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IMPACT OF CLIMATE CHANGE ON YIELDS OF WHEAT IN ETHIOPIA: AN AUGMENTED COBB-DOUGLAS PRODUCTION FUNCTION APPROACH

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ABSTRACT

The study analyzed the impact of climate change on yields of wheat crop in Ethiopia by employing Cobb-Douglas Production Function Approach using time series data for the period 1981 – 2018. The study confirmed that long-season rainfall and crop growing season maximum temperature have negative and significant effects on wheat yield. The result implies that a rise in maximum temperature during crop growing period and variation in long-season rainfall could have adverse impact on yield of wheat crop. The findings further showed that fertilizers, improved seed, and irrigation applied on wheat crop have all positive and significant impact on yield of wheat, implying that use of fertilizer, improved seed and irrigation inputs have vital role in increasing yields of wheat crop. Conversely, the study indicated that land area cultivated under wheat cropping showed negative and significant impact on yield of wheat crop, implying that any area expansion under wheat crop production would have negative impact. In view of the findings of the study, it is recommended that adaptation strategies that could offset the adverse effects of climate change should be designed and adopted. An increased use of irrigation is recommended, particularly in potential lowland areas to mitigate the adverse effect of climate sensitivity on wheat crop. Use of improved wheat seed varieties of short duration and tolerant to warm and moisture stress conditions are recommended to increase productivity and production of wheat crop. Increased use of fertilizers in cooler mid and highland areas can be another option to increase the productivity of wheat crop in Ethiopia.

Key words: Climate Change, Wheat Yield, Cobb-Douglas Functional Model, Ethiopia.

INTRODUCTION

Wheat is among the most important food crop in Sub-Saharan Africa (SSA), occupying cultivated land area of 2.9 million hectares and production volume of 7.5 million tons (FAO, 2017). The most important producers of wheat in SSA include: South Africa, Ethiopia, Sudan, Kenya, Tanzania, Nigeria, Zimbabwe, and Zambia in descending order.

Ethiopia is considered as the second biggest producer of wheat in SSA, next to South Africa with about 0.88 million ha cultivated land area and total production of 4.63 million tons (White, *et al.*, 2001). In Ethiopia, wheat is considered as the fourth most important cereal crop in terms of both areas cultivated and volume of production after teff, maize and sorghum (CSA, 2018). Wheat crop is largely grown in the highlands as well as mid-highlands (Dega and Weyna Dega agro-climatic zones), which lie amid 7.05 and 13.3° N latitude and 37.5 and 42.2° E longitude, at an elevations ranging from 1,500 to 3,200 meters above sea level (Hailu, 1990). As a cool-weather cereal crop, the major wheat growing belts are Oromia (i.e., Arsi, Bale and Shewa) and Amhara (East and West Gojam) highlands of the country. The crop is mainly grown during the main rainy (long-rainfall) season from June - September and harvested from October through January. Additionally, the crop grows during the short-rainy season in all Shewa zones as well as in North and South Wollo zones, which contributes about 5 – 10 percent of cereal output.

Currently, climate change induced challenges coupled with other factors such as increased intensity of biotic and biotic (diseases and pests) stresses have adversely reduced production and yield of wheat (Tadese, *et al*, 2018). East African countries as part of Sub-Saharan Africa; Ethiopia, Kenya and Tanzania showed an increasing tendency in extreme temperature indices and irregular rainfall patterns (Gebrechorkos, *et al.* 2018). The yield of wheat crop is adversely affected by environmental stresses such as high temperature, soil moisture deficit, low light intensity; among which high temperature is the crucial one (Modarresi *et al*, 2010; Kajla *et al*., 2015). The adverse effects of climate change and related variables in this context were not studied well in Ethiopia.

