frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 06 March 2024
DOI 10.3389/fsufs.2024.1322568

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RECEIVED 16 October 2023
ACCEPTED 09 February 2024
PUBLISHED 06 March 2024

CITATION
Mbiafeu MF, Molua EL, Sotamenou J and Ndip FE (2024) Climate, agroecology, and farm returns: differential impacts with implications for agricultural progress in the face of climate change.
Front. Sustain. Food Syst. 8:1322568.
doi: 10.3389/fsufs.2024.1322568

Climate, agroecology, and farm returns: differential impacts with implications for agricultural progress in the face of climate change

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Climate change is expected to have differential impacts on different zones. In this study, we employed the Ricardian technique, estimated through ordinary least squares (OLS) to assess the impact of climate change on farmers' revenue. We use survey data from two distinct agroecological zones in Cameroon. Our results show that rainfall is the main climatic variable affecting farmers' revenue. The results are statistically different for the two agroecological zones. While rainfall in the dry season affects revenue in the western highland zone. No climatic variable seems to affect farm revenue in the bimodal forest zone. These results suggest that the abundance of forest in the bimodal zone maybe be shielding the zone from the effects of climate change. We therefore recommend that farmers employ water harvesting and low-cost irrigation methods to cope with changes in rainfall pattern especially in extended dry seasons. Facilitating farmers' access to climate information particularly with respect to the onset and cessation of rains will improve the planning of farm operations.

KEYWORDS
climate, agroecology, farm revenue, Ricardian analysis, agriculture

1 Introduction

Climate change is one of the grand challenges of contemporary society (Arora, 2019; IPCC, 2023). Its negative impacts have been consistent; historically and presently, affecting several facets of human civilisation. The importance of climate change to current society's developmental discourse stems from its interconnectedness with other facets of human development. The climate is linked to several of the United Nations Sustainable Development Goals such as health (WHO, 2021; Romanello et al., 2022; Moyo et al., 2023); sustainable consumption and production; and energy (Hernandez et al., 2020; Adedoyin et al., 2023). Additionally, climate change affects water availability with ensuing effects on women's labour time, and their welfare (Fonjong and Zama, 2023). Climate change has also been associated with conflicts (Koubi, 2019; Hendrix et al., 2023). There is ample evidence pointing to the fact that climate change will affect agriculture, impacting not just the world's objective of reducing food insecurity and poverty, but reducing poor people's ability to escape poverty. Eichsteller et al. (2022) posit that climate related changes are one of the most important exogenous factors that prevent farmers from transitioning from poverty to wealth. Such effects are expected to worsen given that heavy precipitations, floods and droughts are expected to be more recurrent by 2100 (Calvin et al., 2023; IPCC, 2023). Such effects warrant attention on climate change.

Although Climate change affects major facets of society, the agricultural sector, especially of developing countries, is positioned to be the hardest hit from climate change owing to the sector's reliance on climatic parameters like rainfall, precipitation, and temperature which are crucial for agricultural production (Mendelsohn, 2009; Arora, 2019; Ngoma et al., 2021; Filho et al., 2022; Molua, 2022; Pickson and Boateng, 2022; Bedeke, 2023). Thus, climate change has direct impacts on agriculture. Shocks related to climate change have an effect on all aspects of food security, including availability, access, utilization, and stability through effects on yields, production and distribution (Mahmood et al., 2019; Ilboudo Nébié et al., 2021). Moreover, poor smallholder farmers dominate the agricultural sector in developing countries with limited ability to cope either through mitigation or adaptation (Beg et al., 2002; Ali and Erenstein, 2017; Arora, 2019; Bedeke, 2023). This is particularly worrying as it sabotages efforts aimed at reducing poverty and food insecurity especially in developing countries which rely on these sectors for survival. Exacerbating this is the fact that most developing countries, especially in Africa are already plagued by poverty and food insecurity (Castañeda et al., 2018; Debela et al., 2021; FAO et al., 2022).

The importance of agriculture to developing countries cannot be overemphasised. It contributes to over 25% of GDP and employment, making it the main source of livelihood for most people (Cohn et al., 2017; World Bank, 2023). Moreover, it is argued to be an important sector for pro-poor growth (World Bank, 2023). Agriculture's importance for sustenance, fibre, building materials, biomass, and "green energy" remains sacrosanct (Sakai et al., 2022; Soto-Gómez and Pérez-Rodríguez, 2022; Viana et al., 2022; Sovacool, 2023). Its linkages with the environment are both a curse and a blessing. A curse in that it suffers the effect of climate change and a blessing in that it can preserve the environment through carbon sequestration and crop diversification which prevent biodiversity loss. While it also contributes to the preservation of the environment, agriculture related challenges are increasing, thus impeding societies' comprehensive reliance on agriculture and the photosynthetic pathway for sustainable food production (Hussain et al., 2022; Ward, 2022; Gobo and Marcheselli, 2023; Kasuga, 2023). This reliance on agriculture therefore puts it at the center of the climate change discourse. On the one hand, climate change effects on agriculture exposes the world to an existential threat. On the other hand, it warrants that more efforts should be geared at curbing the effects of climate change on the agricultural sector. It is therefore important to assess the effects of climate change on agriculture especially in a developing country context where majority of households rely on agriculture for survival.

Here, we estimate the impact of climate change on farm revenue. Although climate change has been argued to negatively affect agriculture, farmers have constantly sought adaptation measures to cushion against such impacts (Tesfaye et al., 2021; Ngaiwi et al., 2023; Tabe-Ojong et al., 2023). Hence making a statement whether climate change affects farmers income or not is an important empirical question. A question whose importance has dominated both local and international policy debates. Investigating the importance of climate change on farm income is important for several reasons. Firstly, farm income is important for food and nutrition security (Sibhatu and Qaim, 2017, 2018; Gupta et al., 2020; Ogutu et al., 2020; Ochieng and Ogutu, 2022). If climate change affects income, then it puts the lives of millions of people at risk of food and nutrition insecurity both at the local and national levels. Secondly, farmers are the main agents of change in rural areas with significant contributions to the rural economy. In fact, Terlau et al. (2019) posit that smallholders are primordial for attaining the SDGs. If their income is affected by climate change, it may stifle rural development efforts. Thirdly, these farmers are already at the mercy of the climate. Further reduction of their income may imply loss of ability to cope with a changing climate as income has been shown to play an important role in adaptation (Dhakal et al., 2022). Lastly, understanding which particular climatic variable is likely to affect farm revenue which guide policy effort at climate change mitigation.

Some previous studies have analysed the effect of climate change on farm income. In Nigeria, Ojo and Baiyegunhi (2021) reveal that rice farmers' net income reduced owing to climate change. A similar finding on negative income is reported across three southeast Asian countries (Abidoye et al., 2017a,b). They further reported that farmers had to alter their production calendars to accommodate such changes. This impact mostly results from extreme temperatures and erratic rainfall. Hossain et al. (2019) equally report that climate change reduces net farm income of farmers in Bangladesh. Our study differs from previous studies in different ways. Firstly, we add to the sparse literature on the effects of climate change on farmers' income in Cameroon. To our knowledge, only the studies by Molua, (2009, 2022) have evaluated the effect of climate change on farm income in Cameroon. This is surprising given that Cameroon like most developing countries is already exposed to climate change and its impacts (Molua et al., 2010, 2023; Molua, 2022; Bomdzele and Molua, 2023; Ngaiwi et al., 2023). Other studies from Cameroon have largely focused on adaptation strategies of farmers (Bele et al., 2011; Awazi et al., 2022; Ngaiwi et al., 2023). Secondly, Cameroon is usually referred to as "Africa in miniature" due to the existence of different agroecological zones which depict the African Continent (Molua, 2022). This suggests that the impact of climate change may differ with these agroecological zones, hence generalisations may be misleading. In line with this, our second contribution is that we focus on two distinct agroecological zones in Cameroon; the humid forest western highland and the Bimodal zone.

Climate change directly affects small farmers' ability to meet increasing food demand at the local level. Cameroon is a resource-rich country plagued with food insecurity concerns, partly because of the lack of due attention to the agricultural sector by the government (Amungwa, 2015; Fonjong and Wanki, 2019). The agricultural sector, which employs a high proportion of the population and over 90% of some rural populations in the less developed countries (Tume and Fogwe, 2018), and contributes about 30% of national income, is left in the hands of poorly equipped smallholders.

Food availability decline is an attribute of environmental tribulations, population growth, political instabilities, poorly conceived developmental policies, and fluctuation in food prices. It is also caused by natural disasters, and other socioeconomic factors, which impede household food security situation coupled with weak household asset accumulation (Arora et al., 2011). Food insecurity constitutes a humanitarian crisis in which approximately 23% of the population is undernourished in the SSA [Food and Agriculture Organisation (FAO), 2017].

Even with diverse climate change adaptation methods, such as local irrigation, delayed sowing dates, land conservation, two-season farming, and inter-cropping (Awazi et al., 2019), small-scale farming in Cameroon is increasingly threatened by climate change and climate variation.

