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Impact of climate change on cotton production: The case of three major cotton producing provinces in Zimbabwe

Njanji M.[1] and Parwada C.[2]*

[1]Faculty of Agricultural Sciences, Women's University in Africa, P. O. Box GD 32, Greendale, Harare, Zimbabwe.
[2]Department of Agricultural Management, Faculty of Agricultural Sciences, Zimbabwe Open University, Corner Samora Machel and Leopold Takawira Street, Harare, Zimbabwe.

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The objective of this study was to describe effects of temperature regimes and rainfall patterns on cotton production in Zimbabwe. A 30 years climate data was sourced from Zimbabwe Department of Meteorological Services and cotton statistics from Department of Agriculture and Rural Extension (AREX), Zimbabwe. Descriptive statistics was used to determine observed trends between the recorded climatic data and the cotton yield. The SPSS 10.0 version was used to analyse the bivariate correlation and linear regression for the cotton yield and climate change. Descriptive statistics indicated an inconsistent effect of rainfall or temperature on the overall seed cotton production during the 30 years. The regression showed that changes in rainfall quantities had more significant (P<0.05) effects on cotton yield variation than the temperature during the 1990 to 2020 period. There were no clear relationships that were observed between rainfall or temperature regimes and the declining cotton yield during the study period suggesting effects of other factors other than climate may have on the continuous decline in production. Therefore, explanations for cotton yield variability should be analysed from other factors e.g. agronomic practices and selling prices.

Key words: Cotton, production, rainfall, temperature, yield.

INTRODUCTION

Agriculture is a main economic activity that drives social development in the Southern African region (Gwimbi, 2009). In Zimbabwe agriculture is a major issue toward economic growth, employment, income generation and food security (Parwada et al., 2010). The cotton sector in Zimbabwe remains an engine of growth in the rural areas and the national economy at large. It is the most structured agricultural sub-sector which guarantees producers an annual income. Unfortunately, growing of the cotton has not always succeeded in eradicating the poverty among the rural cotton farmers. Cotton is the most common cash crop and represents one of the country's main sources of agricultural income in Zimbabwe. It contributes 20 to 40% of export revenues

*Corresponding author. E-mail: cparwada@gmail.com.

depending on the level of production and between 1 and 4.3% of gross domestic product (GDP) depending on the total yield per year (Gwimbi, 2009). Recently, the cotton yield is declining and among the rural farmers in particular has rarely exceeded 0.6 t ha^{-1} in the last two decades (Ouedraogo et al., 2006). Thus, the low yield has become a problem that does not allow farmers to optimize their production. This is threatening the sustainability of the cotton sector in Zimbabwe as it does not allow producers to take maximum advantage of the cotton production.

Over the two decades, there has been a permanent disruption of the rainfall patterns. The rainfall has been so irregular and unevenly distributed over time and space making the technical recommendations for sowing dates difficult to observe. The planting dates of the cotton, phytosanitary treatments and harvests are disrupted and compromised by droughts (Parwada et al., 2010). It is therefore important to determine the impact of rainfall on cotton production which can enable us to make informed technical suggestions that would reduce the negative impact of rainfall on cotton production hence poverty reduction (Yingjie and Erda, 2008). Several factors influence cotton production in Zimbabwe, but climate change is increasingly becoming a key factor in determining the yield (Gwimbi, 2009). The influence of climatic conditions on cotton growth and productivity is due to the persistent droughts and increase in temperature. Yingjie and Erda (2008) argued that climate change is one of the most complex, multifaceted and serious threats facing the world.

Researchers that relate crop production and climate effects agreed that the climate change had significantly reduced productivity with most severe effects observed among the rural poor farming communities due to limited adaptive capacities (Affholder et al., 2013; Kurukulasuriya and Mendelsohn, 2008). Unfortunately, these resources constrained rural poor farmers are highly dependent on climate-sensitive resources such as rainfall for their livelihoods and agricultural production systems (Schlenker and Roberts, 2009; Molua and Lambi, 2007). Afifi et al. (2014) and Ouedraogo et al. (2006) agreed that climate change will raise average temperatures and change rainfall patterns which will have a negative impact on crop production. Effects of the climate change on cotton production are observed by increased temperature, irregular rainfall and soil degradation that reduce both the quantity and quality of cotton output (Owusu-Sekyere et al., 2011).

