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Climate Change Impacts on Net Revenues of Sorghum and Millet in North Kordofan Environment

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Abstract Climate change (global warming) is often influence temperature and rainfall, which will directly have effects on the productivity and hence the net revenues of crops. This study was carried out to assess the impacts of climate changes (rainfall and temperature) on the net revenue for sorghum and millet crops in North Kordofan state environment, Sudan, during the period 1990-2012 using the Ricardian model. The results revealed that the elasticities to change in maximum temperature, minimum temperature and standardized rainfall for sorghum net revenue are: -1349.37, -598.098, -60.8788 respectively and for millet net revenue are: 2602.7, 258.1875 and 207.0783 respectively. The net revenues for both crops decreasing at increasing rate when there are increasing in maximum temperature. In case of minimum temperature, millet net revenue increase at increasing rate where sorghum net revenue increase at decreasing rate.

Keywords: *climate change, ecosystem. desertification, elasticity, Ricardian model*

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1. Introduction

Crop production threatened by climate change is one of the most important challenges in the 21st century to supply sufficient food for the increasing population while sustaining the already stressed environment [1]. Climate change has caused significant impacts on rain-fall, crop production and net revenues especially for African countries, as well as to the whole world [2]. Studies on climate impacts are increasingly becoming major areas of scientific concern (impacts on the production of crops such as sorghum, millet, maize, wheat and rice) [3-9]. Crop productivity and soil water balance have been studied with crop growth models by using parameters from different climate models. Meanwhile, climate variability is one of the most significant factors influencing year to year crop production, even in high-yield and high-technology agricultural areas. In recent years, more and more attention has been paid to the risks associated with climate change, which will increase uncertainty with respect to food production [10]. Change in climate caused shifts in food production as temperature rise and rainfall decrease. Such change in climate affects soil temperature and moisture level, also determines the vitality of both beneficial organisms and pests. In 1984/5, Sudan experienced a particularly severe drought and famine [11,12]. The climate and environment in the Sudan have shown localized changes during the course of last century, and recurrent droughts in the last 30 years [11]. It is estimated that 60% of the country is affected by desert or desertification [28]. Frequent droughts and desertification are notice environmental problems of Sudan. El Moghraby [13] claimed that the basic environmental problems of Sudan are related to the absence of an acceptable strategic master land use plan, the growing conflicts in land use policies, the depletion of natural resources and the unchecked population growth (due to lack of a coherent population policy).

North Kordofan is one of the four largest states in Sudan with a population of 2.9 million as the 2008 population census. North Kordofan is semi-arid and prone to both drought and desertification and lack of water is one of the key issues in the state and has been for decades. Consequently, North Kordofan is exposed to both chronic and sporadic food shortages. Moreover, poverty is a key challenge in the state, particularly in rural areas. North Kordofan is traditionally an agro-pastoral community, and the main source of livelihoods is a combination of rainfed cultivation and livestock keeping. The key economic activity is farming, followed by animal husbandry and trade. During the last decades, drought as well as pest infestation has led to an increasingly difficult situation in North Kordofan [14]

North Kordofan has been classified in the range of 'very severe' to 'moderately' affected zone by desertification. The desertification-affected area is estimated at 40% of the total State area [15]. It lies within the dominantly limited and seasonal rains. The mean annual rainfall ranges from less than 100 mm in the north to about 350 mm in the south. The length of the rainy season depends to a large extent on the latitude [16]. Rainfall precipitates in short high intensity storms of over six months from May through October, with concentration of 80 to 90% in July, august and September. Rainfall shows a great variability both in time and space [17]. The mean annual isotherm is 27° C with extreme temperatures ranging between 10°C to 46° C. Mean relative humidity ranges from 20% in winter to 75% during August, in the middle of the rainy season [18]. The rainfall averages in the last four decades in some major station in the north Kordofan state are shown in Table 1. Annual rainfall has been declining for several times, which has led to weak production performances among cereal crops and made them highly vulnerable to climate change.