Despite the plethora of studies knowledge gaps still exist to allow for a comprehensive policy response to address the climate related challenges faced by farmers. This is particularly relevant for a developing country like Cameroon, where Agriculturalists continue to suffer from climate variability as it exerts varying effects on crop yields. Farmers have therefore devised a variety of adaptation strategies that allow them to adjust to a changing climate. To employ a specific climate adaptation strategy, however, farmers must first experience climate change before implementing adaptation measures. According to Mukete et al. (2017), these adaptations are interventions and adjustments that occur in response to any external change to capitalize on opportunities or mitigate losses. Farmers may decide on the process of entry and exit of farming activities which continues to play an important role in maintaining competition in agriculture and allocating resources between agriculture and other sectors (Ahmad et al., 2023a,b).

Farmers frequently have multiple objectives, including financial success, independence, and production, which they may prioritize differently based on the circumstances. According to Leeuwis and Aarts (2021), the third set of perceptions relates to an individual's capability and propensity to adopt new behaviours considering available resources and present biophysical and sociocultural conditions. Like Glover et al. (2019), they emphasize the significance of aligning the recommended agricultural practices with producers' implementation capacities. Understanding farmers' response and adaptation techniques in Cameroon's various regions will aid in the creation of measures to enhance production to meet the need for animal protein while also supporting rural livelihoods (Tendonkeng et al., 2018).

The poor socioeconomic conditions of smallholder farmers in Cameroon make them vulnerable to negative impact of climate change. It is therefore important to implement resilience to the lives of farmers and use existing coping strategies to climate change. But before using the coping strategies, it is important to understand the perception of climate change by smallholder farmers in Cameroon.

To operationalize our study, we study the effect of climate change on farmers' revenue in two Agro ecological zones of Cameroon Western Highland and the Humid Rainfall Forest agro-ecological zones. The remainder of the paper is structured as follows. In section two, we discuss the empirical literature review and the state of agriculture and climate change in Cameroon. In section three, we provide a simple conceptual framework on how climate change affects farm revenue, while the materials and methods are presented in section four. We present and discuss the results in section five and conclude, give implications and limitations in section six.

2 Literature review

2.1 Empirical literature review

From the studies below it is clear that climate change continues to effect negatively the revenue of farmers and thus their financial status.

Gadédjisso-Tossou et al. (2016) employed a Ricardian modelling approach to measure the impact of climate change variables such as temperature and rainfalls on smallholder famers' crop net revenue in Togo. Their results showed that climate has a nonlinear effect on crop net revenue. In rainy season, the marginal impact of temperature on revenue shows that if the temperature increases by 1°C, the net crop revenue may fall by US$340.33/ha. On the other hand, if rainfalls increase by 10 mm, the net revenue may increase by US$35.5/ha. Consequently, policies aimed at improving those factors could improve smallholder farmers' wellbeing.

According to Hossain et al. (2020) the impact of climate change on farmland value is still very limited in developing countries. They studied the impact climate change on farmland value in Bangladesh with the help of the Ricardian model and their results showed that farmland values are sensitive to climate. Rainfall accompanied with flood is responsible to the reduction of the value of farmland especially in lowland areas. Among the socio-economic variables, the availability of extension services and access to irrigation facilities were positively correlated with farmland value. The estimated marginal impact results suggested that increases in temperature were associated with losses in small farmland value, whereas the precipitation levels in both seasons positively influenced farmland value. Sultan (2021) uses a Ricardian technique on a small territorial scale to assess the economic impact of climate change on agriculture for the Island of Mauritius, driven by the island's microclimate system. The Ricardian calculations demonstrated that the agricultural industry reacted unfavourably to variations in mean summer temperatures and precipitation using a cross-sectional farm data set of 392 farmers. With an elasticity of −0.13 assessed at mean temperature, the economic effects of a 1°C increase in mean temperature are US$26.6 per acre per year. At mean precipitation, the elasticity of mean farm revenue is 0.03. The results indicated that this island needs to invest in climate change adaptation measures.

Futhermore, Hossain et al. (2018) show that crop production may be impacted by climatic changes in both positive and negative ways. Nonetheless, the effects will be more pronounced in nations where agriculture is the main industry. They used the Ricardian approach to estimate the link between net crop revenue and climate variables in order to quantify the economic effects of climate change on crop cultivation in Bangladesh. The findings showed that Bangladesh's net crop income is influenced by the weather, especially the seasonal temperature. Farmers in locations with adequate irrigation facilities observed a favourable correlation between temperature rise and net crop income. According to estimated marginal impact, a monthly increase in rainfall of 1 mm and a temperature increase of 10°C will result in an increase in net crop income per hectare in Bangladesh of between US$4 and $15. The effects will, however, differ significantly in terms of location and season. Applying the Global Circulation Model predictions to the study, the predicted effect in net crop income for the nation was from US$25-84 per hectare.

Ali et al. (2021) pointed out that because of the scarcity of studies, knowledge about how climate change will affect crop production in Pakistan is still limited. They sought to fill this gap by analyzing the economic impact of climate change on net profits from crop production. Data of 635 farmers and climate change data were collected from five agro-ecological zones (AEZs) of KP (Khyber Pakhtunkhwa). Results using the Ricardian method showed that increases in annual mean temperature and decreases in precipitation are strongly associated with net revenue deficits. The impact of increased rainfall is observed to be beneficial, while increasing temperature is expected to have a negative impact on net revenues. Ojo and Baiyegunhi (2021) also investigated the determinants of climate change perception (CCP), level of awareness and its impact on net farm income of rice farmers. They used the Ricardian approach and the double hurdle model (DH). The results of the DH estimation model showed that farmers' location, access to credit, education level, and household size are statistically significant factors influencing climate change perception (CCP). Results for the second hurdle showed that the perceived severity of climate change is influenced by smallholder rice farmers' farm size, farming experience, marital status, and education level. The results of the Ricardian model showed that farmers' income was influenced by the CCP and farmers' socio-economic characteristics. The results also showed that the net income of rice smallholder farmers is sensitive to small changes in temperature and precipitation. Their study recommended that government policies and investment strategies should focus on educational support and improving farmer cooperatives, credit systems, and climate change information, especially for small-scale rice farmers in Nigeria.

It is obvious that a negative impact of climate change on farmers' income will have a significant negative influence on farmers' livelihoods, with some choosing to either adopt coping mechanisms or leave the farming industry in search of better living options. Despite the fact that the majority of the workforce is dependent on farming, farmers in agriculture-based countries like Pakistan frequently transfer from farming to off-farm activities as part of an apparent livelihood transition strategy (Ahmad et al., 2020). The authors (op cited) demonstrated that almost 19% of households have entirely switched from farming to non-farm pursuits.

The process of starting and stopping farming operations is still crucial to preserving the level of competition in the industry and dividing resources between it and other industries. The transition of rural household livelihood in the context of farm entry and exit decisions in rural Pakistan was investigated in a study by Ahmad et al. (2023a,b). The percentage of farm entry (24%) was found to be greater than the percentage of farm exit (15%). Crop inputs sold by farmers on net cash during the financial crisis, crop inputs used as credit with a large mark-up, climate shocks, and inadequate climate investment all had a significant role in the farm departure.

Additional analysis showed that awareness, perception, education, crop production, soil fertility and annual revenue are highly influential on farmers' climate change impacts adaptation. The findings revealed that effective adaptation to climate change impacts is highly dependent on the extent of community awareness and how farmers perceive the impacts of climate change (Shukla et al., 2019). To ensure the existence of the farm, according to Ahmad et al. (2023a,b), farm experience dramatically lowers the chance of farm exit and enhances the chances of adapting to climate change. Second, having cattle and land increases the likelihood that a farm will survive adaptation techniques and lowers the likelihood that the farm would close. Thirdly, farm exit is positively and significantly impacted by climate disasters. Fourthly, extension services have a negative and significant impact on adaptation methods and raise the likelihood that farms will quit if they do not obtain timely information on climate change adaptation measures.

2.2 Agriculture and climate change in Cameroon

The agricultural sector in Cameroon contributes 30% of the country's Gross Domestic Product, generates approximately 15% of the country's government revenue, and employs approximately 60% of the economically active population (MINADER, 2023). In addition, agricultural activity induces most spill-over effects on other economic sectors, thereby contributing to export diversification, employment creation, and poverty reduction (MINADER, 2023). Agriculture is the human activity most directly impacted by the effects of climate change in the country. Given agriculture's extreme vulnerability to the negative effects of climate change and the importance of this sector in Cameroon, it is imperative that mitigation and adaptation strategies continue to be implemented (IPCC, 2007, 2014).