Cotton requires at least 600 to 800 mm of rainfall for the duration of its growing cycle, and the water demand is higher between early flowering and the opening of the capsules stages. The quantity of water should be reduced as the capsules mature and these dry periods are needed to preserve the cotton quality. This rainfall requirement pattern is now not an obvious phenomenon even in areas known to be ideal for cotton production in Zimbabwe due to the changing of the climate. Therefore, negatively affect the cotton quantity and quality. Zimbabwe, like other countries, is experiencing unpredicted patterns of rainfall both quantity and distribution due to climate change (Parwada et al., 2010; Schlenker and Roberts, 2009). Changing of climate is therefore one of the challenges to cotton production in Zimbabwe since cotton production is climate-dependent. Hence, the need to develop appropriate strategies that can mitigate the impact of climate change on cotton production. Currently, there are few studies that look directly on the impact of changing rainfall patterns and temperature regimes on the cotton production in Zimbabwe. Hence, the aim of this study was to assess the impact of climate change on cotton production and productivity of the small-scale cotton farmers in Zimbabwe. The specific objectives were to describe the effects of temperature and rainfall recorded over a long period (30 years) on overall cotton production (t/year) and determine effects of the temperature and rainfall on the physiological growth performance of the cotton.

MATERIALS AND METHODS

Study site

The study was done in three major cotton producing provinces of Zimbabwe (Figure 1). The three provinces were Midlands, Masvingo, and Mashonaland Central. Midlands province is 274 km south-west of Harare, Masvingo is 293 km in the southern direction, and Mashonaland Central is 88 km North West from Harare (Figure 1). The demographic characteristics of the provinces are shown in Table 1. The Midlands and Mashonaland Central provinces ranked first and third, respectively in terms of numbers of cotton growers (Table 1). The main source of livelihoods among the rural people in these provinces is agriculture. Cotton is the main cash crop grown in these areas. Rainfall and temperature in these cotton growing areas has been recorded since 1980 up to date (COTTCO, 2020).

Research design

This study used the climate and cotton production data that was recorded for 30 years (1990-2020) in Zimbabwe. Hochman et al. (2013) supported that accumulation of crop yield and climate data for a period ≥ 15 years can be useful in showing effects of climate change and volatility of the correlation between the climate and yield.

Determination of cotton growth and yield

The physiological data on cotton growth and yield response measured from the field cotton using climate and non-climate-related variables. This was aimed to determine the physical impact of climate change on the yield. Cotton growth performance and yield was measured from 10 randomly selected farmers per province from October to May 2020-2021. The cotton growing season (October to May) was divided into four growing stages (GS). Stage 1 was the planting time and germination (1st October to 30th November), second stage was the vegetative growth (1st December to 28th February), third stage as the development of fruiting and vegetative branches (1st March to 31st March) and lastly the maturity stage (1st April to 31 May).

Figure 1. The selected provinces shown by the black.
Source: www.mapsofworld.com

Table 1. The characteristics of the selected provinces.

Province	Demographics	Main economic activity	No. of districts	Total No. of cotton farmers
Midlands	1.6 million	Mining and cotton production	8	88 300
Masvingo	1.4 million	Cotton and sugarcane production	7	79 207
Mashonaland Central	1.1 million	Mining and cotton production	7	69 307

Source: AGRITEX (2021).

From the obtained data, average annual seed cotton yield Y was the dependent variable then modelled as follows:

