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CLIMATE CHANGE AND COCOA PRODUCTION IN THE BRAZILIAN AMAZON BIOME

ABSTRACT: In the current context, projections indicate that the agricultural sector is one of the most vulnerable to the impacts caused by climate change. Thus, this work aimed to identify the relationship of the current scenario of edaphoclimatic adequacy with the production and productivity of cocoa. As well as investigate the edaphoclimatic suitability in future scenarios. For this purpose, the determination of the correlation between the variables was performed using the formula of Pearson's correlation coefficient. The results indicated that there is a low or no correlation in the current scenario with the production and productivity of cocoa. Furthermore, there will be large losses in soil and climate suitability in future scenarios. Therefore, it was possible to conclude that it is necessary to take measures to avoid the intensification of climate change, such as combating illegal deforestation in order to prevent future climate change scenarios from occurring.

KEYWORDS: Edaphoclimatic suitability, Agriculture, Theobroma cacao L.

MUDANÇAS CLIMÁTICAS E A PRODUÇÃO DE CACAU NO BIOMA AMAZÔNICO BRASILEIRO

RESUMO: No contexto atual, projeções indicam que o setor agrícola é um dos mais vulneráveis aos impactos causados pelas mudanças climáticas. Dessa forma, este trabalho objetivou identificar a relação do cenário atual de adequação edafoclimática com a produção e a produtividade de cacau. Assim como, investigar a adequação edafoclimática em cenários futuros. Para tanto, foi realizada a determinação da correlação entre as variáveis com o uso da fórmula do coeficiente de correlação de Pearson. Os resultados indicaram que existe uma baixa ou nenhuma correlação no cenário atual

com a produção e produtividade de cacau e também que haverá grandes perdas de adequação edafoclimáticas nos cenários futuros. Portanto, foi possível concluir que é necessário se realizar medidas que evitem a intensificação das mudanças climáticas como o combate ao desmatamento ilegal no sentido de evitar que os futuros cenários de mudanças climáticas ocorram.

PALAVRAS-CHAVE: Adequação edafoclimática, Agricultura, *Theobroma cacao* L.

CAMBIO CLIMA Y PRODUCCIÓN DE CACAO EM EL BIOMA DE LA AMAZONIA BRASILEÑA

RESUMEN: En el contexto actual, las proyecciones indican que el sector agrícola es uno de los más vulnerables a los impactos provocados por el cambio climático. Así, este trabajo tuvo como objetivo identificar la relación del escenario actual de adaptación edafoclimática con la producción y productividad del cacao. Así como investigar la adecuación edafoclimática en escenarios futuros. Por tanto, la determinación de la correlación entre las variables se realizó mediante la fórmula del coeficiente de correlación de Pearson. Los resultados indicaron que existe poca o ninguna correlación en el escenario actual con la producción y productividad del cacao y también que habrá grandes pérdidas de adaptación edafoclimática en escenarios futuros. Por tanto, se pudo concluir que es necesario tomar medidas para evitar la intensificación del cambio climático, como la lucha contra la deforestación ilegal para evitar que se presenten escenarios futuros de cambio climático.

PALABRAS CLAVES: Edaphoclimatic idoneidad, Agriculture, *Theobroma cacao* L.

INTRODUCTION

Cocoa *(Theobroma cacao* L.) is a native species of the Amazon biome, which has as its center of origin the northwest region of South America (ZARRILO et al., 2018). In general, this species is cultivated in agroforestry systems by farmers who have small properties (VAAST, SOMARRIBA, 2014), with much of the cocoa production destined to the chocolate industry (MENEZES et al., 2016) and its derivatives such as chocolate candy, chocolate powder and cocoa butter (NURHADI, 2016).

Brazil is the seventh largest cocoa producer in the world (FAO, 2019). In the Amazon biome region, the states of

Pará and Rondônia are the first and third largest national producers, respectively (IBGE, 2019). Therefore, it is an extremely important crop for the economy of the local production chain and is composed mainly of family farming, representing about 90% of cocoa-producing properties (IBGE, 2017).

