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Vulnerability of smallholder farmers to climate change in Sokoto state, Nigeria

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Abstract
The risk climate change poses to all sectors of the global economy has attracted the attention of scientists and policymakers in recent times. The agricultural sector in developing countries that is heavily dependent on climate is the most vulnerable. Quantifying the impact of climate change may contribute towards articulating a sustainable livelihood. This paper applies the Ricardian technique to assess the impact of climate change on smallholder farmers in Sokoto State, Nigeria. The study made use of data collected from 430 farmers across 3 agricultural zones. Climatic records from 1970 to 2015 for northern Nigeria was also used as the secondary data. The result revealed that there is a significant relationship between climate change and net revenues from agriculture. With every increase in 1 ºC and 1mm of temperature and rainfall respectively, there is an increase in net revenue. Moreover, the study reveals that farm characteristics have a mixed effect on net revenue. Conclusively, climate change exerts a significant effect on smallholder net revenue from agriculture. This calls for concern of all stakeholders on the greatest environmental threat of our time.

Keywords: Ricardian model, net revenue; climate change; smallholder farms, Sokoto state

Introduction

All regions of the world are subjected to the influences of climate change, which causes momentous distresses that can be asserted to be natural systems that have impacts on humans and the environment [16]. These impacts, according to [13]. can befall either through direct or indirect means. Societies that are largely dependent on agricultural production, are considered to be the most vulnerable to the adverse effects of climate change. Attention is given to the different impacted facets like agriculture, ecological systems, water, forestry, and fisheries, which are deliberated to be essential to humans [16]. [13] Agriculture is an important sector of the world economy. Much of the world's food supply came from agriculture, besides other products of agriculture from crops, livestock, and seafood grown or raised contributes goods and services worth billions of dollars to the world economy each year. Crops and livestock production are highly dependent on specific climatic conditions. Slight changes in climate could directly affect crop yield and livestock productivity [33, 30]. Climate change-induced drought may also threaten pasture and feed supplies as well as an increase in the prevalence of parasitic diseases that affect the livestock.

In Nigeria, agriculture is one of the most viable sectors of the economy. The sector contributed a large share of the GDP by up to 22% in 2019 [24]. Despite the crucial role agriculture plays towards the social and economic development of Nigeria, agricultural production is dominated by smallholder farmers and is rainfed dependant; thus, subjected to the adverse effects of climate change [2]. Evidence from scientific studies predicted the impact of climate change on agriculture in many regions of the world. Like most countries, Nigeria is experiencing changes in climate in form of variable rainfall, drought and desertification, increase in temperature, rise in sea level and flooding, land degradation, erratic weather, loss of and biodiversity [8, 7, 28]. It is estimated that the damage due to climate change in Nigeria and other countries in sub-Saharan Africa would reach between 1.5% to 3% of GDP each year by 2030, it was predicted that crop yield would decline by 10-20% by 2050 [5]. Total dependence on agriculture by a large percentage of the citizenry, poor climate change adaptation policies exacerbated by its geographical position makes Nigeria even more vulnerable.

Although many studies were conducted on the impact of climate change in Nigeria [14, 10, 8, 7] no attempt was made to investigate the impact of climate change on the net revenue of smallholder farmers. The dominant role of small scale farmers in ensuring food security and the overall agricultural development of Nigeria coupled with negative forecast of the impact of climate change on Nigeria's agriculture calls for in-depth assessment to provide information on the vulnerability of smallholder farmers. The knowledge is crucial for developing appropriate farm adaptation strategies aimed at cushioning the impact. This is yet to happen as current literature on the impact of climate change on smallholder farms is deficient in Nigeria.

This study adopts a Ricardian approach to analyze the following objectives:

1. correlation between climate variables (temperature and rainfall) and farmer's net revenue
2. assess the impact of marginal climate change on net revenue from smallholder farmers
3. Observe the impacts of future change in climate change on net revenue from smallholder farmers.

Findings from this study could be used in formulating practical adaptation modalities in the framework of climate change in Sokoto State. This paper is structured as follows: an introduction is the first part followed by the methodology, and then the result and lastly the conclusion and managerial implication.

