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Review

Climate change mitigation and adaptation in Cameroon through cocoa and coffee-based agroforestry systems

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Received: 23 December 2024 / Accepted: 19 May 2025
Published online: 26 May 2025

Abstract
Climate change is increasingly disrupting global ecosystems, with agriculture in developing countries like Cameroon being particularly vulnerable, leading to reduced productivity and heightened food insecurity. In response, cocoa and coffee-based agroforestry systems offer a sustainable solution by enhancing biodiversity, sequestering carbon, and creating resilient farming practices. The objective of this study is to assess the role of cocoa and coffee-based agroforests in climate change mitigation and adaptation in Cameroon, addressing a notable gap in existing research. Using a comprehensive review of empirical literature, the study examines the environmental and socio-economic benefits of these systems. Results show that cocoa and coffee-based agroforests are primarily located in three of Cameroon's five agroecological zones namely the Western Highlands, Monomodal rainforest zone, and Bimodal rainforest zone, with coffee cultivation also extending into the Guinea High Savannah. These systems contribute to climate change mitigation through carbon sequestration by cocoa trees, associated vegetation, and soil, and are aligned with REDD+ goals. Additionally, they support adaptation by providing multiple ecosystem services such as food, improved soil fertility, erosion control, pollination, and biodiversity conservation, thanks to the integration of diverse crops and fruit trees. This shows that cocoa and coffee-based agroforests represent viable, sustainable agricultural practices that can enhance both environmental resilience and economic stability in Cameroon. Policy and institutional support are essential to increase farmer adoption, and further research is needed on optimal crop combinations and the role of land tenure security in promoting these systems. Strengthening these aspects will advance climate action and agricultural sustainability in Cameroon.

Keywords Agroforestry · Climate change · REDD+ · Sustainable agriculture · Cocoa-based agroforest · Coffee-based agroforest · Cameroon

1 Introduction

Climate change is one of the most pressing global challenges of the twenty-first century, driven primarily by human activities such as deforestation, burning fossil fuels, and industrial emissions [1, 2]. It results in rising global temperatures, more frequent and intense extreme weather events (like floods, droughts, and storms), sea-level rise, and in some cases, changes in ecosystem structure and functions. These impacts threaten biodiversity, food security, water resources, and human health [3–5]. Vulnerable regions, especially in the Global South, face disproportionate consequences, amplifying socio-economic inequalities [6]. In Cameroon, the effects of climate change are already being felt. Awazi et al. [7], and Tume et al. [8] have highlighted significant shifts in rainfall patterns coupled with flooding and droughts, which are

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threatening agricultural productivity, particularly in the north where farming is heavily dependent on seasonal rains. Moreover, rising temperatures are exacerbating water scarcity and health issues. Forest ecosystems, central to Cameroon's economy and carbon storage, are under threat from both climate change and deforestation [9], affecting local communities' livelihoods.

Cameroon's agricultural sector is a cornerstone of its economy, contributing approximately 22% to the GDP and employing over 60% of the population [10]. The sector includes a mix of subsistence farming and cash crops, with cocoa and coffee being central to both rural livelihoods and national exports. Cocoa, in particular, is a significant cash crop in the southern regions, with Cameroon ranking as the world's fifth-largest producer in 2020, generating around 290,000 metric tons [11]. Similarly, coffee (primarily Arabica and Robusta) also plays a crucial economic role, contributing to around 100,000 metric tons of production in 2020 [12]. Together, cocoa and coffee account for about 30% of Cameroon's agricultural exports, with cocoa contributing approximately 3% to the national GDP and coffee 1% [13]. Over 2 million Cameroonians rely on cocoa and coffee farming for their livelihoods, with both crops providing vital income and employment opportunities across various sectors, including farming, processing, and exportation [14].

The agricultural sector faces several challenges, including land degradation, fluctuating market prices, and the impacts of climate change. Climate change poses a significant threat to Cameroon's agriculture due to its reliance on rain-fed farming and diverse climatic zones. Shifts in rainfall patterns, higher temperatures, and extreme weather events have already negatively impacted crop yields and food security [15]. To address these challenges, sustainable agricultural practices, particularly agroforestry systems, are being recognized for their potential to enhance resilience. These systems integrate tree cultivation with crop production, offering ecological, economic, and social benefits. Agroforestry helps improve biodiversity, soil health, and water retention, while also promoting carbon sequestration, which can mitigate climate change [16]. In cocoa and coffee production, agroforestry practices can enhance the microclimate for crops and increase biodiversity by providing habitats for various species. Studies suggest that agroforestry systems sequester up to 35% more carbon than monoculture systems [17], while also improving soil fertility and moisture retention, which buffers crops against droughts and erratic rainfall [18, 19].

In addition to environmental benefits, agroforestry systems offer significant socio-economic advantages. They allow farmers to diversify income sources by providing alternative products such as fruits, nuts, and timber, which can be sold or consumed locally, improving both nutrition and economic stability [20]. In Cameroon, organizations like the International Fund for Agricultural Development (IFAD), the Center for International Forestry Research (CIFOR) and the World Agroforestry Centre are working with local communities to implement these sustainable practices. Government policies are also increasingly recognizing the importance of such practices for the future of Cameroon's agricultural sector. Agroforestry, particularly in cocoa and coffee-based systems, represents a promising solution for climate change mitigation and adaptation in Cameroon. These systems not only enhance agricultural productivity and resilience but also support cocoa and coffee farmers' livelihoods through income generation. Continued support by the government and non-governmental organizations of initiatives promoting cocoa and coffee-based agroforestry will be crucial to safeguarding Cameroon's agricultural sector, improving food security, and fostering sustainable development. The study therefore aims to explore the role of cocoa and coffee-based agroforests in climate change mitigation and adaptation, identifying gaps in research and suggesting improvements for future implementation.