$$Y = (T_{GS}, T_{GS}^2, R_{GS}, R_{GS}^2, VT_{GS}, VR_{GS}, P_c, D) \quad (1)$$

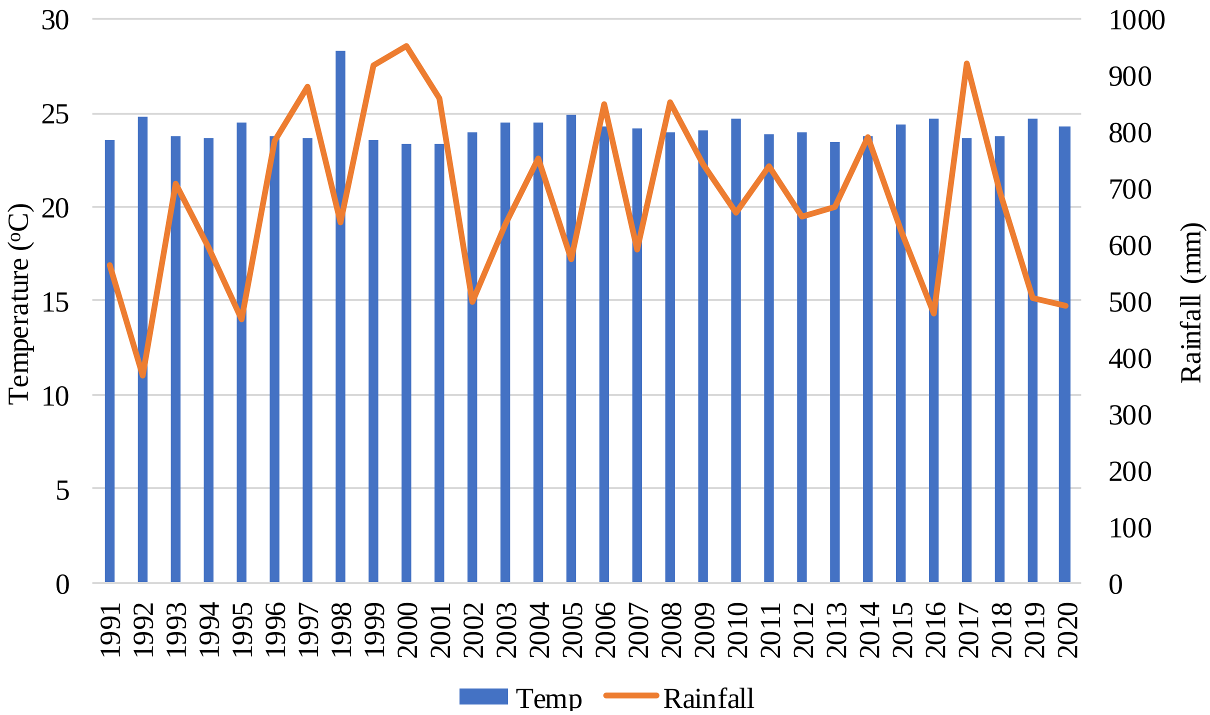

Figure 2. The observed temperature and rainfall trends during 1990 to 2020 in Zimbabwe.
Source: www.mapsofworld.com

The explanatory variables were: T_{GS}, decadal average temperature of growing stage (°C), R_{GS}, decadal average rainfall of growing stage (mm), VT_{GS}, standard deviation of decadal temperature of the growing stage, VR_{GS}, standard deviation of decadal rainfall of the growing, P_c, current price of cotton and D, time trend to consider technical progress

This model adopted a non-linear for each climate variable where the linear and quadratic terms were used as regressors, to show impact of a physiologically optimised yield. Changes in rainfall and temperature from the historical data were used to factor effect of an extreme weather event on the seed cotton yield. The model was used time series data over the period 1991-2020. Annual seed cotton production (t/year) and annual price seed (USD/kg) were provided by the COTTCO, Zimbabwe.

Data collection

The cotton yield data used in this study was in two parts: total cotton production yield recorded at a national level vis-à-vis data on the effects of climate on the physiological growth of the cotton. A 30 years climate data was sourced from Zimbabwe Department of Meteorological Services and cotton statistics from COTTCO, Zimbabwe. Cotton growth and performance under different temperature and rainfall regimes was physically measured from 2020-2021 growing seasons.

Data analysis

Descriptive statistics was used to show the relationships between the overall cotton production yield over the 30 years. Correlation analysis was also done to show the relationships between climate and overall cotton production yield in Zimbabwe for the selected study period. The physiological response of the cotton to climate and non-climate variables was modelled. The chain value approach was used to assess the impact of change in cotton yield on farmers' gross income. Data was analysed with JMP version 18 statistical package.