In the current context, projections indicate that climate change could promote major transformations that humanity must face by the end of the 21st century (SOUZA et al., 2019, FARRELL et al., 2018). Among them, the agricultural sector is one of the most vulnerable to the impacts caused by such climate change (CLAPP; NEWELL; BRENT, 2018). According to FAO (Food and Agriculture Organization of the United Nations) data, the reduction in agricultural production will be between 10 and 25% by 2050 (FAO, 2016). Thus, there may be a reduction in food supply, which will cause increased food insecurity, especially in countries with higher rates of poverty (ROSEGRANT; TOKGOZ; BHANDARY, 2013). Therefore, that studies with the purpose of estimating the possible impacts on agricultural production chains caused by climate change are considered of great relevance.

Projections to predict climate change have been the focus of several studies due to the importance of investigating the impacts that these changes on climate will cause to humanity. The *Intergovernmental Panel on Climate Change* (IPCC), in the framework of the *Coupled Model Intercomparison Project Phase* 5 (CMIP5) of the global climate research program, developed a set of future scenarios based on anthropogenic forces related to the concentration of greenhouse gases called *Representative Concentration Pathways* (RCPs). In this sense, four scenarios were created (RCP 2.6, 4.5, 6.0 and 8.5), which are characterized according to the estimate of greenhouse gas emissions. With this, the RCP2.6 scenario is the one with the least intense climate change, as opposed to the RCP8.5 scenario (IPCC, 2013).

The objective of this work consisted of identifying the relationship of the current scenario of edaphoclimatic adequacy (degree of adequacy of climatic conditions and soil characteristics to the full development of a given crop), and cocoa production, as well as identifying whether there will be major changes in the edaphoclimatic adequacy in future scenarios (RCP 4.5 and 8.5), which may indicate negative impacts on cocoa production in the municipalities of the Brazilian Amazonian biome.