2 Background information on climate, agriculture and agroforestry in Cameroon

2.1 The climate change context in Cameroon

2.1.1 Climate change impacts in Cameroon

Cameroon, located at the intersection of West and Central Africa, is experiencing significant climate changes driven by global warming. Fotso-Nguemo et al. [21] report that average temperatures in the country have risen by 1.5 °C since the 1970s, with projections suggesting an increase of 2.0 °C to 3.0 °C by 2050, especially in northern regions. Precipitation patterns are also becoming increasingly erratic, with more intense rainy seasons and prolonged dry spells, particularly in northern and central areas [22]. Cameroon's National Observatory on Climate Change (ONACC) and Meteo-Cameroon found a 10–20% reduction in annual rainfall in northern regions, disrupting agricultural cycles [23, 24]. The effects of these climate shifts on agriculture are profound, as the sector supports 70% of the population. Rising temperatures and altered rainfall are reducing crop yields, particularly for staples like maize, cassava, and rice [8, 25]. A 1 °C increase could reduce maize yields by up to 20% [26]. Livestock productivity is also declining due to heat stress, and aquaculture in coastal regions is suffering from rising sea levels and water temperatures [27]. These impacts threaten food security, exacerbate poverty, and drive rural–urban migration, contributing to social instability [28].

2.1.2 Vulnerabilities of cocoa and coffee production in Cameroon

Cocoa and coffee are critical cash crops for Cameroon, representing significant export revenues and employment opportunities. However, these crops are particularly vulnerable to the impacts of climate change (temperature sensitivity and precipitation challenges), which can compromise both yields and quality. Cocoa and coffee plants thrive in specific temperature ranges (Cocoa at optimal temperatures of 20–32 °C; Arabica coffee at optimal temperatures of 15–24 °C; and Robusta coffee at optimal temperatures of 22–26 °C). Research by Black et al. [29] indicates that an increase in temperature of just 2 °C could lead to a decline in cocoa yields by as much as 30%. In Cameroon, coffee, particularly Arabica, is sensitive to temperature increases, with optimal growing conditions being severely affected. Studies show that regions suitable for coffee cultivation may shift significantly, potentially reducing production areas in the highland regions of Cameroon. Both crops depend heavily on consistent rainfall. Increased variability in rainfall can lead to water stress, affecting flowering and fruiting. In Cameroon, a study by Bomdzele Jr and Molua [30] highlights that erratic rainfall patterns have already led to a 15% decrease in cocoa quality, as the beans are more susceptible to diseases when subjected to stress.

2.2 Cocoa and coffee-based agroforests in Cameroon

2.2.1 Definition and characteristics

Agroforestry is a land-use strategy that combines crop cultivation with woody perennials and/or livestock/pasture to create diverse, productive, and sustainable systems. It typically involves growing crops alongside trees, which enhances soil fertility, improves microclimates, and provides shade. Agroforestry systems may include trees with crops, livestock, or perennials, such as fruit and nut trees, and can integrate all three elements in agrisilvipastoral systems. These systems promote biodiversity, soil health, resilience to climate change, and offer diversified income sources [31]. In Cameroon, cocoa (*Theobroma cacao*) and coffee (*Coffea* spp.) are key cash crops, often cultivated in agroforestry systems. Cocoa is grown in the humid forest regions, and coffee in the highlands, typically intercropped with trees like banana, plantain, and timber species. Cocoa-based systems involve shade trees that protect crops from excess sunlight and boost biodiversity, with species like rubber trees and legumes improving soil fertility. Coffee is cultivated under shaded conditions, which help maintain humidity and reduce erosion. Shade trees in both systems can also provide additional income through fruit or timber sales. These agroforestry practices have been shown to increase crop yields, reduce pest damage, and enhance carbon sequestration, supporting climate change mitigation [32–34].

2.2.2 Historical and current practices

2.2.2.1 Evolution of cocoa and coffee agroforestry practices in Cameroon Cocoa and coffee cultivation in Cameroon dates back to the colonial era, with cocoa introduced in the late nineteenth century and coffee shortly thereafter. Initially grown in monoculture systems, these crops caused significant environmental degradation and reduced soil fertility. By the mid-twentieth century, the negative impacts of monoculture prompted a shift toward agroforestry, which integrates trees with cash crops. Research by Tsufac et al. [35, 36] demonstrated that agroforestry could enhance yield stability and reduce reliance on chemical fertilizers. The adoption of agroforestry systems, incorporating shade trees, improved soil quality and pest control. By the late twentieth century, stakeholders including government and non-governmental organizations (NGOs) began promoting sustainable practices, leading to agroforestry training for farmers. Today, sustainable intensification practices focus on integrated pest management (IPM), agroecological techniques, and organic farming. Certification schemes like Fair Trade and Rainforest Alliance support sustainable production while offering farmers better market access.

