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Impact of Climate Change on the Economic Performance of Farms in the Tillabéri Department, Niger: Statistic Modeling

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Abstract

The department of Tillabéri is primarily affected by climatic phenomena, impacting crop yields, growing cycles, and consequently, the economic outcomes of agricultural operations. The objective of this study is to analyze these impacts of climate disruption on the economic performance of farms. The methodology adopted for this study combined documentary research with field surveys conducted on a sample of 250 randomly selected farmers. The analytical methods used mainly consisted of linear regression, profitability calculations, and linear programming. The findings indicate that all productions across different crops have experienced a decrease over the past 30 years. For instance, the production of millet, sorghum, and cowpea, which were respectively 812 kg/ha, 260 kg/ha, and 100 kg/ha between the last 30 and 20 years, has now dropped to 412 kg/ha, 106 kg/ha, and 46 kg/ha respectively. A negative and significant effect on agricultural net margin was observed due to variables such as flooding, drought, pest invasion in rice fields, and temperature changes. Smallholder farms show a relatively low margin (46%) to cover their fixed costs, which may indicate a risk if fixed expenses are high. Furthermore, the analysis results from linear programming reveal that farmers could achieve an additional net profit per hectare of 116,861 FCFA, 217201.5 FCFA, and 291988.2 FCFA respectively for small, medium, and large producers by managing variable costs and health-related expenses for households.

Keywords

Farms, Climate Change, Economic Performance, Tillaberi

1. Introduction

Due to the increase in population, income, and demand for biofuels, coupled with the effects of climate change, global prices for major agricultural crops such as rice, wheat, corn, and soybeans are expected to rise from 2000 to 2050 [1]. According to the IPCC, 8% of current agricultural lands will become climatically unsuitable by 2100, and up to 30% according to the most pessimistic scenario. As a result, the price of rice is projected to increase by 62%, corn by 63%, soybeans by 72%, and wheat by 39%. Climate change will bring additional price increases: a total of 32% to 37% for rice, 52% to 55% for corn, 94% to 111% for wheat, and 11% to 14% for soybeans. In developing countries, climate change will lead to a decrease in the production of the most important crops [2]. Climate disruption has a very strong influence on agriculture [3] and will have negative impacts on agricultural production if no action is taken. The loss of agricultural yield due to drought is estimated at 25% between 1961 and 2006, according to the IPCC. By 2071-2100, if the planet warms by 1.5 to 2˚C, this drought-related loss will increase by 9% to 12% for wheat and more than 18% for rice compared to the period from 1961 to 2016 [4]. Rural populations in developing countries will be the most severely affected. In some regions, 80% of food needs are met by the production of small farms (approximately 500 million worldwide) [5]. Indeed, agriculture is the main economic sector for many African states. According to World Bank statistics, it represents 17% of the continent's GDP and about 30% of the GDP of sub-Saharan African countries, excluding South Africa, and ensures the survival of the majority of the African population (65%) [6]. However, climate change is expected to make agricultural development in this continent more difficult in many places. Weather conditions are becoming less favorable in most cases, increasing the volatility of crop and livestock yields. Climate warming is unequivocal [7] [8] and will have certain impacts on agriculture [9]. Cultivated lands, pastures, and forests, which represent 60% of the Earth's surface, are increasingly exposed to heightened variability and climate change [10]. The risks that agriculture faces due to climatic hazards negatively affect crops. Thus, farms are called upon to meet the challenges of increasing productivity in this unfavorable climate characterized by high climatic variability, rainfall deficits, and frequent droughts [11]. Temperature and precipitation changes are both major determinants in the recent trends observed in agricultural production in sub-Saharan Africa [3]. Both the increase in temperatures and, especially, the decrease in precipitation have led to production deficits since the 1970s [12]. The impacts of climate change on agriculture and human well-being include biological effects on crop yields and downstream impacts, including those on prices, production, and consumption [2]. Drought and land salinization, due to their impacts on this sector, can reduce the incomes of populations who, even in urban areas, still heavily depend on these activities [13]. It is evident that for farmers, climate and production trends are closely linked [14]. For example, according to a study, if annual losses related to climatic hazards for maize are expected to increase in Malawi, they are projected to decrease in Kenya and Niger under the same climate change scenario [15]. Indeed, Niger is among the most vulnerable countries in the world due to its climatic context, environment, and economy [16]. The Intergovernmental Panel on Climate Change (IPCC) has already warned of potential crop yield declines ranging from 10% to 25% or more that could become widespread by 2050. Climate change and its influence on agricultural potential do not imply the same economic impacts depending on the prevailing sociodemographic context in the region [17]. If significant efforts are not made to help small farmers adapt to climate change, the agricultural economy may further deteriorate, rural population instability may increase, and internal and cross-border imbalances may intensify. Rural areas are exposed to the impacts of climate change and the associated risks for both farmers and the economic performance of their agricultural operations. In the next ten years, extreme weather events related to climate are likely to increase significantly [18]. This situation could lead to food insecurity issues and socio-economic consequences linked to declining agricultural incomes. From an economic perspective, in light of the warning signs of climate change, it is crucial to understand how this alteration in climate will affect agricultural production systems and ultimately the well-being of the population in the future [19] as well as the economic outcomes of these systems. Therefore, the objective of this study is to analyze the impacts of climate disruption on the economic performance of agricultural operations in the department, specifically in the rural commune of Kourtheye.

