DF-454
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Economic Impact of Climate Change on Food Crop Production using Ricardina Approach: A Case of Kellem Wollega Zone, Ethiopia

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10.18805/ag.DF-454

ABSTRACT

Background: Historical records and increased scientific consensus provide strong evidence that the global climate is changing. Future climate change would lead to an increase in climate variability and the frequency and intensity of extreme events. Agriculture that is dependent on climate conditions is inherently sensitive to climate changes. Today's world agriculture has gone through challenges from population growth and has adapted to changing economic conditions, technology and resource availabilities. But uncertainty remains concerning the ability of agricultural systems to adapt to climate change. Thus, climate change adaptation of the essence for a resilient food crop production system requires economic transformation by arrangement of institutional and technology.

Methods: This study uses the Ricardian model to examine the economic impact of climate change on agriculture in Kellem Wollega Zone, Ethiopia. The net farm revenue is regressed against climate variable (temperature and precipitation), soil and socio-economic variables to help determine the factors that influence variability in net farm revenues. The study was based on the data from a survey of 400 smallholder farming households interviewed across the zone.

Result: The Ricardian model analysis shows the coefficients of summer, autumn and winter temperature are positive whereas the coefficient of spring temperature is negative. Regarding the precipitation, the coefficients of summer and spring precipitation are positive while coefficients of autumn and winter precipitation are negative. The marginal impact analysis results show an increase in summer and spring temperatures has mostly negative effects on net farm revenues implying that further temperature increases would be harmful to agricultural activities while increases in autumn temperatures increase net farm revenues in the study area. The summer and spring precipitation would increase the net farm revenue but the autumn precipitation reduces the farm revenue. The elasticity results show that net farm revenues are highly sensitive to changes in climate and the elasticity is relatively high for both summer temperature and precipitation. The impacts of climate change under the three special Reports on Emission Scenarios, (Canadian General Circulation Model, Hadley Centre for Climate Prediction and Research and Parallel Climate Model) predicted that by 2100 net farm revenues would decrease across all farms per hectare by US$ 942.83, US$ 1048.16 and US$ 1024.32 respectively. The finding suggests there is a great need for the concerned bodies to provide up-to-date information about climate change and rainfall patterns in the forthcoming season so that the farmers make informed decisions and develop adaptation strategies.

Key words: Climate change, Crop production, Ethiopian, Ricardian analysis.

INTRODUCTION

Climate change is the most significant environmental threat of the 21st century. It is endangering the world's environment, the agricultural productivity and the human well-beings. The climate change is also observed as warming of the earth from the rising air and ocean temperature, widespread melting of ice and snow and rising global mean sea level (Umunakwe *et al*., 2015). Climate change is already having significant impact particularly in developing countries and on most ecosystems (Boko *et al*., 2007).

The sensitivity of agriculture to climate change has become a dominant area of research and hence is frequently cited as a sector vulnerable to anticipated global climate change (Parry and Carter, 1985; Rosenzweig and Parry, 1994). There is a relatively rich literature available that attempts to quantify the economic impacts of climate change on agriculture globally (Delincé *et al*., 2015; IPCC, 2013, 2014; Moore *et al*., 2017; Parry *et al*., 2004). Food crop production is mainly dependent on climate conditions for the developing nations and it is characterized as predominance of rain fed agriculture and capital scarcity for adaptation measures *i.e.* irrigation practices. Thus, the climate change makes agriculture specifically the food crop production more vulnerable than other economic activity (Nhemachena and Hassan, 2007).

In Ethiopian agriculture plays a key role in reducing poverty and to bring growth in the economy. Nowadays, the country is experiencing changes in its climate. Agricultural production and food security, including access to food, in many of the regions are likely to be severely affected by climate change exhibiting recurrence of drought. In Ethiopia, impact assessment of climate change (Deressa and Hassan,

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How to cite this article: Terefe, M.K. (2022). Economic Impact of Climate Change on Food Crop Production using Ricardina Approach: A Case of Kellem Wollega Zone, Ethiopia. Agricultural Science Digest. DOI: 10.18805/ag.DF-454.