2. Methodology

Study Area

Geographically, Sokoto State is located between latitudes 7^0 and 14^0 North and longitudes 3^0 and 15^0 East of the equator, it covers an estimated area of 25,973 km^2 and has a population of 4,998,090 based on 2016 projection [24]. According to [17] over 80% of people living in state practice agriculture. The state is in the dry Sahel, surrounded by sandy savannah and isolated hills. With an annual average temperature of 28.3 °C (82.9 °F). The rainy season is from June to October during which showers are a daily occurrence. From late October to February, during the cold season, the climate is dominated by the Harmattan wind blowing Sahara dust over the land. Sokoto State generally has a mean annual rainfall of about 500mm.

Sampling

The target populations are households who are into agriculture in Sokoto State, the units of analysis are farmers whose farm holdings are less than five hectares. Sampling of respondents was done in stages, firstly, local government areas and districts that have a high potential for agriculture were purposively chosen for the study, and at the second stage, respondents from 12 districts in 6 local government areas of Sokoto state were randomly selected via a lottery method. These sampling techniques ensure that respondents with the desired characteristics are chosen for the study. It also provides accurate and cheap measures, although in using the technique certain elements of biases could be introduced.

The superiority of a systematic random sampling technique over other methods is its applicability to a large sample population and provides adequate representation for the majority of the population. To improve survey usability and reduce the risk of measurement errors large sample size was provided. Five hundred (500) respondents were selected from the sampling frame as in [22, 15]. In the end, a total of 430 surveys were completed from which 360 were valid, this number represents about 72% response rates. The analysis for the study was based on all the 360 surveys. The experience sampling method (selecting respondents based on availability) was used to determine the sample size. This was the only feasible option due to the limitation on the size of the sampling frame.

Data Collection

The situation under which the study was conducted makes the questionnaire survey the most feasible option as in the case of [20, 31, 25, 3]. Data for the study were collected in 12 districts in 6 local government areas Sokoto State. The local government are Silame, Wamakko Bodinga, Kebbe, Rabah, and Sabon Birni.

Model Specification

When studying agricultural production, the Ricardian technique is widely used. David Ricardo (1770-1823) developed the model when studying the net productivity of land values, and the same method was introduced to estimate the impact of climate change by [18]. Globally, the Ricardian model was used in various studies. In Africa, [20, 9, 6, 29] completed their work using the model. This implies that climate, soils, and economic situations are the determinants of land values or net agricultural revenue.

To apply the Ricardian technique, the net revenue function is specified as:

$$R = \sum P_i Q_i (X, F, G, Z) - \sum P_X X \quad \text{equation (1)}$$

Where R=Net Revenue /Ha, P=Market Price of $Crop_i$, Q=Output of Crop

X=Vector of Purchase Output, F=Vector of Climate Variables, G=Set of Economic Variables such as Livestock Ownership, Z=Set of Soil Variables, P_X =Vector of Input Prices

Following [18] the net revenue model for Sokoto State is specified as:

$$V=\beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 G + \beta_4 Z + U \quad \text{equation (2)}$$

Where V= Net farm revenue, F = Vector for climatic variables, G = Set of economic variables, Z=Soil variables, U=Error term

In applying the Ricardian model in addition to the linear term of climatic variables (temperature and precipitation) quadratic term is also introduced to capture the known nonlinear relationship between net revenue and climate, a positive sign of the quadratic term means that the net revenue function is U shaped, and a negative sign indicates that the relationship is hill shape.

Marginal impact analysis examines the impact of an infinitesimal change in temperature and precipitation on net revenue, the marginal value of each climate component (f_i) depends on both the linear and quadratic climate coefficients. The marginal effect of climate variable (f_i) on net revenue calculated at the mean of the sample is given as:

$$dV/f_i = \beta_{1,i} + 2 \times \beta_{2,i} \times f_i \quad \text{equation (3)}$$