Like most developing countries, Cameroon is not excluded from climate change impacts (Molua et al., 2010, 2023; Molua, 2022). It manifests through changes in temperature and rainfall. Already observed extreme events in Cameroon include more frequent and severe storms, rising temperatures, floods, mass migrations, droughts, strong winds, and soil erosion (PNACC, 2015). According to the PNACC (2015), the average rainfall in Cameroon between 1981 and 2000 was 20 to 40% lower than between 1961 and 1980. Since 1960, precipitation has decreased by approximately −2.2% per decade, or − 2.9 mm per month (PNACC, 2015). March, April, and May are the months in which this regression is most pronounced, followed by June and August. In addition, the duration of the rainy season is decreasing across the country. Thus, on a national scale, Cameroon obtains less precipitation annually, but it is more concentrated. Rainfall in Cameroon exhibits a high degree of geographical variability. Figure 1 shows the trend of average precipitation in Cameroon and the study areas considered. The figure shows considerable variation in precipitation both at the national level and in the study areas, though average precipitation in the latter is greater than that in the former. This suggests that these regions are some of the least affected by climate change in the country. Well, such zones are known for higher rainfall patterns. Going by the regions, the bimodal rainforest zone shows more variability relative to the Western highland zone. This is quite surprising since the bimodal rainforest zone has an abundance of forest, which can offset the impact of climate change through carbon sequestration.

Temperature change is another obvious form of climate change. Throughout Cameroon, temperatures have risen (PNACC, 2015). From 1960 to 2007, the average annual temperature in Cameroon rose by 0.7°C. This represents a rate of 0.15 degrees Celsius per decade on average. In Cameroon, all agroecological zones (AEZs) are experiencing an increase in average temperature. The months of March, April, and May typically have the highest growth rates with 0.19° per decade. However, in the Sudano-Sahelian AEZ, December, January, and February and September, October, and November have the highest warming rates, between 0.2 and 0.4 degrees per decade (IPCC, 2007). According to the IPCC (2007), sub-Saharan Africa's Sudano Sahelian AEZs, high savannahs, and forests with bimodal rainfall have experienced a temperature increase of between 0.22 and 0.47 degrees Celsius over the past five decades. The observations of Molua and Lambi (2007) indicate an increase of 1.04°C in the coastal AEZ, indicating that the temperature in Cameroon has risen by nearly one degree Celsius during the 20th century. Figure 2 shows the trends of temperature in Cameroon and the studied area. The figure shows that the country as well as the bimodal forest zone have relatively higher temperatures compared to the Western highland zone. The western highland zone is known for very low temperatures naturally. However average temperature has been on the rise at both the national

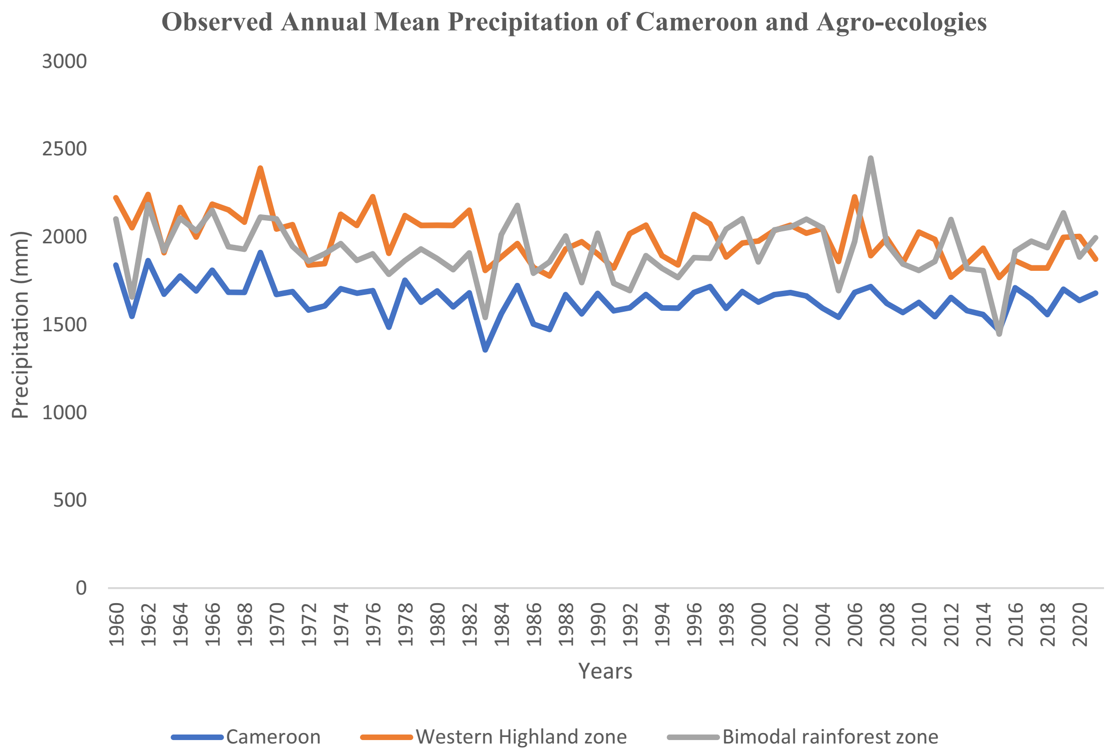

FIGURE 1
Annual precipitation of Cameroon and the study areas from 1960–2020. Source: constructed by authors with data from climate change knowledge portal (2023).

level and the study areas. While such changes may appear subtle, they may still cause significant impacts on the environment. For example, IPCC (2023) posits that changes of about 1.5°C are enough to exacerbate floods and droughts in the long run.

The figures show marked differences in climate change manifestations in different parts of the country suggesting that a one-size-fits all approach may be inappropriate in tackling climate change. It is therefore important to understand how these distinct agroecological zones are affected since the specificity of the zones warrants the cultivation of different crop types. While the impacts of climate change are glaring, there are very few studies that evaluate the impacts on agriculture especially on farm revenues. Some studies have rather evaluated the direct impact on crop production and they show varying impacts. For example, a study by Bomdzele and Molua (2023) show that climate change affects cocoa production while other studies have shown that it affects food crop production as well (Ngondjeb, 2013; Sotamenou and Saleu, 2013; Defang et al., 2014). This study provides additional empirical evidence on the impact of climate change on farm revenue in Cameroon.

3 Conceptual framework

The links between climate change and agriculture are obvious, especially in developing countries. Although climate change may take many forms, the most glaring manifestations are changes in temperature and rainfall (Molua, 2009; Yila et al., 2023). Changes in rainfall and temperature directly affect agricultural production which in turns affects farm revenue. In Figure 3, we provide a conceptual framework on how climate change affects our outcome variable of interest; farm revenue. Agriculture in developing countries is largely rainfed, hence changes in rainfall patterns will affect agriculture (Crost et al., 2015). Changes in rainfall alters agricultural calendar (Ochieng et al., 2016; Yila et al., 2023). Farmers usually plan their farming operations with the onset and cessation of rains. Hence, because of climate change, there may be a delay on the onset of rains, affecting farmers' plans and consequently production. For example, delays in the onset of rains imply a longer dry season and delayed planting. Also, some plants are highly sensitive to precipitation and the timing of their production matters. So as rainfall patterns change, it may affect necessary agronomic practices like germination, flowering etc. This may intend reduce agricultural production and yields. In Kenya, Ochieng et al. (2016) show that changes in rainfall patterns affect agricultural production. New diseases and pests may emerge and proliferate owing to changes in rainfall patterns (Mansaray et al., 2020; Han et al., 2023). For example, most insect pests thrive in the absence of rains. On the other hand, excessive rainfall may lead to rot of crops, affecting the aesthetic and economic value of crops and consequently, farm revenue.

On the other hand, temperature changes may also take a toll on agricultural production (Ochieng et al., 2016). Temperature increases provide a favourable environment for the proliferation of pests and diseases. These do not only affect the production of crops but also their aesthetic value. Like rainfall, excess temperatures may also affect important biological processes of plant growth such as planting and ripening reducing yields and farm revenue.

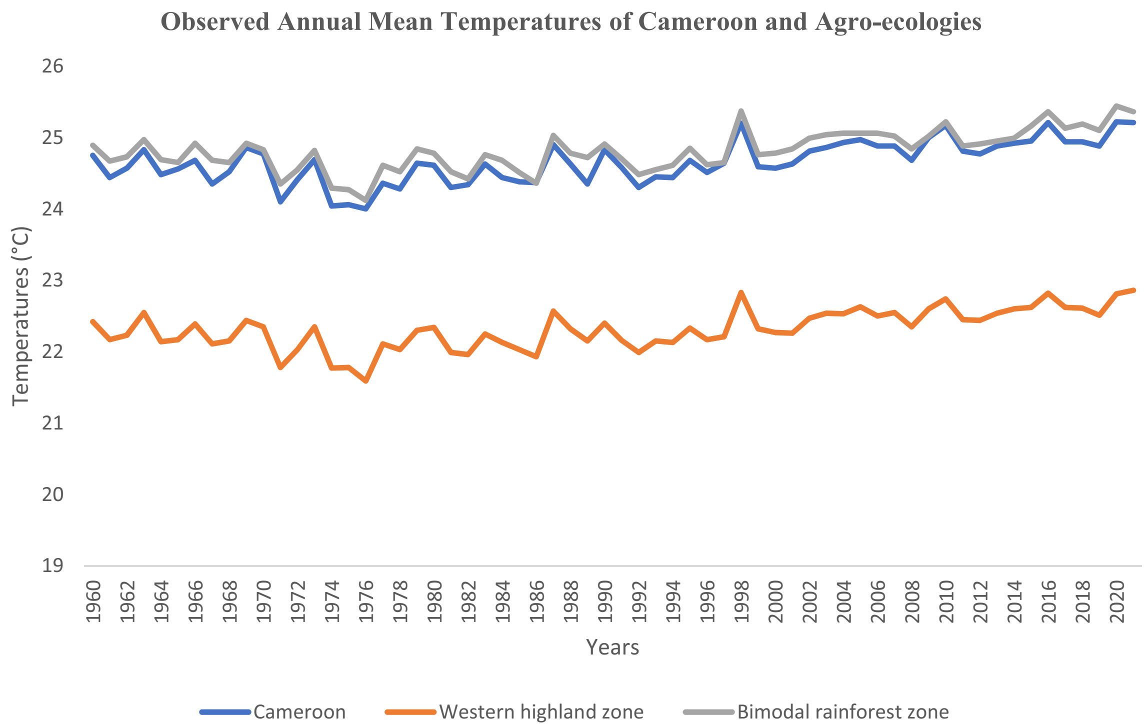

FIGURE 2
Mean temperature of Cameroon and the study areas from 1960–2021. Source: constructed by authors with data from climate change knowledge portal (2023).