Submitted: 28-01-2022 **Accepted:** 03-08-2022 **Online:** 20-08-2022

2009) and adaptation strategies to cope the impact (Gebrehiwot *et al*., 2013; Hadgu *et al*., 2015; Tazeze *et al*., 2012; Tessema *et al*., 2013) were studied but not specific to the study areas. Thus, this paper used Ricardian approach to analyses the impact of climate change on net revenue of the smallholder farmers by regressing net farm revenue against climate variables (precipitation and temperature), soil and socio-economic variables to help determine the factors that influence variability in net farm revenues; forecast damage to households' net revenue under climate change scenarios in the coming years. The finding of this research is expected to contribute to formulate appropriate adaptation strategies to cope the impact of climate change in the study area.

MATERIALS AND METHODS

The data for the analysis is based on cross sectional data from 400 randomly selected sample food crop producing farmers in kellem wollega zone found in the western part of oromia regional states of ethiopia. The data collection instrument focused on socioeconomic factors, climate change adaptation strategies used by the farmers, land, capital resource and agrochemicals used. Identification of climate information for the study area was made by taking the climatic data of the nearest meteorological station to the study site. Based on the number of meteorological stations in the area, sample farm households within a 50 km radius of the nearest meteorological station was selected. Climate data were collected from Meteorology Agency of Ethiopia which includes the monthly mean temperature and precipitation in the 2019/20. Average climatic data were calculated according to season based on classification: the winter (from December to February), summer (from June to August), spring (from March to May) and fall (from September to November).

The Ricardian approach is the common cross-sectional method that has been used to measure the impact of climate change on agriculture. Ricardian models completed in many countries and areas over the world; Europe (Passel *et al*., 2017), united states (Mendelsohn *et al*., 1994, 1996); Italia (Bozzola *et al*., 2018),in Africa (Seo *et al*., 2009); in Ethiopia (Falco *et al*., 2012) to examine the sensitivity of agriculture to changes in climate.

The Ricardian cross-sectional approach automatically incorporates farmer adaptation by including adaptations farmers would make to reduce the impact of a changing climate. Farmers adapt to climate change to maximize profit by changing the crop mix, planting and harvesting dates (Mendelsohn *et al*., 1994, 1996; Mendelsohn and Dinar, 1999). Available studies on effects of climate change on agriculture made use of this model, which capture climate variables like temperature and precipitation to look at the effect of climate on crop and livestock. In Ricardian model net revenue or land value were used as the dependent variable modelled against temperature and precipitation and other variables as the explanatory variables. This approach has been applied to examine the sensitivity of agriculture to changes in climate (Mendelsohn and Dinar, 2003) and assess economic impacts of climate change on agriculture (Devkota and Phuyal, 2016; Fonta *et al*., 2018; Huong *et al*., 2018; Mishra and Sahu, 2014).

As climate change has impact on crop production, this model makes it possible to account for the direct impact of climate on crop yields. It also indicates potential adaptation to a climate change by showing indirect as well as the indirect substitution among different inputs including the introduction of various activities. By regressing land values or net revenue on a set of environmental inputs, the Ricardian approach makes it possible to measure the marginal contribution of each input to farm income as capitalized in land value (Deressa and Hassan, 2009).

Following (Mendelsohn *et al*., 1994, 1996; Mendelsohn and Dinar, 2003)the principle of Ricardian approach is captured by the following equations:

$$V = \sum P_i Q_i (C, X, Z, G) - \sum P_x X \quad ......1$$

Where,
P_i = The market price of crop i.
Q_i = The output of crop i.
X = A vector of purchased inputs (other than land).
C = A vector of climate variables.
Z = A vector of soil variables.
G = A vector of socio-economic characteristics.
P_x = A vector of input prices.