Data Analysis

Data for the study was obtained through a farm survey conducted in January 2020 using a structured questionnaire. The questionnaire was designed to obtain farm-level data on agricultural production across 3 agricultural zones in Sokoto state. Information on crop production practices, production costs, marketing, soil type, socio-economic factors, climate change perceptions, and farm adaptations options that explained variations in farm net revenue among the respondents was obtained. The questionnaire was structured into 5 sections. Section I involves questions about agricultural/environmental problems. Section 2 centered on agricultural production practices and production cost, section 3 deals with the economic characteristics of the respondents, section 4 focused on climate change perception and finally, section 5 was on the respondent's demographic variables. Secondary data for the study involves two climatic elements (Temperature and rainfall). Data on climate was obtained from Nigeria meteorological agency (NIMET) the agency is charged with the responsibility of managing meteorological data for Nigeria. Nigeria reconnaissance soil survey 2009 report obtained from the Federal Department of Land Resources provides the soil data used in the study. The report describes the characteristics of Nigerian soils and their fertility levels.

Variables for the Study

Dependent Variable

Land value is used as the dependent variable in the

Ricardian analysis. However, certain modifications were made to correctly apply the technique in developing countries. One of the modifications was the use of net revenue/ha as the dependent variable. The use of net revenue as the dependent variable as an option was due to a lack of a precise measure of land values in many developing countries.

In Sokoto State, there is no record of agricultural land value because of the nature of the land tenure system given this shortcoming the study adopts the use of net revenue per hectare as the dependent variable. Net revenue/ha is calculated as the product of gross net revenue (price multiplied by the quantity in kg) minus total production costs such as (seeds, fertilizer, chemicals, tillage, weeding, harvesting, transport, storage, and processing) divided by the farm area in hectares.

Explanatory Variables

Climate variables, soil variables, and relevant socio-economic variables were used as the explanatory variables for the study.

Climatic Variables

Agricultural production in Sokoto State is mainly dependent on climate and is largely carried out during the rainy season however pockets of areas where irrigation is practiced are found in the dry season or the rainy season as a supplement to rainfall during a drought situation. The climate of Sokoto State is characterized by two marked seasons the dry season and the rainy season. Two important elements of climate; Temperature in (^{0}C) and rainfall in (mm) were considered by the study. In line with the climatic setup of Sokoto State, the elements i.e. temperature and rainfall were included in the study as rainy season (May to October) and dry season (November to April). The dry season temperature is defined by the average temperature of the dry season (November to April) for all the sampled states. The rainy season temperature is included as the average temperature of the rainy season (May to October). A similar pattern was followed in defining the rainy and dry season precipitation.

Soil

To examine the relationship between soil and revenue soil variable was included. Six groups of soils in the area were identified and ranked according to fertility based on the Nigeria reconnaissance soil survey 2009 classification. These are Orchic luvisol, Orchic acrisol, Dystric regosol, Ferric luvisol, Eutric fluvisol, and Ferric acrisol. The different soils showed variation in their physical and chemical properties, likewise their fertility status. These properties are important determinants of soil quality the combined effect of which together with climate can directly affect yield which in turn determines net revenue.

Socioeconomic Factors

Until now only climatic and soil variables were considered, socio-economic attributes are likewise vital in explaining the variation of farm technology and net revenue. To examine the role of socioeconomic factors on net revenue the study tested the effect of farm power, farm size, house size, market, and livestock keeping. A dummy for farm power was included in the model as (Hand, animal, and tractor) to test the influence of farm power. The size of a farm is hypothesized to affect net revenue a variable for farm size was included to test the effect of farm size. A variable for house size was also incorporated in the analysis to stand in for labor that was left out of the estimations for the net revenue. Inclusion of house size was due to the difficulty experienced in arriving at an accurate wage for household labor which most households relied on. Market distance could also affect net revenue; the distance of the input market in kilometers was included to assess its relationship with net revenue. Another farm attribute that is forecasted to positively contribute to net revenue is the number of animals kept by the farmer. Livestock keeping is an important component of agriculture in Sokoto State. Animals are kept as a source of farm power; they provide the much-needed manure and serves as a strategy for risk management.

