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Original article

Vulnerability and adaptive capacity in coffee plantations in the lowlands of Cuba in the face of climate change

Vulnerabilidad y capacidad adaptativa en cafetales de zonas llanas de Cuba ante el cambio climático

Yusdel Ferrás-Negrín[*], Ciro Sánchez-Esmoris, Noel Bermúdez-Ramírez, Merardo Julio Ferrer-Viva, Nosleiby Ortíz-Gómez

Unidad de Ciencia y Técnica de Base, Estación Experimental Agro-Forestal Jibacoa, Manicaragua, Cuba.

ABSTRACT: In recent years, the impact of climate change on coffee production has intensified. Coffee growers must implement agronomic practices in their production systems to adapt and minimize the risks of climate variations. The objective of the research was to analyze, through surveys, the vulnerability and adaptive capacity to climate change on coffee farms in low-lying, flat areas of Cuba, receiving technical advice. Coffee cultivation was established on four low-lying producer farms in central-western Cuba with specialized technical advice. The analysis of vulnerability and adaptive capacity to climate change was conducted using a diagnostic tool. Rising temperatures, decreasing rainfall and regularity, and the risk of hurricanes and tropical storms were the climatic variables that caused concern for producers. The agronomic actions implemented in the production systems allowed three of these to be classified as vulnerable with moderate adaptive capacity; and one to be classified as low vulnerability with high adaptive capacity. Farmers in the low-lying plains of west-central Cuba have an understanding of climatic variables related to coffee cultivation. Coffee farms using agroforestry systems with integrated technical practices have shown that coffee cultivation is possible while reducing vulnerability and increasing adaptive capacity to climate change.

Key words: adaptability, low altitude, *Coffea* spp, agroforestry systems, climatic variables.

RESUMEN: En los últimos años se ha intensificado el impacto del cambio climático sobre la producción de café. El caficultor debe implementar prácticas agronómicas en su sistema productivo para adaptarlo y minimizar los riesgos de las variaciones del clima. El objetivo de la investigación fue analizar a través de encuestas la vulnerabilidad y capacidad adaptativa al cambio climático en fincas cafetaleras asesoradas técnicamente en zonas llanas de Cuba con baja altitud. En cuatro fincas de productores con baja altitud en la zona centro-occidental de Cuba se estableció el cultivo del café con asesoría técnica especializada. El análisis de la vulnerabilidad y capacidad adaptativa al cambio climático se hizo con la herramienta de diagnóstico. El incremento de las temperaturas, la disminución de la cantidad y regularidad de las lluvias, y los riesgos de ocurrencia de huracanes y tormentas tropicales fueron las variables climáticas que causaron preocupación a los productores. Por las acciones agronómicas desarrolladas en los sistemas productivos, permitió que tres de estos clasifiquen como vulnerabilidad con capacidad adaptativa moderada; y uno se ubique entre esta categoría y vulnerabilidad baja con alta capacidad adaptativa. Los productores de las zonas llanas de baja altitud en el centro-occidente de Cuba, tienen percepción de variables climáticas que están relacionadas con el cultivo del café. Las fincas cafetaleras bajo sistemas agroforestales con la implementación integrada de actividades técnicas, reflejaron que es posible su cultivo con disminución al grado de vulnerabilidad y aumento en su capacidad adaptativa ante el cambio climático.

Palabras clave: adaptabilidad, baja altitud, *Coffea* spp, sistemas agroforestales, variables climáticas.

[*]Author for correspondence. yusdel.ferras@gmail.com

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INTRODUCTION

In the last two decades, a great interest has been expressed in agriculture to analyze and measure the effects of climate change (1). This is considered one of the greatest future challenges for humanity (2). It refers to significant variations in climatic parameters such as temperature and precipitation, where global warming is the most evident manifestation (3). Scientific evidence demonstrates the occurrence of this phenomenon (4). In the last ten years, its impact on coffee production has intensified worldwide; in this sense, it represents a challenge that coffee farmers must evade for their future prevalence, since altering the ecological characteristics for coffee cultivation can cause production losses between 20 and 80 % (5).

Coffee cultivation is very sensitive to changes in temperature and precipitation caused by the effects of climate change (6,7). In the last century, the Earth's temperature increased by 1 °C (±2); forecasts indicate increases between 1.2 and 3 °C by the year 2050 (8). These climatic variations are a threat to the future sustainability of coffee production (9). For these reasons, it is forecast that these global temperature increases will reduce the areas with the required conditions for coffee plants; even up to 50 % of the total by 2050 (5,10).

