Journal of Agriculture and Environment
Vol. 20 No. 1, 2024: 77-84

Ricardian analysis of the impact of climate change on millet farms in Sokoto state

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ABSTRACT

In recent years the main global concern about climate change is the risk it poses to food production, especially in countries that relied heavily on agriculture for survival. Current forecast of the impact of climate change in Nigeria reveals that crop yield will significantly decline. Millet which is widely grown in Sokoto state will also be affected. The main objective of this study is to measure the economic impact of climate change on maize productivity in Sokoto state. Ricardian technique involving panel data was used for the study. The units of analysis were farmers who grow millet crop. Sampling of respondents was done in stages, firstly, local government and districts that produce millet on wide scale were purposively chosen for the study, at the second stage respondents from two districts in the chosen LGA's were randomly selected via systematic random sampling method. About 500 respondents were selected from the sampling frame. In the first stage of the analysis the model measured the economic impact of climate change on millet and in the second stage; marginal and future impacts of climate change were estimated. Results showed that climate change will have varying impact on net farm income from millet crop, element of temperature will impact more on net income as against rainfall. In addition, market, farm size and farm power significantly affected farm income. Findings of the study revealed that future change in climate will lead to decline in farm income.

Keywords: Ricardian analysis; climate change; impact; millet farms; Sokoto State

INTRODUCTION

Climate change is recognized by today's world as the most important environmental problem affecting humanity (Robinson, 2024). Recent change in climate was mainly attributed to human activities from industrial revolution. Warmer temperatures, heavy rainfall, drought, floods and cyclone are some of the manifestations of climate change. In many developing countries, agriculture is an important sector; it contributes to food security, employment of labor and export earnings. In Nigeria agriculture also remains an important economic sector. It employs a large percentage of labor force and contributed 19.48 to real GDP in the first quarter of 2022 (CBN, 2022). Agricultural sector in many countries is more vulnerable to the impact of climate change; due to heavy reliance of the population on natural systems and low capacities to adapt.

Emerging facts from scientific literature predicted the impact of climate change on agriculture in many regions of the world, considerable reduction in rainfall was forecasted in

https://www.ajol.info/index.php/jagrenv
ISSN: 1595-465X (Print) 2695-236X (Online)
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https://dx.doi.org/10.4314/jagrenv.v20i1.8

Nigeria; this will reduce crop yields. The impact of climate change on crop yield will be more severe in Sokoto state because a larger percentage of its citizens relied on agriculture for survival, and the state is located in drier parts of Nigeria. In spite of these dire consequences to agriculture, in Nigeria empirical studies that assessed the impact of climate change on agriculture are insufficient they include (Bosello *et al*., 2013; Fonta, 2018; Edet et. *et al*., 2018; Agba et. al., 2017; Tajuddeen et. el., 2022). Despite the importance of millet in Nigeria and its position in Sokoto state as a staple crop, literature is almost silent on the impact of climate change on millet crop which is widely grown in Sokoto state; and therefore, no clear picture of how climate change will affect millet productivity in the state. The study is important in assessing the impact of climate change on millet as a food crop in Sokoto. The main objective of this study is to measure the impact of climate change on millet farms in Sokoto state.

Pearl millet is the third major crop in Africa, widely grown under rain-fed in the arid and semi-arid regions of Africa. Africa accounts for almost half of global millet production. Nigeria is the second largest producer in the world with 5,000,000 tonnes and first in Africa. In Nigeria, Sokoto state is the largest producer. Millet is an important crop in terms of production and consumption in Northern Nigeria, where it is mainly produced (Usman *et al*., 2014; Abdullahi *et al*., 2006). The dominant millet species grown in Nigeria is pearl millet, classified into *Gero, Maiwa* and *Dauro* depending on maturity period (Usman *et al*., 2014). The yield range between 500 and 1500 kg/ha. The crop provides both food and economic security to the populace. Climate change adversely affects production of millet due to drought, flooding and heat stress that caused total failure of millets in Nigeria.

