ISSN Print: 2664-844X
ISSN Online: 2664-8458
Impact Factor: RJIF 5.6
IJAFS 2022; 4(2): 88-100
www.agriculturaljournals.com
Received: 05-09-2022
Accepted: 04-10-2022

Abera Gayesa Tirfi
College of Agriculture and Environmental Sciences, University of South Africa (UNISA), Ethiopia Regional Learning Centre, Debrezeit Road, Addis Ababa, Ethiopia

Corresponding Author:
Abera Gayesa Tirfi
College of Agriculture and Environmental Sciences, University of South Africa (UNISA), Ethiopia Regional Learning Centre, Debrezeit Road, Addis Ababa, Ethiopia

Sorghum yield response to climate and other input factors in Ethiopia

Abera Gayesa Tirfi

Abstract
The objective of the study was to examine the trend and variability of climatic and yield parameters and determine impacts of weather factors influencing sorghum yield in Ethiopia. Cobb-Douglas production model, linear trend, and standardized anomalies were employed as analytical tools. Long-season rainfall demonstrated an increasing trend with magnitude of 1.19 mm/year, while short-season rainfall exhibited a decreasing trend with a magnitude of (-0.798 mm/year). Equally, maximum and minimum temperatures depicted significantly increasing trends with magnitude of 0.012 mm/year and 0.035mm/year, respectively. The increase in temperature variables supports the evidence of rising temperature recorded in many parts of the world. The study exemplified presence of moderate inter-seasonal rainfall variability, which encompasses the highest negative anomaly of 1997-98 occurred due to El Nino. The study further exemplified presence of minimal to moderate variability of maximum and minimum temperatures. The anomalies of sorghum yield exhibited variation with a magnitude ranging from +2.36 to -1.76. The high variability of sorghum yield emanates from variations experienced in climatic parameters.
The results further revealed that the elasticity of short-season rainfall had positive and significant relationship with sorghum yield. The positive elasticity implies that short-season rainfall well aligns with the critical water requirement of sorghum for sowing seeds. As sorghum is long-cycle crop, short-season rainfall is critically important for seed-bed preparation for the crop under study. Conversely, long-season rainfall showed negative impact on sorghum yield; the negative impact registered occurred due to scarcity of rainfall during critical crop growth periods which leads to wilting of leaves and stalks; inhibit proper vegetative growth; and shrinks grain filling. This infers that cultivation of sorghum in greatly depends on rainfall. Conversely, the elasticity coefficients of maximum temperature had negative and significant impact on sorghum yield. It can be judged that maximum temperature and long-season rainfall correlates in exerting harsh effect on sorghum yield. Significant increase in maximum temperature correlates with reduction in amount of main-season rainfall, leading to drought and reduction of yield. Contrastingly, crop growing period minimum temperature had positive impact on sorghum yield.

Keywords: sorghum yield, climate change, Cobb-Douglas production model, Ethiopia

Introduction
Globally, sorghum (*Sorghum bicolor* (L.) Moench) is the fourth most important tropical cereal crop next to wheat, rice and maize [1]. Globally, the five to sorghum producing countries 2020/21 include USA (9.47 million tons), Nigeria (6.59 million tons), Ethiopia (5.06 million tons), Sudan (5.15 million tons), and India (4.81 million tons) [2]. Sorghum supplies approximately 70 million tons of grains from 50 million hectares of land in the world [3]. It is a major food crop among 500 million people who lives in the semi-arid tropics of Africa and Asia, where nearly 80% of the world's area under sorghum is confined. Surprisingly, studies indicate that more than 100 million people in Africa use sorghum as main staple food in the world [4]. Principally, the crop is produced and used by resource-poor small-scale producers who predominantly grow the crop under low-rainfall, arid to semi-arid environments as the crop has excellent tolerance to drought, high temperature stresses and low soil fertility.
In Ethiopia, sorghum is primarily grown as major food crop and ranks the third in area coverage next to teff and maize. Ethiopian is considered as the centre of domestication of sorghum because of the greatest genetic diversity in the country for both cultivated and wild forms [5]. It is grown on 1.83 million hectares (14.2%) with a total production of 5.265 million tons comprising (About 15.7% of the total production next to maize, teff and wheat).

The grain of sorghum is consumed as human food, whereas the residue part is utilized as livestock feed. It supplies staple food to about 25.2 million family members per annum [6]. In terms of altitude, sorghum is extensively grown in the tropics with an elevation ranging from 1400 to 2100 meters above sea level (M.A.S.L). It has high adaptive capacity to adverse environmental conditions which made it a popular crop worldwide.

However, the production of sorghum crop in Ethiopia is adversely affected by climate and non-climate variables. Studies indicate that increasing temperature (warming), drought, low soil fertility, insect pests, *Striga* and weeds were recognized as the major factors affecting sorghum production in eastern Africa [7]. In Ethiopia, drought and *Striga* weed were identified as major important constraint hampering the yield and production of sorghum in the northern and north-eastern parts of the country [8]. Other research has cited moisture stress during grain filling as critical constraint in Ethiopia [9].

Among the various restricting factors, climate change is nowadays becoming a global and regional concern that seriously influence sorghum yield and production in developing and least developed countries which predominantly depend on rain-fed agricultural production [10]. The adverse impacts of climate change and variability, in developing and least developed countries like Ethiopia, is recently growing over time and exerts pressure on agricultural production systems which changes the balance among key determinants of sorghum production and yield enhancement. According to the Ethiopian Ministry of Agriculture [11], agriculture is highly vulnerable to climatic extremes and variability, primarily caused by its high dependence on rain-fed systems. Many researchers have explored that climate change initiated disparities had contributed to the occurrence of frequent droughts, flooding and mounting mean atmospheric temperatures which in return critically affected production of crops over huge areas of the country [12]. In Ethiopia, climate change derived drought is the major factor limiting the yield and production of sorghum in drought-prone low land areas of the country. In the lowlands, the traditional farming practice lies on rain-fed crop production system, which is characterized by poor crop production and low yields. The most important factor influencing the productivity of sorghum in the region is the erratic rainfall patterns [13]. However, few studies have been conducted on assessing the sorghum production system and identifying production constraints in the sorghum growing belts of the country. Wortmann, *et al.* [14] identified the major production constraints in major sorghum-growing regions of Ethiopian as high inconsistency of climatic parameters, i.e. irregular rainfall and increasing temperature. Zewdu, *et al.* [15] discovered that temperature and precipitation had negatively affected sorghum production and yield in the north eastern parts of Ethiopia.

However, it is evident that these studies were focused on the north eastern parts of the country and neglected other parts of sorghum growing belts of the country. Therefore, it becomes extremely important to examine climate and non-climatic parameters hampering sorghum yield and production covering the whole sorghum growing belts using nationally pooled data. The main objective of the study was to examine the trend and variability of climatic and yield parameters and determine the impacts of weather (Precipitation and temperature) and non-weather factors influencing sorghum yield in Ethiopia.

Materials and Methods

Description of Study Area

The study has been conducted in sorghum growing belts of Ethiopia at aggregated national level. Ethiopia is located in East African region within 3^0 and 15^0N latitude and 33^0 and 48^0E longitude [16] Assefa, et al., 2020]. The country is bordered with Somalia to the east, Djibouti to the northeast, Kenya to the south, Eritrea to the north, and South Sudan and Sudan to the west. It has a wide range of altitudinal variations with the highest peak at Ras Dejen (4620 m.a.s.l) and the minimum 126 meters below seas level in the Afar depression [17; 18].

The topography of the country is highly diverse; more than 45% being dominated by high plateau with a chain of mountain ranges that are divided by the East African Rift Valley [19]. The country is both mountainous and highland (with elevation greater than 1500 m) and lowland (with elevation less than 1500 m). The topography composes some nine major river basins, the drainage systems of which originate from the centrally situated highlands and make their way down to the peripheral or outlying lowlands.

Climatically, the country enjoys varied climate conditions depending on elevation that ranges from hot and arid climates in the lowlands to cool climates in the highlands. The country has three seasons; the *bega* season from October to January, the short/belg rainy season from February to May, and the long /*kiremt*) rainy season from June to September [20]. The possession of such a wide elevation gradient and rainfall seasons allows the country suitable for growing different types of crops [18]. Sorghum crop is among the crops grown under varied climatic and topographic as well as under adverse conditions such as low input use and marginal lands. According to Demeke, *et al.* [21], sorghum is well adapted to a wide range of precipitation and temperature levels and is produced from sea level to above 2000 M.A.S.L. Its drought tolerance and adaptation attributes have made the crop the favorite crop in drier and marginal areas.

