the Soconusco region, Chiapas, Mexico.

3.3 Climate change scenarios by weighting

Changes in areas with coffee and cocoa potential are presented in Table 4, considering that the total area of the study region was approximately 590 thousand ha. As shown in Table 4, there were no percentage changes between scenarios (A2 and B2) for either model, even though a difference was observed in the precipitation output and temperature values of each model. The above was due to the fact that during the reclassification of the maps, they were assigned the same skill level because the difference between the values was not sufficient to classify them into different skill ranges according to Tables 1 and 2. There was also a minimal change between the two models due to the difference in data processing for each model.

In the case of coffee, the GFDL model showed that the most affected area of the study was the southeast in the municipalities of Frontera Hidalgo, Suchiate, Tapachula, Huehuetan. Also, the municipalities Mapastepec and Acapetahua in the northwest of the region lost potential in areas near the coast. Potential-free areas were also reduced in Cacahoatan and northern Tapachula; the decrease in potential-free areas was mainly due to the higher temperature rise, which allowed a better development of the crop from 450 to 550 meters above sea level. On the other hand, the Hadley model indicated a reduction in suitability in the same municipalities as the previous one, although it also marked an expansion of the potential-free zones in the north of Tapachula and Tuxtla Chico and the east of Cacahoatan, due to a minimal increase in precipitation at lower altitudes in those areas. The Hadley model showed a less encouraging sceneraio (Figure 6).

Table 4. Area (%) by suitability range for coffee and cocoa crops with climate change scenarios in the Soconusco region, Chiapas, Mexico.

	Coffee			Cacao		
Scenarios	Very suitable	Marginally suitable	Not suitable	Very suitable	Marginally suitable	Not suitable
Base	37.8	61.0	1.1	59.2	24.3	16.5
GFDL A2	33.3	66.3	0.4	52.0	31.7	16.3
GFDL B2	33.3	66.3	0.4	52.0	31.7	16.3
Hadley A2	33.0	64.9	2.1	49.9	33.5	16.6
Hadley B2	33.0	64.9	2.1	49.9	33.5	16.6

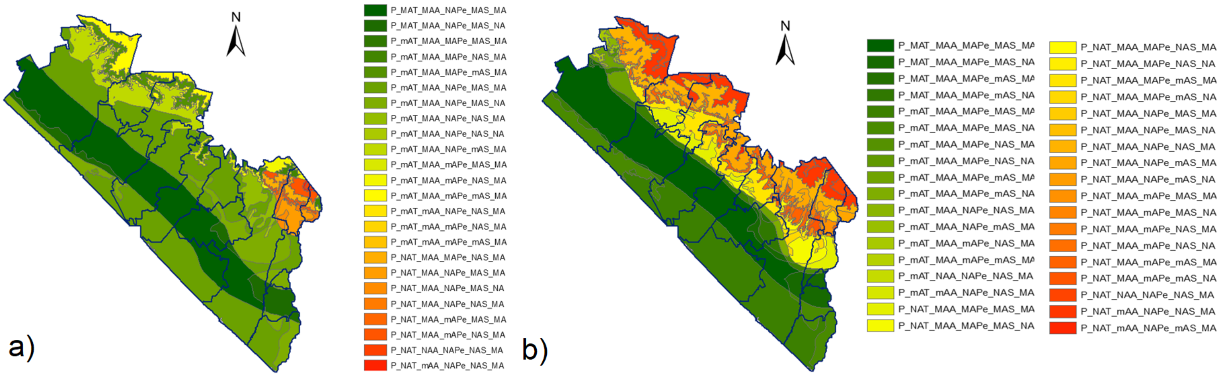

Figure 5. Current land suitability with the constraint method of coffee (a) and cocoa (b) in the Soconusco region, Chiapas, Mexico.