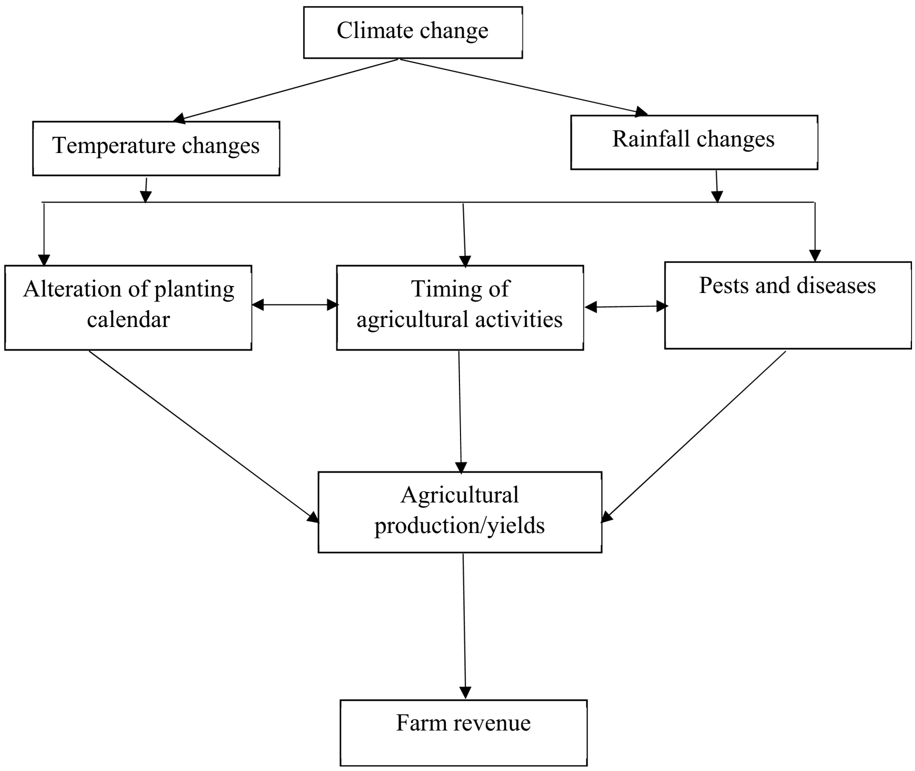

FIGURE 3
Conceptual framework of the impacts of climate change on farm revenue, source: authors' conceptualisation (2023).

Also, there are interdependencies between changes in agricultural calendar, timing of agricultural activities and the proliferation of pests and diseases. Changes in agricultural calendar may imply that farmers plant when pests are very prevalent. Similarly, the prevalence of pests may also force farmers to change altering their planting calendars to attenuate the effects of such pests and serve as an important coping mechanism.

Taken together, these factors may reduce agricultural production and productivity of households. Since such households usually have a dual motive of production; home-consumption and income generation, such reductions may reduce the quantity of produce available for sale, thus reducing farm revenues.

However, the effects of temperature and rainfall may vary with the type of crop. Studies have shown that while temperature and rainfall changes may reduce yields of some crops, such changes may rather improve yields of other crops (Ochieng et al., 2016; Gershon and Mbajekwe, 2020). Such effects may also vary with the type of agroecological zone, suggesting that the effects of climate change may be different in different areas.

4 Materials and methods

4.1 Study area

The current study focuses on two distinct AEZs; Western Highlands and Bimodal Rainforest. The Western Highland agro-ecological zone comprises the North West and West administrative regions of Cameroon. It is the most densely populated agro-ecological zone in Cameroon, with between 200 and 400 inhabitants per square kilometre. This zone receives between 1500 and 2000 mm of precipitation annually, with over 180 rainy days, heavy precipitation, moderate temperatures, and savannah vegetation (MINADER, 2023). The region is one of the major food production regions in the country owing to rich volcanic materials. Major crops produced in the area include maize, sweet potatoes, Irish potatoes, beans, groundnuts, sweet potatoes (Nanganoa et al., 2020; Andrianarison et al., 2022). However, climate change seems to affect the production potential of the zone. According to Ngum and Bastiansen (2021), the zone experiences the highest seasonal fluctuation of rainfall and temperature. This has led to proliferation of pests and diseases, flooding, soil erosion and consequently reduction in yields.

The Bimodal Rainfall Humid Forest is the largest agroecological zone in Cameroon covering over 39.9% of the country (Nfornkah et al., 2020). It encompasses the administrative regions of the East, South, and Center. It has a surface area of approximately 165,770 km2 and annual precipitation between 1500 and 2000 mm, with two distinct humid seasons. Unlike the other zones, this zone has two rainy seasons which allow farmers to cultivate crops at least twice per year. The major crops cultivated in this zone include, plantains, bananas, cocoa, cassava, maize, peanuts, oil palm, and pineapples (Andrianarison et al., 2022; MINADER, 2023). Non-timber forest products (NTFPs) are also exploited. However, owing to climate change, there has been a reduction in such products (Ngum and Bastiansen, 2021) (see Figures 4, 5).

4.2 Farm survey

The data was thus collected in two agroecological zones of Cameroon; the Western Highlands (West region) and the Bimodal Rainfall Humid Forest (South region). The farmers studied were chosen using the two-stage sampling procedure. Since farmers are dispersed across a large geographical area, the population of farmers was divided into 8 clusters in the first stage (Valee du Ntem, Mvilla, Ocean and Dja et Lobo in the South region), and (Noun, Menuoa, Mifi and Nde in the West region). In addition, 20 farmers were chosen at random from each cluster in the second stage to obtain the study sample size, of about 400 farmers per region as shown in Table 1. The 20 farmers chosen randomly were for 5 villages per cluster.

The sample size was determined using the procedure pioneered by Yamane (1967), as follows $n = \frac{N}{1 + N(e)^2}$ where n = Sample size, N = Population size and e = level of precision at 5%. This formula which guides the process of drawing a sample from a larger population to make inferences, uses a confidence level of 95% (Cochran, 1977; Ziegel, 2000; Israel, 2003; Mukhopadhyay, 2008). From Table 1, based on the data from the Central Bureau of Census and Population Studies (BUCREP, 2005) on the rural and urban household statistics for Cameroon, we determine the sample size of approximately 399 and 400 farmers for each of the West and South regions.

However, the implementation of the field survey generated 154 completed questionnaires for the West region and 168 for the South region. We note that the samples surveyed are less than half of the needed samples according to the formula used in each region. This is an important limitation of our study. Nonetheless, this shortfall was due to multiple challenges faced in the field such as absence of some farmers in their homes, since the survey took place during the rainy season in these regions making it very difficult to reach many villages. In addition, we had some incomplete and poorly administered questionnaires. More important, the survey excluded livestock-only farmers. This was basically to avoid bias generated by the costs involved in animal farming, as well as the disruptions recorded from episodes of cattle disease outbreak in the study area with significant consequences for the subsector. Finally, studying exclusively crop farmers increased the chance of such farmers being pooled.

Globally, the primary data collected consists of demographic, socioeconomic, institutional, and biophysical characteristics of the farming households, their community and their farms. We also included producers' perceptions of temperature and precipitation patterns over the past 30 years. The survey questionnaires and unobtrusive field observations used for the primary data collection were implemented during the period of October and November. This primary data was further supplemented with information from secondary sources to produce an apt description of the farming households and the farming system.