The main sorghum producing regions in Ethiopia are Oromia and Amhara, which account for nearly 76 percent of the total production. The leading sorghum producing zones are East and West Hararge in Oromiya and North Gondar, North Shew and North Wolli in Amhara. Two regions, SNNPR and Tigray, are relatively less important, contributing 15.5 and 3.6 percent of the national production, respectively [22]. See Table 1 and Figure 1 for details. In Africa, Ethiopia is the second largest producer of sorghum, next to Sudan.

Table 1: Sorghum Area, Production and Yield by Regions (2020/21)

Region	Area (hectare)	Production (tons)	Yield (ton/ha)	Share of prod. (%)
Oromia	676,075.00	1,836,612.66	2.72	40.7
Amhara	597,440.83	1,588,192.14	2.66	35.2
Tigray	232,636.49	700,856.08	3.01	15.5
SNNP	62,926.09	161,787.87	2.57	3.6
Others	110,198.65	229,901.47	2.09	5.0
Ethiopia	1,679,277.06	4,517,350.22	2.69	100

Source: Author's calculation based on CSA 2020/21 data

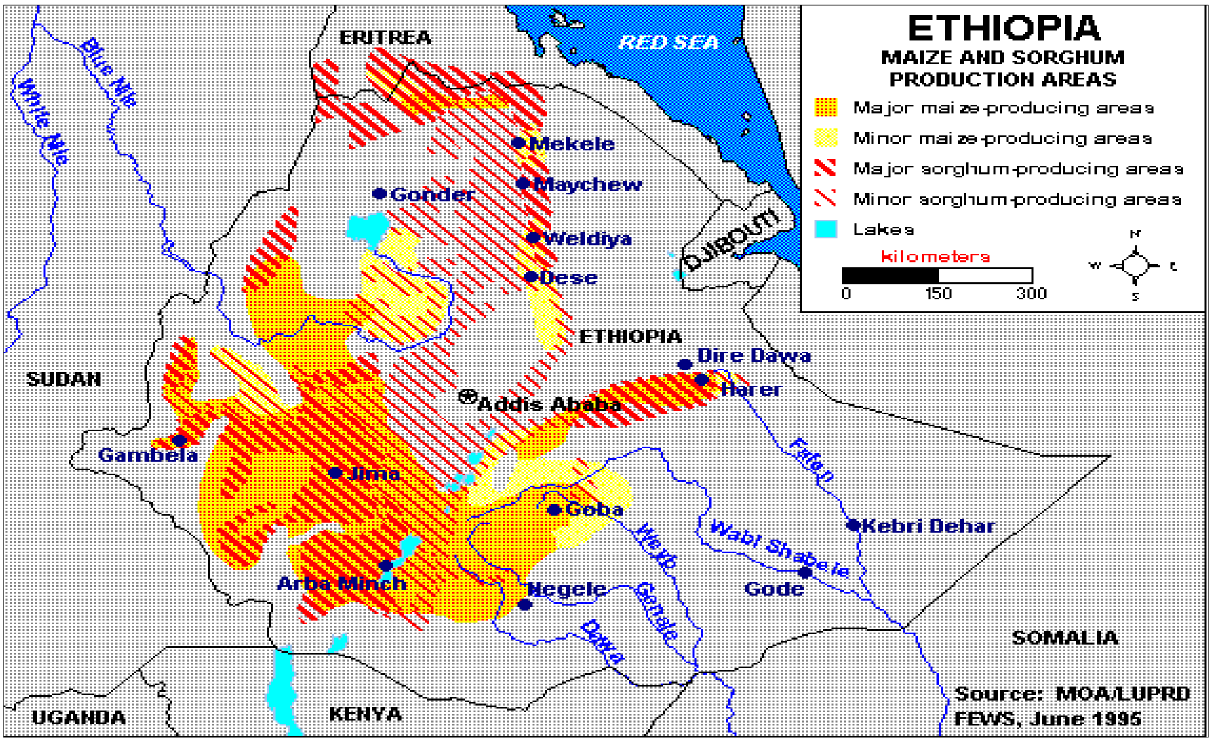


Fig 1: Major sorghum producing areas of Ethiopia

Data Type and Source

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

Data on weather conditions (*temperature and precipitation*) for the period covering 1981 to 2020 (40 years) were purchased and taken from the National Meteorological Agency (NMA) of Ethiopia. Data for 12 representative weather stations based in major *sorghum growing belts* were selected from Oromia and Amhara Regional States, as the two regions accounted for (14.2%) the total cultivated area and 15.7% of total production of sorghum during 2019/20 production year [6]. For *precipitation*, average monthly data for *Short/belg-Season* (F-M) and *Long/Meher-Season/*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 sorghum crop data, nationally aggregated data on yield per hectare, area cultivated, area irrigated under sorghum, and fertilizer applied were compiled from CSA subsequent publications or website covering the period from 1981 to 2020. Any gap in these variables was complemented from Food and Agriculture Organization (FAOSTAT) database.

Empirical Model Specification

In this study, Cobb-Douglas production function model was employed to measure the impact of climate and non-climate variables influencing the yield of sorghum. Many researchers used the production function approach since the model allows measure the impact of climatic variables on the productivity of cereal crops by considering the interaction effect [23]. Most researchers have established that the production function model is more representative and adaptable to research questions related impact of climatic parameters on crop yields. They reported that production function approach attempts to explain the variation in crop yields employing the variation in climatic variables.

The functional form of Cobb-Douglas Production model for estimating climate and non-climate variables influencing sorghum yield can be specified as follows:

$$SoYi_t = f\,(RF, Temp, SoAr, IrrgAr, SoFert) \qquad (1)$$

Where, SoYi represents sorghum yield at time t, RF represents crop growing period rainfall at time t, Temp is mean temperature over crop growing period, SoAr represents area cultivated under sorghum at time t, IrrgAr represents irrigated area under sorghum at time t, and SoFert is fertilizer quantity applied on sorghum production.

In Ethiopia, the rainy season is divided into two; viz. *short/ belg-season* and *long/ main-season* rainfalls. *Short/ belg-season* rain covers the period from February to May (F-M), during which sorghum seed is sown, and *long/ main-season* rain is from June to September (J-S) the period when crop vegetative growth, grain filling and maturity takes place. For this study, rainfalls of both *short-* and *long-seasons* were selected and included in the model. Equally, crop growing period mean temperature (minimum and maximum) and average maximum temperature covering the period from February to September (F-S) were selected for the analysis. Then, the functional model was rewritten as:

$$SoYi_t = f\,(SoAr, IrrgAr, SoFert, SSRF, LSRF, MaxTemp, MeanTemp) \qquad (2)$$

Where, SoYi represents sorghum yield at time t, SoAr represents area harvested under sorghum, SoFert presents fertilizer applied, SSRF shows *short-season* rainfall, LSRF represents *long-season* rainfall, MaxTemp is maximum temperature during crop growing period, and MeanTemp is crop growing period mean temperature.

The Cobb-Douglas production function, in its stochastic form [24], can be specified as:

$$SoYi_t = AX_1^{\beta 1}X_2^{\beta 2}\ldots X_n^{\beta n}\ e^{\varepsilon} \quad (3)$$

Where, *SoYi* is sorghum yield, X_s' are independent explanatory variables included in the model, β_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 (OLS) by taking natural log on both sides of equation (3), which becomes log-linear form. Estimates of this form of production function give direct elasticities of variables and can be expressed as:

$$\ln SoYi_t = \beta + \beta i \sum_{i=1}^{n} \ln X_i + \varepsilon i \quad (4)$$

Where $lnSoY_t$ shows sorghum yield (quintal per hectare) at time t, X_i is farm inputs variables including cropped land area, irrigated area, fertilizer, etc. Based on previous crop yield response studies in Africa and other continents, the Cobb-Douglas functional model assumes the following form:

$$\ln SoYi_t = \alpha + \beta_1 \ln SoAr_t + \beta_2 \ln IrrgAr_t + \beta_3 \ln SoFert_t + \beta_4 \ln SSRF_t + \beta_5 \ln LSRF_t + \beta_6 \ln MaxTemp_t + \beta_7 \ln MeanTemp_t + \varepsilon_t \quad (5)$$

Where: $\ln SoYi_t$ is the natural log of yield of sorghum (quintal per hectare), $\ln SoAr_t$ is natural log of cropped land area under sorghum, SoFert*t* is fertilizer applied, $\ln SSRF_t$ is natural log of *short/Belg-season* rainfall, $\ln LSRF_t$ is natural log of *long/Meher-season* rainfall, $\ln MaxTemp_t$ is natural log of crop growing period maximum temperature, and $\ln MeanTemp_t$ is natural log of crop growing period mean temperature, t = time period from 1981 – 2020, α_0, β_1, β_2, β_3, β_4, β_5, β_6, and β_7 are unknown parameters to be estimated, and ε_t is the error term.