Therefore, the adverse and negative impacts of the climate change described above should be studied and analyzed in-depth. In Ethiopia, such studies are inadequate to provide national level aggregated information (Deressa, 2007). Most of the available studies were confined to some regions and local areas. For instance, Bekele, *et. al.* (2017) investigated the effect of rainfall on wheat yield in Sinana Woreda of Ethiopia. Equally, Yibrah, Korecha, and Dandesa (2018) studied the character of past rainfall and temperature variability and their effects on wheat and barley production in Enderta district of Ethiopia using decadal rainfall and temperature data covering the period 1984-2014. Shumate, *et al* (2017) investigated the impact of climate variability on the yield of cool weather cereal crops (wheat and barley) in Central Highlands and Arssi farming systems of Ethiopia. The purpose of this study was undertaken to narrow the research gap observed on wheat yield analysis to provide nationally aggregated information for policy planners and researchers. Specifically, the objective of the study was to analyze the impact of climate change on yields of wheat in Ethiopia. The results are expected to provide valuable information for management practices at national and regional levels. The information can further be used to design strategies that sustain wheat production in the country.

MATERIALS AND METHODS

Description of the study area

According to Library of Congress (2005), Ethiopia is located in eastern part of Africa. It is bordered by Sudan on the west, Eritrea on the north, Djibouti and Somalia on the east, Kenya on the south, and South Sudan on the south west. Geographically, Ethiopia lies between the Equator and Tropic of Cancer; between 3^0N and 15^0N Latitude or 33^0E and 48^0E Longitude. The country has a total area of 1.127 million square kilometers. Administratively, Ethiopia is structured into eleven Regional States and two City Administrative Councils. Based on the United Nations (2020) population projection, the current population of Ethiopia is about 114.44 million with an annual growth rate of 2.7 percent.

The major cereal crops including wheat are grown in the traditional climatic zones of Ethiopia (Dessie, 2018). Wheat, the focus of this study, is largely grown in the Ethiopian highlands; which lie between 6^0 and 16^0N and 35^0 and 42^0E, at altitudes ranging from 1500 to 3200 meters above sea level (Hailu, 1991). The most suitable areas for wheat production, however, fall between 1900 and 2700 masl. In the highlands, rainfall distribution is bimodal which ranges between 600 and 2000 mm per annum.

In Ethiopia, wheat is grown mainly as rainfed crop by smallholders in the highlands. In most of the country, only a single wheat crop is grown during the second longer rainy season (meher) which usually starts in June. The *short-season* rains (belg), starting in February, are less reliable in most parts of Ethiopia. However, in the southeast part of the country (e.g., Bale zone of Oromia Region), rainfall distribution is bimodal. Growing wheat in the short-season implies harvesting during long-season, which often results in high grain moisture levels and sprouting. Thus, wheat crops are typically sown in June or July and harvested in November or December (Hailu, 1991).

In general, wheat is a cool-weather grain crop that is commonly grown in the highlands and mid-highland areas of the country at elevations ranging from 1,500 to 2,800 meters above sea level, with major ***growing belts*** in Oromia (i.e., Arsi, Bale and Shewa) and Amhara (East and West Gojam) highlands. The crop is regularly grown during the main rainy season (meher) from June to September and harvested from October through January.

Data Type and Method of collection

In this study, the researcher used time series secondary data for all the variables. The type of data collected consisted climatic and non-climatic data. Climatic data consisted temperature and rainfall data while non-climate data included: aggregate yield and cropped area under wheat and fertilizer and improved seed used in wheat crop production.

Data on weather conditions (*temperature and precipitation*) for the period covering 1981 to 2018 were mainly taken from the National Meteorological Agency (NMA) of Ethiopia. Towards this, data for 12 representative weather stations based in major *wheat growing belts* were selected from Oromia and Amhara Regional States, since these two regions accounted for 85.8% of the total cultivated area and 87.9% of the volume of wheat production during 2017/18 (CSA, 2019). For *precipitation*, average monthly data for *Short-Season/ belg* (F-M) and *Long-season/ Kiremt/* crop season (J-S) were taken as recorded in the NMA database. For *temperature*, *crop growing season* (February – September) mean minimum and maximum temperatures were taken as recorded in the NMA database.

For wheat crop, nationally aggregated data on area cultivated, yield per hectare, fertilizer and improved seed applied, and area irrigated under wheat crop were compiled from CSA subsequent publications or website covering the period from 1981 to 2018. Any gap in these variables were complemented from Food and Agriculture Organization (FAOSTAT) database.

Empirical Model Specification

In order to address the *objective* of this study, augmented Cobb-Douglas Production Functional model was employed to estimate the regression coefficient for the mean yield function, *f(x)*.