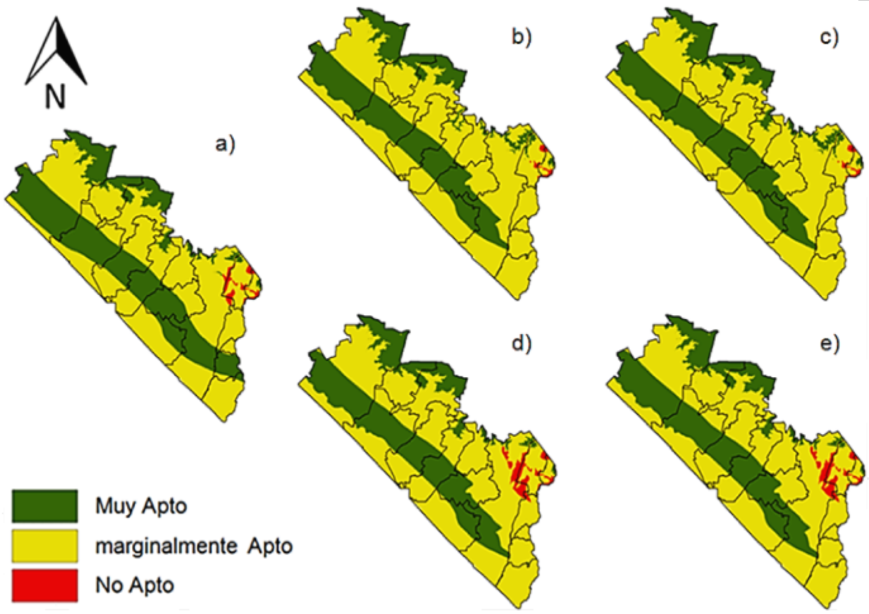

Figure 6. Zoning for coffee cultivation: A) Current fitness and; Climate change scenario readiness for 2030: b) GFDL A2, c) GFDL B2, d) Hadley A2 and e) Hadley B2.

The most important changes in municipalities occurred in Acapetahua, Huehuetan, Mapastepec, Metapa, Suchiate, Tapachula and Frontera Hidalgo, the latter with a fitness reduction of up to 82.5% of its surface area. However, the GFDL model showed small positive changes such as the fitness increase of up to 4% in the municipality of Cacahoatan, (Table 5).

For cocoa, the GFDL model indicated that cocoa potential reduced significantly in the southeast in the municipalities of Suchiate, Frontera Hidalgo, Metapa, Tuxtla Chico, Tapachula and Huehuetan; as well as the coastline of Mapastepec, Acapetahua and, in a smaller proportion, Villa Comalitlan. On the other hand, the potential-free areas were reduced in the north of the municipalities Huixtla and Tuzantan, due to the increase in the temperature from 1250 to 1500 meters/3ft in the upper zones. The Hadley model indicated the same trend as the previous one, reducing potential areas in the same municipalities, although with a higher proportion (2.1%) and reducing potential-free areas in the municipalities of Huixtla and Tuzantan; in addition to an increase in the latter in the north of the municipality of Mapastepec, also due to the increase in temperature, but in this case in low areas (Figure 7). Again, the Hadley model was less favorable in its prediction.

Similarly, the most significant changes in municipalities were observed in Acapetahua, Huehuetan, Mapastepec, Metapa, Tapachula, Tuxtla Chico, Tuzantan, Villa Comaltitlan, Frontera Hidalgo and Suchiate, the latter two with a fitness reduction of up to 38% of their surface area. In this case, there were no positive changes in fitness for either of the two models (Table 6).

All A2 experiments in the Pacific Climate Impact Consortium Special Report on Emission Scenarios (IPCC, 2013) reported that on average there will be an increase of $2°C$ in the average temperature of the study region compared with the current one by the mid-80 of this century. On the other hand, the annual precipitation was more erratic in terms of its prediction, since it showed positive and negative percentage changes, although most models indicated a significant increase, including the Hadley model.

Table 5. Comparison of areas (%) at the municipal level of the base scenario with climate change scenarios for coffee cultivation in the Soconusco region, Chiapas, Mexico.