2. Methodology

Study Area

The rural commune of Kourtheye is located in the southwestern band of the Tillabéri Department, situated between 13˚45' and 14˚27' North latitude and 1˚30' and 1˚52' East longitude. Geographically, the commune of Kourtheye is bordered to the north by the urban commune of Tillabéri; to the south by the rural commune of Karma; to the southwest by Namaro; to the east by the rural commune of Simiri and the urban commune of Ouallam; and to the west by the rural commune of Gotheye. The climate is Sahelian, characterized by a negative gradient of precipitation from south to north. The average annual rainfall totals range from 250 mm in the north to 400 mm in the south. Temperatures, even at their minimum, remain quite high, averaging between 18˚C and 45˚C throughout the year. This climate is characterized by three distinct seasons: a dry and cool season from November to February; a dry and hot season from March to June; and a rainy season from June to October.

Data and Sampling

Climate change is a phenomenon whose impacts are assessed over several years. Data were collected through surveys, focus group discussions, observations, and interviews with other resource persons. The data on climate change indicators were obtained based on farmers' perceptions (**Figure 1**).

The sample was determined by applying the following formulas: The first step (1) involves determining the initial sample size (ISS). Its calculation formula is as follows:

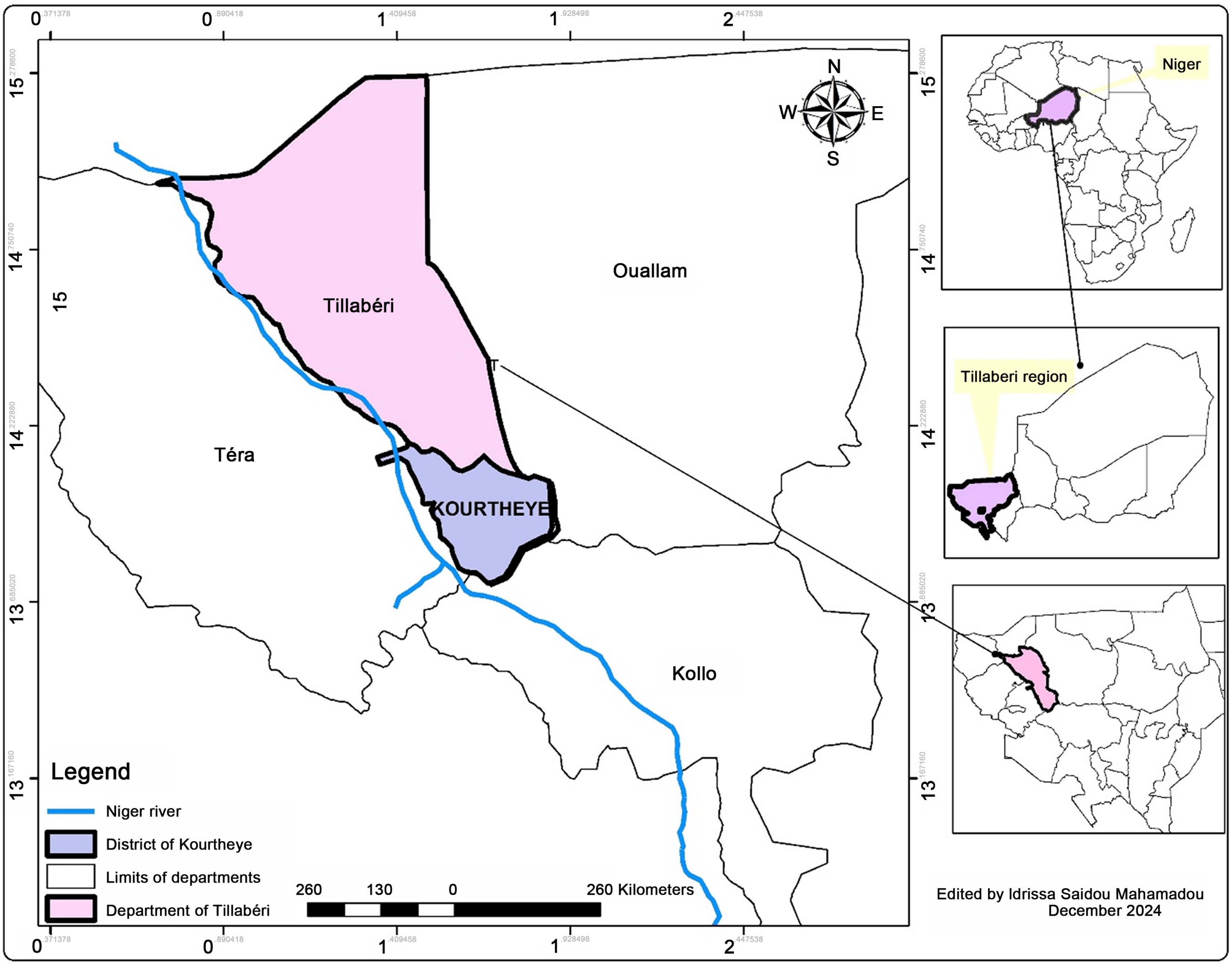

Figure 1. Localization of Tillaberi and the rural district of Kourtheye.