In line with production theory, it is more likely that the relationship between climate and non-climate variables and crop yield takes non-linear form (Afzal, *et al*, 2017; Mahmood, *et al*, 2012; Chen, *et al*, 2004 and Just and Pope, 1979). According to Chen, *et al* (2004) and Just and Pope (1979), the model provides more significant results compared to other linear functional forms. The model assumes that crop productivity (yield) is a function of endogenous variables like irrigated area under crops, application of fertilizers, utilization of labours and use of tractors; and exogenous factors like literacy rate and farm harvest crop price.

Furthermore, the model assumes that agricultural production is a function of many endogenous and exogenous variables like cultivated area, irrigated area, fertilizers, improved seed, etc. The Cobb-Douglas production function, in its stochastic form (Gujarati, 2004) can be expressed as:

$$Y_t = AX_1^{\beta 1} X_2^{\beta 2} \ldots X_n^{\beta n \; e\varepsilon} \qquad (2.1)$$

where, Y_t is a dependent variable (yield of wheat), $X_{s'}$ are vectors of independent variables incorporated in the regression analysis and $\beta_{s'}$ are parameters to be estimated. *A* is the constant term, *e* is the base of natural logarithm and ε is the error term with zero mean and constant variance. This non-linear form of Cobb-Douglas production function can be estimated using ordinary least squares by taking natural log on both sides of equation (2.1), which becomes log-linear form. Estimates of this form of production function give direct elasticities of the variables. The log-linear form of Cobb Douglas production function in this regard is expressed as:

$$\ln Y_t = \beta + \beta i \sum_{i=1}^{n} \ln X_i + \varepsilon i \qquad (2.2)$$

where lnY_t shows wheat yield (quintal per hectare) at time t, X_i is vector of farm inputs including cropped land area, fertilizer, improved seed, and irrigated area. However, time series data were not available for some of the farm inputs like farm machinery, oxen power, and laborers. In its functional form, the Cobb-Douglas production function under equation (2.2) can be specified as:

$$\ln Y_t = \alpha_0 + \beta_1 \ln La_t + \beta_2 \ln Fert_t + \beta_3 \ln IS_t + \beta_4 \ln Irrga_{it} + \varepsilon_t \qquad (2.3)$$

where, $\ln Y_t$ is the natural log of wheat yield (kilogram per hectare), $\ln La_t$ is natural log of cropped land area under wheat crop, $\ln Fert_t$ is natural log of fertilizer used on wheat crop, IS_t is natural log of improved seed used on wheat crop, and $Irrga_t$ is natural log of irrigated land area used for wheat crop at time t.

The Cobb-Douglas production model further assumes that climatic factors are input factors for yield of crops (Nastis *et al.*, 2012). Climatic variables considered in this study were rainfall and temperature, where mean minimum and maximum temperatures for crop growing period (i.e. February to September) and mean rainfall for *Short*- (FMAM) and *long-seasons* (JJAS) were selected. ε is the usual error term independently and identically distributed. After incorporating climatic variables, equation (2.3) in its log-linear form has been specified as follows:

$$\ln Y_t = \alpha_0 + \beta_1 \ln La_t + \beta_2 \ln Fert_t + \beta_3 \ln IS_t + \beta_4 \ln Irrga_t + \beta_5 \ln SSRainfall_t + \beta_6 \ln LSRainfall_t + \beta_7 \ln MinTemp_t + \beta_8 \ln MaxTemp_t + \varepsilon_t \qquad (2.4)$$

where: $\ln Y_t$ is the natural log of wheat yield (kilgram per hectare), $\ln La_t$ is natural log of cropped land area under wheat, $\ln SSRainfall_t$ is natural log of *short-season* rainfall, $\ln LSRainfall_t$ is natural log of *long-season* rainfall, $\ln MinTemp_t$ is natural log of crop growing season mean minimum temperature, $\ln MaxTemp_t$ is natural log of crop growing season mean maximum temperature, $\ln Fert_t$ is natural log of fertilizer used under wheat, $\ln IS_t$ is natural log of improved seed used under wheat, $Irrga_t$ is natural log of irrigated area under wheat, t = time period from 1981 – 2018, α_0, β_1, β_2, β_3, β_4, β_5, β_6, β_7, and β_8 are unknown parameters to be estimated, and ε_t is the error term..The

Cobb-Douglas production model specified by equation 2.4 was estimated using ***MedCal- Version 19.1 software*** **and** ***SPSS 24 Statistical packages***.