The effects of climate change on coffee ecosystems depend both on the sensitivity of the varieties used in this crop, as well as on the management of associated plants and other adaptation practices (10). Hence, it requires coffee growers, through the adoption of agronomic technologies and practices, to adapt their production system to minimize the risks that these climate variations may cause (11). Adaptation to climate change pursues the purpose of moderating its negative effects through actions aimed at the vulnerable system, as well as measures to take advantage of opportunities caused by climate change (6).

Therefore, this research was developed with the objective of analyzing, through surveys, the vulnerability and adaptive capacity to climate change in technically advised coffee farms in lowland areas with low altitude in Cuba.

MATERIALS AND METHODS

The research was conducted during the years 2024-2025 on four coffee farms located in lowland areas with low altitude above sea level, in agroforestry systems. These were located in different provinces of west-central Cuba (Table 1).

The coffee farms were established through constant technical advice and the execution of research projects carried out by researchers and specialists from the Jibacoa Agro-Forestry Experimental Station. Technical activities were implemented in an integrated manner on the farms, following the technical guidelines for coffee cultivation (12,13). In addition, technical criteria for sustainable coffee production in the face of climate change were added to these activities (13), in order to implement actions that mitigate existing limitations and achieve coffee farms with low vulnerability and high adaptive capacity to climate change.

Preparation and administration of the surveys

Surveys were applied to the producers of the four farms to gather their views on the impact of climate change on the vulnerability and adaptive capacity of coffee agroecosystems in lowland areas with low altitude. The diagnostic tool was used to determine vulnerability based on three fundamental variables: exposure, impact, and adaptive capacity (13,14) (Table 2). The assessment was based on the subjective information provided by the producer, taking into account their experiences and the observations made by the surveyor during farm visits.

Twenty-five questions were asked (Table 2). Each question had three response options: a) "Yes", the phenomenon positively influences the farm; b) "+/-", the phenomenon occurs at an intermediate level; c) "No", the phenomenon does not positively influence the farm.

Analysis of the surveys

The limitations that most strongly influence the coffee farms were identified by considering the producers who selected the "No" response criterion.

Once the 25 questions were answered, the result of the sum of the "Yes" criteria plus half the sum of the "+/-" criteria was subtracted from the result of the sum of the "No" criteria. Subsequently, vulnerability and adaptation to climate change were classified using a scale employed in similar studies (14,15) (Table 3).

For data analysis, Microsoft Excel spreadsheet software was used.

Table 1. Location, coffee species, and shade species of farms evaluated regarding vulnerability and adaptive capacity to climate change in low-lying low-altitude areas

Farm	Years since planting	Localization	Municipality, Province	Coffee species	Main shade tree species
1	3	23°01´960” N-82°11´380” W	San José, Mayabeque	Robusta	Albicia procera (*Albizia procera* (Roxb.) Benth.), Honduran mahogany (Swietenia macrophylla *G. King*.),
2	5	22°09´239” N-79°41´246” W	Fomento, Sancti Spíritus	Robusta	Purging nut (*Gliricidia sepium* (Jacq.) Kunth ex Walp.), avocado (*Persea americana* Mill.), mamey (*Pouteria sapota (Jacq.) HE Moore & Stearn*.).
3	7	22°93´42” N-81°79´26” W	Madruga, Mayabeque	Arábico	Avocado.
4	2	22°06´208” N-79°31´978” W	Cabaiguán, Sancti Spíritus	Robusta	Carob tree (*Samanea saman (Jacq.) Merr*)

Table 2. Assessment survey for vulnerability and adaptive capacity to climate change on coffee farms

No.	Questions on the effects of climate change on coffee production	Yes	+/-	No
Exposure variables				
1	Has temperature changed in recent years?			
2	Have rainfall patterns been irregular in recent years?			
3	Have intense rains with flooding and landslides increased?			
4	Is there a risk of hurricanes or tropical storms in your region?			
5	Have there been droughts in the area, or a decrease or lack of water on your property in recent years?			
6	Have there been strong winds, or have strong winds increased in recent years?			
Impact variables (sensitivity + exposure)				
7	Do most soils in the coffee plantations and other parts of the farm show signs of erosion?			
8	Have soils been decreasing in fertility in recent years?			
9	Is there irregular flowering on the coffee plants?			
10	Have pests and diseases increased in recent years?			
11	Is there an increase in leaf drop, flower drop, or coffee bean drop?			
12	Has the average coffee yield been decreasing in recent years?			
Adaptive capacity variables				
13	Are soil conservation practices lacking in most coffee plantations?			
14	Is the coffee plantation soil without weed or leaf litter cover?			
15	Is there very little diversity of trees, other crops, or wild animals in the coffee plantation?			
16	Are there areas of the coffee plantation in full sun with less than 20% shade or more than 70% shade?			
17	Is the coffee plantation more than 15 years old?			
18	Are coffee varieties resistant to diseases or resistant to high temperatures and droughts absent from your coffee plantation?			
19	Is the annual practice of pruning and sucker removal absent from your coffee plantation?			
20	Is the annual practice of coffee replanting absent?			
21	Is more than 200 kg ha^{-1} year^{-1} of nitrogen applied as chemical fertilizers?			
22	Is the practice of applying organic fertilizers and crop residues in the coffee plantation absent?			
23	If there are water sources and streams on the farm, are most of these sources and streams without forest cover?			
24	Do most of the areas of the farm not used for coffee (other uses) have tree cover?			
25	Is organization for climate change mitigation and adaptation absent?			
Total				