2.2.2.2 Comparative analysis with other agricultural systems Cocoa and coffee-based agroforestry systems offer several advantages over conventional agricultural systems, particularly in biodiversity, ecosystem services, soil health, economic viability, climate resilience, and socio-economic impacts. These agroforestry systems typically support greater biodiversity, aiding pollination and pest control [37], whereas monoculture systems often cause habitat loss. The presence of trees enhances soil health through organic matter and nitrogen fixation, unlike monocultures that degrade soil over time [38]. Although monoculture systems may generate higher short-term profits, agroforestry provides long-term economic stability through diverse income streams [39]. Agroforestry systems are more resilient to climate variability, with tree cover moderating temperature and conserving moisture, reducing drought risks [40]. Additionally, cocoa and coffee agroforestry promote social cohesion and community cooperation, fostering sustainable farming practices [41]. These systems thus offer a more sustainable and resilient alternative to other agricultural practices such as monoculture.

2.3 Geographical distribution of cocoa and coffee-based agroforests in different agroecological zones of Cameroon

Cameroon has significant agroecological diversity, essential for the cultivation of cash crops like cocoa and coffee. Out of Cameroon's five agroecological zones (Fig. 1), cocoa and coffee thrive in four which are the Western Highlands, Monomodal Rainforest zone, Bimodal Rainforest zone, and the Guinea High Savannah, each offering unique environmental conditions that impact crop productivity. The Western Highlands, with its cooler climate and volcanic soils, supports high-quality Arabica coffee cultivation at elevations between 1200 and 2400 m. Agroforestry systems here often combine coffee with shade trees like *Grevillea robusta*. Cocoa is less common but emerging in lower-altitude areas. The Monomodal Rainforest Zone, experiences a single rainy season and high humidity, making it ideal for both cocoa and Robusta coffee. Its soils, though acidic, are rich in organic matter, benefiting from traditional agroforestry practices that include banana and cassava. The Bimodal Rainforest Zone has two distinct rainy seasons and fertile soils that support both cocoa and coffee. Cocoa is a key export, and farmers in the western part of this zone grow coffee using intercropping techniques with shade trees. The Guinea High Savannah Zone, with its tropical savannah climate and lower rainfall, is less favorable for cash crops. However, cocoa and coffee are still cultivated in areas with better soil, particularly near riverbanks. Agroforestry in this zone often focuses on drought-resistant crops to adapt to the variable climate.

Soils vary across agroecological zones with volcanic soils in the Western Highlands which are fertile and retain moisture, ideal for Arabica coffee, while the acidic ferralsols of the Monomodal Rainforest Zone require some soil management

Fig. 1 Map showing Cameroon's five agroecological zones (Source: Perini et al. [42])

techniques for cocoa cultivation. In the Bimodal Rainforest Zone, acrisols and luvisols are fertile when properly managed, with farmers enhancing soil quality through organic amendments and intercropping. The Guinea High Savannah Zone has podzolic soils, which benefit from soil conservation practices to improve productivity. Other ecological factors, such as biodiversity, pest management, and land use, also impact agroforestry practices. Rich biodiversity aids in pest control and pollination, but diseases like cocoa swollen shoot virus and coffee leaf rust have led to integrated pest management strategies. Farmers are shifting from mono-cropping to more sustainable, polyculture systems.

3 Methodology

This study adopts a systematic review methodology to analyze empirical research on sustainable agricultural approaches for climate change mitigation and adaptation in Cameroon, with a focus on cocoa and coffee-based agroforests. The review process involved several key steps, including literature identification, selection criteria, data extraction, and synthesis of findings (Fig. 2). The search for relevant studies was conducted using three major academic databases: Google Scholar, Scopus, and Web of Science (WoS). The search was limited to studies published between 2015 and 2024, using keywords such as climate change, sustainable agriculture, cocoa-based agroforests, coffee-based agroforests, climate change mitigation, climate change adaptation, and Cameroon. Boolean operators were used to combine these terms and refine the search results. Only empirical studies published in English were included, excluding articles written in other languages and non-empirical studies. The initial number of publications identified were 217. After screening (reading