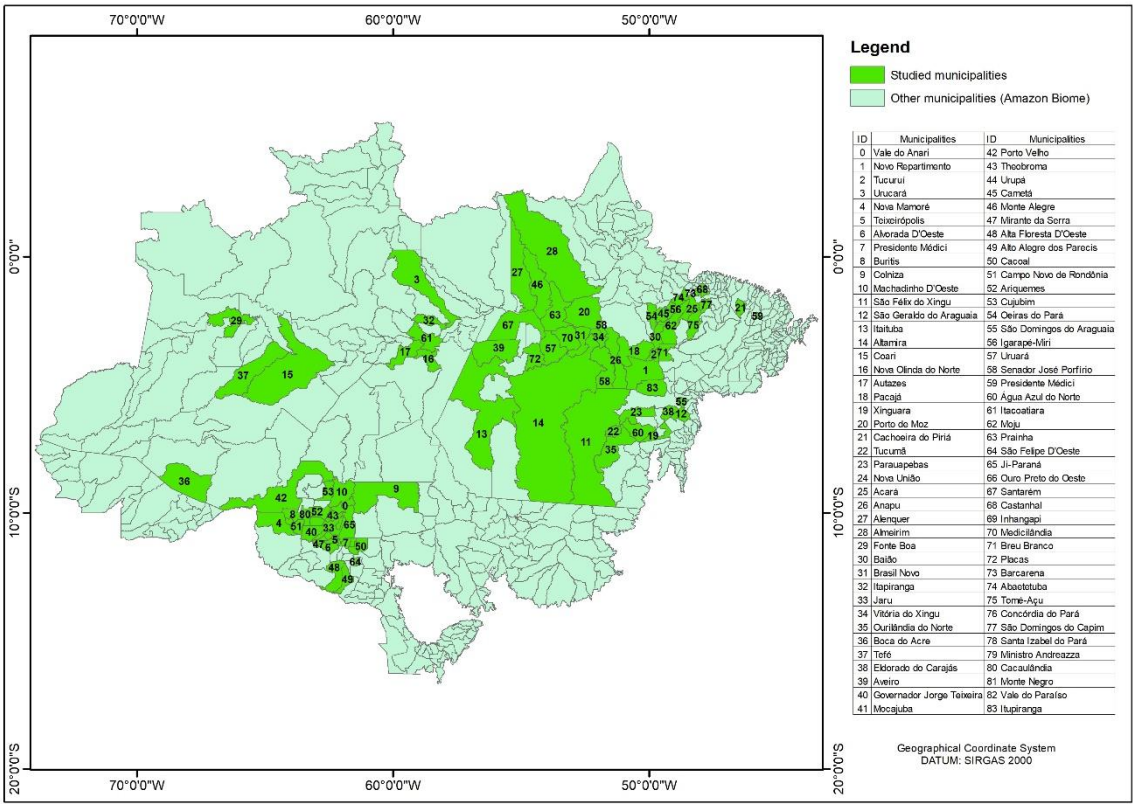
MATERIAL AND METHODS

At first, data were obtained regarding the edaphoclimatic adequacy of cocoa in a previous study (IGAWA, T.K., 2021). The edaphoclimatic adequacy was elaborated with the use of cocoa occurrence data and its relationship with bioclimatic variables through statistical models (*Classification and Regression Trees* (CTA), *Generalized Boosted Regression* (GBM), *Random Forest* (RF), *Generalized Linear Models* (GLM), *Generalized Additive Models* (GAM), *Multivariate Adaptative Regression Splines* (MARS), *Flexible Discriminant Analysis* (FDA), *Surface Range Envelope* (SRE), MaxENT and *Artificial Neural Network* (ANN)), in order to characterize climate adequacy. From this procedure, these data were cut in the areas of soils that best suit cocoa cultivation to determine the edaphoclimatic adequacy of cocoa in the Brazilian Amazon biome, that is, the regions most adapted from the pedological and climatic point of view to cocoa plantation for the current and future scenario (2050). This future projection for the year 2050 was chosen because it is a year to which projections such as that of FAO (2017) indicate reductions of 10 to 25% in world agricultural production. Therefore, this work will serve to investigate whether cocoa production will follow this same trend. The future climate scenarios chosen were RCP 4.5 and 8.5, because in the RCP4.5 scenario, there is a stabilization of methane emissions and a slight increase in carb dioxide by 2040, until reaching 650ppm of CO_2 in the second half of the 21st century. On

the other hand, RCP8.5, is the most pessimistic scenario, characterized by the sharp increase in carbon dioxide emissions, which considers that there will still be high dependence on fossil fuels and that there will be no effective public policy for reducing greenhouse gas emissions (SILVEIRA et al., 2016).

Finally, the final step of data collection occurred with the collection of data regarding the harvested area (ha) and the quantity produced (ton.) of cocoa in the Municipal Agricultural Production database of the Brazilian Institute of Geography and Statistics (IBGE) for the year 2019 for 84 municipalities in the Brazilian Amazon which are in the areas contemplated by the edaphoclimatic adequacy as can be seen in figure 1.

Figure 1. Location of cocoa producing municipalities in areas contemplated by edaphoclimatic adequacy



ID	Municipalities	ID	Municipalities
0	Vale do Anari	42	Porto Velho
1	Novo Repartimento	43	Theobroma
2	Tucuruí	44	Urupá
3	Urucará	45	Cametá
4	Nova Mamoré	46	Monte Alegre
5	Teixirópolis	47	Mirante da Serra
6	Alvorada D'Oeste	48	Alta Floresta D'Oeste
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9	Colniza	51	Campo Novo de Rondônia
10	Machadinho D'Oeste	52	Ariquemes
11	São Félix do Xingu	53	Cujubim
12	São Geraldo do Araguaia	54	Oeiras do Pará
13	Itaituba	55	São Domingos do Araguaia
14	Altamira	56	Igarapé-Miri
15	Coari	57	Uruará
16	Nova Olinda do Norte	58	Senador José Porfírio
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19	Xinguara	61	Itacoatiara
20	Porto de Moz	62	Moju
21	Cachoeira do Piriá	63	Prainha
22	Tucumã	64	São Felipe D'Oeste
23	Parauapebas	65	Ji-Paraná
24	Nova União	66	Ouro Preto do Oeste
25	Acará	67	Santarém
26	Anapu	68	Castanhal
27	Alenquer	69	Inhangapi
28	Almeirim	70	Medicilândia
29	Fonte Boa	71	Breu Branco
30	Baião	72	Placas
31	Brasil Novo	73	Barcarena
32	Itapiranga	74	Abaetetuba
33	Jaru	75	Tomé-Açu
34	Vitória do Xingu	76	Concórdia do Pará
35	Ourilândia do Norte	77	São Domingos do Capim
36	Boca do Acre	78	Santa Izabel do Pará
37	Tefé	79	Ministro Andreazza
38	Eldorado do Carajás	80	Cacaulândia
39	Aveiro	81	Monte Negro
40	Governador Jorge Teixeira	82	Vale do Paraíso
41	Mocajuba	83	Itupiranga