To estimate the Cobb-Douglas production model specified by equation 5, MedCal- Version 19.1 software and SPSS 24 Statistical packages were used.

In order to examine the trend and variability of selected climatic and sorghum yield parameters, linear trend line and standardized year to year anomalies of the variables were employed. To investigate the trends prevailed in rainfall (long-season rainfall) and temperature (maximum), the following linear trend lines have been fitted for crop growing seasonal scenarios:-

$$LSR_t = \alpha + bR_t \text{ for long-season rainfall, and} \quad (6)$$

$$MaxT_t = \alpha + bT_t \text{ for Maximum temperature} \quad (7)$$

Where, LSR_t presents long-season rainfall at time *t*, $MaxT_t$ presents maximum temperature at time *t*, R_t is long/main-season rainfall of a particular year *t*, T_t is crop growing period mean maximum temperature at year *t*, and α & *b* are parameters to be estimated.

Subsequently, the long term standardized anomaly of long-season rainfall (ΔR_t) for a pool of locations over a period *t* is given by:-

$$\Delta R_t = \frac{Rt - \bar{R}t}{\sigma} \quad (8)$$

Where, ΔR_t is standardized long-season rainfall anomaly, R_t is long/main-season rainfall of a particular year *t*, $\bar{R}_t$ is the long-term mean over a period of observation, and σ is the standard deviation of long-season rainfall over the period of observation. Similarly, the long-term standardized anomaly of temperature (ΔT_t) for a given pool of locations over a period *t* is given by:

$$\Delta T_t = \frac{Tt - \bar{T}t}{\sigma} \quad (9)$$

Where, ΔT_t is standardized maximum temperature anomaly for period *t*, T_t is crop growing period maximum temperature of a particular year *t*, $\bar{T}_t$ is crop growing period maximum temperature over a period of observation, and σ is the standard deviation of crop growing period mean temperature over a period of observation.

Subsequently, the inter-seasonal variability of national level aggregated long-season rainfall and crop growing period maximum temperature variables were assessed using coefficient of variation (CV), which can be expressed as:

$$CV_{R,T} = 100 \times \frac{\sigma}{\bar{R},\bar{T}} \quad (10)$$

Where, $CV_{R,T}$ represents the CV of long-season rainfall/CGP maximum temperature variables, σ is the standard deviation of long-season rainfall or CGP maximum Temperature data series, and $\bar{R},\bar{T}$ are mean of long-term rainfall and maximum temperature variables, respectively.

Method of Estimation

In order to analyze the yield response of crops, several approaches have so far been documented in literature, including simple Ordinary Least Squares (OLS) estimation of multiple regression, Nerlovian adjustment cum adaptive expectation model, and cointegration analysis [41]. In this study, ordinary least squares method (OLS) has been used to estimate sorghum yield response to explanatory variables. The models have been estimated consistently by Ordinary Least Squares 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.

Since the study uses time series data for the period between 1981 and 2020, the data series will be subjected to various tests to confirm various properties required for OLS to give results that are efficient and consistent. In this regard, the series must be tested for satationarity/ *unit root* and related tests using appropriate methods and tools. In this study, two widely used methods were chosen: Augmented Dickey-Fuller (ADF) test [26] and Phillips-Perron (PP) test [27] to check the presence of unit roots in the data series. The ADF test for stationarity in a series y involved estimating the equation:

$$\Delta y_t = \mu + \beta_t + \gamma\, y_{t-i} + \sum_{i=1}^{p} \emptyset_i \Delta y_{t-i} + \varepsilon_t \quad (6)$$

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: $\gamma = 0$ (unit root) was tested against the alternative hypothesis H_A: $\gamma < 0$ (no unit root). If the computed test statistic was found greater than the critical value then the null hypothesis was not rejected. If H_0 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) [24; 15].

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

$$\Delta Y_t = \theta_0 + \sum_{i=1}^{m} \delta_i \Delta Y_{t-i} + \varepsilon t \quad (7)$$

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_0 could not be rejected, then the time series variable contained a unit root and hence non stationary, otherwise it was stationary.

Results

Unit Root Test

The time series data used in this study was subjected to various tests including unit root tests and multicollinearity tests. Augmented Dickey Fuller (ADF) and Phillips Perron (PP) tests were used to test the presence of unit root in the data series. In the ADF and PP tests for presence of unit root in time series, the null hypothesis for unit root is rejected when the test statistic is greater than the critical value at desired level of significance otherwise the null hypothesis is not rejected.

The ADF and PP unit root test results are presented in Table 2. The estimated outcome of both ADF and PP tests reflected that the following variables are stationary at level or order I(0): LnSOYi, LnSOAr, LnSOFert, LnLSRF, LnMaxTemp, and LnMeanTemp. Conversely, the following variables were found to be integrated of order I(1): LnIrrgAr and LnSSRF. Thus, the variables used in the 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 [28, 29].

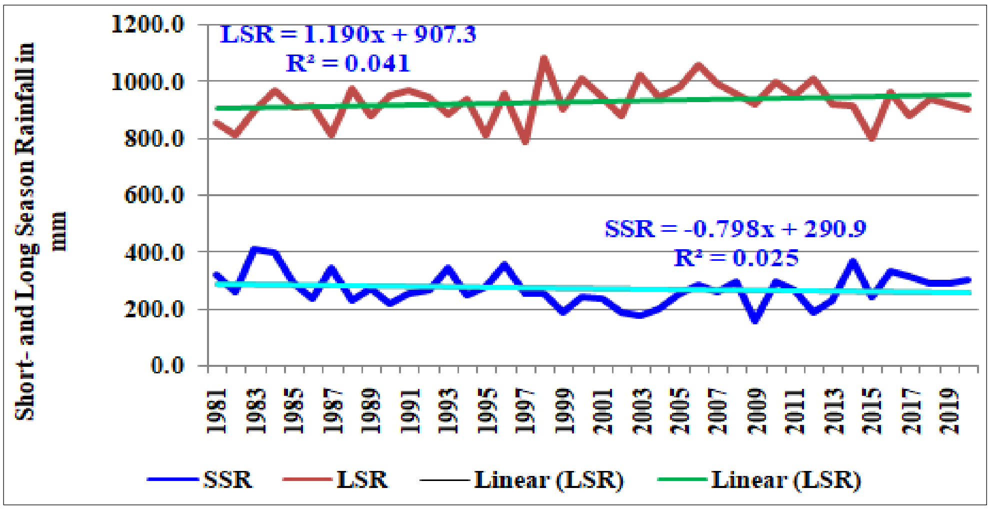
Table 2: Result of unit root tests

Variables	ADF				PP				Result
	Level		First Diff		Level		First Diff		
	Computed t-Statistic	Critical value	Computed t-Statistic	Critical value	Computed t-Statistic	Critical value	Computed t-Statistic	Critical value	
LNSOYI	-2.9288***	-4.2191	-1.6965***	-4.29673	-3.3232**	-3.52976	-17.6996	-3.1983	I(0)
LNSOAR	-3.1182***	-4.2268	-6.2878	-4.21913	-2.76721***	-4.21186	-6.3782	-3.1983	I(0)
LNIRRGAR	-4.23422	-3.1964	3.3948***	-4.23497	-4.23438	-3.19641	-12.3707	-3.1983	I(1)
LNSOFERT	-3.8975***	-4.21187	-6.69167	-3.20032	-4.0053***	-4.21187	-8.94132	-3.19831	I(0)
LNSSRF	-4.90405	-3.19641	2.37486***	-4.22681	-4.97284	-3.19641	-20.2479	-3.19831	I(1)
LNLSRF	-3.2749***	-4.21913	-15.78329	-3.19831	-6.98045	-3.19641	-40.7894	-3.19831	I(0)
LNMAXTEMP	-3.3072***	-4.21187	-6.44629	-3.19831	-3.38298***	-4.21187	-7.08521	-3.19831	I(0)
LNMEANTEMP	-4.0228***	-4.21187	-7.19927	-3.19831	-4.0228***	-4.21187	-7.53553	-3.19831	I(0)

** & *** indicates significance level of 5% and 1% respectively

Trend of Climatic Parameters in Sorghum Growing Areas

In this study, a linear trend line has been fitted to *long/main-seasons' rainfall* and *crop growing period mean maximum temperature* data series to identify the extent and direction of changes in both variables in sorghum growing areas. Figure 2 presents the trend of *long-season rainfall* (LSR) and *crop growing period mean maximum temperature* (CGPMaxT) in sorghum growing areas. As can be seen from the figure, long/main-season rainfall demonstrated an increasing trend over the observation period of 1981 to 2020. The rate of increase was 1.19mm/year, although statistically insignificant. Conversely, the *short-season rainfall* exhibited a decreasing trend over the observation period with a magnitude of (-0.798mm/year), though found non-significant (see table 2).