Ricardian method is a cross-sectional technique, widely used in agriculture to assess the contributions of climate to net farm income across wide climatic zones. The principal idea of using the Ricardian cross sectional approach to measure economic impact of climate change is to use the model to value climate attributes in terms of marginal effects on net revenue as a proxy for change in farm welfare (Nhemachina, 2010). Ricardian method is a recent technique that is widely applied to assess the impact of climate on net farm income. The climate impact is measured by conducting a regression of farm income on climatic and farm specific variables. The method assumes farmers change the use of inputs and outputs continuously to suit the immediate environment and as a result adaptation options are implicitly taken.

METHODOLOGY

Study Area

Sokoto state is geographically located between 13° 0' 21.1428" N and 5° 14' 51.1872" E. The State covers a total land area of approximately 28,232.37sq kms with a projected population of 6,391,000 people in 2022 (NBS, 2023). Over 80% of the populations are farmers. Predominant crops grown in the area are millet, guinea corn, maize, rice, sweet potatoes, cassava, groundnut, and beans for food and wheat, cotton and vegetables for cash. Annual temperature ranges between 23-43ºC. The annual rainfall is between 500 mm and 1300 mm (Sokoto State Government, 2022).

Sampling

The target populations are households who engage into millet farming, the units of analysis were farmers who grow millet crop. Sampling of respondents was done in stages, firstly, eight local government areas and sixteen districts that produce millet on wide scale were purposively chosen, at the second stage respondents at districts level were systematically selected. The selection at district was made from a sampling frame of 500 respondents obtained from agriculture departments of the selected local governments using systematic random sampling, as in Molua (2007); Tajuddeen *et al*. (2022). At the end, a total of 410 surveys were completed from which 376 were valid. The analysis for the study was based on all the 376 surveys.

Data Collection

Primary data for the study were obtained from a survey of households in the 2022 farming season to source socioeconomic data for the study, while climate record for the state from 1975-2020 was used as the secondary data. Questionnaire survey was used because it is the most appropriate choice to collect data for the study as in Kurukulasuriya (2007); Seo & Mendelsohn (2007); Ajetomobi *et al*. (2011); John & Seini (2013). Soil data were sourced from 2009 Nigeria reconnaissance soil survey.

Data Analysis

Stata 14 statistical package was used to estimate the Ricardian models for Sokoto state. In the first stage climatic variables were regressed with soil variable, to estimate the model without adaptation. At the next stage, farm characteristics such as farm power, house size, farm size, livestock ownership and distance to market were integrated into the first model to define the model with adaptation. This was to enable the study to assess the role of adaptation in reducing climate change impact on net income from millet crop. Values for marginal impact of climate change on income were calculated from the coefficients of the regression results. Finally, the coefficients were used to estimate the economic impact of future climate change (temperature & precipitation change) on millet farms in the study area.

Model Specification

To achieve the main objective of the study, which is to measure the impact of climate change on income from millet farms in Sokoto state, a Ricardian model for Sokoto state was specified as a quadratic formulation of climatic variables (Kurakulasuriyya, 2007; Mendelsohn & Dinar, 2009).

$V=\beta_0+\beta_1F+\beta_2F^2+\beta_3G+\beta_4Z+U$ …………………………………………… 1

N = Net Farm income
F = Vector for climatic variables
G = Set of socioeconomic variables
Z=Soil variables
U = Error term

Net farm income from millet farms was used as the dependent variable, while climate and socioeconomic variables were the independent variables. To measure nonlinear relationship between net farm income and climate, the estimation includes both linear and quadratic terms for climatic variables. The quadratic term was included in order to estimate known nonlinear relationship between net income and climate variables.

In order to measure the impact of marginal change in climate change on income from millet farms in Sokoto state. Analysis of the marginal impact of climate variable (Ci) on net farm income evaluated at the mean of that variable was carried out as follows:

$E [dR/ (dC_i)] = \beta 1_i + 2 \times \beta 2_i \times E [C_i]$ ………………………………………… 2

Impact of future change in climate on farm income for millet Sokoto state was projected through the equation below:

$U = R (C_1) - R (C_0)$ ……………………………………………………… 3

The change is beneficial if it increases net farm income and harmful if it decreases net farm income. Nigeria's forecast for A2 emission scenario of the Global Circulation Model (GCM) was used to forecast future impact of climate change on net income for Sokoto state.

