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An augmented Cobb-Douglas production functional modeling of the impact of climate change on Teff yields in Ethiopia

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Abstract
The study analyzed the impacts of climate change and related factors on yields of teff crop in Ethiopia using quantitative time series data for the period 1981 – 2018. The study adopted Augmented Cobb-Douglas Production Functional model to examine the impact of climate and non-climatic factors on yield of teff in the country. The study confirmed that long-season rainfall has negative and significant impact on yields of teff. The results indicate that an increase in rainfall during long-rainfall season, the period when crop vegetative and reproductive growth is high (J-S), revealed harmful impact on the yield of teff. This witnesses that excessive rainfall affects the yield of teff crop negatively. Conversely, the regression coefficient for maximum temperature and CO_2 during crop growing season in teff growing areas portrayed positive and significant (at 5 percent) impact on yield of teff, implying that a rise in maximum temperature and CO_2 concentration in teff growing areas would increase the yield of teff per unit area, i.e., would affect teff yield positively. Furthermore, the estimated coefficients for land area under teff crop production has positive and significant impact on teff yields. In general, based on the validating proofs of the current study, the hypothesis stating there is ‘‘no impact of rainfall and temperature variables’’ on yield of cereal crop is rejected, signifying that changes in climate adversely affects yields of teff, wheat and maize crops.

Keywords: Climate change, Teff Yield, Cobb-Douglas model, Ethiopia

Introduction

The production and consumption of teff ranks the highest among all the cereal crops in Ethiopia; it is also cultivated as food grain in Eritrea (FAO, 2015). Teff (*Eragrostis Teff*) is a nutritious small grained cereal, which can be likened to millet. It is believed that teff came into existence in Ethiopia and was subsequently adapted as a domestic staple food crop by Ethiopian farmers between 3 and 6 millennia ago (Samuel and Sharp, 2008) [21].

Virtually, it is estimated that half of farming households in Ethiopia grow teff, and even more in the highlands. Teff accounts for 23 percent of all cultivated land during 2017 and 2018. Though teff is primarily grown in mid-highlands (*Weyna Dega Zone*) and upper-lowlands of the country, it can also be cultivated under a wide-range of agro-climatic environments of the country. In terms of altitude, teff can be grown up to elevations ranging from 0 - 2,800 meters above sea level (masl), but under an equally extensive diversity of humidity, temperature, and soil situations. Besides, there exists a concurrence between its optimum growing conditions and its conventional production vicinities or belts: 1,800–2,100 masl, with mean annual precipitation of 750–1,000mm, and mean annual temperature of 10–27^{0}C. The two major regions of the country where teff is primarily grown are Amhara and Oromia regions, both places contributed to the total cultivated area and production of an aggregate of 85.4 and 87.5 percents between 2017 and 2018, respectively. In Ethiopia, East and West Gojam zones of Amhara and East and West Shoa zones of Oromia are specifically recognized as the highest teff growing production belts.

However, climate change induced challenges coupled with other factors such as drought, extreme events like floods have adversely reduced the production and yield of teff (Tembo, 2018) [24]. It is shown by periodical extreme events in form of frequent droughts of previous years (1974, 1983/1984, 1987, 1990, 1991, 1999, 2000, 2002 and 2011). Therefore, annual climatic factors have had critical influence on teff (*Eragrostis teff*) yields, one of the major food crops for Ethiopia. According to FAO (2010), the rising temperature and variability in rainfall pattern have direct impact on crop production and food security.

Despite increased frequency and intensity of climate risks in the country empirical studies on climate change impacts on teff yield are lacking. Therefore, an in-depth investigation of the impacts of climate change becomes essential to provide information that may give directions for future coping and adaptation strategies for the country (Deressa *et al.* 2014) [4].

The main objective of the study was to analyze the impacts of climate change and related factors on teff production and yield. The information generated will be used to inform policy makers, scientists, development workers and rural communities on the likely effects of climate change using teff as a case study.