Methods of Estimation and Test for Time Series Properties

The wheat crop yield model selected for this study has been estimated using ordinary least squares method. The models have been estimated consistently by Ordinary Least Squares (OLS) if the error term (ε_j) is a white noise process or more generally, if the error term has a zero mean, constant variance and uncorrelated with the explanatory variables and its previous realizations.

The models were estimated using annual time series data for the period between 1981 and 2018. Prior to model estimation, the data series were subjected to various tests to confirm various properties required for OLS to give results that are efficient and consistent.

Since this study uses time series data, it was necessary that, before estimation of the equations, the data series must be tested for satationarity/ *unit root* and existence of *co-integration* using appropriate methods and tools. In this study, two widely used methods were chosen; Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979) and Phillips-Perron (PP) test (Phillips and Perron, 1988) to check the presence of unit roots in the data series. The ADF test for stationarity in a series, ‘‘y_t’’ involved estimating the equation:

$$\Delta y_t = \mu + \beta_t + \gamma\, y_{t-i} + \sum_{i=1}^{p} \emptyset_i \Delta y_{t-i} + \varepsilon_t \qquad (2.5)$$

wWhere μ is the drift (intercept), t is the trend, i is equal to the number of lags in Δy_{t-i}, p is the maximum number of lags determined using Akaike Information Criterion (AIC) and Schwartz Criterion (SC), and ε_t is the random error term. The null hypothesis H_O: $\gamma = 0$ (unit root) was tested against the alternative hypothesis H_A: $\gamma < 0$ (no unit root). If the computed test statistic is found greater than the critical value, then the null hypothesis is not rejected. If H_O could not be rejected, then the time series variable contained a unit root and hence non stationary, otherwise it is stationary. If its first difference is then tested and found stationary, the series will be concluded to be an I(1) (Green, 2008; Gujarati, 2004; Dickey and Fuller, 1979).

Time series data were also subjected to a Phillips –Perron (PP) test which has a higher power. The PP test took the form:

$$\Delta Y_t = \theta_0 + \sum_{i=1}^{m} \delta_i \Delta Y_{t-i} + \varepsilon t \qquad (2.6)$$

where ΔY_t is the first difference of the dependent variable; i is the number of truncation lags, *i=1, 2,…, m*; θ and δ are coefficients and ε_t is the error term. The null hypothesis of, H_0: $\delta_i = 0$ (unit root) is tested against the alternative, H_A: $\delta_i < 0$ (no unit root). If the computed test statistic is found greater than the critical value at 5% level of significance, then the null hypothesis could not be rejected. If H_O could not be rejected, then the time series variable contained a unit root and hence non stationary, otherwise it is stationary.

RESULTS AND DISCUSSION

Results of the Time Series Unit Root Test

Tests for unit root, cointegration and related diagnostic tests were performed before estimation of the Cobb-Douglas Production Function equation. The major reason for conducting such tests was to establish the order of integration that are crucial for setting up the econometric models from which implications are made. Since most of the economic data are normally non stationary, OLS regressions based on such data are likely to give spurious results. Thus, all the series used in this study were tested for presence of a unit root using ADF and PP.

Table 3.1 presents the results of the stationarity tests on unit root employing Augmented Dickey Fuller (ADF) and Phillip Pherron (PP) unit root test to identify prevailing order of integration.

The unit root test results, indicate that the following variables are stationary at order (I(0)): log wheat yield, log area under wheat; log fertilizer quantity used in wheat growing areas, and log irrigated area under wheat.

Conversely, the following variables were found to be integrated of order (I(1)): log improved wheat seed; log mean rainfall, and crop growing period mean minimum and maximum temperatures in wheat growing areas. The test result disclosed that the variables used in this study are a mixture of I(0) and I(1). In case time series data exhibit a mixture of I(0) and I(1) researchers and econometricians recommend Cobb-Douglas or ARDL modeling as best approach (Sharma and Singh, 2019 and Dushko, *et al* 2011). In order to employ ARDL approach, bounds test of integration, model stability test and variance error correction model (VECM) should be conducted to detect the presence of long-term cointegration (Sharma and Singh, 2019). In case of Cobb-Douglas production model similar tests would be carried out as that of ARDL model (Dushko, *et al* 2011). Cobb-Douglas production function model further needs VAR stability, serial correlation (LM), multicolinearity, Heteroscedasticity, Wald F-statistic, stability and RESET Tests.