RESULTS

Result of regression for net income model with adaptation is presented in Table 2. In this result the signs of the coefficients for the quadratic term of the climatic variables were negative and opposite of the linear term. This direction indicates a non-linear relationship between income and climate. As presented in column 2 of the Table the coefficients for rainy and dry season temperature, rainy season precipitation, experience level of farm technology, farm size and access to market were significant, this signals their relationship with farm income.

Table 1: Regression for net income function

Variable	Coefficients	Robust Std. error	t-value	P>|t|
Constant	−44.362	9.196	−4.82	0.000
Rainy season temperature	−22.621***	5.104	−4.43	0.000
Dry season temperature	3.605***	0.673	5.35	0.000
Rainy season precipitation	2.554***	0.675	3.78	0.000
Rainy season temperature2	−11.310***	2.552	−4.43	0.000
Dry season temperature2	−1.802***	0.336	−5.10	0.000
Dry season precipitation	− 0.264	0.183	1.45	0.482
Rainy season precipitation2	−1.277***	0.337	−3.78	0.000
Dry season precipitation2	0.132	0.091	1.20	0.323
Soil	0.008	0.043	0.19	0.848
Livestock keeping	0.046	0.035	1.28	0.199
Experience	0.046*	0.027	1.73	0.084
Level of farm technology	0.360***	0.061	5.88	0.000
Farm size	−0.258***	0.030	−8.45	0.000
House size	−0.011	0.025	−0.47	0.641
Proximity to market	0.029**	0.013	2.17	0.030
Access to credit	0.002	0.003	0.70	0.482
Number of observations	718			
R squared	21			
F	16			

Note: p-value ***, significant at 1%; **significant at 5%; * significant at 10%

Marginal Impact Analysis

Marginal impact analysis was done to examine the impact of one degree change in temperature or one millimetre change in precipitation. Following Mendelsohn and Dinar (2009), the marginal value of each climate component (f_i) depends on both the linear and quadratic climate coefficients. The results presented in Table 2 showed that there will be a decline of ₦118 /ha on net income due to slight increase in temperature in the dry season and a decrease in net income of ₦724/ha for a marginal rise in temperature in the rainy season. The total annual impact due to marginal rise in temperature was a decline in net income worth ₦842/ha. The Table also presented the impact due to marginal rise in rainfall, although the marginal impact of rainfall is slightly above two naira in the dry season, the marginal impact of rainfall during the growing season is worth ₦1447/ha decline in income. A loss in income worth ₦1449 was calculated as the total annual impact due to marginal rise in precipitation.

Table 2: Marginal impact of climate on net income from millet production

Climate	Marginal impacts Mean seasonal	Annual impact
Temperature (₦/ha/^{0}C)		
Dry season temperature	−118	
Rainy season temperature	−724	−842
Precipitation(₦/ha/mm)		
Dry season precipitation	2.11	
Rainy season precipitation	1447	1449

Projected Impact of Future Climate Change for Sokoto State

The study used the A2 emission scenario of the Global Circulation Model (GCM) to project the future impact of climate change on net income. This gave a picture of how future climate scenarios will affect net income millet farms. The analysis forecasted impact for the years 2030, 2060 and 2090 using the coefficients for the net income function. Projection on the impact of temperature was made based on forecast of increasing temperature for Nigeria by as much as 1^{0}C in 2030, 2.3 ^{0}C in 2060 and 3.7 ^{0}C in 2090 as well as a slight increase in precipitation by 0% in 2030, 1% in 2060 and 4% in 2090 (IPCC, 2007).

Results of the impact of future climate scenario were shown in Table 3 below. By the year 2030 about ₦892/ha will be lost due to 1 degree rise in temperature. 2.3 degree rise in temperature will result to decline in net income amounting to ₦920/ha by 2060. 3.7 ^{0}C increases in temperature forecasted will lead to a loss of ₦963/ha in the year 2090; this finding agrees with (Niggol Seo and Mendelsohn, 2008).