To ensure the quality of the data, we trained several enumerators on how to ask the questions and record the responses. With the help of a structured questionnaire household heads were interviewed. The survey consisted of different sections such as household demographic information, crop production information as well as climate change adaptation measures. The climate data was obtained from meteorological station centres in the study regions. The National Observatory on Climate Change (NOCC) made this possible by collecting climatic data on Length of Rainy Season in days, Dry Season Temperatures in degrees Celsius (°C), Rainy Season Temperatures in degrees Celsius (°C),

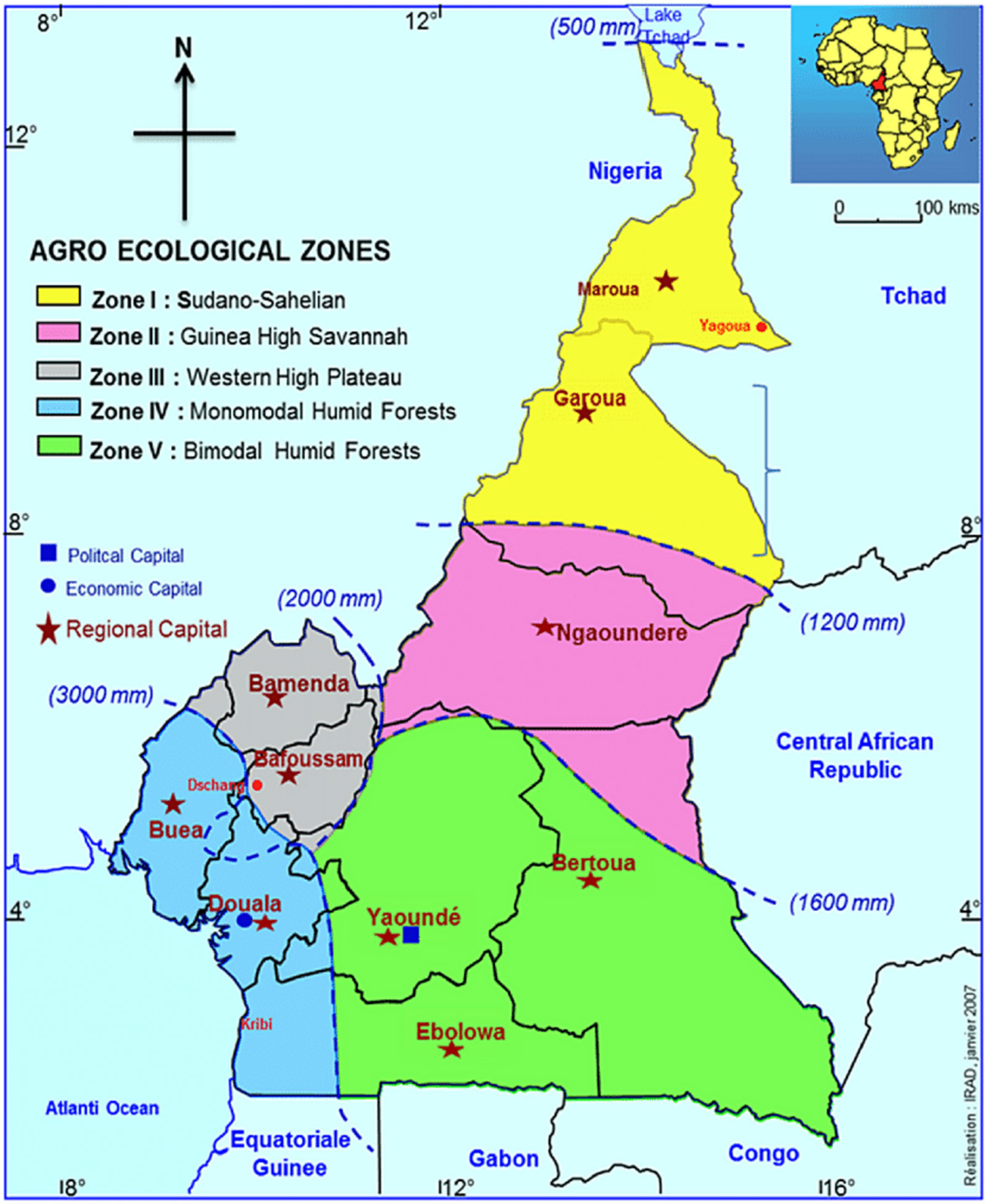

FIGURE 4
Map of Cameroon showing the study areas. The study areas are zones III and V. Source: MINADER (2015).

Rainfall in Rainy Season in millimetres (MM), Dry Season Rainfall in millimetres (MM), and Rainfall Starting Date in days. To gain more insights on agricultural production in the area, we equally conducted focus group discussions and key informant interviews with farmers and local leaders.

4.3 Empirical modelling

The objective of this study is to assess the impact of climate change on farm revenue of smallholder farmers in Cameroon. We employ the Ricardian cross-sectional method. In the past two decades or so, two

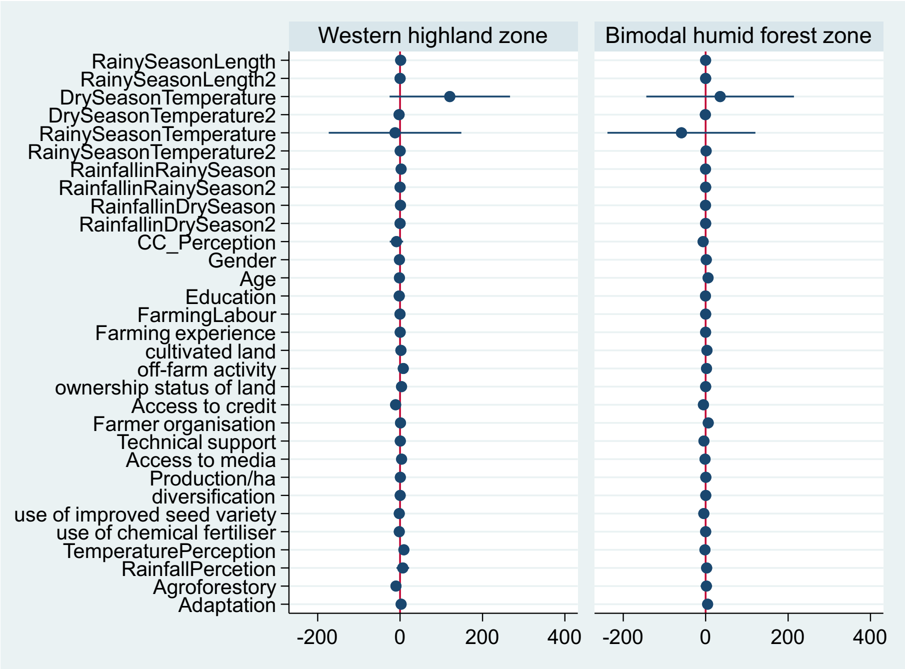

FIGURE 5
Effects of climate change on farm revenue in the western highland and bimodal humid zones. Source: constructed from survey data, 2023.

TABLE 1 Region and rural/urban distribution of ordinary households.

Regions	Number of households by milieu		
	Sample frame in urban area	Sample frame in rural area	Total
Adamawa	59,206	91,667	150,873
Centre	480,353	170,546	650,899
East	53,021	93,917	146,938
Far-north	117,427	383,913	501,340
Littoral	513,250	45,538	576,788
North	81,013	201,979	282,992
North-west	122,832	182,387	305,219
West	201,559	147,422	348,981
South	56,324	97,315	153,639
South-west	134,168	147,509	281,677

Source: MINADER (2015).

methods have been devised to assess the effects of climate change on the agricultural sector: the production-function approach (Rosenzweig and Iglesias, 1994) and the Ricardian approach (Mendelsohn et al., 1994). The Ricardian model is arguably more suitable because it takes into consideration farmers responses to climate change (Mendelsohn, 2009; Hossain et al., 2019). Moreover, it has been widely used in other empirical studies to model the impacts of climate change (Abidoye et al., 2017a; Hossain et al., 2019; Mahmood et al., 2019; Ojo and Baiyegunhi, 2021). The Ricardian approach takes into consideration adaptation by measuring economic damages as reductions in net income or land value (Mendelsohn, 2009). The model is also cost-effective, as secondary data on cross-sectional sites on climatic, production, and socioeconomic factors are comparatively simple to collect (Kurukulasuriya and Mendelsohn, 2007; Yesuf et al., 2008). Equation 1 demonstrates a set of well-behaved functions in the form of:

$$Q_i = Q_i\left(K_i, E\right), i = 1, \ldots, \ldots n \quad (1)$$

Where Ki = [Ki1,…Kij,…KiJ] is a vector of all purchased inputs in the production of good i; Kij = the purchased input j (j = 1,.j) in the production of good i; E = [E1,…Em,…EM] is a vector of site specific exogenous environmental inputs such as temperature, precipitation, and soils. Given a set of factor prices wi for Kj, E, and Q, cost minimization leads to cost function (Equation 2):

$$C_i = C_i\left(Q_i, W, E\right) \quad (2)$$

Where C is the cost of production of good i and W = (W1,…Wi,…Wj) is the vector of factor prices. Assuming a set of utility maximizing consumers with well-behaved utility functions and linear budget constraints, who take prices as given, this leads to a system of inverse demand functions for outputs i = 1,.,n. Equation 2 was modify to obtain Equation 3 as follows:

$$\mathrm{P}i = D^{-1}\left[Q_a, \ldots Q_i, \ldots . Q_n, Y\right] \quad (3)$$

Where Pi and Qi are, respectively, the price and quantity of good I and Y is the aggregate income. Given market prices, profit maximization on a given site yields (Equation 4) below:

$$\max \mathrm{P}_i Q_i = C_i - \left(Q_i, W, E\right) - \mathrm{P}_L L_i \quad (4)$$