Table 3.1. Time Series Unit Root Test Results for Wheat Yield and Related Independent Variables

Variable	**ADF**		**PP**		**Outcome**
	Level	**First Diff.**	**Level**	**First Diff.**	
LNWY	-0.2925***	-1.8247	-0.2925***	-1.3252	I(0)
LNWAR	-0.27204***	-1.10663	-0.27204***	-1.10663	I(0)
LNWIMS	-0.91607	1.67292*	-0.91608	-1.4504	I(1)
LNFERTW	-0.59566***	-1.2101	-0.59566***	-1.21014	I(0)
LNIRRGAW	-0.44296***	-1.43478	-0.44296***	-1.43478	I(0)
LNMEANRF	-1.27530	0.49852**	-1.27530	-1.56314	I(1)
LNMINTEMP	-0.75834	0.405839***	-0.758336	-1.27162	I(1)
LNMAXTEMP	-0.90770	0.47402***	-0.90771	-1.49304	I(1)

*, ** and *** indicates 10%, 5% and 1% level of significance Source: Computed from time series data collected by the investigator, Dec. 2021

According to McCarl *et al.*, (2008) variables with I(1) must be first differenced before estimation of the model. Since most of the variables are not integrated at the same order under the models, a multiple regression analysis using OLS method with the differenced variables was performed (Gujrati, 2004). The test for cointegration involved running a regression of log wheat yield. Residual series were obtained from the estimated equations and tested for the presence of unit root. The null hypothesis stating existence of a unit root, which implies there is no cointegration, was rejected at 5% level of significance for the estimated residuals. The cointegration test results are shown in Table 3.2. The results show that linear combination of the variables in each regression was stationary. The results indicate existence of a long-run relationship among variables in the models.

Table 3.2. Result of Cointegrating Test for wheat output data series

Type of Test	**Test Statistic**	**Critical Values**	**Conclusion**
Wald Test	-5.3689**	4.130	Long-run Cointegration exists

** implies significant at 5 % level

Equally, residual based tests were carried out on all residual series from the output response equation. Normality, serial correlation and heteroscedasticity tests were also performed. The results are presented in Table 3.3. It can be seen from the histogram that the probability values (P values) of the Jarque Bera statistic for normality tests are greater than 0.05 and thus the null hypothesis that standardized residuals are normally distributed could not be rejected at 5 percent level of significance. This implied that the series is normally distributed and *t* and F tests are used for hypothesis testing as they assumed normal distribution.

The Breush-Godfrey Lagrange Multiplier (LM) test for serial correlation was also carried out and the results show no evidence of autocorrelation. The probability (P) associated with the computed test statistic is greater than 0.05 and thus the null hypothesis of no serial correlation in the residuals could not be rejected at 5 percent level of significance. To ascertain whether the standard errors of the estimates are biased the LM test for no autoregressive conditional heteroscedasticity (ARCH) was conducted for the equations. The P value associated with the computed test statistic is greater than 0.05 and thus the null hypothesis of homoscedasticty, could not be rejected at 5% level of significance.

Table 3.3. Residual Properties of Wheat Yield Response Equation

Type of test	**Test statistic**	**Test statistic value**	**Probability**
Normality test-histogram	Jarque Berra	0.23650	0.8885
Breusch-Godfrey Serial Correlation LM Test	Obs*R-squared	0.55634	0.7572
Heteroskedasticity Test: ARCH	Obs*R-squared	2.62662	0.1051

Furthermore, Ramsey RESET test was conducted on the response equations to test whether nonlinear combinations of fitted values help to explain the dependent variable. The intuition is, if nonlinear combinations of the explanatory variable have any power in explaining the dependent variable, the model is misspecified and violates the assumptions of the classical normal linear regression. Table 3.4 presents the results of the Ramsey Reset tests. The findings show that the P values are greater than 0.05 and thus unable to reject the null hypothesis that the powers of the dependent variable have zero coefficients. This implies that the functional form of the model is correctly specified ruling out the possibility of specification errors in the models.