		Base scenario			GFDL A2 and B2 Model			Hadley A2 and B2 Model		
Municipality	Total area (ha)	Very Suitable	Marginal suitable	Not suitable	Very Suitable	Marginal Suitable	Not suitable	Very suitable	Marginal suitable	Not suitable
Acacoyagua	26.160.90	30.3	69.7	-	30.3	69.7	-	30.3	69.7	-
Acapetahua	55.293.90	53.7	46.3	-	47.3	52.7	-	47.3	52.7	-
Cacahoatán	17.996.90	3.8	76.6	19.6	7.8	85.2	7.0	3.2	76.5	20.3
Escuintla	39.464.80	38.6	61.4	-	38.6	61.4	-	38.6	61.4	-
Frontera Hidalgo	11.493.40	84.3	15.7	-	1.8	98.2	-	1.8	98.2	-
Huehuetán	30.644.40	62.3	37.7	-	50.0	50.0	-	49.0	51.0	-
Huixtla	43.295.10	40.4	59.6	-	40.4	59.6	-	40.4	59.6	-
Mapastepec	120.802.30	57.4	42.6	-	52.3	47.7	-	52.3	47.7	-
Mazatán	37.277.50	28.0	72.0	-	28.0	72.0	-	28.1	71.9	-
Metapa	3.054.30	1.8	98.2	-	-	100.0	-	-	100.0	-
Suchiate	22.997.90	4.8	95.2	-	0.2	99.8	-	0.2	99.8	-
Tapachula	95.371.20	26.0	72.1	1.9	23.7	76.3	-	20.9	72.0	7.1
Tuxtla Chico	13.073.20	2.2	97.5	0.3	-	100.0	-	-	95.4	4.6
Tuzantán	20.435.30	8.7	91.3	-	8.7	91.3	-	8.7	91.3	-
Unión Juárez	5.716.00	12.1	64.1	23.8	14.5	62.4	23.1	9.4	66.7	23.9
Villa Comaltitlán	45.800.30	33.8	66.2	-	33.8	66.2	-	33.8	66.2	-

As for O'Connor et al. (2020) concerns due to climate change correspond to the accelerated loss of biodiversity and variation in wildlife distribution; Rice (2018) suggested that there is a decrease in the available space for agriculture, and thus a reduction in the supply of food. In order to see the impact of climate variability in the case of coffee cultivation, it is necessary to know the distribution in the world. This crop can be found as traditional polyculture, commercial polyculture and monocultures. Each form of crop management has advantages and disadvantages. According to Janissen and Huynh (2018) and Torres et al. (2020) traditional polycultures and wild crops reduce leaf perspiration and the speed of night and day heating, resulting in less stress of the plant due to sudden temperature changes.

From an environmental point of view, these systems allow the conservation of a large number of plants and animals, preserving native ecosystems. On the contrary, the commercial polyculture retains the species associated with the crops that generate monetary profits for coffee farmers. Monoculture and commercial polyculture are the most productive in the short term. However, they are the crops most sensitive to pests because they provide a more conducive environment for the growth of pathogens.

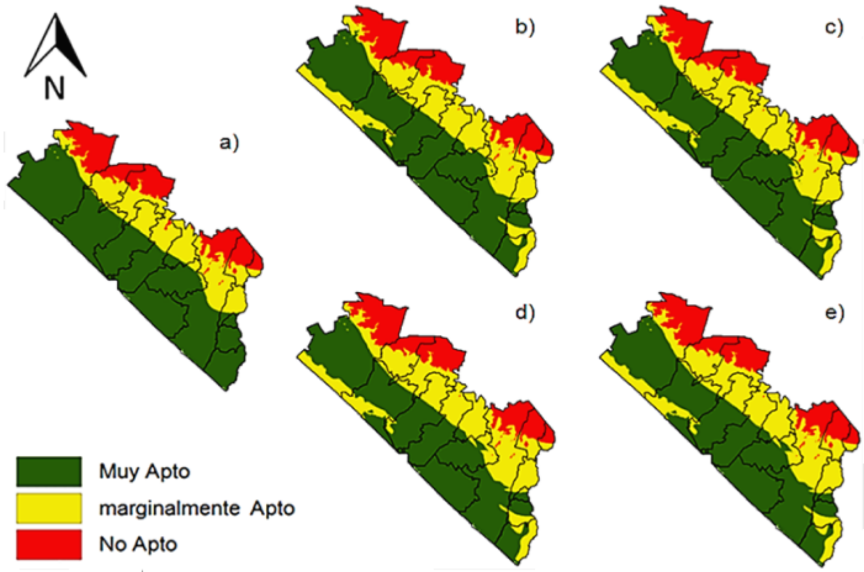

Figure 7. Zoning for cocoa cultivation: A) Current fitness and; Climate change scenario fitness for 2030: b) GFDL A2, c) GFDL B2, d) Hadley A2 and e) Hadley B2.

Table 6. Comparison of areas (%) at the municipal level of the base scenario with climate change scenarios for cocoa cultivation in the Soconusco region, Chiapas, Mexico.