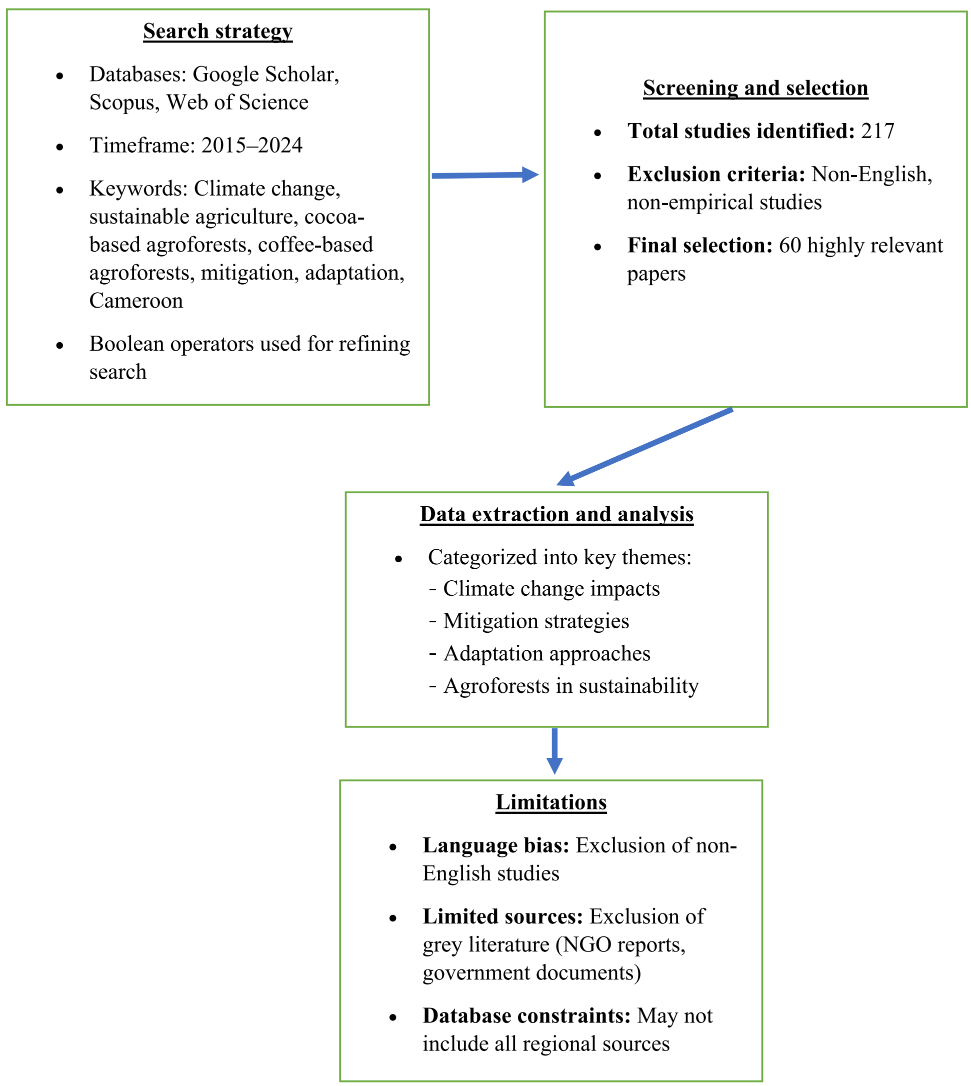

Fig. 2 Schematic presentation of the methodology used in the study

the titles and abstracts of each publication), all publications for their relevance to the research topic, a total of 60 papers were retained for data extraction. The data extracted from the selected studies were categorized into key themes, such as climate change impacts, mitigation strategies, adaptation approaches, and the role of agroforests in sustainability. The methodology however has some limitations such as the exclusion of non-English language publications which may have resulted in language bias, particularly in a multilingual country like Cameroon. Additionally, the focus on peer-reviewed studies may have overlooked valuable grey literature, such as government reports or publications from NGOs. Lastly, the databases used may not have captured all regional sources, which may affect the comprehensiveness of the review.

4 Results and discussion

4.1 The role of cocoa and coffee-based agroforests in climate change mitigation in Cameroon

4.1.1 Carbon sequestration potential of cocoa and coffee-based agroforests

Agroforestry systems, particularly those involving cocoa and coffee, have shown substantial potential for carbon sequestration. Carbon storage in these systems occurs through several mechanisms including aboveground biomass, belowground biomass, soil carbon storage, diversity of associated species. Cocoa and coffee trees sequester carbon in their biomass, including trunks, branches, and leaves. According to a study by Afele et al. [43], mature cocoa trees can store between 30–40 tons of carbon per hectare, while coffee trees contribute an additional 5–10 tons per hectare, depending on management practices and tree density. Root systems of cocoa and coffee trees contribute to carbon sequestration as well. The decomposition of roots and associated soil organic matter enhances soil carbon stocks. Niether et al. [44] found that agroforestry systems could increase soil carbon content by up to 25% compared to monocultures. The incorporation of organic matter from fallen leaves and decomposed plant material enriches the soil, improving its carbon storage capacity. Studies have shown that agroforestry systems can improve soil structure and increase microbial activity, further enhancing carbon sequestration [45, 46]. The integration of diverse tree species in cocoa and coffee plantations can enhance overall carbon storage. For instance, shade trees not only provide canopy cover but also contribute to higher biomass accumulation, thereby increasing the carbon stock. A study by Rai et al. [47] emphasizes that multi-species systems can sequester up to 50% more carbon than single-species systems.

Cocoa and coffee trees, along with associated trees, play a pivotal role in the carbon sequestration process in Cameroon (Table 1). Cocoa trees themselves are significant carbon sinks. The structure and longevity of cocoa trees allow them to sequester carbon over extended periods. Additionally, the management practices, such as pruning and maintenance, can enhance their carbon storage capabilities. Shade trees, such as *Gliricidia sepium* and *Albizia* spp., provide critical canopy cover that protects cocoa and coffee plants from excessive sunlight and maintains humidity levels. These species not only contribute to carbon sequestration through their biomass but also improve the overall health of the agroecosystem, leading to increased productivity and sustainability. Healthy soils are vital for effective carbon sequestration. Practices such as cover cropping and mulching can improve soil organic matter, leading to higher carbon retention. Research by Jhariya et al. [48] indicates that maintaining soil cover through agroforestry practices can enhance soil carbon levels by improving water retention and nutrient availability.