RESULTS AND DISCUSSION

Effects of climate on cotton growth and yield in Zimbabwe

The results indicated that the explanatory variables in Equation 1 had a significant effect on cotton physiology. The model had a high coefficient of determination (R^2 = 0.92) indicating a good explanatory power. The Durbin Waston coefficient (d= 2.1) ≈ 2, hence errors were not correlated in this study.

Trend of temperature and rainfall in Zimbabwe during 1990-2020

Over the past 30 years, the temperature was changing less dramatically as compared to the rainfall pattern (Figure 2). The annual average temperature and rainfall for the study period were 22.5°C and 600.50 mm, respectively. The annual rainfall has been constantly shifting with few periods where it was >800 mm/year, e.g. 1999-2001 and 2016/2017 cotton growing season

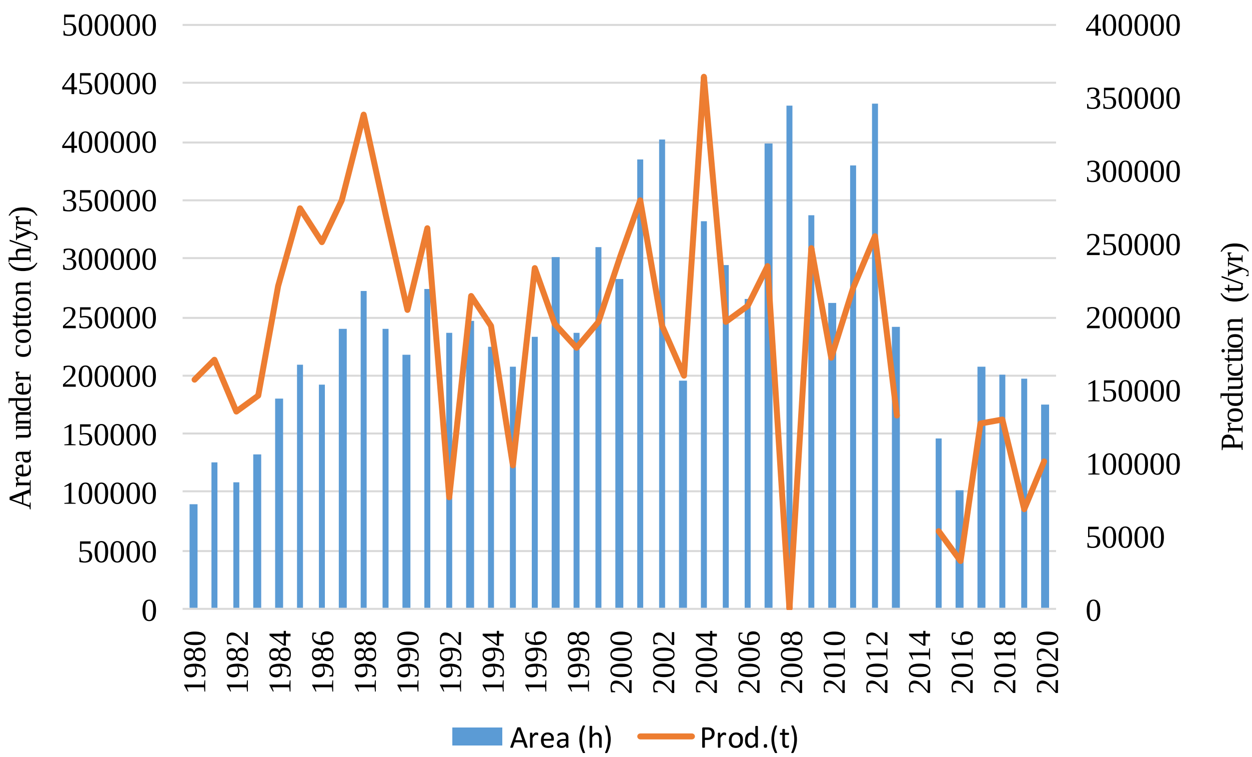

Figure 3. Area under cotton and cotton production trends from1980 to 2020 in Zimbabwe.
Source: AGRITEX (2021)

(October to May) (Figure 2).