Materials and Methods

Description of the study area

According to Library of Congress (2005), Ethiopia is located in Eastern Africa. It borders 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 the 3^0N and 15^0N Latitude or 33^0E and 48^0E Longitude. The country has a total area of about 1.127 million square kilometers. Based on United Nations (2020) [25] 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 teff are mainly grown in the traditional climatic zones of Ethiopia (Dessie, 2018) [5]. Teff primarily grows in elevations ranging from 0 - 2,800 meters above sea level (masl). Besides, there exists a concurrence between its optimum growing conditions and its conventional production vicinities or belts: 1,800–2,100 masl, with mean annual precipitation of 750–1,000mm, and mean annual temperature of 10–27^0C.

Geographically, East and West Gojam zones of Amhara and East and West Shoa zones of Oromia are specifically recognized as the highest teff growing production belts of the country (see Figure 1 for the Map). The two major teff growing regions (Amhara and Oromia) of the country contribute to the total cultivated area and production of an aggregate of 85.4 and 87.5 percents between the years 2017 and 2018, respectively.

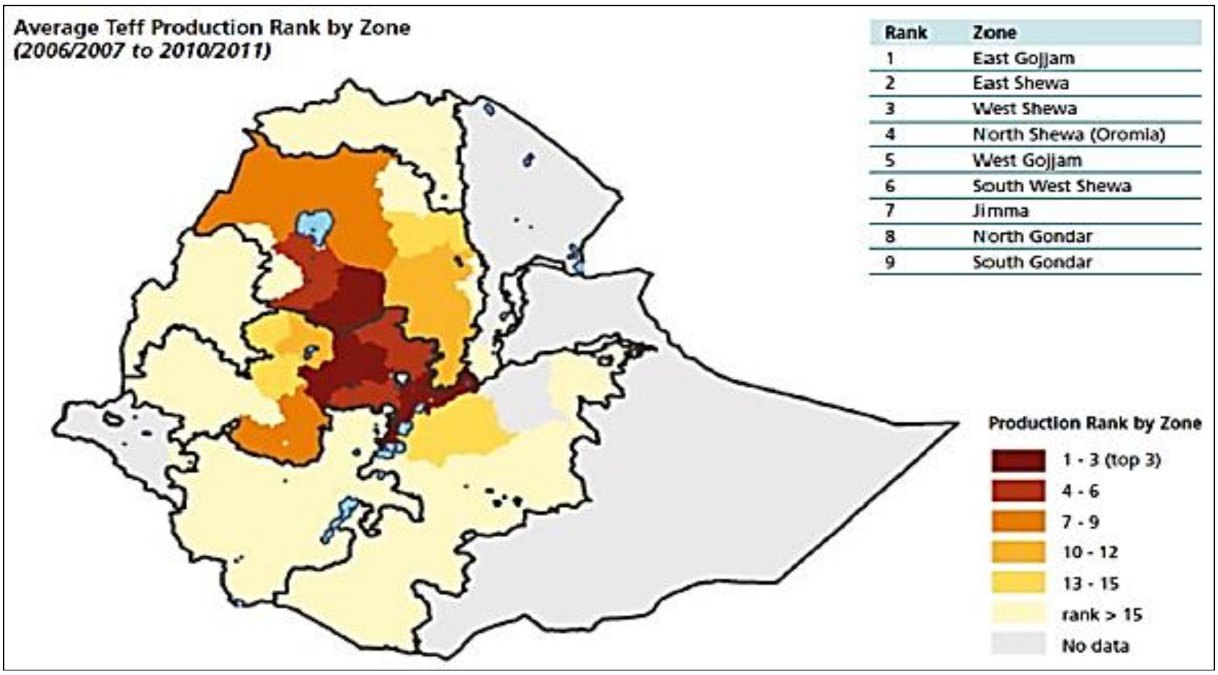

Fig 1: Major teff growing belts of Ethiopia

Teff is primarily cultivated and grown by smallholder farmers in the central, eastern and northern highlands of the country on fragmented lands under rain-fed conditions in both, *Long-rainfall* and *Short-rainfall*, seasons (Engdawork, 2009) [8]. According to FAO (2015), teff is considered as a crop relatively resistant to many biotic and abiotic stresses. It can be grown under different agro-ecological conditions of the country, ranging from lowland to highland areas. Although teff crop is primarily grown during the long-rainy season, it also grows during short-rainy season, particularly in North, SouthWest and EastShew Zones of Oromia Region as well as North and South Wollo Zones of Amhara regions where short-rany season (*Belg*) normally prevails. These zones usually receive *bimodal* type of rainfall during *short-* and *long-rainy* seasons. According CSA and MoA (2005) [19], short-rain season contributes about 10 percent of the total grain production while long-rain season contributes about 90 pecent of the total grain production in the country.