Model Estimation

Stata 13.0 statistical package was used to . The estimated model includes data on farms that are less than five hectares. This will enable the study to examine how climate change affects net revenue in smallholder farms. Strong multicollinearity was found between the linear and quadratic variables for the rainy season temperature. Some of the steps taken to solve the problem include demeaning all the climatic variables and using various functional forms to estimate the model when all these measures failed the last option which was to exclude the variable for the quadratic term of the rainy season temperature was employed based on multicollinearity and non-significance. To establish a strong statistical relationship between variables socioeconomic characteristics such as access to credit, extension, education, and experience that are insignificant and redundant were removed; Dataset was tested to be free from heteroscedasticity using the White heteroscedasticity test. Outliers were detected and removed and data normality was tested using skewness and kurtosis normality test. Robust standard error estimation was used to improve estimation efficiency.

3. Results

Descriptive Statistics

A summary of the basic statistic of the dataset for the variable used in the study was presented in Table 1 below. The result showed that the average net revenue/ ha is ₦43,157. The net revenue ranges from a minimum of ₦1760 to a maximum of ₦91,900/ ha. Six major types of soils were identified and ranked according to their fertility by the study. The mean fertility was 2.30 with minimum fertility of 1.50 and a maximum of 3.50. The average distance to the input market was 10.87 kilometers, the distance varies widely between a minimum of 1.0 kilometers to a maximum distance of 50 kilometers. The average number of cattle owned by the respondents was 3.0 with a minimum of 0 and a maximum of 50. The average land area allocated to agricultural production was 4.07 hectares, a minimum of 0.20 hectares and a maximum of 200 hectares.

Household size is defined as the number of persons related or unrelated living under one roof. The average size of the household was 8 people with a minimum of 0 and a maximum of 40 people. Farm power dummy was included in the model as hand, animal or tractor; this is used as a proxy for farm technology.

Table 1: Descriptive statistics for variables used in the study

Variable	Observation	Minimum	Maximum	Mean	Std. dev.
Net revenue (₦/ha)	425	1760	91900	43157	20266
Dry season temperature (^{0}C)	-	25.80	36	33.70	2.26
Rainy season temperature (0^C)	-	26.80	35	31.84	2.42
Dry season precipitation (mm)	-	0.20	16.60	4.10	4.51
Rainy season precipitation (mm)	-	77	200	146.37	39.55
Soil	-	1.50	3.50	2.33	0.66
Market	-	1.0	50	10.87	5.39
Livestock	-	0	50	3.0	5.08
House size	-	1.0	40	8.32	5.39
Farm size	-	0.20	4.50	1.30	0.91
Animal	-	0	1.00	0.37	0.48
Tractor	-	0	1.00	0.32	0.47

Source: Generated by the authors with data from field survey 2020
Note: Figures in parenthesis are units of measurement; ₦ represent Nigerian currency

Regression Results for Net Revenue Function Model

In this study, to observe the response of smallholder farmers to climate change farms that are less than 5 hectares are were used for the analysis. The result of regression presented in Table 2 showed that the sign of the coefficients both for the quadratic and linear terms for the climatic variables was nearly similar. The coefficient of the dry season temperature was positive and significant while that of rainy season temperature was negative and also negative. The sign of the coefficient for dry season precipitation was positive and insignificant. Similarly, the coefficient for rainy season precipitation was positive and also insignificant. The soil had a positive effect on net revenue as shown by its coefficient. This helps to explain that some classes of soils in the area provide enough fertility for maize production, the coefficient for soil was however not significant. Also, Table 2presents the result that shows the influence of market distance on net revenue. The variable for market distance was negative and statistically significant; this implies that market distance had a negative relationship with net revenue.

The coefficient for livestock surprisingly reveals a negative impact on net revenue. The coefficients for livestock were not significant, the result of the study presented in Table 2 also indicates that the coefficients for farmland size were positive and statistically significant. The coefficient for house size as expected was positive but not significant. For farm power usage the coefficients for both animal and tractor as sources of farm power were positive and significant in the case of a tractor.