The theoretical profit function states as in this study farm household always look to optimize their profits given available input change and they select crops, production type to maximize net income. Input demand of farm household relies on the market price of the input, where as the market price of the output expected under the impact of weather factors, climate and other factors. In Ricardo model it is hypothesized that output and input market prices are expected values in markets and each farmer will seek to maximize net farm revenues by choosing inputs (X) subject to climate, soils and socio-economic factors. The model relies on a quadratic formulation of climate. Consequently, the net value of the land can be expressed as follows (Mendelsohn and Dinar, 2003):

$$V = \beta_0 + \beta_1 C + \beta_2 C^2 + \beta_3 Z + \beta_4 G + \mu \quad ......2$$

Where,
V= Land value.
C= A vector of climate variables.
Z= Set of soil variables.
G= Set of household's socioeconomic variables (education level, farm size, household size and access to extension service and credit and irrigation) the β coefficient of the variables and μ is an error term.

Equation (2) of net revenue climate response function is expressed by quadratic term to reflect the nonlinear shape which indicated how the marginal effect would change as one moves away from the mean (Mendelsohn *et al*., 1994). The Ricardian approach developed to demonstrate the variant of the land value per hectare of cropland over climate (Mendelsohn *et al*., 1994; Niggol Seo andMendelsohn, 2008)and takes adaptation into account by measuring economic losses such as reduction in net income or the value of land due to environmental factors.

The marginal impact of a climate variable on net farm revenue evaluated at the mean is given by (Kurukulasuriya and Mendelsohn, 2008).

$$E\left[\frac{dV}{df_i}\right] = b_{1,i} + 2 * b_{2,i} * E[fi] \qquad ....3$$

Changes in climate that increase net farm income would be beneficial and would be harmful if they lead to decreases in net farm income.

RESULTS AND DISCUSSION

Estimation of empirical Ricardian model

The Ricardian approach estimates the importance of climate (temperature and precipitation) and other variables on the capitalized value of farmland.

The results of the response of net farm revenues to climate variables, soil and socio-economic variables are shown in Table 2. The finding shows that coefficient of summer, autumn and winter temperature is positive and that of spring is negative. The estimated coefficients of summer and spring precipitation are positive while autumn and winter are negative. In the study area agricultural activity particularly crop production mainly concentrated in summer season. The results also show that the positive relationship between farm net revenue and summer temperature and precipitation. It is beneficial to the smallholder farmers those rely on rainfall for their agricultural activity. Autumn season in the study area is season of crop maturity and harvesting (crops do not need any additional rainfall). Therefore, any increase in rainfall in this season would lead to significant decrease in farm net revenues as more rain reduces crop yield. The finding also shows that there is an inverse relationship between autumn precipitation and net revenue implying negative impact of increases in precipitation on net revenue in the study area.

Table 1: Definitions, units and expected sign of the variables.

Variables	Description	Unit	Expected sign
Rev	Crop net revenues	US$	Dependent Variable
Temp	Temperature	°C	(+/_)
Prec	Precipitation	mm	(+/_)
Soil	soil characteristics (1= very fertile, 2=average fertile, 3=fertile, 4=poor		+
Educ	Number of years of formal schooling attained by the household head	Year	+
HH size	Size of the household	No	+
Farm size	Total Crop land area	ha	+
Credit	Access to credit (1=yes, 0=no)	Dummy	+
Extension	Access to extension services (1=yes, 0=no)	Dummy	+
Irrig	Irrigation practice (1=yes, 0=no)	Dummy	+

Table 2: Parameter estimates of ricardian model.

Variable	Coeff.	Variable	Coeff.
Summer_temp	96.127(2.24**)	Winter_precip	-48.451(-6.72***)
Summer_tempsq	-3.743(-1.24)	Winter_precipsq	1.077(2.13**)
Autumn_temp	116.172(3.14***)	Very fertile soil	1.228(4.64***)
Autumn_tempsq	-4.73(-2.57**)	Fertile soil	1.026(3.97***)
Spring_temp	-59.642(-1.76*)	Average fertile soil	1.05(2.16**)
Spring_tempsq	2.163(2.37**)	Poor soil	-0.47(-0.18)
Winter_temp	16.641(1.79*)	Education_years_head	27.512 (8.14***)
Winter_tempsq	-1.09(-1.37)	Household_size	17.592 (2.32**)
Summer_precip	207.642(9.17***)	Total_cropped_area	-63.104(-9.424***)
Summer_precipsq	-.532(-3.16***)	Credit_avaialbility	12.831(2.21**)
Autumn_precip	-133.59(-8.43***)	Extension_contact	27.45(4.38***)
Autumn_precipsq	1.43(3.97***)	Irrigation (1/0)	9.834(2.23**)
Spring_precip	76.614(5.48***)	Constant	174.64(6.74***)
Spring_precipsq	-2.571(-2.33**)		

***p<0.01, **p<0.05, *p<0.1. Values in parenthesis are t-statistic.

Table 3: Marginal effect of temperature and precipitation on net revenue per hectare (US $).