Data type and method of collection

In this study, the researcher used time series secondary data of all the variables. The type of data considered in this study included: climate variables, aggregate yield and cropped area under teff, fertilizer and improved seed used in teff crop production.

Data on weather conditions (*temperature and precipitation*) for the period from1981 to 2018 were mainly taken from the National Meteorological Agency (NMA) of Ethiopia. Data for 12 representative weather stations based in major *teff growing belts* were selected from Oromia and Amhara Regional States, as these two regions accounted for 85.8% of the total cultivated area and 87.9% of production of wheat during 2017/18 production year (CSA, 2019). For *precipitation*, average monthly data for *Short-Season* (F-M) and *Long-season/ Kiremt/* main crop season, (J-S) were taken as recorded in NMA database. For *temperature*, *crop growing season* (February – September) mean minimum and maximum temperatures were taken as recorded in NMA database.

For teff crop data, nationally aggregated data on area cultivated, yield per hectare, fertilizer and improved seed applied, and area irrigated under teff crop were compiled from CSA subsequent publications or website covering the period from 1981 to 2018. Any gap in these variables was 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 has been employed to estimate the regression coefficient for the mean yield function, *f(x)*.

In line with the production theory, it is more likely that the relationship between climate and non-climate variables and crop yield takes non-linear form (Mahmood, *et al.*, 2012; Chen, *et al.*, 2004 [16, 3] and Just and Pope, 1978) [15]. According to Chen, *et al.* (2004) [3] and Just and Pope (1979) [15], the model provides more significant results compared to linear functional form. 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, farm harvest price of specific crops.

Furthermore, 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:

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

Where, Y_t is a dependent variable (yield of teff), $X_{s'}$ are vectors of independent variables included in the regression analysis and $\beta_{s'}$ are parameters to be estimated. A is constant term, e is 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 through ordinary least squares by taking natural log on both sides of equation (1), which becomes log-linear form. Estimates of this form of production function give direct elasticities of variables. The log-linear form of Cobb Douglas production function in this regard is expressed as:

$$\ln Y_t = \beta + \beta i \sum_{i=1}^{n} \ln X_i + \varepsilon i \qquad (2)$$

Where lnY_t shows wheat yield (kilogram per hectare) at time t, X_i is vector of farm inputs including cropped land area, fertilizer, improved seed, irrigated area, etc. However, time series data were unavailable 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) is specified as:

$$\ln Y_t = \alpha_0 + \beta_1 \ln La_t + \beta_2 \ln Fert_t + \beta_3 \ln IS_t + \beta_4 \ln Irrga_{it} + \varepsilon_t \qquad (3)$$

where, $\ln Y_t$ is the natural log of yield of teff (kilogram per hectare), $\ln La_t$ is natural log of cropped land area under teff crop, $\ln Fert_t$ is natural log of fertilizer used under teff crop, IS_t is natural log of improved seed used under teff crop, and $Irrga_t$ is natural log of irrigated land area under teff 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 considered. ε is the usual error term independently and identically distributed. After incorporating climatic variables, equation (3) in its log-linear form has been specified as follows:

$$\ln Y_t = \alpha_0 + \beta_1 \ln La_t + \beta_2 \ln Fert_t + \beta_3 \ln IS_t + \beta_4 \ln Irrga_t + \beta_5 \ln SSRainfall_t + \beta_6 \ln LSRainfall_t + \beta_7 \ln MinTemp_t + \beta_8 \ln MaxTemp_t + \beta_9 \ln CO_{2t} + \varepsilon_t \qquad (4)$$