Where:

$$\text{ISS} = \frac{z^2 \cdot P(1-P)}{e^2}$$

- z is the security level regarding the representativeness of the population. A margin of error $e = 5\%$ was used, hence $z = 1.96$;
- P is the homogeneity of the population, found from previous studies, and $q = 1 - P$.

The second step (2), called adjustment of the sample size, takes into account the number of farmers (ASS). Its calculation formula is: $\text{ASS} = \frac{\text{ISS} \cdot N}{N + \text{ISS}}$.

- Where: N is the total number of farmers.

The third step (3) coincides with the adjustment for the response rate to determine the final sample size (FSS) to ensure a response rate (RR) of 90%. Its formula is written as: $\text{FSS} = \frac{\text{ASS}}{\text{RR}}$.

Analysis Methods

Evaluating the economic impacts of climate change on the agricultural sector requires an approach aimed at providing a detailed picture of the sector and the relationships within it. In this regard, bottom-up approaches (*i.e.*, particularly models applied at the local level but driven by global forces) could be an effective tool for assessing the economic impacts of climate change on the agricultural sector. The literature reveals several methods for measuring the impact of climate change on the agricultural economy. Among these methods is the empirical Ricardian bioeconomic model of farm profitability. Bioeconomic models are based on mathematical programming, which is a simplified yet qualified representation of a real phenomenon [20]. They allow for the evaluation of the profitability of an activity by including economic parameters. The vast majority of mathematical programming models rest on the assumption that the farmer maximizes an expected profit function. In this sense, they rely on the theoretical framework of Homo Economicus, which is based on hyper-rationality of omniscient economic agents capable of making optimization choices guided by the pursuit of maximum profit.

In this context, we also refer to linear programming, which is a powerful tool for optimization in various fields. It involves optimizing, in the sense of maximizing or minimizing, an objective or utility under various constraints [21]. These are decision support tools because they allow for the comparison of the results from a baseline situation against different scenarios. Decisions are always made through comparison [22]: what does the decision-maker lose or gain by making one decision over another? Bioeconomic models simulate the behavior of a farmer who, when faced with a choice among several activities, prefers those that are expected to yield the best overall utility [23]. Therefore, the analysis of agricultural operations relies on descriptors such as production and the use of production factors while considering the resource constraints that weigh on the farmer's choices. Linear programming techniques take into account the scarcity of utilized goods and numerous relationships between factors and productions [24].

The farmer is assumed to maximize his profit through the management of his agricultural activities while satisfying a series of constraints regarding, for example, land, labor, and available capital at the level of his operation [21]. Generally, there are three steps to follow in order to construct a linear programming model. These are:

1) Identify the variables of the problem with unknown values (decision variables) and represent them symbolically (e.g., x_1, y_1).

2) Identify the restrictions (constraints) of the problem and express them as a system of linear equations.

3) Identify the objective or selection criterion and represent it in a linear form based on the decision variables. Specify whether the selection criterion is to be maximized or minimized.

A linear programming problem can be formulated as follows:

Maximize or Minimize $Z = c_1 x_1 + c_2 x_2 + \cdots + c_n x_n$

Under the constraints: $c_{11}x_1 + c_{12}x_2 + \cdots + c_{1n}x_n \le b_1$

$c_{21}x_1 + c_{22}x_2 + \cdots + c_{2n}x_n \le b_2$

$c_{m1}x_1 + c_{m2}x_2 + \cdots + c_{mn}x_n \le b_m, \; x_j \ge 0, \; j = 1, 2, \cdots, n$

where:

- z is the value of the objective function.
- c_j are the coefficients of the objective function.
- x_j are the decision variables.
- a_{ij} are the coefficients of the constraints.
- b_i are the available resources.

$$\text{Max } F = \sum_{i}^{n} B_i X_i$$

In this expression, F is the objective function to be maximized; B_i is the unit contribution (e.g., gross margin per hectare) of activity i to the objective function; X_i is the decision variable (e.g., area allocated to activity i) whose value will be determined endogenously; b_k represents the availability of production factors k; and A_{ki} are the technical coefficients corresponding to the production factor needs k of activity i. Risks play a crucial role in farmers' decision-making as they alter decisions regarding the allocation of production factors.

The programming formulas in this study are formulated as follows.

$$\begin{cases} ax + by \le P_{CP} \\ ax + by \le P_{CI} \\ X \ge 0, Y \ge 0 \\ \text{Max } P = AX + BY \end{cases}$$

To analyze the impacts of climate change on farmers' income, the Ricardian approach has been utilized. This approach relies on the application of the hedonic pricing method to the analysis of agricultural land rent [25]. The economic theory underlying the hedonic pricing method applies more directly to consumer goods than to production factors. This approach focuses on the net income of agricultural operations rather than agricultural yields and, unlike most impact studies, takes adaptation strategies into account. The Ricardian approach generally proceeds through several major steps [26]:

1) Collecting socio-economic information regarding agricultural operations;

2) Calculating the net income of the operation based on this information;

3) Establishing a regression between the calculated net income and various variables such as climate, soil, and a set of economic variables;

4) Utilizing the established link between income and climate.