Source: Prepared by the authors

In order to identify whether the edaphoclimatic adequacy influences the disposition of the current cocoa production scenario and also whether

future scenarios will be transformed to the point of promoting possible indications of damage to cocoa production. An analysis of the correlation between production and productivity with edaphoclimatic adequacy was performed. For that, the RStudio program, version 1.1463, was used, which uses the programming language R (R CORE TEAM, 2020). To perform the correlation analyses of the data, the function 'cor.test' (HOLLANDER; WOLFE, 1973; BEST; ROBERT, 1975) was utilized. In addition, the graphs were elaborated through the use of the libraries 'ggplot2' (WICKHAM et al., 2020) and 'ggExtra' (ATTALI; BAKER, 2019).

From the performance of normality tests, it was possible to identify that the input data did not present a normal distribution, and so, Pearson's correlation was discarded. Thus, Kendall Tau-b's nonparametric correlation was chosen because it presented 'outliers' in the data of the variables analyzed and, therefore, it becomes more robust than Spearman's correlation (MIOT, 2018). The correlation intensity was classified according to Table 1, in which the values are expressed in module. Finally, a map was elaborated to identify the spatial distribution of the possible municipalities affected by climate change. The municipalities characterized as affected by future climate changes are those which are in different ranges of edaphoclimatic adequacy in the current scenario.

Table 1. Correlation strength.

r	Interpretation
0 - 0.29	Little or no correlation
0.3 - 0.49	Low correlation
0.50 - 0.69	Moderate correlation
0.7 - 0.89	High correlation
0.9 - 1	Very high correlation

Source: ASUERO et al. (2006).