Table 1. Average rainfall (1973-2011) in some major station (Elobeid, Bara, Elnuhud, Sudari, Hamra Elwaz) in north Kordofan state

Hamra Elwaz	Sudari	Elnuhud	Bara	Elobeid	Period
148	168	329	257	323	1973-1982
116	134	289	181	299	1983-1992
127	155	281	268	378	1993-2002
114.5	161.2	386.6	303.4	429.5	2003-2011
126.2	154.5	321.5	252.2	356.5	Average

Source: Ministry of Agriculture and Animal Resource North Kordofan (2011).

The changes of environmental factors such as rainfall, temperature have reductive effects on cropping system and crops. Shortening of the crop growing season beside fluctuation of the rain fall between seasons resulted on low productivity for most crop in the area and complete crop failure. also contribution in low productivity. When butting economic factors such as price variation, high labor cost and agricultural policies with surrounding environment together, they would be influential factors in determining the shape of the traditional rain fed subsector. It's clear that the vulnerability of this sector reflected in profitability and revenues gained from it. The damages from climatic change (net revenue) were first predicted in the US by using Ricardian approach [19,20,21].

Seo et.al [22] used Ricardian model to examine the net revenue per hectare of the four most important crops in Sri Lanka. A Structural Ricardian model was developed to analyze impact of climate on choice of farm type and farm revenue by Seo and Mendelsohn [23]. Ricardian model used to captures adaptation of the farmers facing vulnerable climate situation instead of studying the production of specific crops. It is basically a micro-econometric model whereby a farmer chooses j among J crops in the first stage, and maximizes net revenues in the second stage conditional on those choices [24,25,26]. Based on utility theory, a crop is chosen if it gives the farmer highest net revenue as compared to other crops [27].

The objective of this study is to investigate the impact of climate change on net revenue of sorghum and millet in north Kordofan environment using Ricardian method.

2. Materials and Methods

2.1. Sources of Data

Data for the analysis were collated from various secondary sources for the period 1990 to 2012. Environmental data such as (rainfall, maximum temperature and minimum temperature) were taken from Elobied Air Port Metrological Station.

The production and area harvested, productivity and production cost data were taken from the records of the Ministry of Agriculture and Animal Resources (Elobied), prices of millet and sorghum were taken from Elobied Crops Markets. The Central Statistical Bureau was important in providing early statistics on domestic quantities and sales of millet, sorghum and prices in different markets.

2.2. Methodology

2.2.1. Ricardian Model

As Seo et.al [22] stated that farmers maximize net revenues per hectare, NR

$$\text{Max NR} = Pi * Qi\,(R, E) - Ci\,(Qi, R, E)$$

Here Pi and Qi are respectively the price and quantity of good i; Ci (.) is the relevant cost function; R is a vector of inputs, and E reflects a vector of environmental characteristics of the farmer's land including climate. Given that the farmer chooses inputs, R, to maximize NR, one can express the resulting outcome of NR in terms of E alone

$$NR = f\,(E)$$

The advantage of this empirical approach is that the method not only includes the direct effect of environmental factor on productivity, but also the adaptation response by farmers to local climate.

2.2.2. Econometric Ricardian Model

We assume that net revenue is a function of environmental factors

$$NR = f\,(E)$$

Then the model would be as following

$$NR = f\,(R, \text{max temp}, \text{min temp})$$

Where

R = Rainfall

Max temp = max temperature

Min temp = minimum temperature

Seo et.al [22] said that the evidence suggests that the relationship between net revenue and these environmental variables should be hill-shaped. We attempt to capture this hill shape using a quadratic functional form.

Mean functions

The mean function is specified as:

Linear- Quadratic Form:

$$y = \alpha_0 + \sum \alpha_{1j} x_j^2 + \sum \alpha_{2j} x_j + \sum_j \sum_k \left({}_{k \neq j} \right)_{jk} x_j x_k$$

Where x_j *and* x_k are explanatory variables that include maximum temperature, rainfall and $\alpha's$ imply coefficients to be estimated [24].