Source: Author's Construction using raw data from NMA.

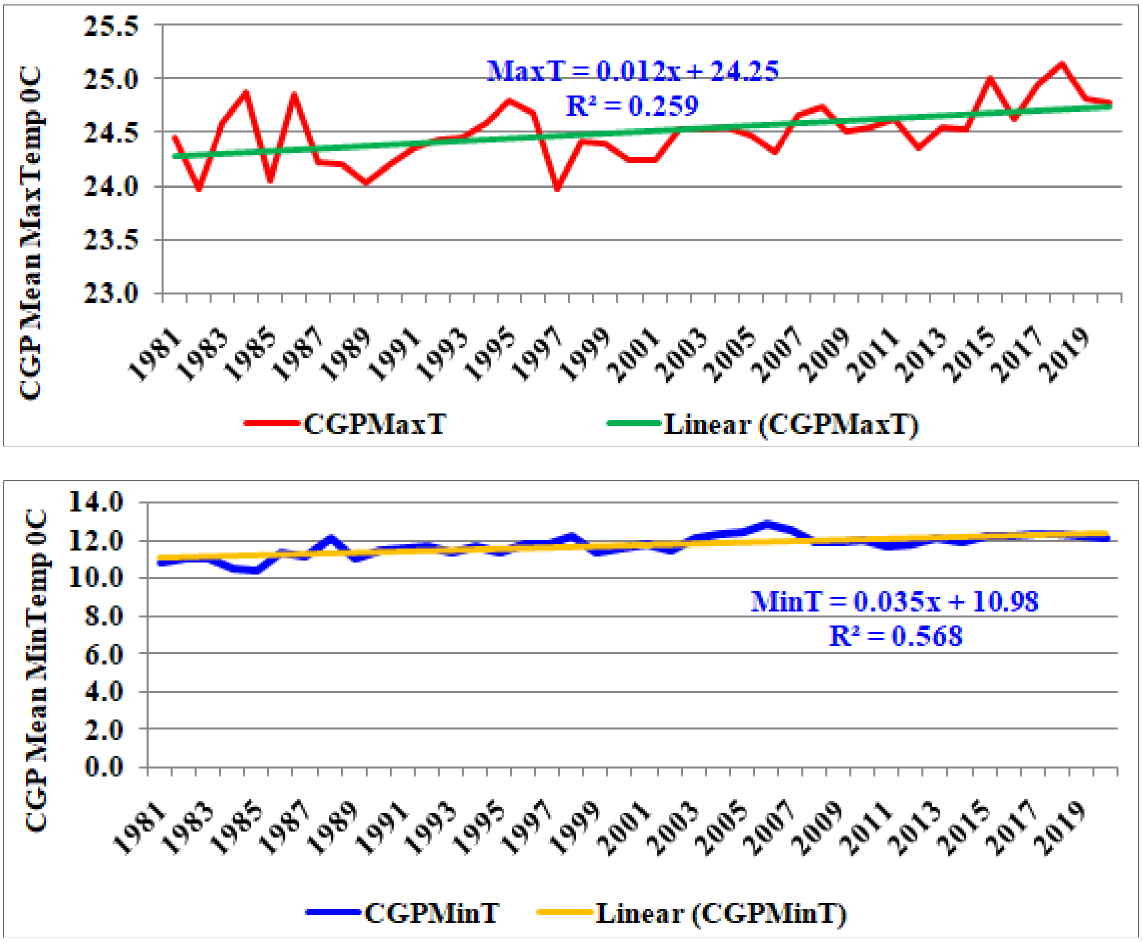
Fig 2: Trend of short- and long/main-season rainfall in sorghum growing areas

Table 3: Linear trend determinant of climatic variables in sorghum growing areas of Ethiopia (1981–2020)

Variables	β (slope)	St. error	t-Stat	Adjusted R^2	PIF
LSRF	1.191	0.926	1.285	0.016	0.206
SSRF	-0.798	0.808	-0.988	-0.001	0.329
MaxTemp	0.012***	0.003	3.553	0.230	0.001
MinTemp	0.035***	0.005	7.089	0.558	0.000

Source: Author's computation using raw data from NMA

Subsequently, the linear trend line fitted to crop growing period temperature variables exhibited an increasing trend over the observation period in sorghum growing areas (see Figure 3 below). Accordingly, crop growing period maximum and minimum temperatures showed an increasing trend with a magnitude of 0.012 mm/year and 0.035mm/year, respectively. The rates of increases for both maximum and minimum temperatures were significant at 1% levels (see Table 3 above). This increase in the temperature variables can be interpreted as evidence of a rising temperature being experienced in many parts of the world.



Source: Author's Construction using raw data from NMA

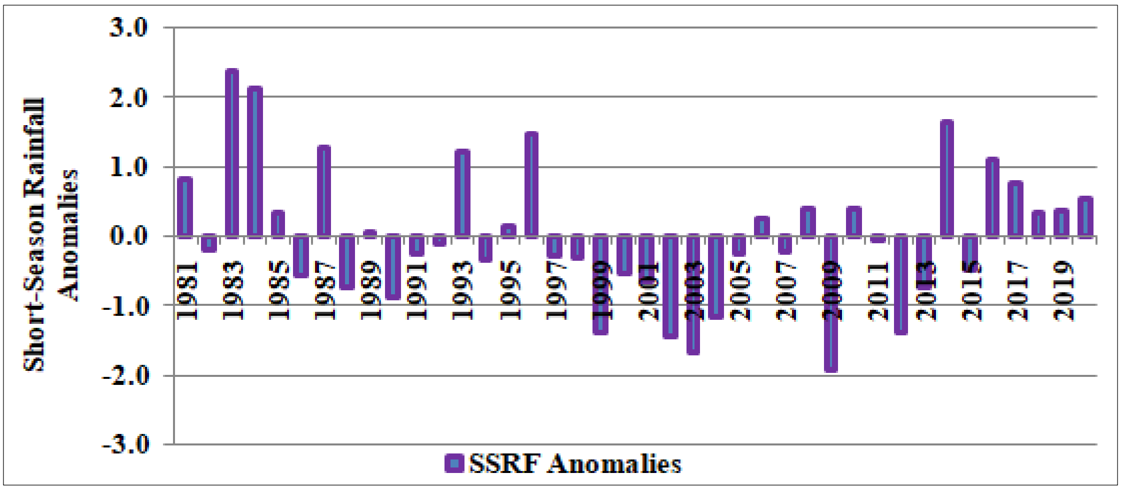
Fig 3: Trend of CGP Maximum and Minimum Temperatures in sorghum growing areas

Variability of Climatic Parameters in Sorghum Growing Areas

The variability of climatic parameters in sorghum growing areas has been assessed using year to year standardized anomalies and coefficient of variations (CV). Figure 4 presents the year to year anomalies of short-season rainfall (SSRF) and long-season rainfall (LSRF) variables in sorghum growing areas. The standardized anomalies for short-season rainfall revealed both positive (45%) and negative (55%) values over the observation period, exemplifying the presence of high inter-annual SSRF variability across the observed time series.

The highest positive anomaly (+2.4) was observed in the year 1983 and the highest negative anomaly (-1.9) was observed in the year 2009. Equally, the standardized anomalies for long-season rainfall exhibited positive (55%) and negative (45%) values over the observation period from 1981 to 2020. The highest positive value (2.2) was observed in 1998 and the highest negative value (-2.1) in the year 1997. It has been observed that the variation in short-season rainfall is more pronounced than that of long-season rainfall.

In similar manner, the variability in temperature variable in sorghum growing areas has been evaluated using year to year standardized anomalies and coefficient of variation (CV). Figure 5 presents the year to year standardized anomalies for mean maximum and minimum temperature variables. The result demonstrated positive (55%) and negative (45%) anomalies for CGP mean maximum temperature over the observation period. Equally, the result revealed both positive (52.5%) and negative (47.5%) anomalies for mean minimum temperature. A positive anomaly indicates that the observed temperature was warmer than the reference value, while a negative anomaly indicates that the observed temperature was cooler than the reference value.