		Base scenario			GFDL A2 and B2 Model			Hadley A2 and B2 Model		
Municipality	Área total (ha)	Very suitable	Marginal suitable	Not suitable	Very suitable	Marginal suitable	Not suitable	Very suitable	Marginal suitable	Not suitable
Acacoyagua	26.160.91	1.1	59.5	39.4	1.1	59.9	39.0	0.5	60.5	39.0
Acapetahua	55.293.91	95.7	4.3	-	77.9	22.1	-	75.2	24.8	-
Cacahoatán	17.996.89	-	39.3	60.7	-	39.4	60.6	-	39.4	60.6
Escuintla	39.464.77	3.2	43.9	52.9	3.2	44.1	52.7	2.6	44.7	52.7
Frontera Hidalgo	11.493.41	100.0	-	-	61.5	38.5	-	61.5	38.5	-
Huehuetán	30.644.37	89.1	10.9	-	84.3	15.7	-	75.1	24.9	-
Huixtla	43.295.09	63.7	34.9	1.4	63.6	36.3	0.1	62.5	37.4	0.1
Mapastepec	120.802.31	64.5	8.6	26.9	54.5	18.7	26.8	52.3	19.7	28.0
Mazatán	37.277.47	100.0	-	-	99.5	0.5	-	99.5	0.5	-
Metapa	3.054.27	99.9	0.1	-	91.9	8.1	-	76.3	23.7	-
Suchiate	22.997.88	100.0	-	-	61.2	38.8	-	61.2	38.8	-
Tapachula	95.371.22	51.2	30.2	18.6	48.6	32.8	18.6	46.4	35.0	18.6
Tuxtla Chico	13.073.17	16.9	83.1	-	10.9	89.1	-	6.2	93.8	-
Tuzantán	20.435.30	18.2	80.8	1.0	14.5	85.5	-	12.2	87.8	-
Unión Juárez	5.716.02	-	32.3	67.7	-	32.4	67.6	-	32.4	67.6
Villa Comaltitlán	45.800.34	70.0	30.0	-	66.6	33.4	-	65.4	34.6	-

3.4 Limiting climate change scenarios for coffee and cocoa cultivation

Like the current skill (base scenario) by constraints, future fitness maps are intended to show how the variability of existing units will behave, i.e., whether the number of different classes will be reduced or increased due to the effect of climate change. Figure 8 shows that the GFDL model showed 27 different classes for coffee cultivation, three more than in the base scenario. On the other hand, the Hadley model presented 28 different units.

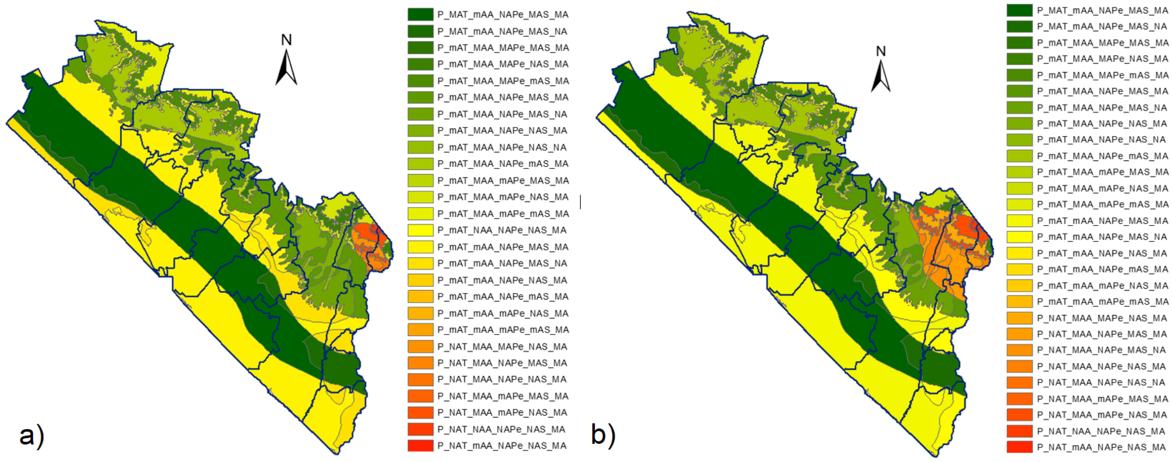

Figure 8. Future suitability by constraints a) GFDL A2 and B2 model, b) Hadley A2 and B2 model for coffee in climate change scenarios in the Soconusco region, Chiapas, Mexico.