The results showed an inconsistent trend line for both the temperature and rainfall from 1990 - 2020. The lowest (23.2°C) and highest (27.4°C) temperatures were recorded in 2001 and 1999, respectively. The mean minimum temperature was 22.5°C with a standard deviation of 0.27°C. The recorded average minimum temperature was suitable for the cotton production. Minimum and maximum annual rainfall were 320.0 and980.5 mm, respectively. The mean rainfall for the period was 600.5 mm with a standard deviation of 280.20 mm. Generally, the recorded annual mean rainfall could support the growing of drought tolerant cotton varieties.

The seed cotton yield (t/ha) have been declining as from 1980 up to 2020, farmers could yield >1 t/ha prior to 1990 but had fallen below 0.6 as from 2010 to 2020 (Figure 3). Given everything constant, the total area under a crop should be proportional to the total production output. Where a large area would correspond to high total production output. Nevertheless, in the current study the total area under cotton showed no clear relationship with the overall seed cotton production quantities (t/year) during the 1990 to 2020 period in Zimbabwe. From 1980 to 1991, Zimbabwe had higher cotton production output per unit area but the production output per unit areas started to decline from 1992 to 2020 (Figures 3 and 4). As from 1992, the average seed cotton yield has been declining regardless of an increase or decrease in the total area under production. This suggests that the declining cotton production levels may be due to other factors e.g. farm efficiency or poor agronomic practices besides the land under the crop.

The average cotton yield per hectare has been continuously declining with time. Cotton yield (t/ha) declined from 1.36 t/ha in 1980 to < 0.4 t/ha in 2020 (Figure 4). The decline yield per hectare was more than 70.5% decline in cotton yield per unit area from 1980 to 2020.

Response of cotton yield to the total annual rainfall was determined and shown in Figure 5. The results showed no specific relationship between the rainfall and the average cotton yield (t/ha). The effects of rainfall were varying in three distinctive periods e.g. the cotton yield positively influenced by the amount of rainfall in the 1991-1996 period. However, from 1997-2001 and 2006-2020, there was high rainfall with lower average cotton yield (t/ha). Hence, the no pronounced effects the cotton yields during these periods (Figure 5).

The total rainfall was gradually declining at a rate of 0.0279 mm/annum from 1991 to 2020, this decline in rainfall corresponded to a decline in cotton yield per hectare at a rate of 0.011 t/ha/year (Figure 5). Hence, the average cotton yield (t/ha) was inconsistently shifting below 1.1 t/ha throughout the recorded study period. During 30 years period, the minimum and maximum yield of cotton was 0.15 and 1.1 t, respectively, mean yield of