Season	Summer	Autumn	Spring	Winter
Temperature	-119.517***(-6.18)	86.83** (2.37)	-93.84* (2.59)	-48.568 (0.43)
Precipitation	171.366** (11.17)	-117.7***(-6.58)	75.65* (1.37)	44.242 (0.65)

***p<0.01, **p<0.05, *p<0.1

Note: The numbers in brackets represent the elasticity.

Table 4: Climate predictions of SRES models for 2050 and 2100.

Model	Temperature		Precipitation	
	2050	2100	2050	2100
CGM2	24.51	29.26	64.75	50.27
HaDCM3	25.07	30.66	83.53	93.46
PCM	23.50	26.69	80.83	85.67

The coefficient of squared terms of summer, winter and autumn temperature are negative while that of spring is positive. Regarding precipitation the coefficient of summer and spring are negative while autumn and winter are positive. This finding is consistent with hypothesis that the relationship between climate variables and net farm revenues is non linear (Mendelsohn *et al*., 1994; Mendelsohn and Dinar, 1999).

The other variable that was included in the Recardian analysis model was soil type. In agricultural production land is a necessary input. The result shows that land with poor fertility had a negative relationship with farm net revenues. Land that is poor in fertility is a marginalized land with a decreasing return to scale in production. The implication of negative relationship between soil fertility and net revenue is that agricultural production on this soil is expected to be low and net returns per unit of land would be limited. The soil variables that were included in the model were generally significant in explaining variability mainly in net revenue. This shows the importance of action to increase soil fertility using different mechanism. Increasing soil fertility can bring more strong spatial deferential impact on net farm revenues combined with other factors in the study area.

Among the socio-economic variables included in the model, more years of education of household head and increased access to extension services are associated with improved farming information that is important for agricultural productivity. Other important factor that has significant effects on net farm revenues was access to credit. For farmers access to credit improves their finance so as to improve their farming activity. In the study area financial institutions that can provide credit to the farmers is either none exiting or they ask for collateral. Thus, for smallholder farmers with limited financial accessibility the impact of climate change will be serous because it limits the optimization benefit of farming. The irrigation variable was significant and positive in explaining the variability of net farm revenues. This result further emphasizes the importance of irrigation as a factor in helping farmers, particularly during the dry seasons. Irrigation and livestock can provide a useful channel of farmer adaptation strategy which will help improve net farm revenues in the smallholder farming sector in the face of changing climatic conditions (Table 2).

Marginal effects of climate variables on farm net revenues

The marginal impacts of a change in each climate variable (temperature and precipitation) also calculated in order to support the interpretation of the climate coefficients. These values depend on the regression equation that is being used and the climate that is being evaluated. The marginal effect of temperature and precipitation is evaluated at the mean for each sample. The results show increase in summer temperatures have mostly negative effects on net farm revenues implying that further increases in temperature would be harmful to agricultural activities in the study area. An increase in summer temperature by 1°C would reduce net farm revenues by about $119.517 per hectare. Increases in the spring and winter temperature also decrease net farm revenues though winter temperature is not significant. However, increases in autumn temperatures are beneficial to crops and increase net farm revenues by about $86.83per hectare for all farms.

Positive relationship was found between farm net revenues and precipitation for summer and spring season. A unit increase of precipitation in summer and spring would result in an increase in net farm revenues by $171.366 and $75.65 for all farmers respectively. The increase in winter precipitation has positive effects on net farm revenues though it is not significant. In the study area the results points the importance of more summer rain for successful farming as most of the farming is rain fed agriculture (Table 3).