Where P_L is the annual cost or rent of land at that site and Ci is the cost function of all purchased inputs other than land. Perfect competition will drive profits to zero:

$$\mathrm{P}_i Q_i^* - C_i^* - \left(Q_i^*, W, E\right) - \mathrm{P}_L L_i^* = 0 \quad (5)$$

If i is the best use for land given E and R, the observed market rent on the land will be equal to the net annual profits from the production of good i. Solving (Equation 5) for P_L gives land rent per hectare to be equal to net revenue per hectare as shown in Equation 6 below:

$$\mathrm{P}_L = \left(\mathrm{P}_i Q_i^* - C_i^* - \left(Q_I^*, W, E\right)\right) / L_i \quad (6)$$

The Ricardian approach is based on the assumptions that climate shifts the production function for crops, that there is perfect competition in both product and input prices (no public intervention on the market and no monopoly), that land values have reached the long-run equilibrium associated with each region's climate, that market prices are unaffected by changes in environmental conditions, and that adaptation occurs, such as the adoption of new crops or farming systems. Standard Ricardian model relies on quadratic climate formulation:

$$NR / ha = \beta_0 + \beta_1 F + \beta_2 F^2 \beta_3 Z + \beta_4 G + u \quad (7)$$

Where NR/ha = net revenue per hectare, F = vector of climate variables, Z = set of soil variables, G = set of socioeconomic variables and u = error term.

From Equation 7 we can derive the marginal impact of climate on household revenue evaluated at the mean as follows:

$$\mathrm{E}\left[dV / df_i\right] = b_{1,i} + 2 * b_{2,i} * \mathrm{E}\left[f_i\right] \quad (8)$$

A standard Ricardian model evaluates the relationship between climate change and land values. However, land markets in developing country have either failed or are inexistent (Hossain et al., 2019). This makes it difficult to get the exact value of land (Mendelsohn, 2009). The value of land can therefore be approximated from the income obtained from such land. Hence, we use farm revenue as our measure for land value in line with other empirical studies such as Hossain et al. (2019) and Ojo and Baiyegunhi (2021).

The weaknesses of the Ricardian method are: it is not based on controlled experiments across farms and may not include all factors. It also does not analyse price and carbon fertilization effects (Mendelsohn et al., 2000). The most important disadvantage is its reliance only on cross-sectional data. Both the agronomic and Ricardian methods do not include analysis of perception of climate change and determinants of the choice of adaptation methods.

The impact of climate change on farm income is not necessarily linear. It can take both u and inverted u-shapes. That is, some climatic changes may positively affect income up to a point where their extremes may negatively affect income. Simply considering a linear relationship will mask such effects. We incorporate quadratic forms of the climate variables to show such non-linear relationships as suggested by Mendelsohn (2009). From Equation 8, the final model used for this study can be specified as Equation 9 below:

$$V_i = \beta_0 + \beta_1 PRS + \beta_2 PSR^2 + \beta_3 RST + \beta_4 RST^2 + \beta_5 RSL + \sigma_j G_i + u \quad (9)$$

Where PRS is quantity of rainfall in rainy season, RST is rainy season temperatures, RSL is rainy season length. G_j is a vector of socio-economics characteristics such as gender, age, literacy rate, land ownership, access to credit, membership in a farmers' organisation, access to technical support, access to media etc. β_j and c_j are coefficients of variables, β_0 is a constant term and u is the error term. Our parameters of interest are β_j which measure the impact of climate change. Since our climatic variables are exogenous, we estimate our model through ordinary least square (OLS).

5 Results and discussion

We evaluate the impact of climate change on the farm revenue of smallholder farmers. Although climate may manifest in different forms, we focus more on rainfall and temperature because these are the most obvious manifestations of climate change. Moreover, other studies have focused on these variables (Mendelsohn, 2009; Abidoye et al., 2017a,b). We present our results in two parts. We start with the descriptive statistics followed by the econometric results.

5.1 Typology of climate and farmers' revenue

Table 2 presents the descriptive statistics. We start by discussing the full sample before turning to the AEZs. For brevity purposes, we will focus on the descriptive statistics of the climate variables and income. The results how that average farm income is about 600,000 FCFA (US$[1] 994) in the full sample. For the AEZs, farmers in the bimodal forest zone have an income of over 920,000 FCFA, about four-fold that of those in the western highland zone which is about 260,000 FCFA. The results reveal that the average rainy season length (RSL) in the full sample is approximately 194 days. Going by the AEZs, the western highland zone has a longer rainy season length of about 242 days while the bimodal zone has a lower rainy season length of about 149 days. This shows that the western highland is better in terms of rainy season length than the bimodal zone. Well, this is expected given that the western highland zone has a single rainy season while the bimodal zone, as the name suggests, has two rainy seasons characterised by dry spells. Such spells apparently reduce the number of rainy season days.

Dry season temperature (DST) is on average 24.45°C in the full sample, but lower in the western highland with an average of 24.02°C. it appears the bimodal is hotter in the dry season with an average temperature of 24.85°C. As earlier pointed out, the bimodal zone is characterised by dry spells which may be attributed to such increases in temperature. Rainy season temperatures (RST) are about

1 At the time of the study, 1USD=603.47FCFA.

TABLE 2 Descriptive statistics.

		Full sample (*N* = 322)		Bimodal forest zone (*N* = 168)		Western highland zone (*N* = 154)	
Variables	Description	Mean	SD	Mean	SD	Mean	SD
Revenue (FCFA)	Total farm revenue	609,026	2.00E+06	923,417	1.46E+06	266,054	2.43E+06
Rainy season length (Days)	The length of the rainy season	193.7	52.26	149.5	30.99	241.8	14.46
Dry season temperature (deg. C)	The temperature in the dry season	24.45	0.736	24.85	0.489	24.02	0.718
Rainy season temperature (deg. C)	The temperature in the rainy season	24.17	1.471	25.45	0.587	22.78	0.639
Rainfall in rainy season (MM)	The amount of rainfall in the rainy season	2,129	1,194	988.1	41.17	3,373	37.25
Rainfall in dry season (MM)	The amount of rainfall in the dry season	253.9	199.1	441.7	43.41	48.99	12.65
Rainfall starting date		62.11	11.73	56.57	4.89	68.14	13.87
Gender (1 = Male)	A dummy for the gender of the household head	0.484	0.501	0.411	0.493	0.565	0.497
Age (>30 = 1)	the age of the household head	0.758	0.429	0.762	0.427	0.753	0.433
Farming labor (man days)	The amount for farm labor used	5.18	2.743	5.798	2.598	4.506	2.747
Farm experience (years)	The number of years in farming	14.14	9.085	13.81	8.321	14.5	9.867
Cultivated land (ha)	The amount of land under cultivation	1.645	1.437	1.523	1.211	1.778	1.642
off-farm activity (1 = yes)	A dummy for off-farm activity	0.842	0.366	0.887	0.318	0.792	0.407
Land status (1 = owned)	A dummy for ownership of land	0.317	0.466	0.28	0.45	0.357	0.481
Access to credit (1 = yes)	A dummy for access to credit	0.354	0.479	0.327	0.471	0.383	0.488
Farmer organization (1 = member)	A dummy for membership in a farming organization	0.283	0.451	0.363	0.482	0.195	0.397
Technical support (1 = yes)	A dummy for receiving technical support	0.174	0.38	0.274	0.447	0.0649	0.247
Access to media (1/0)	A dummy for access to media	0.888	0.316	0.911	0.286	0.864	0.344
Farm output	The total farm output	8.649	8.2	10.93	7.213	6.16	8.505
Crop diversification	A dummy for crop diversification	0.339	0.474	0.298	0.459	0.383	0.488
Seed variety (1 = Improved variety)	A dummy for use of improved variety	0.23	0.421	0.143	0.351	0.325	0.47
Chem fertilizer use (1 = Chemical fertilizer)	A dummy for the use of improved variety	0.059	0.236	0.0536	0.226	0.0649	0.247
Education (1 = at least primary education)	A dummy for education of household head	0.932	0.253	0.946	0.226	0.916	0.279
Climate change perception (yes = 1)	A dummy if a farmer perceives changes in climate	0.86	0.347	0.905	0.294	0.812	0.392
Temperature perception (yes = 1)	A dummy if a farmer perceives changes in temperature	0.0901	0.287	0.101	0.302	0.0779	0.269
Rainfall perception (yes = 1)	A dummy if a farmer perceives changes in rainfall	0.789	0.409	0.792	0.407	0.786	0.412
Climate change adaptation (yes = 1)	A dummy if a farmer uses at least one adaptation measure	0.556	0.498	0.482	0.501	0.636	0.483
Agroforestry (yes = 1)	A dummy if a farmer practices agroforestry	0.0311	0.174	0.0119	0.109	0.0519	0.223

Source: computed from survey data, 2023.