This study utilizes the Ricardian analysis, which is based on the assumption of a direct cause-and-effect relationship between climatic events and the value of the farm. The technique is referred to as the Ricardian method because it heavily relies on Ricardo's observation that land values reflect the productivity of land at a site (under competition). This approach has been used to assess the contribution of environmental conditions to agricultural income. By regressing land values against a set of environmental inputs, one can measure the marginal contribution of each input to agricultural income. In applying this methodology, the equation is given by:

$$\begin{aligned} Y = \beta &+ a(\text{Soil Degradation}) + b(\text{Flooding}) + c(\text{Pest Invasion}) \\ &+ d(\text{Drought}) + e(\text{Age}) + f(\text{Area}) + g(\text{Fertilizer Dose}) \\ &+ h(\text{Herbicide Quantity}) + i(\text{Wind Frequency in Agricultural Operations}) \\ &+ j(\text{Temperature }^{\circ}\text{C}) + h(\text{Sunlight Hours h}) + l(\text{Precipitation}) \\ &+ m(\text{Drought}) + n(\text{Age}) + o(\text{Area}) + p(\text{Fertilizer Dose}) \\ &+ s(\text{Herbicide Quantity}) + r(\text{Storms in Agricultural Operations}) \\ &+ f(\text{Quantity Produced in kg}) + t(\text{Storms in Agricultural Operations}) + e \end{aligned}$$

This equation models the relationship between various environmental and operational factors and agricultural income, where each term represents the contribution of a specific variable to the overall outcome.

Where: *a*, *b*, *c*, *d*, *e*, *f*: the respective contribution coefficients of the climatic factors and *Y*: Net income in FCFA.

Hypothesis Testing of the Model $\begin{cases} \text{H0}: a = b = c = d = \cdots = 0 \\ \text{H1}: a \neq 0, b \neq 0, c \neq 0, d \neq \cdots \neq 0 \end{cases}$

Hypothesis Testing of the Model $\text{H0}: a = 0 \quad \text{H1}: b \neq 0$

The types, measures, and expected effects of these variables are presented in Table 1.

Table 1. Type and expected effects of the model variables.

Variables	Type of Variable	Expected Effect
Soil Degradation	Ordinal	-
Flooding	Ordinal	-
Pest Invasion	Ordinal	-
Drought	Ordinal	-
Age	Continuous	+
Area	Continuous	+
Fertilizer Dose	Continuous	+
Herbicide Quantity	Continuous	±
Temperature (˚C)	Continuous	±
Sunlight Hours (h)	Continuous	±
Quantity Produced in kg	Continuous	+
Wind Frequency in Agricultural Operations	Binary	-
Precipitation	Continuous	+
Storms in Agricultural Operations	Ordinal	-
Net Margin in FCFA	Continuous	±

For the calculations of profitability and/or operating margins, the formulas described in the table below are used (Table 2).

Table 2. Economic performance indicators of farms and theirs applied formulas.

Profitability Indicators of Agricultural Operations	Description of Indicators	Applied Indicator Formulas
Variable Costs (CV)	Costs that depend directly on the level of production	**CV = Cost of inputs + variable labor + energy and fuel costs + external services + other variable costs.**
Fixed Costs (FC)	Fixed agricultural costs are expenses that do not vary directly with the level of production or sales in an agricultural operation	**CF = Depreciation + Rent + Fixed salaries + Insurance + Taxes and duties + Maintenance and repairs + Other fixed costs.**
Production cost (PC)	expenses incurred by farmers to cultivate crops or raise livestock	**PC = VC + FC**
Margin on Variable Costs (MVC)	The amount that remains to cover fixed costs and generate profit once variable costs are paid.	• **MVC = Gross Agricultural Product (GAP) − Agricultural Variable Costs** • If the MVC > 0, the operation covers its variable costs and generates a margin that can be used to cover fixed costs. • If the MVC < 0, the operation does not generate enough revenue to cover its variable costs, and therefore the operation will be in financial difficulty.
Gross Value Added (GVA)	It represents the wealth created by agricultural operations over a given period.	Agricultural GVA = Value of Agricultural Production − Intermediate Consumption
Net Value Added (NVA)	It measures the wealth created by agricultural operations after subtracting the depreciation of the capital used in the production process.	Agricultural NVA = Agricultural GVA − Depreciation
Agricultural Profitability Index (API)	It measures the overall profitability of the operation, taking into account not only the revenues from agricultural activities but also financial charges and taxes.	API = Gross Operating Surplus (GOS)/Total Production Cost (TPC) × 100 • **Index > 100:** The operation is profitable. This means that the operation generates profits (GOS) that exceed its production costs. The higher the index, the more profitable the operation is. • **Index = 100:** The operation reaches the break-even point. Revenues exactly cover production costs, with no net profit generated. • **Index < 100:** The operation is not profitable. It generates profits that are lower than its production costs, which could indicate financial losses.