Table 3. Classification categories for evaluating climate change vulnerability in coffee farms

Category	Score obtained in the assessment	
	From	To
Practically absent vulnerability, excellent adaptive capacity	20	25
Low vulnerability, high adaptive capacity	15	19
Moderate vulnerability and adaptive capacity	8	14
Fair vulnerability and adaptive capacity	1	7
Moderately critical vulnerability and adaptive capacity	-6	0
Critical vulnerability and adaptive capacity	-13	-7
Very critical vulnerability and adaptive capacity	-20	-14
Totally vulnerable with no adaptive capacity	-25	-21

RESULTS AND DISCUSSION

The climatic variables that most concerned the surveyed producers in lowland areas with low altitude regarding coffee cultivation were: increased temperatures, decreased quantity and regularity of rainfall, and the risks of hurricanes and tropical storms (Table 4). In the locality of Jibacoa, Manicaragua municipality, Cuba, producers had the same concerns regarding climate changes in recent years on coffee ecosystems in that area (16).

The perception of producers in these lowland, low-altitude areas regarding sea level is important, as they state that the climatic variables differ from those in mountainous areas where coffee is traditionally grown in Cuba. In this regard, they expressed that temperatures are generally higher and rainfall records are lower. From this perspective, many areas do not possess the optimal conditions for coffee cultivation.

Nevertheless, coffee cultivation can be promoted by increasing measures that mitigate the possible negative effects of these factors, which are exacerbated by climate change. Among these measures, it is important to increase practices that address the limitations identified as positive criteria within coffee agroecosystems (13).

Table 4. Constraints affecting vulnerability and adaptive capacity in coffee farms located in low-altitude lowland regions, Cuba

No.	Questions on the effects of climate change on coffee production	Farms			
		1	2	3	4
Exposure variables					
1	Has temperature changed in recent years?	X	X	X	X
2	Have rainfall patterns been irregular in recent years?	X	X	X	X
3	Have intense rains with flooding and landslides increased?				
4	Is there a risk of hurricanes or tropical storms in your region?	X	X	X	X
5	Have there been droughts in the area, or a decrease or lack of water on your property in recent years?	X	X	X	X
6	Have there been strong winds, or have strong winds increased in recent years?				
Impact variables (sensitivity + exposure)					
7	Do most soils in the coffee plantations and other parts of the farm show signs of erosion?				
8	Have soils been decreasing in fertility in recent years?				
9	Is there irregular flowering on the coffee plants?				
10	Have pests and diseases increased in recent years?				
11	Is there an increase in leaf drop, flower drop, or coffee bean drop?				
12	Has the average coffee yield been decreasing in recent years?				
Adaptive capacity variables					
13	Are soil conservation practices lacking in most coffee plantations?				
14	Is the coffee plantation soil without weed or leaf litter cover?				
15	Is there very little diversity of trees, other crops, or wild animals in the coffee plantation?				
16	Are there areas of the coffee plantation in full sun with less than 20 % shade or more than 70 % shade?				
17	Is the coffee plantation more than 15 years old?				
18	Are coffee varieties resistant to diseases or resistant to high temperatures and droughts absent from your coffee plantation?				
19	Is the annual practice of pruning and sucker removal absent from your coffee plantation?				
20	Is the annual practice of coffee replanting absent?				
21	Is more than 200 kg ha^{-1} year^{-1} of nitrogen applied as chemical fertilizers?	X			
22	Is the practice of applying organic fertilizers and crop residues in the coffee plantation absent?				
23	If there are water sources and streams on the farm, are most of these sources and streams without forest cover?				
24	Do most of the areas of the farm not used for coffee (other uses) have tree cover?				
25	Is organization for climate change mitigation and adaptation absent?	X		X	X

"X" indicates an affirmative answer to the question

The information obtained coincides with the perception of changes in climatic variables reported in studies conducted in Mexico, where it was found that in the Mazateca and Cuetzalan regions, between 73 and 84 % of producers have observed changes in climatic variables over the last 10 years, perceiving greater heat and higher temperatures; and that between 52 and 79 % of them stated that it rains less and irregularly (6). These authors noted that similar results were also identified in Central America and the Sahel region of Africa. In the Huasteca Potosina region, coffee producers agreed with what was reported for other areas, noting that extreme events related to climate variability are becoming more frequent and increasingly affect their production levels (17). Changes in heavy rainfall, drought, and increased temperatures are causing effects on coffee cultivation (5). This crop requires an adequate intra-annual distribution of rainfall and short dry periods (17).