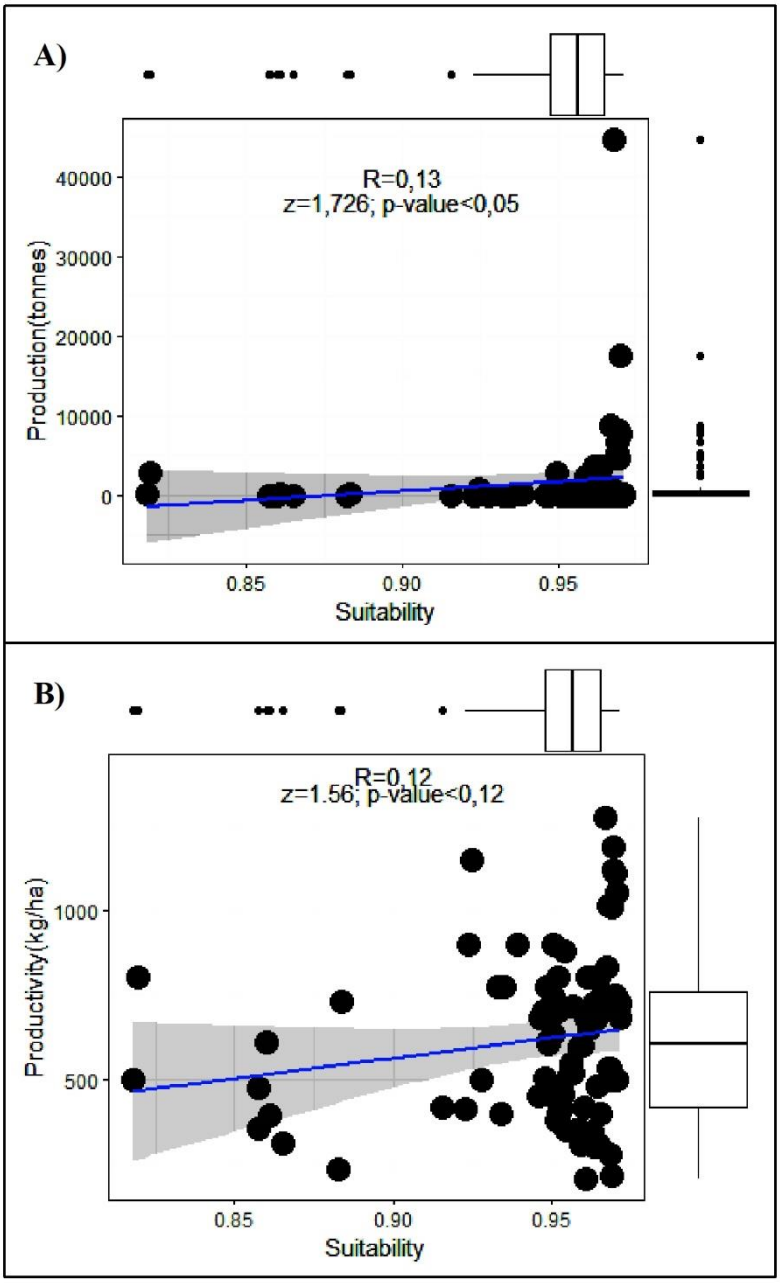
RESULTS AND DISCUSSION

The results indicated a positive relationship between production (ton.) and adequacy (Figure 2A), as well as between productivity (ton./ha) and edaphoclimatic adequacy (Figure 2B). However, they indicate low values of r (0.13 with values of p=0.05 and 0.12 with values of p=0.12), which, according to the interpretation of Asuero et al. (2006), represents little or no correlation. This may characterize that the current climatic conditions are favorable to the full development of cocoa. According to Figure 2, all producing municipalities which are located in soil areas adequate for cocoa cultivation, have adequacy above 0.8.

The decision to implement the cultivation of any agronomic crop requires a previous study of the edaphoclimatic characteristics of the property, thus, the anthropic influence on the choice of areas destined for cocoa plantation is the main factor that contributed to the low level of significance associated with the relationship of production and productivity with the edaphoclimatic adequacy. According to Figure 2, it is possible to prove what was mentioned above from the observation that most producing municipalities (68%) are in locations with edaphoclimatic adequacy above 0.95. In addition, Figure 2B indicated that only in municipalities with adequacy above 0.9 obtained productivity values above 1,000kg/ha.