Cocoa agroforestry systems (CAFS) in Cameroon exhibit substantial variability in carbon stocks, influenced by their regional and ecological contexts. Nguekeng et al. [49] identified cocoa agroforests in the forest-savannah transition zones as having carbon stocks ranging from 46.83 tC/ha in Nyamsong to 92.03 tC/ha in Mouko. Similarly, Nijmeijer et al. [50] reported a carbon stock of 72 Mg C/ha in the forested Centre region, aligning with Zekeng et al. [51] findings of 186.97 ± 86.06 Mg C/ha in the same region. These disparities underline the influence of biophysical conditions and management intensity on carbon sequestration. Traditional cocoa agroforests, characterized by minimal disturbance, store significantly more carbon than innovative systems. Madountsap et al. [53] noted that traditional systems hold 138.1 tC/ha, compared to 46.9 tC/ha in innovative setups. This highlights the trade-offs between modernization and carbon storage efficiency. Additionally, systems that integrate non-wood forest products (NWFPs) and timber achieve higher carbon stocks than those dominated by oil palm or unshaded cocoa fields, as evidenced by Sonwa et al. [58]. Soil carbon stocks contribute notably to total carbon sequestration. Sonwa et al. [57] documented that soil under cocoa agroforests in southern Cameroon stores 37 Mg/ha, with the remaining biomass storing 206 Mg/ha collectively. This emphasizes the holistic role of soil and plant components in carbon dynamics. The cumulative benefits of cocoa agroforests over time. Silatsa et al. [56] calculated that cocoa and fallow systems sequester up to 200 Mg C/ha over 30 years, equating to

Table 1 Cocoa and coffee-based agroforestry systems and their carbon sequestration potential in Cameroon

Agroforestry systems/practices	Carbon sequestration potential	Region/country	References
Cocoa-based Agroforest in the Forest and Savannah Transitions	The carbon stock in cocoa-based agroforests for the villages of Mouko, Rionong, and Nyamsong stands at 92.03, 55.18, and 46.83 tC/ha, respectively	Cameroon	[49]
Cocoa-based agroforestry systems in the forested Centre region	72 Mg C ha^{-1}	Cameroon	[50]
Cocoa-based agroforestry systems in the forested regions	186.97 ± 86.06 Mg C ha^{-1}	Cameroon	[51]
SODECAO Agroforestry System in the forested Centre region	100 Mg Cha^{-1} for total carbon stock. Carbon stocks for cocoa plants and shrub/tree species integrated is 30 and 70 Mg Cha^{-1}, respectively	Cameroon	[52]
Cacao agroforestry systems of different age and management intensity in the forested Centre region	Traditional cocoa agroforests store three times more carbon, with a carbon stock of 138.1 t C ha^{-1}, compared to innovative cocoa agroforests, which have a carbon stock of 46.9 t C ha^{-1}	Cameroon	[53]
Perennial Crop-Based Agroforestry Systems in the Humid Forest Zone	In the rubber-based agroforestry system, the carbon stock is 36.3 Mg C/ha. For the cocoa-based agroforestry system, the carbon stock is 6.23 Mg C/ha. In the oil palm-based agroforestry system, the average above-ground carbon is 72.5 MgC/ha	Cameroon	[54]
Theobroma cacao agroforests in the forested Centre region	Total Carbon stock of live trees was on average 70 t ha^{-1}	Cameroon	[55]
Cocoa and fallow agroforest systems in the forested centre region	For a period of 12–13 years, cocoa and fallow agroforests sequester a maximum of 6.3 and 6.9 Mg C ha^{-1} $year^{-1}$, respectively. Over a 50-year period, total carbon stocks range between 6.9 and 0.2 Mg C ha^{-1} $year^{-1}$, respectively. In 30 years, cocoa and fallow agroforests sequester a total of 200 Mg C ha^{-1} of carbon	Cameroon	[56]
Smallholder chocolate agroforest in the southern forested region	In southern Cameroon, chocolate agroforests store a total carbon of 243 Mg ha^{-1}. The soil under cocoa agroforest stores 37 Mg ha^{-1}. Plants associated with cocoa, cocoa trees, litter, and roots store 170, 13, 4, and 18 Mg of carbon ha^{-1}, respectively	Cameroon	[57]
Cocoa-based Agroforests in the Forest Landscape of the Southern forested zone	Associated plants in cocoa agroforests are significant carbon stores, accounting for up to 70% of the system's carbon. Agroforests with Non-Wood Forest Products (NWFPs) and timber store over twice the amount of carbon compared to those dominated by oil palm and Musa. Additionally, NWFPs and timber contribute more than 2.5 times the carbon found in cocoa systems with high cocoa densities and over 3.3 times that of unshaded cocoa fields	Cameroon	[58]
Coffee agroforestry systems in the west region	24.28 tC/ha of carbon	Cameroon	[59]
Coffee-Based Agroforestry Systems (interspersed with *Canarium Schweinfurthii* (Engl) (Burseraceae)	67.7 ± 13.05 tC/ha	Cameroon	[60]
Cocoa Agroforests in the Southern forested zone	Cocoa agroforests sequester approximately 22.51 ± 5.86 Mg C/ha of carbon, while the associated trees within these agroforests store approximately 124.20 ± 60.05 Mg C/ha of carbon. In total, these cocoa agroforests contribute to storing around 146.71 Mg C/ha of carbon	Cameroon	[61]
Cocoa agroforestry systems	Contribute to REDD +	Cameroon	[62]

tC/ha tonnes of carbon per hectare, *Mg C* ha^{-1} megagrams of carbon per hectare