3. Results and Discussion

3.1. Ricardian Model for Sorghum

The Ricardian model regresses net revenue on climate and other explanatory variables. Results in Table 2 showed that in the analysis of variance the value of f = 5.0663 was high and significant at level of 0.0045. That means the model showed the overall utility in term of overall significant. So, the independent variables for the Ricardian model of sorghum model were jointly statistically significant.

The Ricardian model for sorghum net revenue in Table 2 showed a positive signs were found for the coefficients of: average minimum temperature, standardized total rainfall, average maximum temperature^2, interaction between average maximum temperature and standardized total rainfall, interaction between maximum temperature and minimum temperature. Negative signs were found for the coefficients of: average maximum temperature, average minimum temperature^2, standardized total rain fall^2 and interaction between average minimum temperature and standardized total rainfall. Also, it could be seen from Table 2 that the coefficients of (Intercept, average maximum temperature, average maximum temperature^2, average minimum temperature^2, interaction between average minimum temperature and standardized total rainfall, interaction between average maximum temperature and average minimum temperature) were significantly different from zero at 10% level of significance according to‘t’ statistic.

R-Squared is defined that 0. 778 of the proportion of the variation in the mode of sorghum that is explained (accounted for) by the variation in the X’s. The coefficient of variation is a relative measure of dispersion, computed by dividing root mean square error by the mean of the dependent variable. By itself, it had high value (3.123).

The impact of standardized total rainfall on net revenue of sorghum was positive but not significant and increasing at decreasing rate. Also, it has negative significant impact when interacted with minimum temperature. The impact of maximum temperature on sorghum net revenues was negative according to coefficients sign. The net revenues of sorghum decreasing at increasing rate when there are an increasing in maximum temperature. Minimum temperature coefficient has positive impact on sorghum net revenue and it increased at decreasing rate when Minimum temperature increasing.

3.2. Ricardian Model for Millet

The Ricardian model regresses net revenue on climate and other explanatory variables. Results in Table 3 showed that in the analysis of variance the value of f = 2.829 was high and significant at level of 0.06. That means the model showed the overall utility in term of overall significant. So, the independent variables for the Ricardian model of millet model were jointly statistically significant.

The Ricardian model for millet net revenue in Table 3 showed a positive signs were found for the coefficients of: average minimum temperature, standardized rainfall, average maximum temperature^2, average minimum temperature^2 and standardized total rainfall^2. On the other hand the negative signs were found for the coefficients of: average maximum temperature, interaction between standardized total rainfall and maximum temperature, interaction between standardized total rainfall and minimum temperature and interaction between average maximum temperature and average minimum temperature. Moreover, it could be seen from Table 3 that the coefficients of standardized rainfall and interaction between standardized total rainfall and maximum temperature were significantly different from zero at 10% level of significance according to ‘t’ statistic.

R-Squared is defined that 0.718 of the proportion of the variation in the model of millet that is explained (accounted for) by the variation in the X’s. The coefficient of variation is a relative measure of dispersion, computed by dividing root mean square error by the mean of the dependent variable. By itself, it had high value (-1.189).

Table 2. Ricardian regression equation for net revenue of sorghum

Independent Variable	Regression Coefficient	Standard Error	T-Value (Ho: B=0)	Prob Level
Intercept	16405.05	5672.036	2.8923	0.0125
Average max temp	-1075.825	383.9786	-2.8018	0.0149
Average min temp	187.4654	293.9273	0.6378	0.5346
Standardized rainfall	10.18216	801.1606	0.0127	0.9900
Average max temp^2	10.70785	5.295045	2.0222	0.0642
Average mint emp^2	-16.39779	9.029546	-1.8160	0.0924
Standardized rainfall^2	-74.10548	24.14499	-3.0692	0.0089
Average max*standard	40.70047	27.34395	1.4885	0.1604
Average min*standard	-63.81953	18.27582	-3.4920	0.0039
Average max*average min	15.5681	4.909358	3.1711	0.0073
R-Squared	0.778			
F test	5.0663			0.0045
Coefficient of variation	3.123		\	
T critical	1.770933			