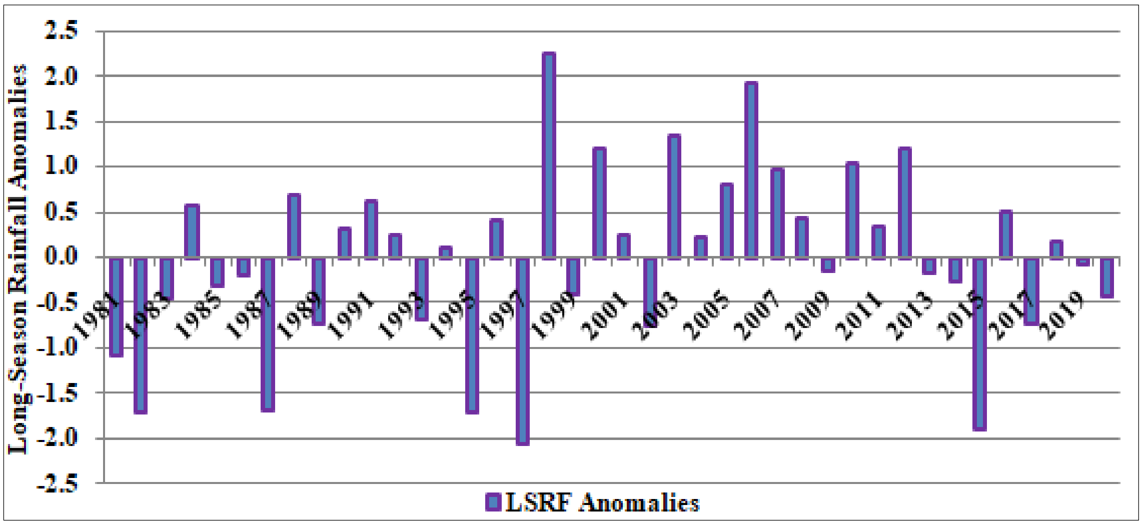
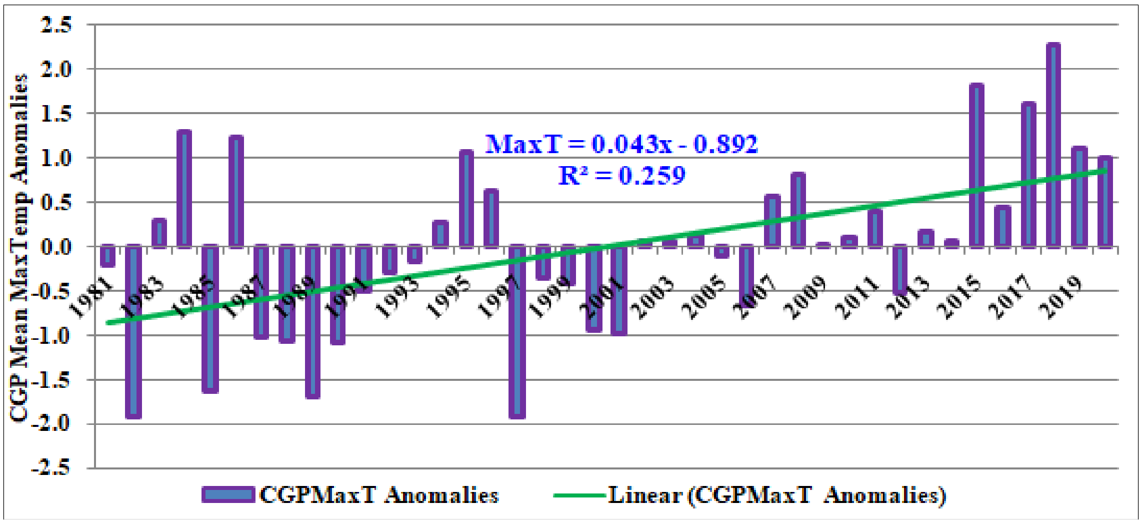


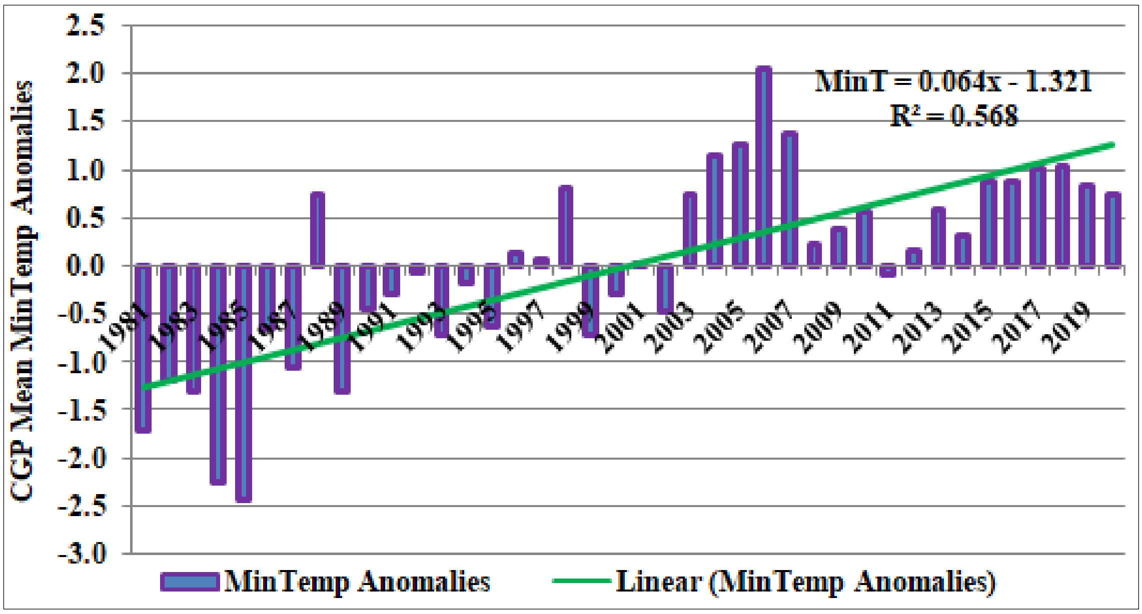
Fig 4: Year to year anomalies of SSRF and LSRF variables in sorghum growing areas

Table 4: Coefficient of Variation (CV) for seasonal climatic parameters in Sorghum Growing Areas

Climatic Parameter	Mean	St. Deviation	CV (%)
Short-season Rainfall	274.6	58.9	21.5
Long-season Rainfall	931.7	68.2	7.3
CGP Minimum Temperature	11.7	0.54	4.6
CGP Maximum Temperature	24.5	0.28	1.1

Source: Computed using data from NMA, 2022





Source: Constructed using raw data from NMA, 2022.

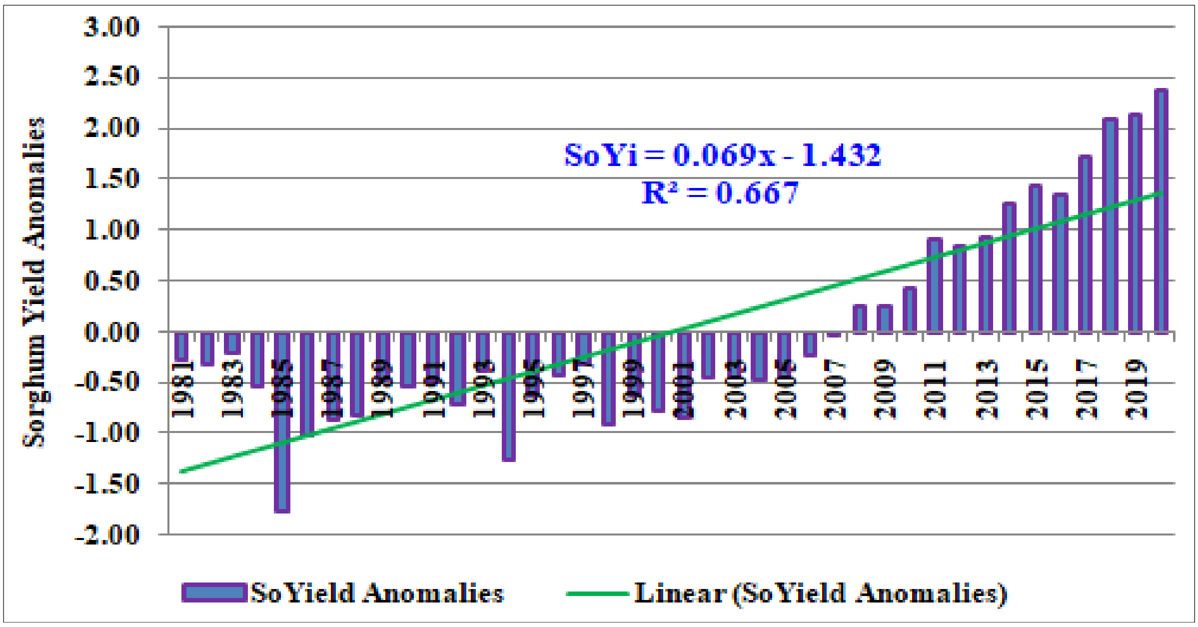
Fig 5: Year to year anomalies for Max Temp and Min Temp in sorghum growing areas