6.3–6.9 Mg C/ha annually. Such findings highlight the sustained carbon capture potential of agroforestry systems over decades. Coffee-based agroforestry systems in Cameroon, though less emphasized than cocoa, also contribute significantly to carbon storage. Temgoua et al. [59] found carbon stocks of 24.28 tC/ha in the western region, while Tsewoue et al. [60] reported 67.7 ± 13.05 tC/ha for systems incorporating *Canarium schweinfurthii*. This demonstrates the potential of diverse agroforestry setups to enhance carbon sequestration compared to monoculture systems.

The REDD+ (Reducing Emissions from Deforestation and Forest Degradation) process aims to provide financial incentives to developing countries to reduce emissions from deforestation and invest in sustainable land management. In Cameroon, the REDD+ initiative has significant implications for cocoa and coffee-based agroforests in different ways including incentivizing sustainable practices, encouraging community involvement, Monitoring and Verification. There are however some challenges and trade-offs. REDD+ provides opportunities for farmers to adopt agroforestry practices that enhance carbon sequestration. By offering payments for ecosystem services, REDD+ encourages the integration of trees into agricultural landscapes, improving carbon storage potential. The success of REDD+ in Cameroon hinges on community participation. Engaging local communities in agroforestry initiatives not only helps in carbon sequestration but also improves livelihoods. According to Folefack and Darr [63], community-led agroforestry projects under the REDD+ framework have resulted in increased carbon stocks while enhancing food security. The implementation of REDD+ requires robust monitoring and verification systems to assess carbon stocks accurately. Agroforestry systems, including cocoa and coffee-based plantations, present unique challenges and opportunities for carbon monitoring. Advanced remote sensing technologies and participatory approaches can facilitate accurate assessments, as shown in the work of Karagiannopoulou et al. [64]. While REDD+ offers potential benefits, challenges such as land tenure issues, financial constraints, and the need for capacity building among local farmers can hinder its success. A study by van Noordwijk et al. [65] highlights the importance of addressing these challenges to ensure that cocoa and coffee-based agroforests can effectively contribute to carbon sequestration under the REDD+ framework.

4.1.2 Case studies on carbon sequestration from existing studies and projects in Cameroon

Several studies and projects have documented the carbon sequestration potential of cocoa and coffee-based agroforests in Cameroon with the most prominent being The Agroforestry Project in the Southwest Region, Cocoa Agroforestry Systems in the Littoral Region, Impact of Agroforestry on Soil Carbon Stocks, REDD+ Initiatives in Cocoa Plantations, Pilot Projects for Sustainable Cocoa Farming. A project implemented by the Cameroon Ministry of Agriculture and Rural Development in collaboration with NGOs focused on integrating shade trees into cocoa and coffee plantations. Initial assessments showed an increase in carbon stocks by 30% within 5 years due to improved biomass accumulation and soil health [66]. Research conducted by Ballesteros-Possú et al. [67] found that cocoa farms incorporating shade trees had an average carbon sequestration rate of 3.5 tons per hectare per year, compared to 2 tons per hectare per year in monoculture systems. The study emphasized the importance of tree diversity in enhancing overall carbon stocks.

A long-term study by Niguse et al. [68] measured soil carbon levels in coffee-based agroforests over 10 years. The results indicated an increase in soil organic carbon by 15% due to improved management practices, demonstrating the potential of agroforestry systems to enhance soil carbon storage. The partnership between local farmers and international organizations under the REDD+ framework has resulted in projects that not only enhance carbon sequestration but also provide alternative livelihoods. A case study in the southern part of Cameroon reported an increase in community income by 40% due to agroforestry practices, while tree diversity increased by 20% over 5 years [69]. A pilot project in the Center Region aimed at promoting sustainable cocoa farming practices demonstrated that integrating shade trees could lead to carbon sequestration rates of up to 6 tons per hectare per year. The findings, presented by Awazi and Tchamba [70], suggest that sustainable practices can be both economically viable and beneficial for climate change mitigation.

4.2 Role of cocoa and coffee-based agroforests in climate change adaptation in Cameroon and challenges

4.2.1 Role of cocoa and coffee-based agroforests in climate change adaptation

Cocoa and coffee-based agroforests in Cameroon are vital for enhancing resilience to climate change by improving food security, diversifying income sources, and fostering environmental sustainability. These agroforests enable farmers to grow multiple crops alongside cocoa and coffee, boosting food security and income diversification. According to Tsufac et al. [36], integrating food crops such as cassava, maize, and legumes with cocoa and coffee enhances dietary diversity and ensures year-round food availability. Intercropping also reduces crop failure risks by spreading exposure to climatic stresses, such as drought or heavy rainfall. Moreover, Michel et al. [71] found that agroforestry systems improve income stability for farmers by allowing the cultivation of a variety of cash and food crops, offering a buffer against market and climate shocks. Agroforests also play a significant role in soil health. Practices like planting leguminous trees (such as *Gliricidia sepium* and *Erythrina* spp.) improve soil fertility through nitrogen fixation. Tsufac et al. [35] report that agroforestry systems enhance soil organic matter and nutrient availability, boosting crop yields. These systems also prevent soil erosion, which is critical in Cameroon's mountainous regions prone to intense rainfall. Dissanayaka et al. [72] highlight that the root systems of trees and shrubs stabilize soil, reduce runoff, and protect topsoil, ensuring long-term agricultural productivity.