Where: $\ln Y_t$ is the natural log of yield of teff (kilgram per hectare), $\ln La_t$ is natural log of cropped land area under teff, $\ln SSRainfall_t$ is natural log of *short-season* season rainfall, $\ln LSRainfall_t$ is natural log of *long-season* rainfall, $\ln MinTemp_t$ is natural log of crop season mean minimum temperature recorded during cropping seasons, $\ln MaxTemp_t$ is natural log of crop season mean maximum temperature recorded during cropping seasons, $\ln CO_{2t}$ is natural log of CO_2, $\ln Fert_t$ is natural log of fertilizer used under teff, $\ln IS_t$ is natural log of improved seed used under teff, $Irrga_t$ is natural log of irrigated area under teff, 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.To estimate the Cobb-Douglas production model specified by equation 4, MedCal- Version 19.1 software and SPSS 24 Statistical packages were used.

Methods of Estimation and Test for Time Series Properties

Teff crop yield model selected for this study has been estimated by 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 have been estimated using annual time series data for the period between 1981 and 2018. Prior to model estimation, the data series have been 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 series 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) [6] and Phillips-Perron (PP) test (Phillips and Perron, 1988) [20] to check the presence of unit roots in the data series. The ADF test for stationarity in a series y involved estimating the equation:

$$\Delta y_t = \mu + \beta_t + \gamma\, y_{t-i} + \sum_{i=1}^{p} \emptyset_i \Delta y_{t-i} + \varepsilon_t \qquad (5)$$

Where μ is the drift (intercept), t is the trend, i is equal 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: γ = 0 (unit root) was tested against the alternative hypothesis H_A: γ < 0 (no unit root). If the computed test statistic was found greater than the critical value then the null hypothesis was not rejected. If H_O could not be rejected, then the time series variable contained a unit root and hence non stationary, otherwise it was stationary. If its first difference is then tested and found stationary, the series was concluded to be an I(1) (Green, 2008; Gujarati, 2004; Dickey and Fuller, 1979) [6].
Time series were also subjected to a Phillips –Perron (PP) test which has a higher power.
The PP test took the form:

$$\Delta Y_t = \theta_0 + \sum_{i=1}^{m} \delta_i \Delta Y_{t-i} + \varepsilon t \quad (6)$$

Where ΔY_t was the first difference of the dependent variable; i is the number of truncation lags, where $i=1, 2, \ldots, m$; θ and δ are coefficients and ε_t is the error term. The null hypothesis of, H_0: $\delta_i = 0$ (unit root) was tested against the alternative, H_A: $\delta_i < 0$ (no unit root). If the computed test statistic was 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 was stationary.

Results and Discussion

Results of the Time Series Unit Root Test

Unit root, Cointegration and related diagnostic tests have been performed before estimation of the augmented Cobb-Douglas Production equation. The major reason for conducting such tests was to establish the order of integration, crucial for setting up the econometric models from which implications are made. Since most of the economic data are non stationary, OLS regression based on such data is likely to give spurious results. Thus, all the series used in this study were tested for presence of a unit root based on ADF and PP.
Table 1 presents the results of the stationarity tests on unit root by employing Augmented Dickey Fuller (ADF) and Phillip Pherron (PP) unit root test of order of integration. The unit root test results indicate that the following climatic and non-climatic variables exhibited existence of stationary (I(0)) in the data series: log teff yield, log area under teff; log fertilizer quantity used in teff production; log improved teff seed, log irrigated teff area; log mean temperature in teff growing areas, log minimum temperature and log maximum temperature in teff growing areas, and log CO_2. and in teff growing areas, log improved teff seed, log fertilizer quantity used in teff growing areas, log irrigated area under teff; log mean temperature in teff yield data series, minimum temperature in teff yield data series, maximum temperature in teff yield data series. Equally, log *short-season rainfall*, and log *long-season rainfall*s exhibited an integration of order 1 in the data series.
The unit root test in this study has demonstrated a mixture of I(0) and I(1) for the climatic and non-climatic variables that have been included in the current study. In case time series data exhibit mixture of I(0) and I(1) most researchers and econometricians recommend Cobb-Douglas or ARDL modeling as best estimation approach (Sharma and Singh, 2019 [22] and Dushko, *et al.* 2011) [7]. In order to employ ARDL approach, bounds test of integration, model stability test and variance error correction model (VECM) should be conducted to test presence of long-term cointegration (Sharma and Singh, 2019) [22]. In case of Cobb-Douglas production model similar tests are conducted as ARDL model (Dushko, *et al.* 2011) [7]. Cobb-Douglas model further needs VAR stability, serial correlation (LM), multicolinearity, Heteroscedasticity, Wald F-statistic, stability and RESET Tests.