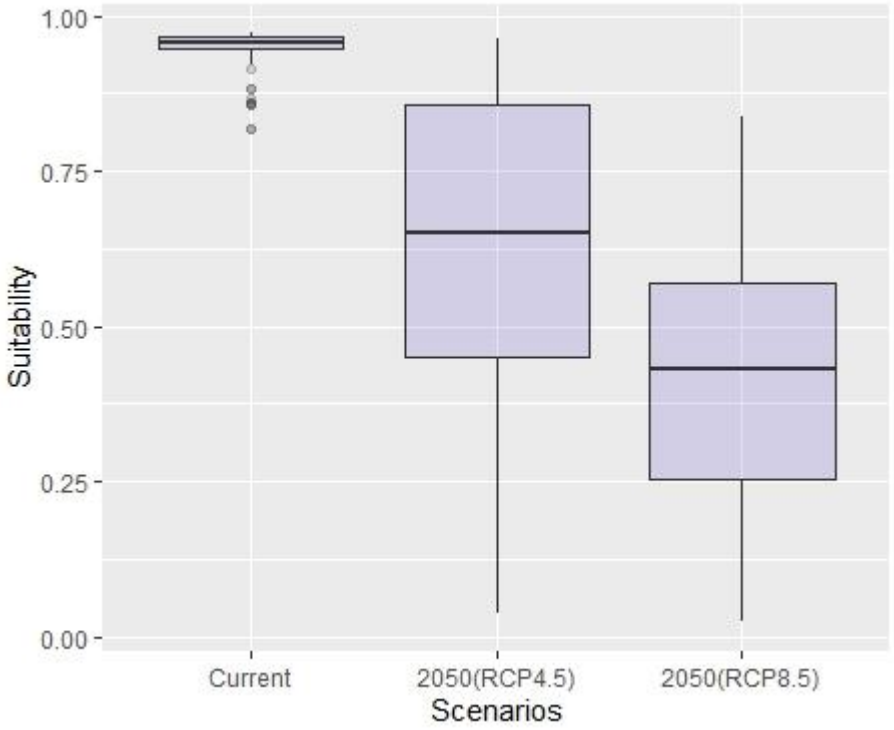
As shown in Figure 3, there is a probability of loss of cocoa productivity promoted by changes in the climate which may have a major impact on losses in edaphoclimatic adequacy. This may occur because these new climatic conditions may be unfavorable to the development of cocoa, because studies indicate that the environments in the forest biomes of South America will be warmer and drier by the end of the century (ANJOS, 2021). This indication of a warmer environment in future projections will contribute to hinder the development of cocoa (NIETHER et al., 2018), considering that it can indirectly cause greater stress in the physiological process of the plant due to an increasing evapotranspirative demand of the air (LÄDERACH et al., 2013).

Figure 2. (A) Relationship between cocoa production (tons) with edaphoclimatic adequacy (B) Relationship between productivity (kg/ha) with edaphoclimatic adequacy.



Source: Prepared by the authors.

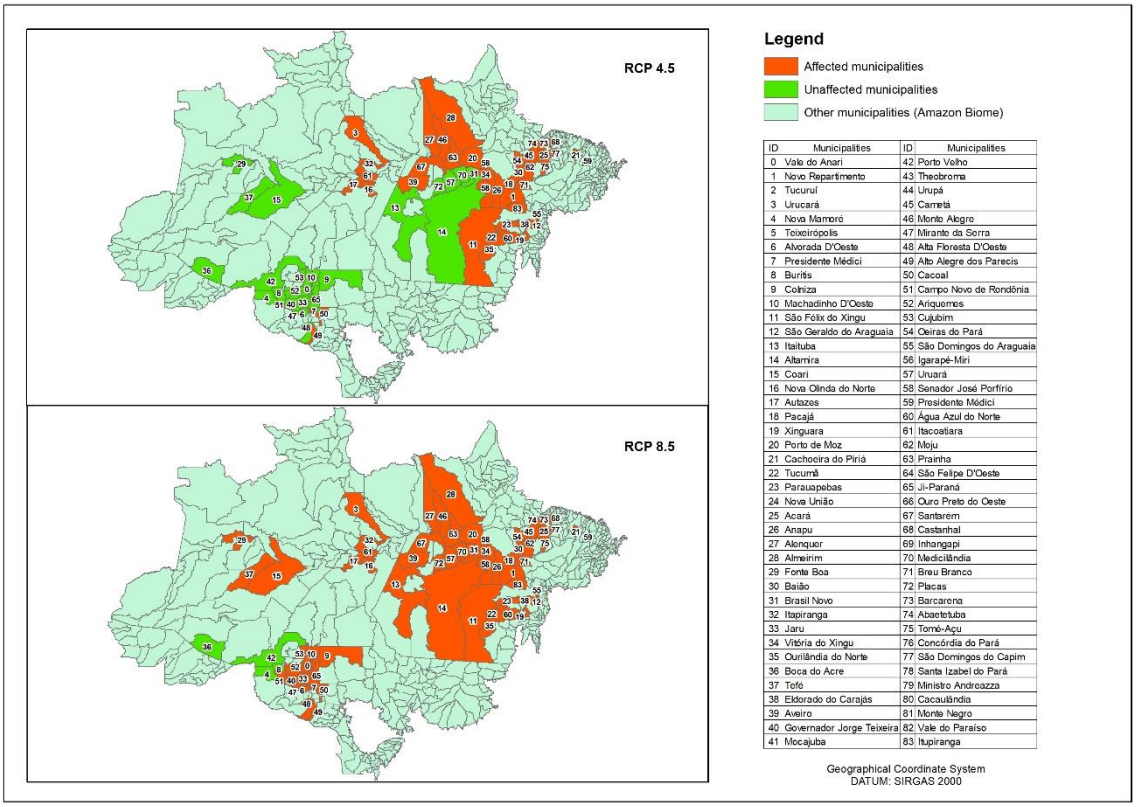
Figure 3. Relationship of edaphoclimatic adequacy and current and future scenarios (2050 - RCP4.5 and RCP8.5).