Table 2: Regression Result for Net Revenue Function Model

Variable	Coefficient	t-value	p>|t|
Constant	−38.501	−1.54	0.124
Dry season temperature	35.657*	2.67	0.008
Dry season temperature^2	−4.956*	−2.73	0.007
Rainy season temperature	− 5.807*	−2.74	0.006
Dry season precipitation	0.143	1.32	0.187
Dry season precipitation^2	−0.036	−1.30	0.193
Rainy season precipitation	3.246	0.82	0.413
Rainy season precipitation^2	−0.453	−1.09	0.275
Soil	0.106	0.64	0.519
Market	− 0.076*	−1.90	0.058
Livestock	− 0.009	−0.29	0.769
Farm size	0.345***	7.94	0.000
House size	0.003	0.07	0.941
Animal	0.122	1.57	0.116
Tractor	0.204**	2.88	0.004
Number of observations	425		
R-squared	0.31		
F	11.4		

***Source*:** Generated by the authors with data from farm survey 2020
Note: p-value ***, significant at 1%; **significant at 5%; * significant at 10%

Marginal Impact Analysis

The marginal impact analysis was done to examine the impact of insignificant change in temperature and precipitation on net revenue/ha from agriculture in Sokoto State. Following [19, 32], the marginal value of each climate component (f_i) depends on both the linear and quadratic climate coefficients. The marginal effect of climate variable (f_i) on net revenue at the mean of the sample can be calculated as:

$$dV/f_i = \beta_{1,i} + 2 \times \beta_{2,i} \times f_i$$

The results presented in Table 3 show the marginal impacts of temperature and precipitation on net revenue. A decline in net revenue amounting to ₦298/ha due to a slight increase in temperature in the dry season and an increase in net revenue of ₦130/ha for a marginal rise in temperature during the rainy season were observed. The annual impact

due to a marginal rise in temperature was a decline in net revenue worth ₦168/ha. On the same Table, the impact due to the marginal rise in rainfall was also forecasted, the marginal impact of rainfall is less than one naira in the dry season (₦0.147) but the marginal impact of rainfall during the growing season result toa decline in net revenue of about ₦130/ha. The total annual impact due to a marginal rise in precipitation led to a decline in net revenue of₦130/ha.

Table 3: Marginal Impact of Climate on Net Revenue

Climate	Marginal Impact	Elasticities
Dry season temperature	− ₦298	11.93
Rainy season temperature	₦130	-1.91
Annual marginal impact	− ₦168	
Dry season precipitation	− ₦ 0.147	0.01
Rainy season precipitation	− ₦130	1.53
Annual marginal impact	− ₦130	

Source: calculated by authors from coefficients in Table 2

Furthermore, the study used the A2 emission scenario of the Global Circulation Model (GCM) to project the future impact of climate change on net revenue.

This gave a picture of how future climate scenarios will affect net revenue from smallholder farms; the analysis forecasted impact for the years 2030, 2060, and 2090 using the coefficients for the net revenue function.

Projection on the impact of temperature was made based on a forecast of increasing temperature for Nigeria by as much as 1^0C in 2030, 2.3 ^{0}C in 2060 and 3.7 ^{0}Cin 2090 and a slight increase in precipitation by 0% in 2030, 1% in 2060 and 4% in 2090 [1, 34, 35].

Results for the impact of future climate scenarios were shown in Table 4.

+It was projected that by 2030 ₦ 179/ha will be lost due to a 1-degree rise in temperature, a 2.3-degree rise in temperature will result to decline in net revenue amounting to ₦210/ha while 3.7 ^{0}C increase in temperature forecasted by the year 2090 will lead to a loss of ₦190/ha. Similarly, the result of the impact of change in rainfall was also estimated.

As shown in Table 4 no change in rainfall is predicted by the year 2030 and revenue was forecasted to slightly falling by ₦129/ha, while by the year 2060 due to a 1% increase in rainfall net revenue will decline by ₦131/ha.

By 2090 4% increase in rainfall was predicted and revenue was estimated to go down by ₦135/ha.