Table 3. Ricardian regression equation for net revenue of millet

Independent Variable	Regression Coefficient	Standard Error	T-Value (Ho: B=0)	Prob Level
Intercept	6300.481	4939.39	1.2756	0.2309
Average max temp	-423.1076	316.944	-1.3350	0.2114
Average min temp	72.486	222.638	0.3256	0.7514
Standardized rainfall	1556.824	659.893	2.3592	0.0400
Average max temp^2	7.530	4.387	1.7156	0.1170
Average min temp^2	1.237	6.896	0.1794	0.8612
Standardized rainfall^2	24.250	20.051	1.2094	0.2543
Max*standardized	-45.153	22.496	-2.0071	0.0725
Min*standardized	-1.9121	13.828	-0.1383	0.8927
Average max* average min	-3.789	4.1444	-0.9144	0.3820
R-Squared	0. 718			
F test	2.829			0.06
Coefficient of Variation	-1.189			
T-Critical	1.8124			

According to the results of Table 3 standardized total rainfall had positive and significant impact on net revenue of millet but at insignificant decreasing rate. Moreover, its interaction with maximum temperature had negative effect on net revenue of millet. The impact of maximum temperature on millet net revenues was negative according to their coefficient`s sign. The net revenues of millet decreasing at increasing rate when there are increasing in maximum temperature. Minimum temperature coefficient was positive for millet net revenue and increased at increasing rate when minimum temperature increasing.

3.3. Elasticities of Climate Variables form Ricardian Model

Since the quadratic models have both quadratic and interaction terms, it is not possible to contrast the signs and extent of the estimated coefficients in the quadratic function to those in the linear function. The elasticities were calculated at the mean values of the explanatory variables to assess the impacts of selected environmental variables on net revenues of both crops. The coefficients for climate variables such as maximum temperature, minimum temperature and standardized rainfall could be translated into elasticities through multiplying by average climate variables and dividing by average net revenue. Table 4 showed the elasticities of climate variables form Ricardian model for sorghum and millet. Table 4 revealed that average maximum temperature had negative impact on net revenue for both crops. So, increasing in average maximum temperature might be promoted farmers to shift out of production of two crops. Moreover, this increasing in average maximum temperature classified as risk-increase for both crops. Average minimum temperature and standardized rainfall had positive impacts on net revenue from millet and negative for one that came from sorghum. Thus, they classified as risk-decrease for millet net revenue and risk-increase for sorghum net revenue.

Table 4. Elasticities of climate variables form Ricardian model

Net revenue function	Climate variable	Elasticity
Sorghum	Average max temp	-1349.37
	Average min temp	-598.098
	Standardized rainfall	-60.8788
Millet	Average max temp	-2602.7
	Average min temp	258.1875
	Standardized rainfall	207.0783

Sudan experienced a particularly severe drought and famine [12,28]. In sum, the agricultural sector in Sudan is highly vulnerable to shortages in rainfall. There has been a substantial decline in precipitation in the dry land parts of the country, and global warming models predict that this trend will continue. The climate and environment in the Sudan have shown localized changes during the course of last century, and recurrent droughts in the last 30 years [11]. The complexity linkages between climate change\environment, poverty and conflict over natural resources are well-known characteristics for North Kordofan State. This situation demonstrates the connection between climate change, resource degradation and conflict on the one hand and vulnerability to food insecurity on the other.

4. Conclusion

It is logically to conclude that production and hence net revenues of millet and sorghum in North Kordofan are vulnerable because of variability in total rainfall. Increasing in maximum temperature will harm the production of millet and sorghum in the State. The response of net revenues of both crops to increase in maximum temperature are elastic and risk-increasing. The impact of minimum temperature on net revenues of both crops in terms of elasticities is risk-decreasing in case of millet and risk-increasing in case of sorghum. The study suggested that implementation of adaptation policies are highly required. That could be possible through executing projects in climate change and agricultural production, which will include strategic researches, demonstration field technology, capacity building and, ensuring food security for alleviating poverty under climate change conditions.

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