Variability of Sorghum Yield

In order to measure the degree of variability in sorghum yield, the study used crop yield anomalies as analytical tool. Figure 6 presents year to year yield anomalies of sorghum crop. The year to year sorghum yield anomalies depicted negative values (67.5%) from 1981 to 2007 and positive values (32.5%) from 2008 to 2020. The positive values represent a positive effect on yield anomalies while the negative values indicate negative effect on yield anomalies. In other words, a positive yield anomaly shows that data is above the mean value (long-term mean), while negative yield anomaly signifies negative impact of the climate or weather and vice versa. It can be observed from the figure that sorghum crop showed moderate yield variability (negative value) over the period from 1981 to 2007 and positive and increasing yield anomalies over the period from 2008 to 2020. In general, the anomalies of sorghum yield in sorghum growing areas varied with a magnitude ranging from +2.36 to -1.76.

Modeling Response of Sorghum Yield to Climate and other Input Factors

Prior to running the Cobb Douglas production function model, the time series data were further tested for serial correlation and multicollinearity. The tests exhibited existence of no serial correlation in the regression models since the Durbin Watson statistic was 1.02. The test indicates that there is no effect of multicollinearity as the values of VIF are less than 10 for sorghum crop yield model.



Source: Computed using time series data obtained from CSA.

Fig 6: Year to year yield anomalies of sorghum crop

Subsequent to the diagnostic tests explained above, the Cobb-Douglas production functional model was estimated. The parameters of the sorghum yield model were estimated using ordinary least square method. The estimated coefficients of the Cobb-Douglas functional model was significant as the F-value (11.898) indicated that the overall regression model was fitted good and followed normal distribution for the present data series. The D'Agostino-Pearson test for normal distribution proposed to accept normality at (P=0.1764). Furthermore, the adjusted R^2 was 0.662 indicating that 66.2% of the variation in the model has been explained by the variables included in the model, which implies good fitness of the estimated model.

The explanatory variables included in the model were in their logarithmic form in order to provide convenient economic interpretations (elasticities) and to reduce heterogeneity of the variance. In the estimation of Cobb-Douglas production function, *short/belg-season* rainfall, *long/main*-season rainfall, crop growing period mean maximum temperature (Feb-Sept) were included. Equally, the non-climatic variables such as land area harvested and irrigated area under sorghum cropping system, and quantity of fertilizer used for sorghum production were incorporated in the yield model.

The elasticity estimates of variables included in the model adopted for sorghum yield analysis are presented in Table 5. The estimated elasticity coefficients for sorghum yield model exhibited that climatic variables included in the model had mixed relationship with sorghum yield. The *short/belg-season rainfall* showed positive and significant relationship with sorghum yield. The result implies that a 1% increase in *short/ belg*-season rainfall mounts sorghum yield by 0.53%. The positive elasticity of *short-season/ belg* rainfall well aligns with the critical water requirement of sorghum crop for sowing seeds. As long-cycle crop, *short/belg-season* rainfall is also crucially important for seed-bed preparation for the sorghum crop.

Conversely, *long/main-season* rainfall showed negative impact on yield of sorghum, although the result is statistically non-significant. The negative impact registered on yield of sorghum during *main/meher-season* can be due to scarcity of rainfall during critical crop growth periods which leads to wilting of the leaves and stalk of the crop; inhibit proper vegetative growth of the crop; and shrinks grain filling. This infers that cultivation of sorghum in Ethiopia greatly depends on rainfall. Equally, the estimated elasticity coefficients demonstrated that crop growing period mean maximum temperature had negative and highly significant impact on sorghum yield. The result indicated that a 1% increase in maximum temperature would decrease sorghum yield by 2.4%. From the result, it can be judged that maximum temperature and *long/main-season* rainfall correlates in exerting harsh effect on yield of sorghum. Significant increase in maximum temperature correlates with reduction in amount of *main-season rainfall* which probably leads to drought and reduction of sorghum yield.

On the contrary, the study exhibited that crop growing period mean temperature (average of minimum and maximum) had positive impact on the yield of sorghum crop. The result indicates that a 1% increase in mean temperature over crop growing period mounts sorghum yield by 2.4%. Similarly, elasticity coefficients were estimated for non-climatic variables included in the sorghum crop model. Accordingly, area cultivated under sorghum, irrigated area under sorghum cultivation, and fertilizer quantity used over the observation period showed positive impact on sorghum yield. Fertilizer quantity used on sorghum production had positive and significant impact on sorghum yield. The result indicates that a 1% increase quantity of fertilizer used will lead to an increase of sorghum yield by 0.1%. The result implies that sorghum yield is highly responsive to use of fertilizers.

Table 5: Estimates of Cobb-Douglas Production Function from sorghum yield model

Independent variables	Coefficient	Std. Error	t-Statistics	P-Value	VIF
(Constant)	7.4445				
LnSOAr	0.1952	0.1558	1.252	0.2195	4.759
LnSOIrrgAr	0.1262	0.08048	1.568	0.1267	1.905
LnSOFert	0.09998**	0.04395	2.275	0.0297	2.832
LnSSRF	0.5257***	0.1605	3.275	0.0025	1.388
LnLSRF	-0.6215	0.4801	-1.295	0.2048	1.445
LnMaxTemp	-2.4131***	0.8946	-2.698	0.0111	2.105
MeanTemp	2.4129	2.2395	1.077	0.2894	2.801
Sample size					40
Coefficient of determination R^2					0.7224
R^2-adjusted					0.662
Multiple correlation coefficient					0.8500
Residual standard deviation					0.1860
F-ratio					11.898
Durbin-Watson					1.021
D'Agostino-Pearson test for Normal distribution	accept Normality (P=0.1764)				

Source: Author's Computation.

** & *** indicates significance level at 5% and 1% respectively

Discussion and comparison with other study results

The study presents the analysis of the variability and trends of seasonal and crop growing period climatic and non-climatic factors in sorghum growing areas of Ethiopia. The findings have broad implications for socioeconomic development and the environment, such as substantial impacts on agricultural production and food security. The analyses of trends and variability in climatic and sorghum yield parameters as well as their impacts on yield of sorghum have been briefly discussed in the following sub-sections.

Trend of Climatic Variables

In this study, long/main-season rainfall demonstrated an increasing trend over the observation period from 1981 to 2020, with magnitude of 1.19mm/year, while the *short-*

season rainfall exhibited a decreasing trend with a magnitude of (-0.798mm/year), though both are non-significant (see table 2). The study result corroborate with the findings of Omoyo [30] who in his study in Kenya explored positive long-rain season (M – J) and annual rainfalls in most of the weather stations analyzed, although statistically non-significant. He also reported negative and declining short-rain season rainfall (O – J) in Mutomo and Mwingi stations. Equally, Panda and Sahu [31] conducted trend analysis of seasonal rainfall in India and reported an increasing trend of seasonal rainfall in the studied region, where the linear regression equation possessed positive slope value (a = 4.104).

Subsequently, crop growing period maximum and minimum temperatures showed a a significant increasing trend with a magnitude of 0.012 mm/year and 0.035mm/year, respectively. The increase in temperature variables can be interpreted as evidence of rising temperature currently being recorded in many parts of the world. The study results on trend of temperature are similar to other researchers such as Hudo [32], who in his study in Sudan has found a positive and significant increasing trend for maximum and minimum temperatures.

Variability of Climatic Variables

The standardized anomalies for *short-season* and *long-season* rainfalls revealed both positive and negative values over the observation period, exemplifying the presence of moderate inter-seasonal rainfall variability across the observed time series. The study result coincides with the highest negative anomaly of 1997-98, which was experienced due to the occurrence of the El Niño that affected the main livelihood of the rural people in different parts of Ethiopia [33]. Subsequently, the CV (21.5%) confirms moderate variability in the *short-season* rainfall. According to literature, CV is used to classify the degree of variability as less (CV < 20%), moderate (20 < CV < 30%), high (CV > 30%), very high (CV > 40%) and CV > 70% indicate extremely high inter-annual variability of rainfall. The study results corroborate with the findings of other researcher like Panda and Sahu [31] who in their study in India found that the amount of rainfall in the study region is extremely variable.