3. Results

Perceptions of the Impact of Climate Change on Crops

Farmers perceive the impact of climate change and variability on crops differently. Indeed, 50% of them confirm that millet, the main crop, is one of the most affected. Following this, a category of farmers reports that speculation (millet, sorghum, and rice) is negatively influenced by this change at a rate of 17.60%. Furthermore, it is observed that individually, in order of importance, rice is ranked after millet as the second most impacted crop by climate change, followed by sorghum (Figure 2).

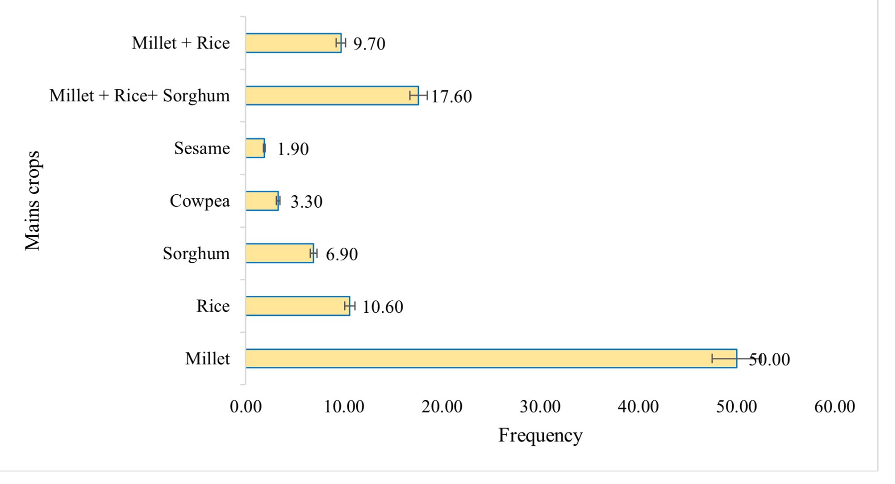

Figure 2. Perceptions of the impact of climate change on crops.

Evolution of Average Production over the Last 30 Years

The assessment of farmers' production levels was carried out over three decades, *i.e.*, 30 years. All productions of the various crops have decreased over the past 30 years. It is observed that the production of millet, sorghum, and cowpea, which were respectively 812, 260, and 100 kg/ha between 30 and 20 years ago, has dropped to 412, 106, and 46 kg/ha, respectively. Climate change could explain this significant decline due to its effects (Figure 3)

Impact of Climate Change on the Economic Outcomes of Agricultural Operations

Economic profitability measures the ability of agricultural operations to generate profit from invested capital while considering climatic factors. The following table provides detailed results on the economic performance of various agricultural operations. In the calculations, the costs associated with household health care are taken into account. These costs vary by category of operation, amounting to 91296.04 FCFA for smallholders, 47825.1 FCFA for medium-sized farms, and 70560.36 FCFA for large agricultural operations (Table 3). It appears that the margin on variable costs per hectare is highest in large agricultural operations, with 571008.01 FCFA, representing a rate of 63%. The profitability rates generated are 33%, 46%, and 49% for small, medium, and large agricultural operations,

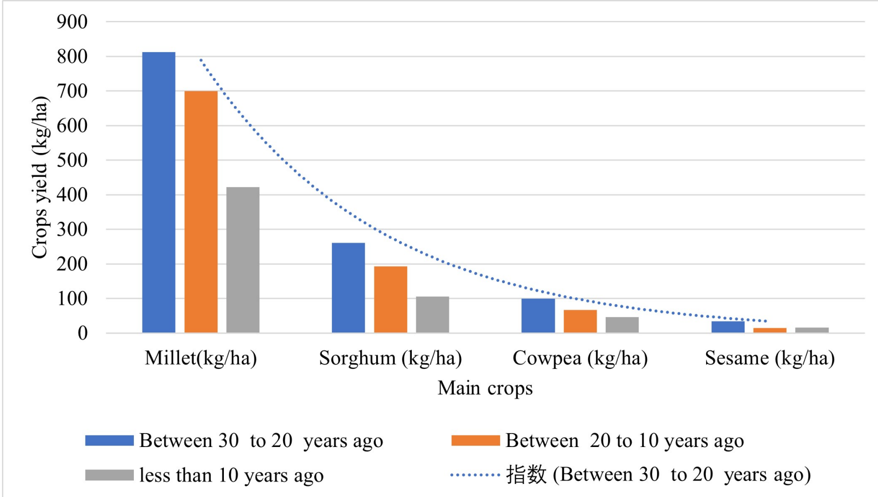

Figure 3. Average productions over the last 30 years.

respectively. The rate of margin on variable costs is 0.46, 0.55, and 0.63 for small, medium, and large farms, respectively. This means that for every FCFA generated in revenue, 46% is available to cover fixed costs and contribute to profits. This rate indicates that the operation has a relatively low margin to cover its fixed costs, which may signal a risk if fixed costs are high for small farms. For the second rate, at this level, the operation has 55% of its revenue available to cover fixed costs. This represents an improvement compared to the previous rate and suggests better management of variable costs or an increase in selling prices. It also allows for a greater capacity to generate profits. The rate of 63% indicates that the operation has a solid margin to cover its fixed costs and achieve profits. This suggests good operational performance and an ability to absorb fluctuations in variable costs without compromising profitability. The break-even threshold without health care coverage costs averages 392,118 FCFA, 375,409 FCFA, and 431,384 FCFA per hectare for small, medium, and large operators, respectively. It should be noted that these thresholds will significantly increase when health care coverage costs are included.