Source: Prepared by the authors.

According to Figure 4, it is possible to identify the spatial distribution of the pronounced reduction in the edaphoclimatic adequacy based on the high number of affected municipalities. In the RCP4.5 scenario, possibly 50 analyzed municipalities will be affected by climate change, representing 59.5% of the total number of municipalities analyzed. In the RCP8.5 scenario, which is considered the most pessimistic in relation to greenhouse gas emission scenarios, 95% of municipalities will be affected. All these municipalities are in a range of edaphoclimatic adequacy below the current scenario. Therefore, they will be affected in different degrees of impact, which will depend on the spatial variability of the changes in the climate.

Figure 4. Spatial distribution of municipalities affected by climate change in future scenarios (2050 - RCP4.5 and RCP8.5).



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Source: Prepared by the authors

Cocoa is considered sensitive to lack of water (DEALMEIDA; TEZARA; HERRERA, 2016). However, the projections characterize that climate change will cause a drier environment in the forest biomes of South America (ANJOS et al., 2021) which will promote damage to the development of cocoa, due to the high water demand of cocoa, which must be greater than 1,400 mm/year (LAHIVE; Hadley; DAYMOND, 2018). Water scarcity can cause a negative effect on leaf physiology (CARR; LOCKWOOD, 2011). In addition, the lack of water in the soil promotes the reduction in the production and growth of the cocoa tree (ALVIM; KOZLOWSKI, 1977), since younger plants are more fragile to water deficit than older plants. Therefore, a prolonged period of drought will have a significant impact on cocoa growth (MOSER et al., 2010).

Cocoa, because it is a native sub-forest plant of the Amazon rainforest (SCHROTH et al., 2004), is typically

cultivated in agroforestry systems (SOMARRIBA et al., 2013). According to Niether et al. (2018), agroforestry systems can dampen extreme weather conditions and reduce stress in cocoa. Such systems may promote several environmental benefits such as increased water and soil retention when compared to open pasture areas, which generally have inclined soils (SCHROTH et al., 2016). In addition, cocoa cultivation in agroforestry systems may also contribute to the increase in carbon sequestration, as storage may be 2.5 times more carbon than cocoa planted in the monoculture system, besides contributing to the reduction of average temperatures protecting from temperature extremes (NIETHER, 2020).

In view of the above, agroforestry systems emerge as an alternative for the sustainable use of land, which jointly enables the conservation of resources and the subsistence of the population (WALDRON et al., 2017; TSCHARNTKE et al., 2011; SAJ et al., 2017). Therefore, the cultivation of cocoa in agroforestry systems can be considered as a measure that increases the resilience of agricultural systems to climate change (ZOMER et al., 2016).

CONCLUSION

Therefore, it was possible to conclude that cocoa production and productivity have no or little correlation with edaphoclimatic adequacy, which may characterize that in these areas of cocoa cultivation, climate is not a limiting factor. In addition, it was possible to observe that in future scenarios the edaphoclimatic adequacy will probably drastically reduce what makes the climate become a limiting factor and that could cause losses to cocoa production in 2050. Thus, we see the need to carry out actions that prevent the worsening of climate change, such as combating illegal deforestation. As well as the implementation of climate change mitigation measures such as the use of Agroforestry Systems.

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