24.17°C in the full sample. Like other climatic variables discussed thus far, the bimodal zone appears hotter with an average temperature of 24.45°C as opposed to 22.78°C of the western highland zones.

Rainy season rainfall in the full sample is on average 2129 mm. The western zone experiences more rainfall in the rainy season with an average of 3373 mm about three times more than that in the

TABLE 3 OLS estimates of the impact of climate change.

	Pool sample	Western highland zone	Bimodal forest zone
Variables	Revenue	Revenue	Revenue
Rainy season length	−0.2063* (0.1120)	1.362 (1.8549)	−0.13 (0.2851)
rainy season length_squared	0.0006* (0.0003)	−0.0026 (0.0038)	0.0004 (0.0009)
Dry season temperature	47.2015 (40.3783)	120.5986 (73.8590)	35.1582 (90.5801)
Dry season temperature_squared	−0.9825 (0.836)	−2.5258 (1.545)	−0.7157 (1.831)
Rainy season temperature	−12.3766 (16.3076)	−12.2056 (81.2420)	−58.8575 (90.7983)
Rainy season temperature_squared	0.2317 (0.3382)	0.211 (1.7844)	1.1302 (1.7806)
Rainfall in rainy season	−0.0303 (0.0281)	2.5125 (3.8217)	−0.2886 (0.6880)
Rainfall in rainy season_squared	0.0004 (0.0001)	−0.0004 (0.0006)	0.0001 (0.0003)
Rainfall in dry season	0.0337 (0.0693)	0.8438* (0.4911)	−0.3472 (0.2335)
Rainfall in dry season_squared	−0.0001 (0.0001)	−0.0081* (0.0048)	0.0004 (0.0003)
Constant	−369.3742 (496.0721)	−5,748.41 (6593.1643)	576.1377 (1569.1594)
Other controls	Yes	Yes	Yes
R-squared	0.4196	0.4355	0.4928
F statistics	5.25***	2.18***	3.73***
Observations	322	154	168

Standard error in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Outcome variables are inverse hyperbolic sine transformations. Source: estimated from survey data, 2023.

bimodal zone with an average of 988MM. while the amount of rainfall in the dry season (DSP) is on average 254 mm in the full sample, that in the western highland is a measly 49 mm, about a tenth of what obtains in the bimodal zone. This comes as no surprise. The western highlands have a more severe and longer dry season while the bimodal zone experiences a shorter rainy season which is usually interrupted by a second rainy season. Hence longer dry seasons are more likely to experience very little rainfall. The double rainy season in the bimodal zone ensures that rains start earlier. By and large, it seems the bimodal zone is more affected by climate change compared to the western highland zone at least by the climatic variables considered thus far. Consequently, the impacts of such changes on farm revenue may be different. This may pass as suggestive evidence why such zones should be studied independently rather than as a full sample.

5.2 Effect of climate change on farm revenue

Table 3 shows the ordinary least square (OLS) estimates of the effects of climate change on farm revenue. The first column is the full sample; the second column is for the western highland zone while the bimodal zone is presented in the last column. For brevity purposes, we present only the results of the climate variables while the full regression is found in the Appendix.

Starting with the pooled sample, the results show that rainy season length negatively affects the revenue of farmers. That is the longer the rainy season, the lower the farm revenue. However, it appears that the relationship between rainfall and farm revenue is not linear but U-shaped. The squared term shows that rainy season length positively affects farm revenue. That is, rainfall only negatively affects farm income to a certain threshold after which it turns to favour farmers This finding corroborates those of other studies which show that rainfall is one of the major factors affecting farm revenue especially in developing countries (Mendelsohn, 2009; Abidoye et al., 2017a). The literature has established that agriculture in developing countries is rain-fed, hence the importance of rainfall on farm revenues. Farmers generally plan their agricultural activities around the onset and cessation of rains. It seems, however, that longer rainfall hampers crop production by affecting important aspects of plant growth like flowering and ripening, thus reducing yields and consequently farm revenue. But after a certain point, such rains become favourable for plant growth.

In the Western highland zone, rainfall is equally a major driver of farm revenue. Here, however, rainfall in the dry season appears to be the most important. The results show a positive relationship between rainfall in the dry season and farm revenue. That is, any additional rainfall increase in the dry season increases farm revenue. Molua (2022) has already shown that climate change affects farm revenue in the western highland zone. The western highland zone has a single dry season which is usually very long and tends to hamper crop production. If rains come early, disrupting the length of the dry season, it avails farmers the opportunities to properly time their agronomic activities such as planting, weeding, etc. It equally ensures that other processes such as flowering and ripening are unperturbed. Moreover, most insect pests that affect yields tend to be prevalent in the dry season (Mansaray et al., 2020). A reduction in the dry season will therefore reduce the prevalence of such pests, increasing yields and farm income. However, the relationship between rainfall in the dry season and farm revenue is an inverted U-shaped one. Increase in rainfall in the dry season will only benefit revenue up to a point where it stops being beneficial. Excess rainfall in the dry season is synonymous to a very long rainy season which may affect plant growth processes. Moreover, it may affect the amount of time available to farmers to prepare their lands since land preparation is mostly done in the dry season.

In the bimodal rainforest zone, none of the climatic variables appear to affect farm revenue. This suggests that climate change may not really be an issue in the area or at least has not started manifesting. Well, the bimodal rainforest zone, as the name suggests, has abundance of forest. This may be important for carbon sequestration, reducing the impacts of climate change at least in the short run. The zone equally has a bimodal rainfall pattern. That is, unlike other AEZs with distinct rainy and dry

TABLE 4 Marginal elasticity of climatic variables.

	(1)	(2)	(3)
Variables	Full sample	Western highland	Bimodal rainforest zone
Rainy season length	−0.0029 (4.3786)	23.2481 (17.9633)	−3.4628 (4.2448)
Dry season temperature	−28.9105 (27.1251)	−47.5442 (35.4451)	19.1700 (45.0990)
Rainy season temperature	−38.2488 (26.6959)	−60.5243 (38.4766)	−7.2603 (38.4300)
Rainfall in rainy season	1.1343 (6.8034)	−16.2366 (96.5217)	−46.6387** (21.3859)
Rainfall in dry season	5.4324 (3.3613)	8.3599** (3.9585)	−5.4377 (8.8806)
Constant	184.9083 (146.2299)	316.0754 (814.5041)	342.8901 (243.7702)
Observations	322	154	168
R-squared	0.0647	0.0584	0.0346

Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source: constructed from survey data, 2023.

seasons, this AEZ has two rainfall season which ensures that there is enough rainfall. The second rainy season usually interrupts the dry season making it shorter and attenuating its effects on agricultural production. Hence in this AEZ, the impacts of climate change may be very subtle, with little effects on agricultural production and hence revenue.

It is in line with the findings of Baylie and Fogarassy (2021) who reported that increased winter and summer temperature and rainfall increase net crop income per hectare of farmers in the Ethiopian Nile Basin. However, PRS^2 negatively affects smallholder farmers' income from agriculture. Also these results can be supported by those of Gadédjisso-Tossou et al. (2016) who supported that temperature or rainy season rainfalls affects the net revenue positively up to a certain level, above which it causes damage to the crops to farmers in Togo. The results also corroborate with that of Hossain et al. (2018).

This result is in line with the findings of Nyuor et al. (2016) who concluded that early season precipitation had negative effects (with coefficient = 530.10) thus the impact of early season precipitation on net revenue of Maize and Sorghum farmers in Northern Ghana was negative (coefficient = 324.50). The outcome of this study also collaborates with that of Ali et al. (2021) that a decrease in precipitation are strongly associated with net revenue deficits.

5.3 Responsiveness to climatic variables

To further understand the responsiveness of farm revenues to climatic variables, we estimated the elasticities. The results are presented in Table 4. In the western highland zone, a millimetre increase in rainfall in the dry season increases farm revenue by about 8.5 FCFA. This result suggest that farm revenues are highly responsive to climatic variables. This is expected given that farmers in these regions highly rely on climatic variables for agricultural production. Particularly, agriculture is still rainfed, making rainfall one of the most important climatic variables for agricultural production. Increase rainfall in the dry season may shorten the length of the dry season, extending the cultivation season and hence higher farm revenue.

In the bimodal rainforest zone, a millimetre increase in rainfall the rainy season reduces farm revenue by about 46.6 FCFA. As expected, revenues will not respond much to changes in rainfall in the rainy season since rainfall is already available for cultivation. Rather increase in rainfall may affect the growth of crops, reducing yields and income.

The results obtained in this section point to the fact that climate change affects smallholder farmers' revenue in the different agro-ecological zones of Cameroon. However, the nature of these effects varies depending on the climatic parameters on the specific agro-ecological zone concerned.