Table 3. Analysis of economic and financial profitability.

Category	Smallholders	Medium-Sized Operators	Large Operators
Variable Costs (FCFA/ha)	449281.57	384169.42	327685.53
Fixed Costs (FCFA/ha)	181294.30	208442.05	274091.28
Production Cost	630575.87	592611.48	601776.83
Yield (kg/ha)	5570.88	5758.43	5991.29
Gross Product (FCFA/ha)	835632.18	863765.02	898693.54
Gross Margin (FCFA/ha)	386350.61	479595.60	571008.01
Net Margin (FCFA/ha)	205056.31	271153.54	296916.72
Health Expenditures	47825.1	70560.3625	91296.04

Continued

Net Health Margin (FCFA/ha)	113760.27	223328.44	226356.36
Profitability	0.33	0.46	0.49
Margin on Variable Costs	386350.61	479595.60	571008.01
Variable Cost Margin Rate	0.46	0.55	0.63
Break-Even Point	392.118.835	375409.9478	431384.6183
Health Break-Even Point	414942.85	399322.50	487832.91
Daily Labor Cost	1000	1000	1000
Average Labor Productivity	205.056312	271.1535419	296.9167232

Impact of Climate Change on Agricultural Income of Farms

Table 4 presents the results from the regression analysis to assess the indicators of climate change on agricultural income. The Fisher test indicates that these regressions are overall significant. The coefficient of determination (R^2) for the model is 0.31. The inclusion of adaptation variables improves the fit quality (with $R^2 = 0.40$). The results show that variables such as precipitation and quantities produced have a positive and significant effect on agricultural income at the 1% level. In other words, an increase in these variables leads to an increase in household agricultural income. However, it should be noted that temperature at certain levels promotes the development of a new pest (which has been unknown until now). Conversely, a negative and significant effect on agricultural income has been observed for variables such as flooding, pest invasions in rice fields, temperature, and droughts. Temperature, through high-intensity heat, could reduce income. This can be explained by the emergence and proliferation of earthworms in the rice fields, which farmers attribute to heat causing a type of disease manifested by gigantism in rice plants, locally referred to as "Fouroumie" or "Tana." This phenomenon is characterized by swelling of the clay around the rice plants, containing earthworms of considerable weight and length, ranging from 10 to 15 cm. This clay mound increases in size and spreads, engulfing the plant up to its leaves or grains. As a result, the plant is smothered, and its growth is slowed and ultimately destroyed. This issue leads to low rice yields and income loss. This phenomenon is observed in almost all target villages in the municipality. These earthworms retreat deep into the soil at the end of the season or in the absence of moisture until the next production cycle.

Table 4. Econometric results.

Model	Impact on Net Margin	Strength of the Link between Factors and Net Margin
(Constant)	211380.0	
Soil Degradation	−69538.905	−0.033
Flooding	−73457.26	−0.193***

Continued

Pest Invasion	−25637.87	−0.270***
Drought	−10774.14	−0.120***
Age	374.990	0.053
Area	310252.2	0.466**
Fertilizer Dose	86.428	0.138
Herbicide Quantity	5266.187	0.110
Temperature (˚C)	−8316.616	−0.135**
Sunshine Hours (h)	−10301.50	−0.075
Quantity Produced in kg	130.907	0.953***
Wind Frequency in Agricultural Areas	−8449.198	−0.128***
Precipitation	317.667	0.160***
Storms in Agricultural Areas	−2603.782	−0.036

Significant at the 10% level; **Significant at the 5% level; ***Significant at the 1% level.

Programmatic Analyses of the Profitability of Agricultural Operations

The results from linear programming indicate that farmers can adjust certain costs at the variable expense level and achieve a profitability level above the break-even point. For small-scale farmers, they can increase their break-even point from 392118.8 FCFA to 508979.83 FCFA, resulting in a programmatic margin of 116861.0 FCFA. It is noteworthy that these categories invest more in variable costs than other categories. Large operators, on the other hand, can maximize their break-even point (431384.6 FCFA) to reach a profitability level of 723372.85 FCFA. Additionally, it is evident that the first category of operations invests more in health per hectare (Table 5).

Table 5. Results of the economic profitability of agricultural holdings.