Table 1: Unit Root Test Results for Teff Yield and Related Independent Variables

Variables	ADF		PP		Outcome
	Level	First Diff.	Level	First Diff.	
LNTY	-002740***	-1.85587	-0.11344***	-1.41357	I(0)
LNTAR	-0.46274***	-1.20853	-0.46274***	-1.20853	I(0)
LNIMS	-0.42047***	-1.58075	-0.64963***	-1.58075	I(0)
LNFERT	-0.55854***	-1.31549	-0.40151***	-0.95384	I(0)
LNIRRGTA	-0.12853***	-1.55988	-022704***	-1.55916	I(0)
LNSSRF	-0.83265	-1.97545	5.40645	-1.55916**	I(1)
LNLSRF	-0.99735	-1.53563	-0.51082	-1.77616***	I(1)
LNMINTEMP	-0.35993**	-1.33122	-0.79429	-1.33158	I(0)
LNMAXTEMP	-0.25366***	-3.14161	-0.53094	-1.40797	I(0)
$LNCO_2$	-0.18356**	-0.99078	-0.54828	-0.97815	I(0)

Source: Computed from time series data collected by the investigator, Dec. 2019
***, ** and * indicates significant levels at 1%, 5% and 10% respectively

According to McCarl *et al.*, (2008) [17] variables with I(1) must be differenced first before estimation. 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) [12]. 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 of 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 2. The results show that linear combination of the variables in the regression was stationary. The results indicate existence of a long-run relationship among variables in the models.

Table 2: Result of Cointegrating Test for teff yield data series

Type of Test	Test Statistic	Critical Values	Conclusion
Wald Test	-5.1689**	4.130	Long run cointegration exists

** implies significant at 5% level

Residual based tests were carried out on all residual series from the teff output response equation. Normality, serial correlation and heteroscedasticity tests were also performed. The results are presented in Table 3. From the histogram the normality tests probability values (P values) of the Jarque Bera statistic 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 carried out in the equations. The P-value associated with the computed test statistic is greater than 0.05 and thus the null hypothesis of homoscedasticy, could not be rejected at 5% level of significance.

Table 3: Residual Properties of Teff Yield Equation

Type of test	Test statistic	Test statistic value	Probability
Normality test-histogram	Jarque Berra	46.59	0.000
Breusch-Godfrey Serial Correlation LM Test	Obs*R-squared	4.4867	0.106
Heteroskedasticity Test: ARCH	Obs*R-squared	0.01746	0.895

Furthermore, Ramsey RESET test has been conducted on the response equations to test whether non linear combinations of fitted values help to explain the dependent variable. The intuition is, if non linear combinations of the explanatory variables have any power in explaining the dependent variable, the model is misspecified and violates the assumptions of the classical normal linear regression. Table 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 models is correctly specified ruling out the possibility of specification errors in the models.