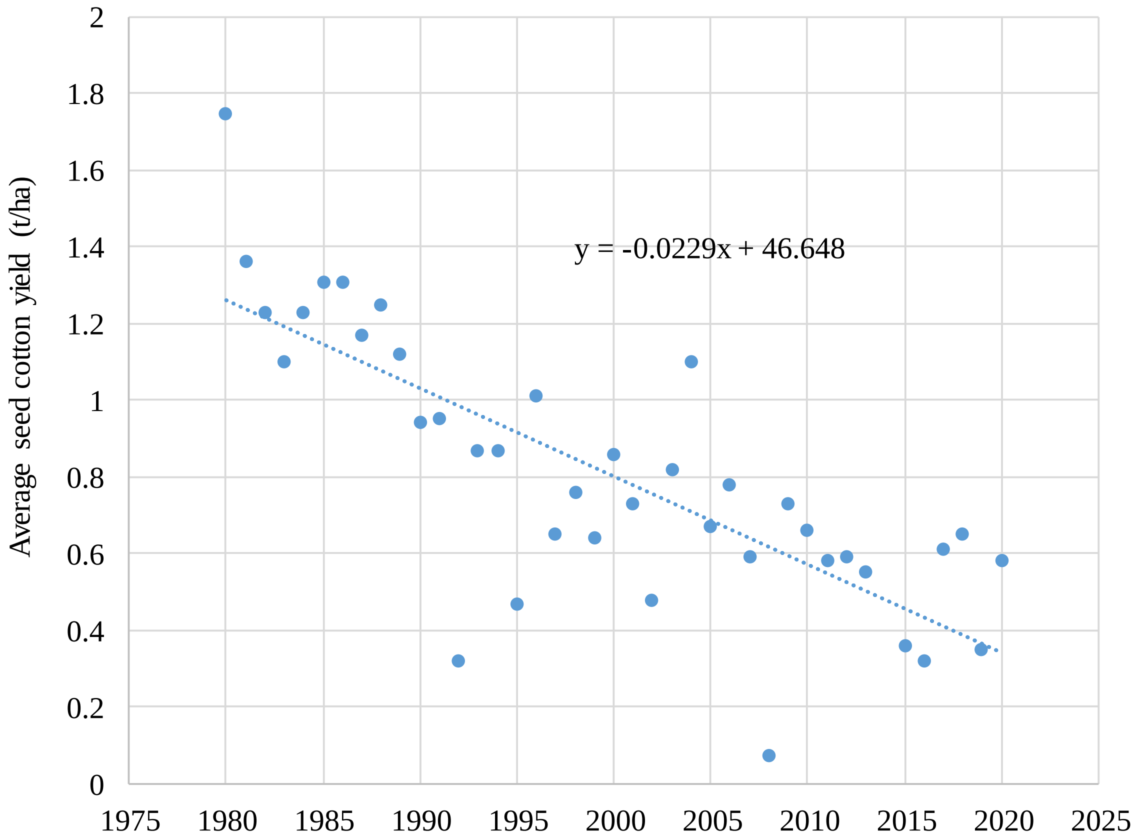

Figure 4. Average seed cotton yield (t/ha) among farmers in Zimbabwe from 1980 to 2020.
Source: AGRITEX (2021)

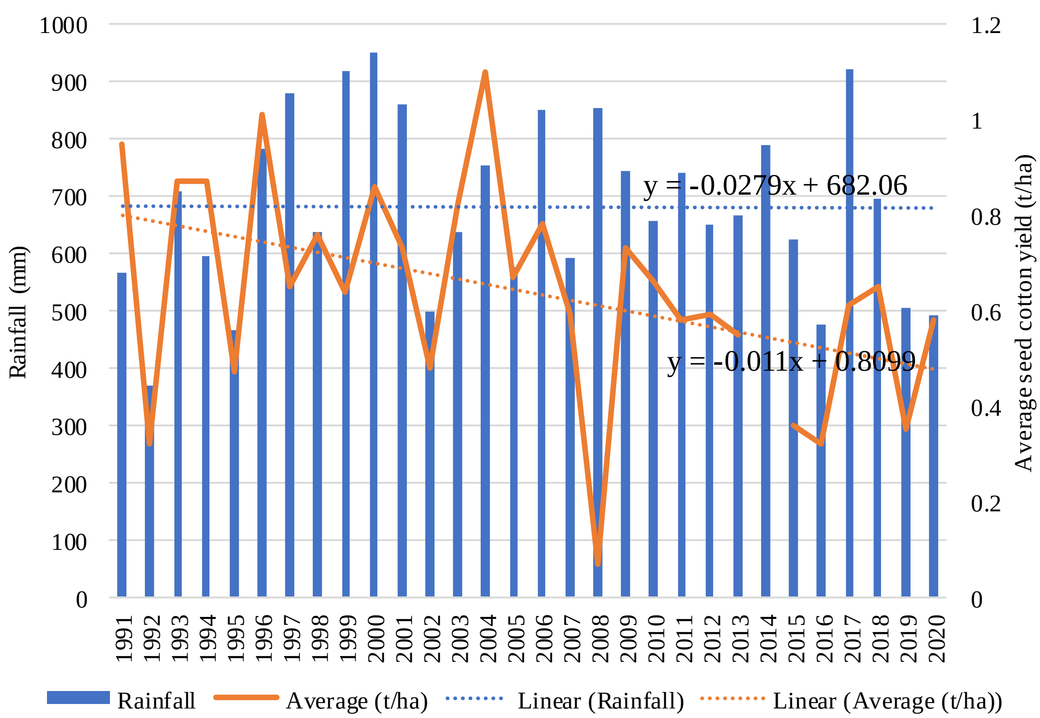

Figure 5. Effect of annual rainfall on the average cotton yield (t/ha).
Source: AGRITEX (2021)

Table 2. Summary statistics of data used in the cotton yield response.