In order to determine parameter constancy, recursive estimations were performed on the crop response equation. In the tests, recursive coefficient tests, CUSUM tests, CUSUM residual squares test, one step forecast test and N steep forecast tests were performed. The result is presented in

Figure 3.1. It can be seen that the plots do not diverge significantly from the zero line and the residuals lie within the standard error band suggesting stability in the parameters of the equation.

Table 3.4. Ramsey Reset Tests Results

Dependant variable	F statistic	Probability	conclusion
Log of wheat output	0.425344	0.6582	No indication of misspecification error

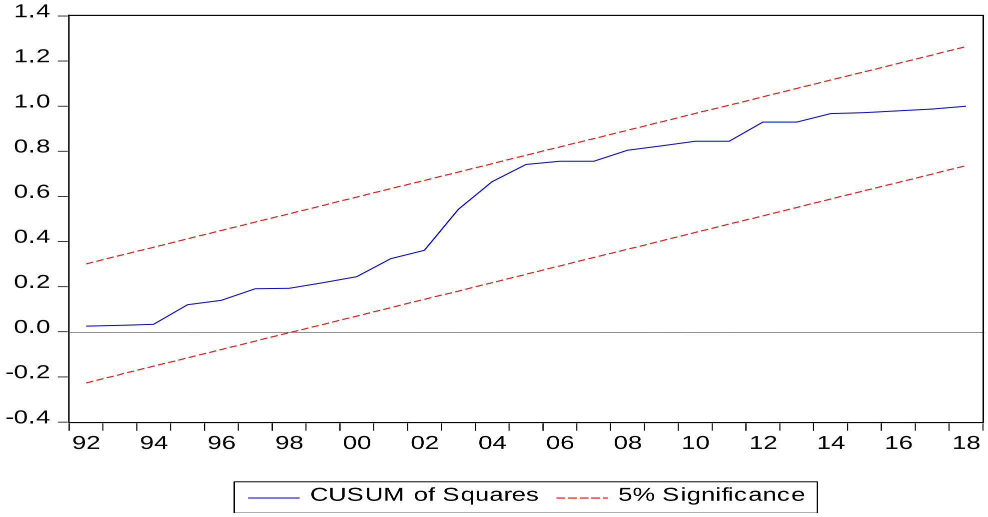

Figure 3.1. Recursive Residuals from the Wheat Output Response Equation

Modeling Impact of Climate and Socioeconomic Variables on Yield of Wheat

Augmented Cobb-Douglas Production Functional model was estimated for wheat crop yield specification as the unit root tests showed that the regressors were a mixture of I(1) and I(0). The test of the data series for serial correlation and multicollinearity showed that there was no serial correlation in the regression models as the Durbin Watson statistic was close to 2 in most cases and the values of VIF are less than 10 for the wheat crop yield model. The explanatory variables incorporated in the wheat yield model estimation were climatic variables (*short-season* rainfall, *long-season* rainfall, crop growing period mean minimum and maximum temperatures) and non-climatic variables (land area under wheat crop, quantity of fertilizer and improved seed used and irrigated area under wheat cropping system). The wheat yield model has been estimated using the ordinary least square technique. The estimated coefficients of the Cobb Douglas production function model were significant as the F-value indicated that the overall regression model best fitted to the present data. The adjusted R^2 values of 0.777 in the estimated wheat yield model implies that 77.7 percent of the variations in wheat yield model are explained by climate variables (*short-season* and *long-season* rainfall, crop growing season mean minimum and maximum temperatures), land area under wheat production, quantity of fertilizer and improved seed consumed, and irrigated area under wheat cropping system.