Table 4: Impact of Future Climate Change on Net Revenue

Climate scenario Temperature (^{0}C)	Year of Projection	Future Impact
+ 1	2030	−₦179
+ 2.1	2060	−₦210
+3.7	2090	−₦190
Precipitation (mm)		
+0%	2030	−₦129
+1%	2060	−₦131
+4%	2090	−₦135

Source: Calculated by the authors using data from GCM climate projections for Nigeria based on A2 climate scenario

Discussion

The vulnerability of smallholder farms to climate change was tested assessed in this study; the results were presented in Table 2. It was believed that smallholder farms have fewer adaptation options and are more vulnerable to climate change than large farms, to observe the behavior of smallholder farms in changing climate farms that are less than 5 hectares were considered for this analysis. The findings of the study showed that smallholder farm income is more sensitive to a higher temperature and therefore more vulnerable to harm due to temperature increase than precipitation increase. The vulnerability of smallholder farms to temperature increase could be explained by a lack of alternative adaptation options that limits their ability to adapt. On the vulnerability of farms to precipitation the result of this study further reveals that smallholder farms are equally vulnerable to an increase in precipitation. However, findings of the study suggest that smallholder farms are more sensitive to temperature increase rather than precipitation changes and revenue tends to be harmed more due to changes in temperature. This result is consistent with the findings of [18] that revealed that small farms are more vulnerable to temperature, while large farms are more sensitive to precipitation than small farms and that higher temperature in the dry season is beneficial to net revenue while the increase in temperature in the growing season is detrimental to revenue. Therefore, the original hypothesis suggests that smallholder farms are prone to the negative impact of climate change holds for an increase in temperature only but does not hold for rainfall increase.

Results of the regression in Table 2 showed that temperature is beneficial for farms in the dry season; this could be explained by the fact that higher temperature in the dry season is required to facilitate crop maturity, ripening, and drying. These processes are important for higher yield and revenue.

In contrast, a negative correlation between temperature and net revenue was observed during the growing season, this may imply that the average temperature in Sokoto State is adequate for agricultural production and a further increase in temperature will affect revenue negatively.

The positive relationship that was found between precipitation and net revenue could be explained by the fact that moisture is essential for all the physiological processes of crop growth and development. Although in all the season's net revenue was positively related to precipitation the impact is higher in the rainy season. Smallholder farms may be more vulnerable to temperature increase than precipitation because of their low moisture requirement and ability to conserve and use moisture efficiently. This factor may explain why moisture is not a major limiting factor to production. The soil had a positive relationship with net revenue implying that fertile soil would contribute more to revenue. The non-significant relationship between the soil variable and net revenue may be an indication that the soil in the area is productive and smallholder farms can depend on the soil if properly managed with little or no requirement for additional inorganic fertilizer.

Similarly, distance to the input market, measured in kilometers was also examined in the study. Findings presented in Table 2 showed that the variable for the market was negative, implying that farms lose revenue if they are located farther away from the market. The result, furthermore, showed that the coefficient for the market is significant; this highlights the sensitivity of net revenue to market distance. This result is expected because the more the distance of the market the more cost is incurred in purchasing inputs and produce marketing. Therefore, farms with proximity to the market are expected to have higher net revenue. Surprisingly, the coefficient for livestock variable was negative as presented in Table 2 the priori expectation is that in small farm holding net revenue should exhibit a positive relationship with livestock keeping this is because of the important role livestock animals plays in adapting the farms to climate change. The contrasting result obtained in this study may be due to the inability of smallholder farms to adequately manage the animals, especially during the dry season when there is no pasture and the cost of feed is high as a result keeping of animals may not be beneficial.

The variable farm size as revealed by the findings of the study (Table 2) had a positive and statistically significant relationship with net revenue. This might not be unconnected with the phase of production of the farmers in that more land translates to more productivity and their input use, such as fertilizer, seed, and labor may be fixed over a small area this is consistent with [20]. However, this trend only applies before diminishing returns sets in. This result shows the need for smallholder farms to increase their landholdings to raise productivity. With regards to house size findings of the study shown in column 2, Table 2 reveals that the variable house size exerts a positive relationship with net revenue, this implies that for smallholder farms net revenue increases as the households grow larger, the variable for the house size is however not significant but the results show that smallholder farms may benefit from large households because of low demand for labor the farms could be managed by the family labor and it is uneconomical to engage hired labor, this is finding is consistent with [20].