To determine parameter constancy, recursive estimations were performed on teff crop response equation. 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 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 4: Ramsey Reset Tests Results

Dependent variable	F statistic	Probability	conclusion
Log of teff output	2.83957	0.1035	No indication of misspecification error

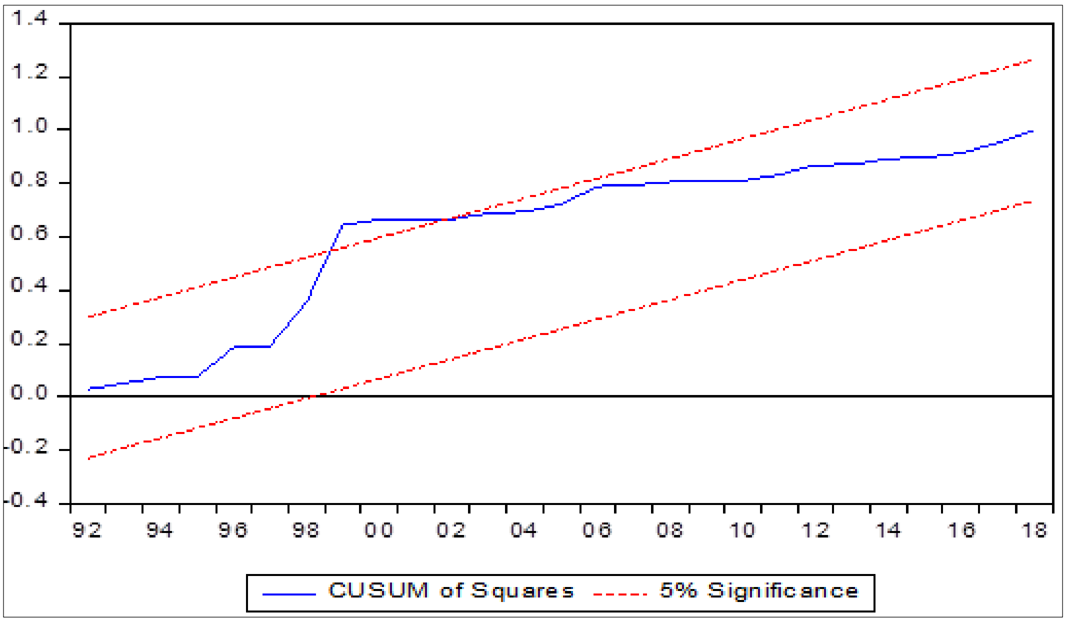

Fig 1: Recursive Residuals from the Teff Output Response Equation

Modeling Impact of Climate and Socio-Economic Variables on Yield of Teff.

In this study, OLS technique has been employed to establish the causal relationships existing between yield of teff and relevant climatic variables, namely temperature and precipitation in teff growing areas of Ethiopia. Contribution of climatic variables to production of teff crop in the country has been represented by variables like crop season mean rainfall, *long-season* rainfall (main season rainfall), mean minimum and maximum temperatures, and CO_2 during crop growing season, i.e., February to September. In addition, non-climatic variables such as area cultivated under teff, quantity of fertilizer consumed as well as irrigated area under teff crop were added to the yield model. The estimated coefficients of the Cobb Douglas production functional model are presented in Table 5. The F-test value for the estimated model depicts good fitness of the overall regression model to the present data series. The adjusted R^2 values of 0.995 in teff yield function implies that 99.5% of the variations in teff yield are explained by climate variables, fertilizer consumed, area under teff crop and irrigated area under teff crop.

As can be observed from Table 5, the elasticity estimates of climatic variables showed mixed impacts on yield of teff crop. The elasticity estimates of rainfall (crop growing season and *long- rainfall season*) and minimum temperature showed negative impact on yield of teff. However, only *long-season* rainfall was found statistically significant at 1% level. This suggests that a 1% increase in the amount of precipitation (mm) reduces yield of teff by 0.35%. This result implies that increases in rainfall during the *long-rain season* will highly affect production and yield of teff crop if it exceeds the optimum level. In practice and theory, as rainfall increases beyond the optimum level, extreme events like flooding, landslide, crop lodging, and erosion of top soil would be contributing to reduction of yield and production of teff crop. In reality and normal cases, teff crop needs *high and optimum* amount of rainfall during the *long-rainy season*, the period when seedbed preparation, seed sowing, weeding, as well as crop vegetative growth takes place. It is the *long-season* rainfall that is important for growing of teff crop as all the agronomic practices take place during this season. For teff, land preparations take place in the month of June, seed sowing and first fertilization from July to mid-August, second fertilization and weeding from mid-August to September, and harvesting and threshing operations from October to December. The negative and significant impact on yield of teff crop was assumed to be induced by extreme rainfall events, particularly an excessive rainfall during *long-season* rainfall. In agronomic terms, such events would damage crop, in addition to leading to crop failure posed by over flooding of teff fields, lodging of crops, and favored weeding and pests, which leads to decline in teff yields.