The results of coefficient estimates of wheat yield regression model are presented in Table 3.5. The results show that *long-season* rainfall (June to September) and maximum temperature variables during crop growing season (February to September) are negatively associated with yield of wheat, both being statistically significant at 10 percent level of significance. The result implies that a 1% rise in maximum temperature and change in long-season rainfall during crop growing period would decrease yield of wheat crop by 2.8% and 0.5% respectively. The study finding on crop growing period mean maximum temperature and wheat yield is in line with the theory proposition that states a rising temperature may result in reduced agricultural productivity (Sigh and Awais, 2019; Amin, *et al*, 2015). The warmer temperatures expected with more extreme temperature events will negatively impact on plant and crops productivity such as wheat, barley, cauliflower, apples etc. With regard to *long*-season rainfall, the theory assumes that more variations in rainfall patterns may adversely affect yield of wheat crop. Amin, *et al*, (2015) in their study on effects of climate change on yield of major crops in Bangladesh also confirmed that temperature (both maximum and minimum) and rainfall increases beyond their optimum requirement would devastate the yield of Aman rice. The results of this study are in line with the findings of other researchers (Singh *et al*, 2017; Shumetie *et al*, 2017; Ajay and Pritee, 2013). Singh, *et al*, (2017) explored that maximum temperature and rainfall showed negative and significant effect on wheat yield in Gujarat State of India. Excessive heat causes reduction in grain number and reduces duration of the grain filling period in wheat, ultimately impacting yield. They further noted that wheat needs cool, dry and clear climate with an optimum temperature ranging between 14-20°C. Shumetie, *et al* (2017) in their study in Ethiopia also reported that the coefficient estimate for *wheat growing season* rainfall was negative and significant at 10 percent level of significance. According to Ajay and Pritee (2013), any increment in maximum temperature has a negative and statistically significant impact on wheat productivity. Increase in maximum temperature by 1% would negatively affect wheat productivity by 2.63%. However, the study results of Ajay and Pritee in respect of minimum temperature are conversely related to the current study in which wheat productivity is negatively affected due to rise in minimum temperature; the regression coefficient for minimum temperature is statistically significant at 1% significance level and it shows that 1% increase in minimum temperature negatively affects wheat productivity by 1.73%.

Table 3.5. Estimates of Cobb-Douglas Production Function from wheat yield model

Explanatory Variables	**Coefficients**	**Std Errors**	**T-Ratio**	**P-Value**	**VIF**
(Constant)	9.1192				
lnWhArea	-0.3542*	0.1955	-1.812	0.0803	12.653
lnFertWh	0.269***	0.0952	2.828	0.0084	10.458
lnImSWh	0.1849***	0.06731	2.747	0.0102	3.354
lnIrrgArWh	0.1529**	0.06745	2.268	0.0310	3.068
ln*Short-season rainfall*	-0.08814	0.1434	-0.615	0.5435	2.018
ln*Long-season rainfall*	-0.498*	0.2888	-1.725	0.3252	1.625
lnMinTemp	0.9149	0.6452	1.418	0.1669	2.134
lnMaxTemp	-2.8099*	1.6121	-1.743	0.6192	3.331
Coefficient of determination R^2		0.825			
R^2-adjusted		0.777			
F-ratio		17.17***			
Multiple correlation coefficient		0.9085			
Residual standard deviation		0.1372			
Sample Size		38			

***, ** and * indicates significance levels at 1%, 5% and 10% respectively. Source: Author's computation

Conversely, the non-climatic factors included in the model such as land area cultivated, quantity of fertilizer used, quantity of improved seed used, and irrigated area under wheat crop were all showed positive and expected results, except cultivated land area. The coefficient estimate for land area cultivated under wheat cropping showed negative and significant impact on yield of wheat crop. The result implies that any area expansion under wheat crop production would have negative impact on wheat yield.

The coefficient estimates for quantity of fertilizers and improved seed used on wheat crop production as well as irrigated area were positive and significant at 1 percent level of significance. The results imply that use of these inputs; fertilizer, improved seed and irrigated area have vital role in increasing yields of wheat crop. The regression results in Table 3.5 show that as fertilizer consumption increases by one percent, wheat yield increases by approximately 0.27%. Similarly, the regression result showed that as improved seed consumption increases by one percent, wheat yield increases by approximately 0.18%. This indicates that use of improved wheat seed is among the options to increase wheat productivity in the country if applied properly. Equally, irrigated area put under wheat cropping system have positive and significant relationship with yield of wheat crop. The result indicates that a 1% increase in irrigated area under wheat production would increases wheat yield by approximately 0.15%.