Parameter	Mean	S.E
Non-climate		
P_c	0.80	±0.25
Climate		
T_1	24.1	±0.10
T_2	23.7	±0.15
T_3	23.6	±0.22
T_4	23.9	±0.22
R_1	160.5	±70.2
R_2	89.4	±40.9
R_3	189.8	±86.2
R_4	99.2	±64.3
Climate shifts		
VT_1	3.1	±1.2
VT_2	2.0	±1.0
VT_3	0.8	±0.6
VT_4	0.9	±0.7
VR_1	395.2	±101.4
VR_2	409.3	±168.7
VR_3	613.6	±246.8
VR_4	382.4	±192.7

Source: COTTCO (2020)

0.6 t with a standard deviation of 0.3 t (Figure 5). Generally, the descriptive statistics showed inconsistent effects of rainfall or temperature on the overall seed cotton production in Zimbabwe. Parwada et al. (2010) and Gwimbi (2009) argued that climate has a significant effect of crop production, where in most cases high temperatures and low rainfall lead to low yield. However, in this study, our results suggested that the declining trend on cotton production could be as a result of other factors which are non-climatic e.g. the agronomic practices, selling price other than the climate change per se.

Effects of climate and non-climatic factors on production and physiological growth of cotton

The summary statistics are shown in Table 2 where temperature showed little variations compared to rainfall (Table 2).

The non-climate variables and the relative price of cotton had a positive and significant impact ($P<0.001$) on cotton yield (Table 3). An increase in the relative cotton price by 1% was associated with an increase in the area under cotton by 0.80% (Figure 3). An increase in temperature in the initial two growth stages of cotton was unfavourable for the yield but positively influenced the yield in the last two growth stages. High rainfall quantities (>800 mm) in the second growth stage did not increase the cotton yield but the high rains at the third and fourth growth stages resulted to high seed cotton yield (Table 3).

Time trend had a positive but insignificant ($P> 0.001$) effect on the cotton yield (Table 3).

Table 4 listed 5 possible combinations of changing climate cases, that 0, +3°C for the temperature and -30, 0 and +30% for rainfall. In case of decreasing rainfall (-30%) and rising temperature (+3) is likely going to reduce the cotton, production causing a decline of cotton yield by about 23.4% (Table 4). This situation will be very negative to the cotton production in Zimbabwe since its climate is naturally hotter and drier compared to some of the Southern African nations.

The chain value approach was used to assess the impact of change in cotton yield on farmers' gross income, foreign earning and tax revenues (Table 5). The data used is from a report on the status of cotton production made by the COTTCO company, Zimbabwe (COTTCO, 2020) for the 2020 seasonal year. As expected, the impact of climate change will have negative effects on farmers' income and the national economy at large. This agrees with Gwimbi (2009) who also showed

Table 3. Variability of cotton yield in response to climate and non-climate variables.

Variable	Cotton growth stage	Variability	p-value
Temperature (°C)	1st	2.33	0.062
	2nd	-4.16	0.005
	3rd	-3.21	0.002
	4th	1.34	0.078
Rainfall (mm)	1st	-0.29	0.005
	2nd	-0.11	0.004
	3rd	-0.40	0.001
	4th	0.06	0.067
Relative price		0.80	0.001
Time trend		0.62	0.064

Source: COTTCO (2020)

Table 4. Change in cotton yield according to scenario.

Scenario	Temperature (°C)	Rainfall (%)	Yield change (%)
1	+3	-30	-23.4
2	+3	0	-33.1
3	+3	+30	-18.9
4	0	-30	-9.3
5	0	+30	+15.2

Source: AGRITEX (2021)

Table 5. Change in income and foreign exchange from 2020 data base.

Scenario	Farmer's gross income change (%)	Foreign exchange earning change (%)
1	-28	-18.6
2	-39	-22.4
3	-25	-16.3
4	-11	-19.1
5	+15	+5.2

Source: AGRITEX (2021)

that the change in climate, particularly low rainfall will reduce cotton yield, which causes a drop in the net revenue.

The results of this study are also similar to the findings of Ouedraogo et al. (2006), where they used the Ricardian approach to relate the net farm values to climate change. In their findings, they concluded that if temperature was to increase by 1°C, the farm revenue would fall by USD 19.9 ha^{-1} and if rainfall was to increase by 1 mm/month, the net revenue could increase by USD 2.7 ha^{-1}. While results from this study agreed to the potential danger of unreliable rainfall on farm revenue, temperature showed not to be a contemporary threatening factor in Zimbabwean cotton production industry.