Variables / Type of Farmers	Cost of Patient Care (FCFA)	Fixed Costs per Hectare (FCFA)	Variable Costs per Hectare (FCFA)	Break-Even Point (FCFA)		Programmatic Margin (FCFA)
				Initial Value	Final Value	
Smallholders	47825.1	181294.3	449281.5	392118.8	508979.83	**116861.0**
Medium-sized farmers	70560.3625	208442.0	384169.4	375409.9	592611.47	**217201.5**
Large farmers	91296.04	274091.2	327685.5	431384.6	723372.85	**291988.2**

Climate Change and Diseases in Rice Fields

The persistence of changes in the rainy seasons over recent years has led farmers to recognize the existence of climate change. This shift in production is evidenced by the emergence of previously unknown pests (see Photo 1) in rice fields, which they had not encountered before or were not accustomed to seeing in this area. The diseases present in the rice fields, which are causing an exaggerated decrease in rice yields, include rice gigantism and stem and leaf disease. For the stem and leaf disease, symptoms are observed through the yellowing of leaves that stick together due to a clear brown liquid, where the responsible pest is not visible to the naked eye. However, the most prevalent of these diseases, which spreads extensively in rice fields, particularly in this area, is rice gigantism. Commonly referred to as "tana" or "foroum" by local inhabitants, it wreaks havoc by constricting the plant and hindering its development through mounds of sand that contain long earthworms measuring 10 to 15 cm in length. This condition also hampers crop growth as the volume and size of the sand mound increase, eventually overwhelming the plant at the edges of the leaves. Consequently, there will be insufficient germination of crops, resulting in low rice yields (see Photo 2). As a result, farmers are increasingly complaining about this chronic disease affecting their rice fields because they have not yet found a solution that can effectively deal with the earthworms present in the rice fields, which multiply rapidly from one field to another. Their lifestyle is closely linked to their environment (temperature and clayey soil with permanent water presence). According to farmers, in the absence of permanent water, earthworms take refuge deep in the soil for a time until a new rice crop emerges and then resurface due to the moisture attraction from the soil. Photo 3 presents a rice farm which is not infected.

Photo 1. Images of the pest.

Photo 2. Field infected by the disease.

Photo 3. Field not infected by the disease.

Strategies for Farmers' Adaptation to the Main Effects of Climate Change

Globally, farmers adopt various strategies to adapt to the impacts of climate change based on the nature and severity of the shocks. The main shocks include flooding, early cessation of rains, sandstorms, delays in the first rains (compared to usual patterns), and the frequency of strong winds. Analysis of Figure 3 shows that regardless of the shock, the choice of crop varieties remains a common adaptation strategy. Assisted natural regeneration (ANR) and land recovery activities (LRA) are the means used to combat strong winds in agricultural operations (see Figure 4).

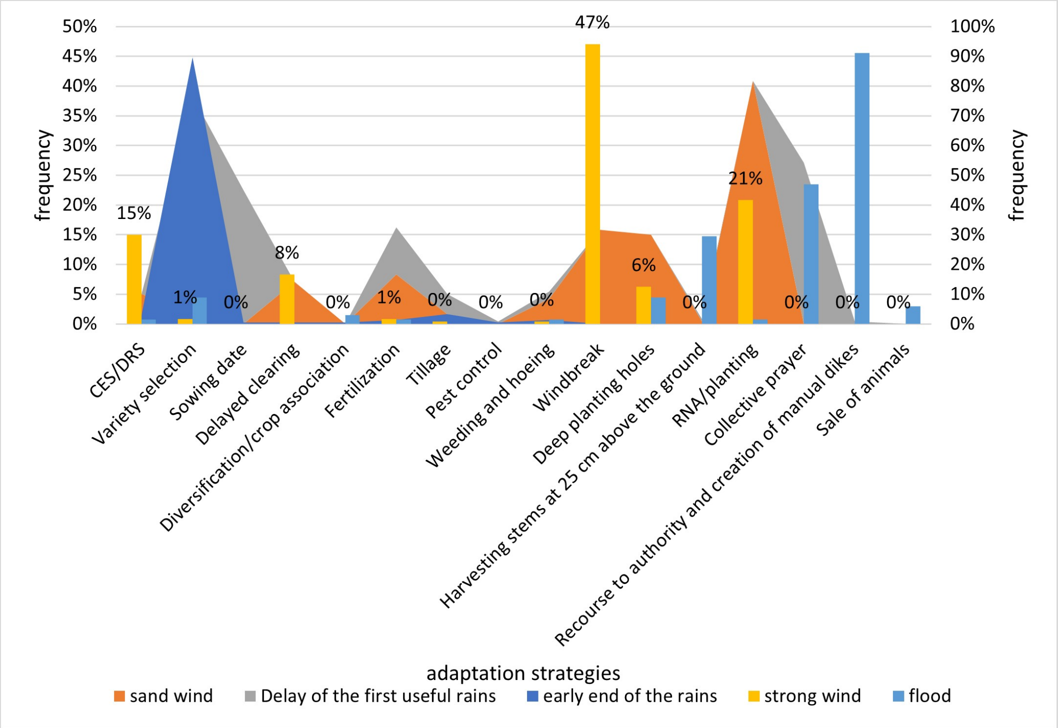

Figure 4. Adaptation strategies facing major climate shocks.