This finding corroborates with theory that suggests an increase in rainfall during crop development phase will reduce the yield and production of crop under consideration. The results of this study correspond with the study results of Ademe (2017) [1], Menya (2011) [18], Mahmood *et al.* (2012) [16] and Singh (2017) [23]. Ademe (2017) [1] assessed the impact of variability in climate variables on yield of cereal crops in Ethiopia and found that crop growing season precipitation has negative and considerable effect on yield of wheat. The result revealed that a 1% increase in the crop growing season rainfall reduces wheat yield by 0.124% . Similarly, Menya (2011) [18] studied rainfall variation due to climate change in Ethiopia. The investigation reported negative and significant effect of the long-season rainfall on crop yield. Essentially, the result of the study portrayed that a 10% increase in long-season rainfall also reduces crop yield by 0.01%. Equally, Mahmood *et al.* (2012) [16] recorded negative and significant coefficient of rainfall variable and further observed that a rise in rainfall during months of crop reproductive and harvesting period decreases crop yield. Correspondingly, Singh (2017) [23] found that the regression coefficient estimate for crop growing season rainfall has negative, but insignificant impact on yield of wheat during Rabi season in Gujarat, India.

In contrast, the elasticity estimates for maximum temperature and CO_2 emission exhibited positive and significant (10 percent and 5 percent level re respectively) impact on yield of teff. The result signifies that a 10% raise in the maximum temperature and CO_2 concentration would increase teff yield by 3.72% and 0.56%, respectively. However, this finding is in contrast with the theory proposition which state an increase in temperature will reduce the yield and production of crops under consideration. The result implies that an increase in maximum temperature during crop growing season would lead to increase in yield of teff crop, which is of benefit to the crops. It cannot be gainsaid that temperature is a determinant factor in the speed of crop development and consequently, it can affect the length of crop growing period including teff. Accordingly, crop vegetative growth would increase as temperatures rises to optimum level. For most crop species, vegetative growth usually has a higher optimum temperature than for the reproductive development process. In the same vein, teff crop needs relatively warmer temperature during grain ripening cycle. In general, as temperature increases, the rate of teff plant growth likewise increases until an optimum temperature is reached. Nonetheless, an extreme temperature such as higher temperature during crop sowing period will necessarily affect seed germination and development of vigor seedling. Besides, it can even bring about failure or drying of seedling. Equally, very cool temperature particularly during nighttime will result in frost which severely shrinks grains of the crop (Hatfield and Prueger, 2015) [13].

Table 5: Estimates of Cobb-Douglas Production Function for teff yield model

Explanatory Variables	Coefficients	Std Errors	T-Ratio	P-Value	VIF
Constant	-6.1533				
lnTAr	6.8791***	0.1600	42.984	<0.0001	3.726
lnIrrgTAr	0.0056	0.0116	0.485	0.6311	4.413
lnFert	-0.0354**	0.0160	-2.215	0.0348	6.119
lnSSRainfall	-0.0010	0.1023	-0.0098	0.9923	2.951
lnLSRainfall	-0.352***	0.0679	-5.184	0.6083	2.794
lnMinTemp	-0.0725	0.0995	-0.729	0.4717	2.466
lnMaxTemp	0.372*	0.2176	1.710	0.8655	2.283
lnCO2	0.056**	0.0263	2.132	0.042	5.660
Coefficient of determination R^2		0.99			
R^2-adjusted		0.995			
F-ratio		854.43***			
Multiple correlation coefficient		0.998			
Residual standard deviation		0.0202			
Sample Size		38			

Source: Author's computation

***, ** and * indicates 1%, 5% and 10% significance level, respectively

The findings of this study is found similar to the submission of Ademe (2017) [1], who in their study on impacts of variability in climate on the cereal crops in Ethiopia reported that crop growing period temperature revealed positive and significant (at 1% level) impact on yields of wheat and barley. The result actually indicated that a 1% increase in crop growing season temperature increases wheat and barley yield by 0.984% and 0.564%, respectively. Mahmood *et al.*'s (2012) [16] carried out a study in Pakistan and discovered that average minimum temperature during crop growing period was positively associated with the yield of rice crop.