Furthermore, the variability in CGP mean maximum and minimum temperature variables in sorghum growing areas demonstrated positive and negative anomalies over the observation period. The result exemplifies minimal to moderate variability of the CGP maximum and minimum temperatures in sorghum growing areas, although the CV showed minimal variation.

Variability in Yield of Sorghum Crop

The study revealed high yield variability in sorghum growing areas with negative yield anomalies over the period from 1981 to 2007 and positive and increasing yield anomalies over the period from 2008 to 2020. In general, the anomalies of sorghum yield in the study area varied with a magnitude ranging from +2.36 to -1.76. The results of this study corroborate with the findings of Omoyo *et al.* [34] and Panda and Sahu [31]. Omoyo *et al.* [34] examined some selected climate variables and maize yield variability in eastern Kenya and reported that the distribution of the entire crop yield data set was varying with magnitude from +3 to −3. Thus, the higher the values of maize yield anomaly, the higher the impact of the climate. Panda and Sahu [31] in their study on climate and crop yield variability in three districts of Odisha, India observed negative crop yields in maize and rice due to rainfall deficits.

Impact of Climatic and Non-Climatic Parameters of Yield of Sorghum

The study results on climatic variables demonstrated mixed relationship with the yield of sorghum crop. Accordingly, *short/belg-season rainfall* showed positive and significant relationship with sorghum yield while long/kiremt season rainfall revealed negative impact on yield of sorghum crop although non-significant. The positive elasticity of *short-season/ belg* rainfall well aligns with the critical water requirement of sorghum crop for sowing seeds. As long-cycle crop, *short/belg-season* rainfall is also crucially important for seed-bed preparation for the sorghum crop. This finding is analogous with that of Kouyate [35], who in his study on effects of climate change on sorghum yield in Mali reported that the coefficient for mean precipitation variable for the beginning cropping season is positive and statistically significant at the 5% level. This implies that the increase in precipitation during the beginning of cropping season (June and July) impacts yield of sorghum positively.

The negative impact registered on yield of sorghum during *main/meher-season* can be due to scarcity of rainfall during critical crop growth periods which leads to wilting of the leaves and stalk of the crop; inhibit proper vegetative growth of the crop; and shrinks grain filling. This infers that cultivation of sorghum in Ethiopia greatly depends on presence and adequate distribution of rainfall. The study by Singh and Sharma [36] supports the current study, who in their study of measuring the productivity of food-grain crops in different climate change scenarios in India found that actual rainfall in Rabi season has negatively associated with yield of barley crop. Equally, crop growing period mean maximum temperature revealed negative and highly significant impact on the yield of sorghum crop. The result implies that maximum temperature and *long/main-season* rainfall correlates in exerting harsh effect on yield of sorghum. This means that significant increase in maximum temperature correlates with reduction in amount of *main-season rainfall* which probably leads to drought and reduction of sorghum crop yield. This finding corroborates with Eggen, *et al.* [37] who in their study on sorghum crop sensitiveness to extreme, sub-seasonal weather condition in the Blue Nile Highlands of Ethiopia highlighted that extremes of low main-season rainfall induced by warmer temperature can diverge significantly from sorghum's response to seasonal drought. They further reported that more rainfall is associated with cooler surface temperature and vice versa.

On the contrary, the study exhibited that crop growing period mean temperature (average of minimum and maximum) had positive impact on the yield of sorghum crop,although non-significant. The study findings in this context are similar to that of Kouyate [35], who studied effect of climate variability and climate change on sorghum yield in Mali explored that main-season average temperature had negative and significant (-5.7525**) impact on sorghum yield. The study by Kumar and Sharma [38] revealed that average minimum and maximum temperatures had positive impact on barley yield (related cereal crop), which implies that average minimum and maximum temperatures are beneficial for yield of barley during Rabi season. Contrastingly, Nasrullah, *et al.* [39] studied the impact of climate change on rice yield (related crop) in Korea and reported that temperature is positively related to average rice yield. The elasticity for temperature is calculated as 0.82-0.89; thus a 1% rise in temperature increases the average rice yield by 0.8 – 0.9%.

Non-Climatic Inputs

The elasticity coefficients estimated for non-climatic inputs demonstrated positive relationship with the yield of sorghum crop. However, only fertilizer quantity used on sorghum production had positive and significant impact on sorghum yield. The result implies that sorghum yield is highly responsive to the use of fertilizer inputs. These findings are similar to the study findings of other researchers. Haile, *et al.* [40], in their study of technical efficiency in sorghum production in Southern Ethiopia discovered that chemical fertilizers used in sorghum crop production had positive and significant impact on sorghum production. The result indicates that a 1% increase in land area and fertilizer quantity used would increase sorghum production by 0.19% and 0.075% respectively. Further, Singh and Sharma [36] in their study on the impact of climate change and variation on agricultural productivity in India reported that irrigated area and total fertilizer consumption positively affected barley yield, fertilizer consumed being significant at 1% level. The result indicates that a 1% increase in fertilizer use increases barley yield by 0.12%. Equally, the findings of Kumar and Sharma [38] corroborates with this study findings; who in their study on productivity of food grain in India during Rabi season reported that cropped area and irrigated area under barley crop (related crop) had positive impact on barley yield, the elasticity coefficients being 0.7356 and 0.0569. These coefficients, however, are statistically non-significant.

Conclusions

The main objective of the study was to examine the trend and variability of climatic and yield parameters and determine the impacts of weather and non-weather factors influencing sorghum yield in Ethiopia. Cobb-Douglas production function model, linear trend, and standardized anomalies of variables were employed as tools. The study demonstrated that long/main-season rainfall demonstrated an increasing trend with magnitude of 1.19mm/year, while the *short-season rainfall* exhibited a decreasing trend with a magnitude of (-0.798mm/year). Subsequently, crop growing period maximum and minimum temperatures depicted a significant increasing trend with a magnitude of 0.012 mm/year and 0.035mm/year, respectively. The increase in temperature variables can be interpreted as evidence of rising temperature currently being recorded in many parts of the world.

The study explored that the anomalies for *short-season* and *long-season* rainfalls revealed both positive and negative values, exemplifying the presence of moderate inter-seasonal rainfall variability across the sorghum growing area. The study result coincides with the highest negative anomaly of 1997-98, which was experienced due to the occurrence of the El Niño that affected the main livelihood of the rural people in different parts of Ethiopia. The result also exemplified minimal to moderate variability of the CGP maximum and minimum temperatures in sorghum growing areas.

The study revealed high yield variability in sorghum growing areas with negative yield anomalies over the period from 1981 to 2007 and positive and increasing yield anomalies over the period from 2008 to 2020. In general, the anomalies of sorghum yield in the study area varied with a magnitude ranging from +2.36 to -1.76. The high variability in yield of sorghum crop emanates from the variations experienced in climatic parameters.

The study results of the estimated elasticity coefficients exhibited that climatic variables included in the model had mixed relationship with sorghum yield. Accordingly, *short/belg-season* rainfall showed positive and significant relationship with sorghum yield. The result implies that a 1% increase in *short/belg*-season rainfall mounts sorghum yield by 0.53%. The positive elasticity of *short/belg -season* rainfall well aligns with the critical water requirement of sorghum crop for sowing seeds. As sorghum is long-cycle crop, *short/belg-season* rainfall is also crucially important for seed-bed preparation for the crop. Conversely, *long/main-season* rainfall showed negative impact on yield of sorghum, although statistically insignificant. The negative impact registered on yield of sorghum during *main/meher-season* can be due to scarcity of rainfall during critical crop growth periods which leads to wilting of the leaves and stalk of the crop; inhibit proper vegetative growth of the crop; and shrinks grain filling. This infers that cultivation of sorghum in Ethiopia greatly depends on rainfall.

Conversely, the elasticity coefficients estimated for sorghum yield model demonstrated that crop growing period mean maximum temperature had negative and highly significant impact on sorghum yield. The result indicates that a 1% increase in mean maximum temperature would decrease sorghum yield by 2.4%. From the result, it can be judged that maximum temperature and *long/main-season* rainfall correlates in exerting harsh effect on sorghum yield. Significant increase in maximum temperature correlates with reduction in amount of *main-season* rainfall which probably leads to drought and reduction of sorghum yield. On the contrary, crop growing period mean temperature (average of minimum and maximum) had positive impact on sorghum yield, although statistically insignificant. The result indicates that a 1% increase in mean temperature over crop growing period mounts sorghum yield by 2.4%. Similarly, elasticity coefficients estimated for non-climatic variables indicate that area allocated under sorghum, irrigated area under sorghum cultivation, and fertilizer quantity used over the observation period had positive impact on sorghum yield. Fertilizer quantity used on sorghum production had positive and significant impact on sorghum yield. The result indicates that a 1% increase quantity of fertilizer used will lead to an increase of sorghum yield by 0.1%. The result implies that sorghum yield is highly responsive to use of fertilizers.