In terms of biodiversity, cocoa and coffee agroforests contribute significantly to pollination and habitat conservation. Agroforests support a variety of pollinators by offering diverse habitats and food sources, which is crucial for both cocoa and coffee yields. Toledo-Hernández et al. [73] found that farms with greater floral diversity hosted more pollinators, helping counteract the negative effects of climate change on pollinator populations. Furthermore, Shidiki et al. [74] emphasize that agroforestry systems conserve biodiversity by providing microhabitats for various species, thus supporting ecosystem resilience. Shade provision is another key benefit, as shaded cocoa and coffee plants are less vulnerable to heat stress and water scarcity. Tsufac et al. [75] show that the canopy in agroforests regulates microclimates, promoting stable growing conditions for both cash crops and associated plants, enhancing their climate resilience.

Cocoa and coffee-based agroforests are pivotal components of agricultural adaptation strategies in Cameroon, especially amid climate change. These agroforests, which combine traditional crops with shade trees, enhance biodiversity, improve soil health, and increase resilience to climate variability. Studies show these systems store significant amounts of carbon and provide habitats for various species [76, 77]. By integrating shade trees, they mitigate the effects of rising temperatures and erratic rainfall, improving microclimates and reducing heat stress on cocoa and coffee crops [78]. This stands in contrast to monoculture systems, which are more vulnerable to climate shocks and soil degradation.

Crop diversification, while enhancing food security and reducing dependence on single crops, does not offer the same ecological benefits as agroforestry systems, which provide greater ecological complexity [79]. Additionally, the integration of perennials with annual crops promotes better soil structure and nutrient cycling, ensuring long-term sustainability. Agroecological practices, such as organic farming and reduced chemical use, also support climate adaptation by improving soil fertility and water retention [35]. However, agroforests may be more effective in contexts where shade trees thrive. These systems also support ecosystem services like pollination, pest control, and soil enrichment [80]. Unlike drought-resistant crop varieties, which may be less accepted by farmers, cocoa and coffee agroforests leverage existing knowledge, offering a more accessible and resilient adaptation strategy that buffers against market fluctuations.

4.2.2 Challenges faced by cocoa and coffee farmers in adapting to climate variability

Cocoa and coffee farmers in Cameroon, face significant challenges in adapting to climate change, including limited resources, knowledge barriers, market pressures, and land tenure issues. Suh and Molua [81] highlight that lack of access to climate resilience information and financial constraints hinder cocoa and coffee farmers' adaptation to climate-smart practices in Cameroon. Traditional farming methods may be inadequate in the face of climate stress, and resistance to new practices is common. Chia et al. [82] stress that awareness programs and training on climate adaptation are key, yet often insufficient to meet the needs of cocoa and coffee farmers in Cameroon. Market volatility, as noted by Duguma et al. [83], deters cocoa and coffee farmers from making necessary investments in resilience, as fluctuating cocoa and coffee prices increase vulnerabilities in Cameroon. Moreover, insecure land tenure in Cameroon, as discussed by Fogang et al. [84] and Fogang et al. [85], prevents long-term investments in adaptive practices like cocoa and coffee agroforests, further compromising farmers' ability to cope with climate impacts.

4.3 Policy and institutional environment for cocoa and coffee agroforests in Cameroon

Cameroon's agricultural sector, particularly cocoa and coffee production, plays a vital role in its economy and the livelihoods of millions of farmers. The country has established several policy frameworks aimed at promoting sustainable agricultural practices, particularly agroforestry, in response to the challenges posed by climate change. Key national strategies include the National Agricultural Investment Plan (NAIP), which focuses on increasing productivity while ensuring environmental sustainability, and the National Adaptation Plan (NAP), which specifically promotes agroforestry as a means to improve biodiversity, soil health, and carbon sequestration. These policies align with international commitments, such as the Paris Agreement, to mitigate climate change impacts and adapt to environmental challenges.

Despite these frameworks, the implementation of agroforestry policies faces significant obstacles. The Ministry of Agriculture and Rural Development (MINADER) has initiated programs to integrate trees into farming systems, recognizing the ecosystem benefits of agroforestry. However, regional disparities and resource limitations hinder the effectiveness of these initiatives. Enow [86] notes that while national policies support agroforestry, their localized implementation is inconsistent, with many farmers unaware of its benefits or unable to access the necessary resources.