Table 3: Projected impact on future climate change scenarios

	2030	2060	2090
Temperature^{0C}	+1	+ 2.1	+ 3.7
Impact in ₦/ha	− 892 (0.89%)	− 920 (0.9%)	− 963(1%)
Precipitation (mm)	+0%	+1%	+4%
Impact in ₦/ha	− 1449(1.4%)	−1900 (1.8%)	−1919 (1.83%)

Note: Climate change by GCM climate projections for Nigeria based on A2 climate scenario; values in parenthesis are percentage change in income due to climate change.

Similarly, result of the impact of change in rainfall was also estimated. No change in rainfall was predicted by the year 2030 presented in the table and income was forecasted to decline by ₦1449/ha while by the year 2060 with a 1% increase in rainfall net income will fall by ₦1900/ha. By 2090 4% increase in rainfall was predicted and income was estimated to fall by ₦1919/ha.

DISCUSSION

Most of the coefficients for the linear and quadratic terms of the climate variables were significant. The positive sign of the dry season temperature coefficient means that increase in temperature in the dry season was beneficial to income. This may be to facilitate crop maturity and ripening. This result is consistent with the findings of (Ajetomobi *et al*., 2011; Ouedraogo *et al*., 2006; Sene *et al*., 2006). In the rainy season the sign of the temperature variable was negative. This implied that higher temperature in the rainy season affects income negatively. This finding agreed with the findings of (Mendelsohn *et al*., 2000; Fonta *et al*., 2018; Ater & Aye, 2012). The signs of the coefficients for the dry season precipitation were positive but not significant; this showed that small amount of rainfall may be beneficial to millet in the dry season. The coefficient for rainy season precipitation was positive and statistically significant ($p>0.001$) as indicated by the result. This implied that rainfall contributed positively to farm income in Sokoto state. Similar results were obtained by Ajetomobi *et al*., (2011).

To observe socioeconomic factors helps in building the resilience of the farmers' relevant socioeconomic factors were included in the model. The variables for soil, livestock and credit were positive and house size was negative, but they do not contribute much to the model. Sene et. al., (2006); Mano and Nhemachina (2007); found that livestock keeping contributed to more income Variable for market was positive; and significant ($p>0.05$) implying that farms located closer to the market gain more income, this was consistent with the findings of (Madison, 2007; Deressa & Hassan 2009).

Based on land size this study categorized millet farms in Sokoto state into large (farms > 5 hectares) and small (farms < 5 hectares). Similar classification was followed by (Chiaka et. al., 2022; Lowder et. al., 2016). Findings of the current study showed that farmland size has a negative and statistically significant ($p>0.05$). This relationship could be explained by the fact that farmers that cultivate bigger farms are not able to manage the farms well and are less productive. This finding contrasts the findings of Fonta *et al*., (2011), but agrees with the finding of (Ajetomobi 2011). The coefficient for household size was negative, implying that members of the family could not provide adequate labor to manage the farms (Deressa and Hassan (2009) reported the same finding. On the contribution of farm power tractor contributed more to net income than animal source. Marginal impact analysis shows that annually a decline of ₦842/ha will be experienced by farmers due to slight increase in temperature, while increase in precipitation will increase net income by ₦1449/ha. Projection of future change in climate shows that from 2030 through to 2090 both temperature and precipitation were forecasted to rise in Nigeria millet farms will witness decline in net income in Sokoto state.

CONCLUSION

The study provided sound empirical evidence of the impact of climate change on net farm income from millet crop in Sokoto state. One of the main findings of the study was that net income from millet production will exhibit high rate of decline due to climate change in Sokoto state. Further analyses of the results revealed that increase in temperature will be harmful to net income, while more rainfall will lead to higher income in the short run for millet farms in Sokoto State. Analysis of marginal impact showed that marginal change in temperature and precipitation will reduce net income. Similarly, projection of the study on future increase in temperature and rainfall will be harmful to net income. The loss in income will increase with future climate change from the year 2030 through to 2090.

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