Acknowledgement

The author is grateful to the different Institutions that provided the various dataset used in this study.

Data Availability

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.

Funding

This work was fully covered by the author; no external funding supported the research work.

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.

Declaration of Competing Interest

The author declares that there have been no competing interests.

References

1. Faostat. Database of agricultural production, Rome: Food and Agriculture Organization of the United Nations; c2013. Available at http://faostat.fao.org/default.aspx
2. USDA (United States Department of Agriculture), World Agricultural Production, Circular Series WAP, 2022, 11-22. https://apps.fas.usda.gov/psdonline/circulars/production.pdf
3. Mojapelo MC, *et al.* Estimation of sorghum supply elasticity in South Africa; Journal of Agribusiness and Rural Development. 2019;2(52):131-138.
4. Alemu G, Haji J. Economic Efficiency of Sorghum Production for Smallholder Farmers in Eastern Ethiopia: The Case of Habro District; Journal of Economics and Sustainable Development. 2016;7(15):44-51.
5. Demeke M, Di Marcantonio F. Analysis of incentives and disincentives for sorghum in Ethiopia, Technical notes series, MAFAP, FAO, Rome; c2013.
6. CSA. Report on area and production of major crops, Statistical Bulletin 587, Addis Ababa, Ethiopia; c2020.
7. Amelework BA, Shimelis HA, Tongoona P, Mengistu F, Laing MD, Ayele DG. Sorghum production systems and constraints, and coping strategies under drought prone-agro-ecologies of Ethiopia, South African Journal of Plant and Soil. 2016;33(3):207-217.
8. Gebretsadik R, *et al*. A diagnostic appraisal of the sorghum farming system and breeding priorities in *Striga* infested agro-ecologies of Ethiopia. Agricultural Systems. 2014;123:54–61.
9. Simane B, Wortmann CWS, Hoogenboom G. Haricot bean agro-ecology in Ethiopia: definition using agro-climatic and crop growth simulation models. African Crop Science Journal. 1998;6:9-18.
10. FAO. Regional overview of food insecurity: African food insecurity prospects brighter than ever. Accra, FAO; c2015. available at http://www.fao.org.
11. MoA (Ministry of Agriculture). Agriculture Sector Programme of Plan on Adaptation to Climate Change. Ministry of Agriculture, Addis Ababa, Ethiopia; c2011.
12. Aragie EA. Climate Change, Growth and Poverty in Ethiopia, Working Paper No. 3, The Roberts S. Strauss Centre for international security and law; c2013.
13. Tadesse G, Tesfahun G. Farming system of Wollo, northeast Ethiopia: farmers circumstances, practices and problems, Progress Report, Welya: Sirinka Agricultural Research Center; c2001.
14. Wortmann CS, *et al.* Atlas of sorghum (*Sorghum bicolor* (L.) Moench) production in eastern and southern Africa. Lincoln, NE: University of Nebraska-Lincoln; c2006.
15. Zewdu E, Hadgu G, Nigatu L. Impacts of climate change on sorghum production in North Eastern Ethiopia, African Journal of Environmental Science and Technology. 2020;14(2):49-63.
16. Assefa M, Cao M, He Y, Mekonnen E, Song X, Yang J. Ethiopian vegetation types, climate and topography; Plant Diversity. 2020;42(4):302-311.
17. Tesfahunegny W. A catalogue for endemic birds of Ethiopia: Journal of Zool. Studies. 2016;3(4):109-133.
18. Banda LB, Tassie N. Modeling the distribution of four-bird species under climate change in Ethiopia; Ethiopian Journal of Biological Sciences. 2018;17(1):1-17. https://www.britannica.com.
19. Enyew BD, Steeneveld GJ. Analysing the Impact of Topography on Precipitation and Flooding on the Ethiopian Highlands; Journal of Geology & Geosciences. 2014;3(2):17. Doi:10.4172/2329-6755.1000173.
20. Meheretu A. Ethiopia: People, flag, religion, population, and facts; Britannica; c2020.
21. Demeke M, Di Marcantonio F. Analysis of incentives and disincentives for sorghum in Ethiopia, Technical notes series, MAFAP, FAO, Rome; c2013.
22. CSA. Report on area and production of major crops; Agricultural Sample Survey 2020/21, Vol. I, Addis Ababa; c2021.
23. Kouyate D. Effects of Climate Variability and Climate Change on Sorghum Productivity in the Cercle of Koutiala in Mali, Asian Journal of Agricultural Extension, Economics & Sociology. 2020;38(12):68-79.
24. Gujrati D. Basic Econometrics, fourth edition. The McGraw-Hill, New York, USA; c2004.
25. Adeyemi B Busayo, Fasakin I James. Rainfall variability and rice production in Nigeria: A co-integration model approach. Int. J Agric. Extension Social Dev. 2021;4(1):10-17.
26. Dickey DA, Fuller WA. Distributions of the estimators for autoregressive time series with a unit root, Journal of American Statistical Association. 1979;74(366a):427-431.
27. Phillips PCB, Perron P. Testing for a unit root in a time series regression. *Biometrika*. 1988;75(2):335–346.
28. Dushko J, Darko L, Cane K. Cobb-Douglas production function revisited, VAR and VECM analysis and a note on Fischer/Cobb-Douglass paradox, Munich Personal RePEc Archive; c2011. available at: https://mpra.ub.uni-muenchen.de/33576/.
29. Sharma S, Singh S. The Validity of Wagner’s Law in India: A Post-liberalisation Analysis, M.J.P. Rohilkhand University, Uttar Pradesh, India; c2019.
30. Omoyo NN. Effect of climate on sorghum yield in the Semi Arid counties of lower eastern Kenya; Journal of Advances in Agriculture. 2020;11:122-137. https://rajpub.com/index.php/jaa.
31. Panda A, Sahu N. Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India; Atmospheric Science Letters. 2019;20(e932):1-10.
32. Hudo NA. Assessment of the Impact of Climate Variability and Change on Sorghum Yield over Gadaref Area in Sudan; Unpublished MSc Thesis, University of Nairobi, Nairobi, Kenya; c2016.
33. Wolde-Georgis T, Aweke D, Hagos Y. Ethiopia: Reducing the impact of environmental emergencies

through Early Warning and Preparedness: The case of the 1997-98 El Nino, Research Report, c2000.

34. Omoyo NN, Wakhungu J, Oteng S. Effects of climate variability on maize yield in the arid and semi arid lands of lower eastern Kenya. Agric Food Security. 2015;4(8):1-13.
35. Kouyate D. Effects of Climate Variability and Climate Change on Sorghum Productivity in the Circle of Koutiala in Mali, Asian Journal of Agricultural Extension, Economics & Sociology. 2020;38(12):68-79.
36. Singh AK, Sharma P. Measuring the productivity of food-grain crops in different climate change scenarios in India: An evidence from time series investigation; Research. 2018;4(16):661-673.
37. Eggen M, Ozdogan M, Zaitchik B, Ademe D, Foltz J, Simane B. Vulnerability of sorghum production to extreme, sub-seasonal weather under climate change, Environmental Research Letters. 2019;14(4):045005. available at: http://doi.org/10.1088/1748-9326/aafe19.
38. Kumar A, Sharma P. Impact of Climate Variation on Agricultural Productivity and Food Security in Rural India; Economics Discussion Papers, Kiel Institute for the World Economy; c2013. http://www.economics-ejournal.org/economics/discussionpapers/2013-43.
39. Nasrullah M, Rizwanullah M, Yu X, Jo H, Sohail MT, Liang L. Autoregressive distributed lag (ARDL) approach to study the impact of climate change and other factors on rice production in South Korea; Journal of Water and Climate Change. 2021;12(6):2256-2270.
40. Haile K, Haji J, Tegegne B. Technical efficiency of sorghum production: The case of smallholder farmers in Konso District, Sothern Ethiopia; Journal of Agriculture and Crops. 2018;4(5):50-62.
41. Boansi D. Effect of Climatic and Non-Climatic Factors on Cassava Yields in Togo: Agricultural Policy Implications; MDPI Climate Journal. 2017;5(28):1-21.