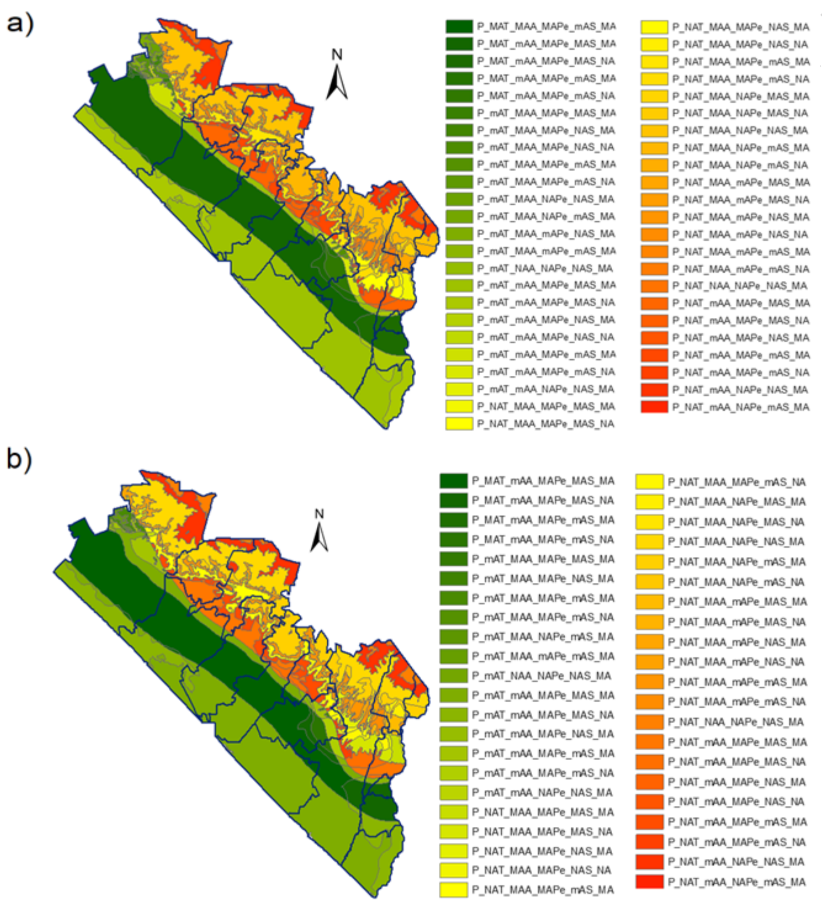

Figure 9. Future suitability by constraints a) GFDL A2 and B2 model, b) Hadley A2 and B2 model for cocoa in climate change scenarios in the Soconusco region, Chiapas, Mexico.

Regarding cocoa, the GFDL model showed 47 different classes, i.e., 11 units more than in the base scenario; the Hadley model featured 43 different classes. Cacao and coffee plantations were suitable for reforesting completely cut areas and can become biological corridors, allowing the repopulation of birds, mammals, reptiles and amphibians, among others, as suggested by Ogata (2007). Agroforestry systems of both coffee and cacao were important tools for the preservation of biodiversity, because they presented different species and forms of plant and animal life, agreeing with what was indicated by Salgado-Mora et al. (2007); these tools also provided many positive advantages, being necessary to characterize the most relevant factors in the socio-economic and environmental aspect to improve the potentialities of the crops studied and to promote themselves as an alternative of sustainable management (Roa-Romero et al., 2009); they can be a "bridge" between agricultural development and preservation, facilitating cooperation and collaboration between farmers and conservationists (Parrish et al., 1999).

4 Conclusions

The GFDL model predicts a reduction of 4.5 and 5.3 % for coffee and cocoa cultivation in areas with very high potential, and an increase of 4 and 7.4 % in areas with marginal potential; while the potential-free areas have a reduction of 0.7 % and 0.2 %, respectively; the latter case represents a positive impact of climate change, even if it is less than the one produced in areas with very high potential. Regarding the Hadley model, it predicts a reduction of 4.8 % for coffee and cocoa in areas with very high potential, and an increase of 3.9 and 9.2 % in areas with marginal potential, and an increase of 1.0 % and a decrease of 0.1 %, respectively, in areas without potential.

The future fitness of both crops will be adversely affected by climate change. The decrease in the area with a very suitable level for the establishment of both crops over time agrees with the reduction in production volume that occurred in the last decade, according to historical production data. By 2030, between 5.5 and 5.8 % of potential coffee areas will be lost; while between 7.2 and 9.3 % of the potential areas will be lost in cocoa.

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