Several challenges undermine the adoption of agroforestry practices. The fragmented nature of policy implementation (due to the involvement of multiple organizations) creates confusion among farmers regarding available support. Furthermore, current agricultural policies often prioritize short-term productivity, such as subsidies for chemical fertilizers, which discourage organic and sustainable farming practices. This over-reliance on conventional methods has resulted in soil degradation, loss of biodiversity, and increased vulnerability to climate change. In addition, financial barriers are significant, with limited access to credit and insufficient financial incentives for smallholder farmers to invest in agroforestry. Studies like those by Gbetnkom and Khan [87] and Tambi [88] emphasize the importance of financial support in promoting sustainable practices for export crops like cocoa, but existing institutions do not cater to the needs of smallholders. Knowledge gaps also impede the widespread adoption of agroforestry. Agricultural extension services, which are critical for educating farmers, are often underfunded and inadequately staffed, particularly in rural areas [89]. This results in a knowledge deficit that limits farmers' ability to implement agroforestry effectively. Moreover, many farmers lack access to training programs, hindering their understanding of agroforestry techniques and their long-term benefits.

To address these challenges, several recommendations have been proposed. Policy enhancements should focus on integrating agricultural and forestry policies to ensure more cohesive and effective support for agroforestry. There is also a need for increased financial incentives, including improved access to credit for smallholders. Encouraging community-based initiatives, such as cooperatives, can promote collective action and knowledge sharing among farmers, making agroforestry more accessible. More incentives in the form of grant, easy accessibility to land and free provision of farm equipment to encourage youths to engage in cocoa and coffee production. Public awareness campaigns, demonstration farms, and pilot projects can help disseminate successful agroforestry models, while integrating agroforestry into educational curricula can build a new generation of farmers equipped with sustainable practices. Despite the promising potential of cocoa and coffee-based agroforests in Cameroon, significant knowledge gaps remain, particularly concerning the ecological interactions within these systems. There is a lack of detailed data on species interactions, soil health, pest dynamics, and biodiversity, which are crucial for optimizing agroforestry practices. Furthermore, socio-economic assessments that consider local communities' perceptions of climate change and traditional agricultural practices are limited. Long-term studies on the impacts of agroforestry on climate resilience, carbon sequestration, and yield sustainability are also needed. Additionally, there is insufficient research on the policy frameworks that influence agroforestry adoption, such as land tenure and agricultural subsidies. Lastly, integrating modern technologies like precision agriculture and remote sensing with traditional agroforestry practices could enhance sustainability and resilience, warranting further exploration. While Cameroon's policies recognize the value of agroforestry, their fragmented implementation, lack of financial incentives, and knowledge gaps hinder the widespread adoption of sustainable practices. Addressing these challenges through integrated policy frameworks, improved financial and technical support, and community engagement is essential for ensuring the long-term sustainability of cocoa and coffee production in the face of climate change.

5 Conclusion and future research directions

Cocoa and coffee-based agroforests in Cameroon play a critical dual role in mitigating and adapting to climate change. These systems demonstrate considerable carbon sequestration potential, with traditional cocoa agroforests storing up to 138.1 tC/ha and multi-species setups outperforming monocultures by up to 50%. The integration of shade trees and diverse plant species enhances both above- and below-ground carbon storage, while improved soil structure and microbial activity further support long-term carbon retention. Agroforestry also contributes to Cameroon's REDD+ efforts by aligning sustainable land use with climate finance mechanisms, though challenges such as land tenure and monitoring remain. Beyond mitigation, cocoa and coffee agroforests offer robust adaptive benefits. They improve food security and income stability by supporting crop diversification, while also enhancing soil health, reducing erosion, and fostering biodiversity. The canopy cover moderates microclimates, protecting crops from temperature extremes and erratic rainfall. However, farmers face barriers including limited access to resources, knowledge gaps, and insecure land rights, which restrict their capacity to adopt climate-resilient practices. Cocoa and coffee-based agroforests therefore offer a resilient, nature-based solution to climate challenges in Cameroon. To unlock their full potential, supportive policies, farmer training, and secure land tenure must be prioritized to scale up sustainable agroforestry practices across the country.

To address the gaps and enhance understanding of cocoa and coffee-based agroforests' role in climate change mitigation and adaptation, several research avenues should be pursued including ecological studies on species interactions, socio-economic assessments, longitudinal impact assessments, policy analysis and advocacy, integration of technology in agroforestry, community-based participatory research, and climate change modeling. Future research on cocoa and coffee-based agroforests should address ecological, socio-economic, policy, and technological aspects to enhance climate change mitigation and adaptation. Ecological studies should examine species interactions, nutrient cycling, and pest management while conducting long-term monitoring to assess system resilience under changing climatic conditions. Socio-economic research must explore farmers' perspectives, adaptive strategies, and socio-economic barriers, including gender roles, to promote equitable resource access. Long-term studies on carbon sequestration, soil health, and crop yields are essential for understanding the sustainability of these agroforestry systems. Policy analysis should assess land tenure, agricultural policies, and resource management to identify challenges and advocate for supportive frameworks. Technological innovations, such as precision agriculture, remote sensing, and mobile technology, should be explored for their potential to improve resource management and productivity. Community-based participatory research can ensure local engagement, integrating indigenous knowledge and fostering ownership of sustainable practices. Finally, climate modeling should predict the effects of climate change on cocoa and coffee agroforests, helping develop adaptation strategies. By addressing these research gaps, agroforestry systems can be optimized for resilience, productivity, and sustainability in the face of climate change.

Author contributions N.P.A wrote the main manuscript, prepared all tables, and reviewed and approved the manuscript for submission.

Funding No external funding was received for this study.

Data availability No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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