The study results of input usage on wheat crop production are consistent with the findings of other researchers (Shumetie, *et al*, 2017; Birthal *et al*, 2014; Ajay and Pritee, 2013). Shumetie et al (2017) explored that inorganic fertilizer had significant and positive effect on yield of wheat and barley crops, which means small unit increment in its application could enhance crop yield significantly. Ajay and Pritee (2013) in their study on the impact of climate variation on agricultural productivity in rural India found that any fertilizer usage increment could enhance wheat, maize, barley and sorghum productivity as well as increase in irrigated area under crop is important factor to increase wheat productivity, which was a finding corroborated with the above model result for cereal crops. Birthal *et al* (2014) found that irrigation has significant impact on wheat yield; where the coefficient of irrigated area was significant and had the expected signs in wheat cropping system, implying that irrigation is important to counterbalance the harmful effects of climate change on wheat crop. Zahid (2016) in his assessment of impact of climate change on farm production in Punjab of Pakistan discovered that fertilizer, improved seed, and irrigated area had positive and statistically significant (at 1% level) impact on crop productivity. The results indicate that use of these inputs is very important to increase yield of crops.

CONCLUSION

The ultimate objective of this study was to analyze the impact of climate change on yields of wheat crop in Ethiopia using quantitative time series data covering the period 1981 – 2018. The study adopted Cobb-Douglas Production Functional model to examine the impact of climate and non-climatic factors on yield of wheat in the country.

The findings of this study confirmed that *long-season* rainfall (June to September) and crop growing period (February to September) maximum temperature had negative and significant (at 1 percent level) impact on yield of wheat crop. The result implies that a rise in maximum temperature during crop growing period and change or variation in *long-season* rainfall could have adverse impact on yield of wheat crop in wheat growing belts. The study finding on the relationship between crop growing period mean maximum temperature and wheat yield is in line with the theory proposition that states a rising temperature may result in reduced agricultural productivity. With regard to *long*-season rainfall, the theory assumes that more variations in rainfall patterns may adversely affect yield of wheat crop. However, mean minimum temperature during crop growing period (F-S) and *short-season* rainfall (February to March) portrayed positive association with yield of wheat, but only mean minimum temperature is found significant at 1 percent level. *Short-rain* season is the period when land preparation activities for wheat crop partly take place requiring modest rainfall and minimum temperature.

The study also revealed that fertilizer, improved wheat seed and irrigation are important factors to increase productivity of wheat crop. The study finding explored that fertilizers and improved seed as well as irrigated area under wheat crop had positive and significant impact on yield of wheat crop. The results imply that use of these inputs; fertilizer, improved seed and irrigation have vital role in increasing yields of wheat crop. Contrarily, the study indicated that land area cultivated under wheat cropping showed negative and significant impact on yield of wheat crop. The result implies that any area expansion under wheat crop production would have negative impact on wheat yield. This can be due to the fact that marginal land put under cultivation would decrease wheat yield although it increased total volume of production.

In view of the findings of this study, it can be concluded that every crop has an optimum minimum and maximum temperatures and rainfall requirement limit for their reproductive and vegetative growth. When temperature exceeds the upper limit, crop production changes drastically. Moreover, excessive rainfall may create water logging condition and flooding that also destroys crop production.

Given high vulnerability of wheat yields to climate variations in Ethiopia, it is recommended that different adaptation strategies need to be adopted to offset the adverse effects of climate change. Based on the empirical findings of this study, increased use of irrigation is recommended, particularly in lowland areas where potentials prevail to mitigate the adverse effect of climate sensitivity of wheat crop. Increase in use of fertilizers and improved seed varieties that are tolerant to drought can be another option to increase the productivity of wheat crop in Ethiopia.

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Author’s Contributions

The author has contributed to the study conception and design. The author (*Abera Gayesa Tirfi*) has also performed all the material preparation, data collection and analysis, and writing up of the manuscript. The co-author (*Abayomi Samuel Oyekale*) has contributed to the research paper in reviewing and correcting the draft manuscript and helped to take the current final shape.

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Competing Interests

The authors declare that there are no competing interests.

Data Availability

All data generated during this study are included in this article. The data used for this study can be made available upon request provided there is going to be compliance with the owners’ policy concerning sharing.

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