Regarding socio-economic variables, the elasticity estimates of area cultivated under teff crop and irrigated area under teff crop showed positive impact on yield of teff, although only area harvested under teff crop was found significant at 1% level. The result evinces that a 1% increase in area allocated for teff crop increases teff yield by 6.88%. The result implies that any area expansion and allocation under teff production would contribute to the growth of teff production, particularly in terms of volume. This finding is in consonance with the results of Byishimo (2017) [2] on the impacts of climate change on crop yields in Rwanda. Byishimo (2017) [2] asserted that area harvested under teff crop has positive and significant impact on teff yield, denoting that a 10% increase in area harvested under teff crop increases yield of teff by 3.31%.

On the contrary, the study results showed that the quantity of fertilizer applied on teff farms has negative and significant (at 5% level) impact on yield of teff. It follows that a 10% increase in quantity of fertilizer used reduces teff yield by 0.354%. Therefore, it means that any increase in quantity of fertilizer used under teff cultivated area will lead to a reduction in the yield of teff, which consequently necessitates the use of fertilizer only up to optimum level. This result is similar to the results submitted by Issahaku (2014) [14], who studied the impact of climate change on productivity of agriculture and poverty in Ghana. The results showed a negative effect of fertilizer on productivity of Cassava, but statistically insignificant.

The elasticities estimated for the explanatory variables included in the Cobb-Douglas production model for teff yield totaled to 6.798, and this affirms an *increasing return to scale*. This implies that there is an increasing return to scale in teff production business.

Conclusion

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

The findings of the study from teff yield regression model revealed that the coefficients of rainfall variables during *crop growing* (F-S) and *long-rainfall* (J-S) seasons were both negative; but only long-rainfall season was significant at 1 percent significance level. The results indicate that an increase in rainfall during *long-rainfall* season, the period when crop vegetative and reproductive growth is high (J-S), revealed harmful impact on the yield of teff. This witnesses that excessive rainfall affects the yield of teff crop negatively. The coefficient of minimum temperature during crop growing period in teff growing areas also revealed negative impact, but statistically insignificant.

Conversely, the estimated regression coefficient for maximum temperature during crop growing season (F-S) in teff growing areas is positive and significant at 5 percent significance level, implying that a rise in maximum temperature in teff growing areas would increase the yield of teff per unit area, i.e., would affect teff yield positively. Further, CO_2 showed positive and significant (5 percent level) impact on teff yield per unit area.

Furthermore, the estimated coefficients for land area under and irrigated area under teff crop production are positive, but only land area under teff cropping system is found significant at 1 percent level, implying that use of land for teff production has vital role in increasing yield of teff crop. However, use of fertilizer has resulted in negative impact, although non-significant.

The current study revealed that teff yield has a log-linear relationship with *short*- and *long-season* rainfall as well as mean temperature during crop growing period. The result revealed that higher temperatures may be helpful to teff crop up to the level favorable for the growth and development of the crop. The combined impact of higher temperatures and erratic rains affects teff crop during crop vegetative growth and flowering period as well. Furthermore, these noted variations as a matter of course associated with temperature and rainfall could make land presently assigned for teff crops unsuitable for growing (Yumbya, *et al.*, 2014) [26]. These conditions invariably would lead producer farmers to extreme climate risks as it activates a shift in crop production that eventually reduce the quantity and quality of teff output. Thus, this study revealed that *long- seasons rainfall* (J-S) have negative impact on teff yield, which is significant (at 1% level).

In general, based on the validating proofs of the current study, the hypothesis stating there is *''no impact of rainfall and temperature variables''* on yield of cereal crop is rejected, signifying that changes in climate adversely affects yields of teff, wheat and maize crops.

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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.

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