On-farm power usage shown in Table 2 the coefficient for both animal and tractor was positive but only the coefficient for a tractor was significant. This shows the importance of tractor as a source of power. An important implication of the findings on-farm power usage is that using a more advanced level of farm power such as animals and tractor may be more beneficial. The positive sign of the coefficient for power could be explained by the fact that smallholder farms may be more effectively covered with animals or machines. Using animals and tractors ensures timeliness and cost-effectiveness in important farm operations, such as tillage and planting during the onset of the rainy season, as well as harvesting, processing, and transportation at the end of the farming season. This result implies that employing the use of animals and machines in executing farm operations by the smallholder farms is beneficial to net revenue and could be used as a climate change adaptation option.

Furthermore, the study estimated the marginal impact of climate change on net revenue the result was presented in Table 3. It was shown that due to 1^0C rise in temperature and 1mm increase in precipitation net revenue will decline. The negative impact on the marginal rise in temperature and precipitation was estimated at₦168/ha and ₦130 respectively. To provide a clear understanding of how net revenue will be damage by future climate change the study forecasted future impact for the years 2030, 2060, and 2090. It was predicted that temperature will rise by 1 ^{0}C, 2.1^{0}C, and 3.7^{0}C by 2030, 2060, and 2090 correspondingly net revenue will fall by ₦179/ha, ₦210/ha, and ₦190/ha respectively. Similarly, the analysis predicted the trend of a decline in net revenue due to the future rise. Using forecasts from different models which projected a slight increase in precipitation across Nigeria, the impact due to 0%, 1%, and 4% increase in precipitation by 2030, 2060, and 2090 showed that net revenue will be slashed by ₦129/ha, ₦131/ha, and ₦135/ha. It is worthy to note that the future impacts of both temperature and precipitation on net revenue are not only negative but also decline at an increasing trend. The nature of the future impact is that although both temperature and precipitation increase could lead to a decline in net revenue rise in temperature will be more harmful.

The debate on the declining farm revenue due to climate change has attracted the attention of researchers to agriculture, specifically the food crops sector. This study investigated the potential impact of climate change on net revenue from agriculture in Sokoto State. The study contributed to the literature by being the first study that measured the impact of climate change on net revenue from agriculture across the Sokoto state using the Ricardian technique. The assessment of the study was based on smallholder farms that comprised a larger percentage of farmers in Sokoto state, this is another exceptional contribution of the study. Evidence from the sampled analyzed in the study demonstrated that climate change can influence net revenue from smallholder farms in Sokoto State. One of the most important conclusions of the study was that increase in temperature exerts a negative influence on net revenue from smallholder production while precipitation has a positive relationship with net revenue. The study also predicted that in future climate change specifically rise in temperature will harm revenue from smallholder production. The significant relationship between temperature and net revenue clearly showed that a rise in temperature is an important consideration for smallholder production in Sokoto State. This is consistent with the findings of previous studies that postulated that climate change affects crop yield and consequently farm revenue [20, 32, 15, 3, 4].

Conclusion and Managerial Implications

The study represents a significant finding on the impact of climate change on net revenue from smallholder farms in Sokoto State. Depending on the survey of smallholder farms, the study reveals that climate change might be one of the most important determinants of net revenue for small farms in the area. The study based on empirical evidence concludes that an increase in temperature will be harmful to net revenue, while rainfall will be beneficial to net revenue in the short run. Analysis of future climate change projections from 2030 through to 2090 reveals that there will be a decline in net revenue as a result of an increase in both temperature and precipitation. The decline in revenue showed an upward trend with future climate change. Additional observation of the study is the sensitivity of small farms to temperature increases. Notable features of this study are that most of the area of Sokoto State known

for large scale maize production was covered. The analysis specifically considered small farm holdings that made up over 70% of farms and account for up to 80% of the food produce in Sokoto state. Furthermore, the analysis measured the impact due to marginal and future climate change for the area. A notable contribution of this analysis distinguished it from previous studies. The current study limits itself to two climatic elements (temperature and rainfall) future studies should explore other important factors of climate that are hypothesized to affect net revenue from smallholder farms effort should also be made to consider the entire agricultural sector in the country level.

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