It was noted that in Cuba there has been a trend of increasing temperature from 1951 to 2019, with the most recent decade (2010-2019) having the highest average temperature (16). Moderate and severe drought events in Cuba during the 1961-1990 period doubled compared to the 1931-1960 period; particularly for Villa Clara province, 11 seasonal drought periods were reported between 2000 and 2017, with a trend toward an increase in the dry season due to decreased rainfall in the May-June bimonthly period of the rainy season (18). In this regard, the climate in Cuba during the second half of the 20th century was characterized by an increase in air temperature, more frequent severe drought events, and an increase in the destructive capacity of prefrontal storm lines and severe local storms (4).

The coffee areas under agroforestry systems had between 4 and 6 limiting factors (Table 4). This yielded scores that resulted in three of these farms being classified as having moderate vulnerability and adaptive capacity, and one farm falling between this category and low vulnerability with high adaptive capacity; good physiological condition of the plantations was observed in these cases (Table 5).

Table 5. Classification of vulnerability and adaptive capacity of coffee farms in low-altitude lowland areas, Cuba

Score obtained in the assessment	Classification
11	Moderate vulnerability and adaptive capacity
14	
12.5	
14.5	Between moderate vulnerability and adaptive capacity and low vulnerability with high adaptive capacity

These results reflect that, under existing changing climate conditions and those projected for the future, it is vital to integrate technologies in pursuit of better and environmentally friendly coffee farming. In this sense, a relationship may exist between vulnerability and adaptive capacity and the productive stability of coffee ecosystems. In this regard, in coffee ecosystems in Jibacoa, Cuba, a lack of integration of the implemented technologies was observed, leading to 93.6 % of the diagnosed areas having moderately critical and critical vulnerability and adaptive capacity (16). In those results, 48.4 % of the respondents stated that their production has been tending to decrease in recent years. This analysis reflects that, in coffee plantations under agroforestry systems with the integrated implementation of technical activities, it is possible to cultivate coffee with a reduction in the degree of vulnerability and an increase in adaptive capacity to climate change.

There are diverse practices aimed at adapting to the effects of a changing climate on coffee cultivation; however, to define which may be most suitable, the particular characteristics of each area must be considered (10). Taking these criteria into account, one important aspect observed in this research is the need to establish coffee under agroforestry systems in lowland areas with low altitude. Shade in coffee plantations is related to all three variables considered in the assessment (exposure, impact, and adaptive capacity), helping to mitigate the effects of climate change on coffee cultivation. In this regard, significantly higher maximum temperatures ($p < 0.01$) were reported at the site without tree cover throughout the year (average 1.9 °C); furthermore, it was noted that under agroforestry systems, the maximum values of this variable were reduced by up to 7 °C (10).

Shade trees act as conditioners of areas for coffee planting in regions that present adverse conditions for cultivation. When the maximum temperature exceeds 22 °C, it can be reduced by 20% through the use of these practices (11). Shade reduces the impacts of rainfall intensity, thus diminishing its falling force and soil erosivity; it also regulates surface water runoff and contributes organic matter (10). In this sense, it has been demonstrated that the use of these systems provides important mechanisms to face the impacts of climate change (5,19).

The agronomic implementation of agroforestry system designs appropriate for each soil and climate condition contributes to making the production system more resilient to climate variations (20).

For coffee ecosystems in lowland areas of low altitude in Cuba, the importance of establishing shade tree species with economic value, such as avocado, was observed. Under these conditions, the coffee plants were seen to be in good physiological and productive condition. Furthermore, the income derived from avocado stimulates producers to implement integrated cultivation practices that contribute to resilience in the face of this changing climate, which creates adverse conditions for the proper development of these plants. In this regard, it has been reported that a lack of economic resources is associated with the low adaptive capacity that producers have to face climate change-related threats; high income is a condition that favors the implementation of adaptation strategies (6). This practice of crop diversification through shade tree species has been progressively adopted by farmers over time; it also contributes to improving adaptive capacity to climate change and the sustainability of coffee production (19).

CONCLUSIONS

Producers in the low-altitude lowland areas of west-central Cuba have a perception of the climatic variables that are related to coffee cultivation.

Coffee farms under agroforestry systems with integrated implementation of technical activities reflected that it is possible to cultivate coffee with a reduction in the degree of vulnerability and an increase in adaptive capacity to climate change.

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