The elasticity results show that net farm revenues are highly sensitive to changes in climate and the elasticity are relatively high for both summer temperature and precipitation. In the study area summer is main cropping season and changes in climate variables in this season have relatively high impacts on net farm revenues compared to the other seasons. Rains fed farms are highly sensitive to changes in temperature and precipitation and they are affected most by these changes as they have relatively high elasticity. In autumn, the time for harvesting, the net farm revenues are highly sensitive to change in precipitation.

Impacts of forecasted climate scenarios

The impact of climate change on the net revenue per hectare was analyzed using the climate scenarios from the Special Report on Emission Scenarios (SRES). It was report of future emission scenarios for driving climate change models in developing climate change scenarios (IPCC, 2001). Future climate change scenarios from deferent climate change models are used to analyze the impact of climate change

Table 5: Impacts of forecasted climate scenario on average net revenue per hectare (US $).

Scenario	2050			2100		
	CGM2	HaDCM3	PCM	CGM2	HaDCM3	PCM
ÄNet	-327.12	-762.93	-462.42	-942.83	-1048.16	-1024.32
revenue/hectare	146.67%	129.16%	98.14%	254.71%	214.62%	147.2%

on economic system (Kurukulasuriya *et al.*, 2006). Predicted values of temperature and rainfall from three climate change models Canadian General Circulation Model, (CGM2) Hadley Centre for Climate Prediction (HaDCM3) and Research and Parallel Climate Model (PCM) were applied to help understand the likely impact of climate change on Ethiopian agriculture. Predicted values were obtained from Hydrological Component of the project from Colorado University (Table 4).

By using parameters from the fitted net revenue model, the impact of changing climatic variables on the net revenue per hectare is analyzed as:

$$\Delta\nu = \nu' - \nu$$

$$NRh = \sum_{1}^{n} \frac{\Delta\nu}{n}$$

Where,

ν'= Predicted net revenue per hectare from the estimated net revenue model under the future climate scenario.

ν= Predicted value of the net revenue per hectare from the estimation model under the current climate scenario.

Δν= Difference between the predicted value of the net revenue per hectare (under the new climate scenarios and the current climate scenario),

NRh= Average change in the net revenue per hectare and n is the number of observations.

The results for the predicted impacts from the SRES scenarios are presented in Table 5. The result shows that all the predicted values used from every SRES model result in the reduction of the net revenue per hectare in both 2050 and 2100. For the CGM2 scenario, the reduction in net revenue is 146.67 per cent for the 2050 and 254.71 per cent for the year 2100.In the case of the HADCM3 scenario, the net revenue reduction amounts to 129.16 per cent for the year 2050 and 214.62 per cent for the year 2100. The reduction in the net revenue per hectare in the case of the PCM scenario amounts to 98.14 per cent for the year 2050 and 147.24 per cent for the year 2100. Net revenue reduction was observed for all models and for both 2015 and 2100 though it is greater in the year 2100 than 2050. This implies that unless adaptation to climate change is appreciated continues increase in climate change would increase damage to crop production and net revenue of farmers (Table 5).

CONCLUSION

This paper describes economic impact of climate change on farm households' net revenue using Ricardian analysis in Kellem Wollega Zone, Ethiopia. In the results of the response of net farm revenues to climate variables, the coefficient of summer temperature and precipitation were found positive and significant. Negative relationship found between autumn precipitation and farm net revenue implying negative effects of increases in precipitation in this season. The result of marginal effect of temperature shows increase in summer and a spring temperature significantly reduces the net farm revenues. However, increases in autumn temperatures are beneficial to crops for all farms. Increase in precipitation during summer and spring significantly enhance net farm revenues. The increase in autumn and winter precipitation has positive effects on net farm revenues. The predicted values used from every SRES model indicate the reduction of the net revenue per hectare by both 2050 and 2100 for the three models (CGM2, HaDCM3 and PCM). There is a great need for technological development of adaptation packages for agricultural production by those years. Therefore, government and concerned bodies has to initiate investment in research and development to come up with farming package for smallholder farmers that will enable them to adapt to the climate change by the years 2050 and 2100. Future crop productivity, change in price, future technological advancement that may affect the net revenue was not incorporated in the analysis.

Conflict of interest: None.

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