4. Discussion

Climate has a significant influence on agriculture, which is considered the human activity most dependent on climatic variations [27]. Indeed, climate disruption is no longer a mere hypothesis; it is a reality that is severely impacting agriculture. Several agronomic consequences are anticipated by researchers, including the development of yellow rust, a decrease in photosynthesis, and changes in the duration of the plant life cycle. Variability in precipitation and temperature, as well as strong winds, negatively affect agricultural operations. These effects are characterized by the proliferation of crop pests, the emergence of crop diseases, sand accumulation around young seedlings, crop desiccation, and soil degradation. The cumulative effects lead to significant yield losses. In this context, [28] results from Burkina Faso suggest that an increase in temperature may not be as beneficial as expected. A rise in temperature will also lead to an increase in pests that survive winter and can thus complete more reproductive cycles. Fifty percent of farmers perceive the impact of this change on millet cultivation and 17.60% on millet, sorghum, and rice. Yet, these are the main staple crops that feed local populations. Over the past twenty years, the production of these cereals has decreased by 15 to 20%, and this could worsen in the coming years, directly threatening food security for residents [29]. The combination of rising temperatures and decreasing precipitation suggests a downward trend in yields. However, temperature has the greatest responsibility for this observation [30]. In the study by [26], it is demonstrated that when warming exceeds 3˚C, a deficit in simulated yield is observed regardless of the rainfall anomaly considered (within a realistic range of −20% to +20% based on minimum and maximum future projections). This impact is particularly manifested in the region through droughts, floods, pest invasions, and the development of certain diseases that reduce crop yields. Each year, farmers perceive climatic events affecting their agricultural operations. A decline in cereal production has also been perceived by farmers over the past three decades. This can be explained by the fact that during the 20 to 30-year period, there were not many production issues as the rainy seasons were generally acceptable, accompanied by fertilizer application and high soil fertility. From the 20 to 10-year interval, there began to be a shortage of arable land, a lack of fallow land, and insufficient fertilizer application. Additionally, there was a decrease in the intensity and duration of the rainy seasons, leading to low agricultural yields. In the last decade, irregularity and shortening of the rainy seasons have been recorded, alongside a significant decline in soil fertility caused by the overexploitation of arable land and lack of fertilizer application. Furthermore, it is important to note the rise in temperatures, which could negatively affect agricultural operations at certain times. Analysis of the evolution of average cultivated areas, agricultural production, and agricultural yields over the past thirty years shows a progressive regression across decades. According to their results, the areas planted with major staple crops experienced a significant decline. Indeed, between 2010 and 2015, this decrease was 11.39% for millet and 11.83% for cowpeas. Regarding production, there is a noticeable regression: 11.28% for millet, which is the main staple crop, and 66.24% for sesame. Agricultural yield decreased from 736 kg/ha to 513 kg/ha, representing a loss of 223 kg/ha, estimated at 30.29% lower than 51.14%. This variability has impacted the economic outcomes of agricultural operations. This can be explained by the fact that part of the costs associated with agricultural activities is indeed allocated for patient care at their expense [31]. Agricultural income is influenced by several climatic factors in this case. Among these factors is temperature, which, although beneficial, could be responsible for the development of certain pests (previously unknown and not combated by farmers) in the area. The decline in this income due to rising temperatures can be explained by the fact that this new pest thrives at higher temperatures and develops rapidly within agricultural operations. This will consequently reduce agricultural yields and, as a result, the net income from farming. The study by [32] shows that the marginal impact of temperature on agricultural income is −19.9 USD per hectare, while that of precipitation is +2.7 USD per hectare. The analysis of elasticities indicates that agriculture is highly sensitive to precipitation; a 1% increase in precipitation leads to a 14.7% increase in agricultural income. Conversely, a 1% increase in temperature results in a 3.6% decrease in agricultural income. Regardless of the regression model estimated, a significant portion of the variation in agricultural income remains unexplained by the variables considered. Assisted natural regeneration and land recovery activities are the means used to combat strong winds in agricultural operations (20.59% and 14.71%, respectively). The same results were obtained by [33] and [9]. However, the study of [34] reveals that temperature favors agricultural yields. This can be explained in our study by the emergence and proliferation of earthworms in the rice fields, which farmers attribute to heat causing a type of disease manifested by gigantism in rice plants.

5. Conclusion

Data analysis shows that in the rural commune of Kourthèye, the last three decades have been characterized by significant changes, particularly marked by sequences of severe drought, a rising temperature trend, the emergence of new pests not previously known, and a decrease in the frequency of rainfall events leading to shorter seasons. These phenomena, coupled with demographic pressures, have exacerbated the continuous decline in soil fertility and the loss of arable land. Additionally, there has been an increase in crop diseases such as stem and leaf rot, yellowing of leaves, and dwarfism. The cumulative effects of these observed changes negatively impact agricultural production. Agricultural yields have since been in clear regression. In fact, the decline in net agricultural income is largely explained by these extreme climatic events affecting farming operations. Several studies have demonstrated the effectiveness of water and soil conservation techniques.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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