The study of Sultan (2021) demonstrated that the agricultural industry reacted unfavourably to variations in mean summer temperatures and precipitation using a cross-sectional farm data set of 392 farmers. With an elasticity of −0.13 assessed at mean temperature, the economic effects of a 1°C increase in mean temperature are USD26.6 per acre per year. At mean precipitation, the elasticity of mean farm revenue is 0.03. The results indicated that this island needs to invest in climate change adaptation measures. The study (Ahmad et al., 2020, for example) looked into farm exit in relation to farmers' shift from on-farm to off-farm activities, but it did not look into farm exit in light of climate change. In order to explore the relationships between the negative effects of climate change and farm statuses that is, whether they were abandoned or survived they incorporated extensive data on tactics for adapting to climate change together with other variables. According to this study, adapting to climate change is a strategy for farms to survive in an environment of rising temperatures, droughts, floods, heavy rainfall, uncontrollably occurring pest and insect attacks, and other crop diseases that ultimately result in significant losses for farms under unforeseen climate change conditions and natural disasters.

6 Conclusion and policy implications

6.1 Conclusion

Climate change constitutes one of the biggest challenges of contemporary society. Its effects cut across various sectors but the largest effects are expected in the agricultural sector, especially those of developing countries which rely on agriculture for survival. In developing countries like Cameroon where the importance of agriculture cannot be overemphasised, it is important to evaluate the impacts of climate change on agriculture and farmers' revenue. Moreover, due to unique nature of AEZs, the impact of climate change may vary, making it important to evaluate the impact on different areas.

Using survey data from 322 smallholder farmers from two distinct agroecological zones in Cameroon, we evaluate the impact of climate change on farmers' revenue. We employ a Ricardian framework which allows us to evaluate the impact of climate change taking into consideration farmers' response to changes as well as changes in ecosystem. As climate change largely manifests through changes in temperature and rainfall patterns, we focus on these two variables as our indicators of climate change. Since the relationship between climatic variables and farm revenue is not linear, we use other polynomial forms of the variable to capture non-linear relationships. Our results show that rainfall is the main climatic variable that affects farm revenue. In the full sample, the rainy season length shows a U-shaped relationship with farm revenue suggesting that there is a threshold at which rainfall becomes beneficial. The results are quite distinct for the AEZs. In the western highland zone, rainfall in the dry season is the major driver of farm revenue probably because such rainfall disrupts the long dry season. In the bimodal forest zone, no climatic variable appears to affect farm revenue. This is probably because of the abundance of forest in the zone which may be sequestrating carbon, hence reducing the impacts of climate change. Further analysis shows that revenue is quite responsive to rainfall.

6.2 Implications and recommendations

Based on our findings, we provide some recommendations. Since rainfall appears to be the major driver of farm revenue, policy makers can make available irrigation facilities to provide farmers with water for crop production. This will allow farmers to appropriately time their farming operations leading to increased yields and farm revenue. This will be particularly important in the dry season which seems to appear longer owing to climate change. Also, farmers should be provided with essential climate information such as the onset and cessation of rains as this will allow them to effectively plan their farming seasons. The different results in the AEZs suggests that some zones require more attention. Since the western region already shows some effect of climate change, policy makers should focus on farmers in this region by providing them with adaptation and mitigation strategies. Thus helping farmers to survive to the different adverse consequences of climate change on farm revenue. Moreover, the same measures may not work in the forest zone. Probably the existence of the forest in the bimodal forest shields it from climate change. Measures should therefore be put in place to maintain such forests to limit the impact of climate change in the future. Farmers can be educated on the importance of the forest in combatting climate change. Also, they can be provided with alternative livelihoods to prevent them from exploiting the forest for agriculture. These means will prevent farmers from exiting the farming sector to other sectors.

Although our study area is Cameroon, we have focused on two AEZs which reflect climatic conditions across Africa. The findings of this study therefore traverse the boundaries of Cameroon and can be instructive in other countries in Africa with similar climatic conditions. Of course, the context must be considered as farmers in different areas may devise different adaptation measures leading to different effects of climate change.

6.3 Limitations of the study

- Though this study is properly calibrated, there are some exogenous factors that limit the veracity of its findings. Firstly, the cross-sectional analysis is vulnerable to omit such variables. Secondly, the study does not take into account the fertilisation effects of higher CO_2 concentration. In fact, evidence from agronomic experiments suggest that CO_2 concentration has the potential to offset in part the negative effects of global warming on agriculture, but the magnitude of this effect is still debated.
- In the two regions studied not all the villages in these regions were examined causing a limitation to generalize about the finding of the research study.
- The study looked at crops overall and did not examine the specific impact of climate change crop by crop.
- The abundance of rainfall which threatened to retard the movement of survey enumerators.
- Limited time to carry out complete work on the survey forms due to the difficult terrain in the hinterlands.
- The distances from one farm to another was long, time consuming and costly.
- The farmers in this area were not very cooperative in responding and completing the survey forms.
- The Problem of communication due to poor network was pervasive.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

MM: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. EM: Methodology, Supervision, Writing – review & editing. JS: Methodology, Supervision, Writing – review & editing. FN: Conceptualization, Data curation, Formal analysis, Methodology, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

The authors are grateful to the reviewers of this journal whose comments on earlier versions of the manuscript improved the quality of the final version. We also gratefully acknowledge the support and cooperation of farmers' union in the West and South Regions of Cameroon whose leadership cooperated with the researchers in the data gathering phase. We hereby declare that all the information and statements made in this research are true and we take responsibility for any observed shortcomings.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Appendix

TABLE A1 Complete OLS estimates of the impact of climate change on farm revenue.

	Full sample	West highland zone	Bimodal forest zone
Variables	Revenue	Revenue	Revenue
Rainy season length	−0.2063* (0.1120)	1.362 (1.8549)	−0.13 (0.2851)
Rainy season length_squared	0.0006* (0.0003)	−0.0026 (0.0038)	0.0004 (0.0009)
Dry season temperature	47.2015 (40.3783)	120.5986 (73.8590)	35.1582 (90.5801)
Dry season temperature_squared	−0.9825 (0.8356)	−2.5258 (1.5451)	−0.7157 (1.8308)
Rainy season temperature	−12.3766 (16.3076)	−12.2056 (81.2420)	−58.8575 (90.7983)
Rainy season temperature_squared	0.2317 (0.3382)	0.211 (1.7844)	1.1302 (1.7806)
Rainfall in rainy season	−0.0303 (0.0281)	2.5125 (3.8217)	−0.2886 (0.6880)
Rainfall in rainy season_squared	0 0.0000	−0.0004 (0.0006)	0.0001 (0.0003)
Rainfall in dry season	0.0337 (0.0693)	0.8438* (0.4911)	−0.3472 (0.2335)
Rainfall in dry season_squared	−0.0001 (0.0001)	−0.0081* (0.0048)	0.0004 (0.0003)
CC_Perception	−6.1992** (2.9847)	−8.8921 (8.1344)	−6.2006* (3.6414)
Gender	0.3497 (1.2009)	−1.5591 (2.1465)	1.5427 (1.6290)
Age	1.6659 (1.5500)	−1.691 (2.5855)	5.7556*** (2.0661)
Education	−1.3432 (2.3685)	−2.1418 (3.5421)	−0.4715 (3.7006)
Farming labour	0.0498 (0.2298)	−0.2164 (0.3929)	0.0815 (0.3052)
Farming_experience	0.0427 (0.0726)	0.1916 (0.1229)	−0.1082 (0.1120)
Cultivated land	2.5267*** (0.4383)	2.0244*** (0.6228)	3.0889*** (0.8145)
Off-farm activity	4.8673*** (1.6368)	7.8162*** (2.4842)	2.1285 (2.5250)
Land ownership	2.2359 (1.3756)	3.451 (2.2863)	0.0736 (1.8861)
Access to credit	−9.3430*** (1.3480)	−10.7904*** (2.3815)	−5.3948*** (1.8156)
Farmer organisation	5.2619*** (1.4873)	0.9265 (3.1578)	6.2953*** (1.8801)
Technical support	−2.9532 (1.7907)	0.4559 (4.9370)	−4.1101** (1.8999)
Access to media	1.5839 (1.9576)	3.6153 (3.2833)	−1.4538 (2.7399)
Production	0.4746*** (0.0766)	0.5547*** (0.1210)	0.4225*** (0.1112)
Diversification	0.9542 (1.6906)	0.2505 (2.8972)	0.2209 (2.4726)
Use of improved variety	−1.8574 (1.6602)	−2.0672 (2.8028)	−4.3914 (2.6625)
Chemical fertiliser	−1.3265 (2.5486)	−1.9357 (4.1191)	0.0983 (3.5230)
Temperature perception	3.9295* (2.1827)	9.1941* (4.7401)	−1.7214 (2.7939)
Rainfall percetion	4.6385* (2.4826)	6.4709 (7.7633)	2.3538 (2.7300)
Agroforestry	−7.6823** (3.4732)	−10.0102** (4.6982)	1.7263 (7.0376)
Adaptation	2.4361 (1.7767)	2.5516 (3.0831)	4.7706* (2.6103)
Constant	−369.3742 (496.0721)	−5,748.41 (6593.1643)	576.1377 (1569.1594)
Observations	322	154	168
R-squared	0.4196	0.4355	0.4928