In further evaluating the relationship between climate (rainfall and temperature) and cotton production (physiological growth patterns) correlation analyses were done with the null hypothesis (H_o) stating that there is no statistically significant (P=0.05) correlation between climate element (rainfall and temperature) and growth stages of the seed cotton.

The Unstandardized Coefficients indicated what would happen to the cotton yield if there is an increase in one of

Table 6. The estimated coefficients values for the effects of climate on the average cotton yield (t/ha).

Model	Unstandardized coefficients		Standardized coefficients	T	Sig.	Collinearity statistics	
	B	Std. error	Beta			Tolerance	VIF
Constant	5.123	0.231	-	22.167	0.015		
Rainfall	-0.612	0.180	0.683	-3.420	0.001	0761	1.134
Temperature	0.092	0.037	0.038	2.485	0.024	0.981	1.109

Dependent variable: Average seed cotton yield (t/ha)
Source: Meteorological Services Department, Zimbabwe

Table 7. The model summary for the effects of climate variables on the average seed cotton yield.

Climate variable	Model	R	R square	Adjusted R Square	Std. error of the estimate
Rainfall	1	0.715	0.680	0.670	0.5321
P-value		0.010	0.010	-	-
Temperature	1	0.320	0.038	0.037	0.4314
P-value		0.316	0.316	-	-

[a]Predictors: (Constant), rainfall, temperature. [b]Dependent Variable: average seed cotton yield (t/ha)
Source: Meteorological Services Department, Zimbabwe

the independent variables by exactly one unit. In this case, if rainfall were to decrease by one unit, the model expects seed cotton yield (t/ha) to decrease by 0.612 units (Table 6). The standard errors were used to calculate the t-values. If we take the unstandardized coefficient of rainfall (-0.612) and divide this by its standard error (0.180), we should get a value which is approximately the t-value of the -3.400. Overall, the results indicated that we have developed a useful model that satisfies the assumptions of regression analysis.

The effects of rainfall on cotton yield, the correlation coefficient of -0.62 is interpreted as a strong negative relationship between the two variables (Table 7). The significance 2-tailed gives p value of 0.010 which is less than 0.05, hence, the H_o is rejected, that study does provide enough evidence to conclude that there is statistically significant correlation between the received rainfall and cotton growth. In the regression, H_o is that, there was a supported relationship between the recorded rainfall and cotton growth (b=0). The results give R value of 0.715 and R^2 value of 0.680 meaning rainfall explains about 68.0% of the cotton growth and yield. The regression equation is:

$$Y = a + b^{\times} X \quad (2)$$

$$Y = 1.24 - 0.0014^{\times} Rainfall \quad (3)$$

where Y was the expected seed cotton yield (t/ha).

The same H_o as for rainfall was used in determining the relationship between temperature and the cotton growth stages. The analysis used maximum temperature values. Temperature and cotton growth stage provide correlation coefficient of 0.320 interpreted as weak positive relationship. The significance 2-tailed is 0.316, hence, H_o is retained since 0.316 > 0.05. The regression indicates R value of 0.320 and R^2 of 0.038 indicating that the temperature accounts for only 3.8% of variation in cotton growth and yield.

$$Y = 0.69 + 0.021^{\times} Temperature \quad (4)$$

where Y was the expected seed cotton yield (t/ha).

The increase in temperature found by IPCC (2007) 1.4°C between 1961 and 2000 which compares with global estimates showed that the rising temperature in Zimbabwe was minimal during the 1990-2020 period. Therefore, temperature did not explain much of cotton growth and yield variation but the rainfall has been generally low (<800 mm/year). The annual variability in rainfall has been a very good indicator of cotton growth and yield variations at the 1st, 2nd and 3rd growth stage as reported in many climate related studies (Owusu-Sekyere et al., 2011). The results are similar to Gwimbi (2009) who observed a decline in cotton production with a decrease in rainfall in Zimbabwe. The correlation analysis indicates coefficient of the cotton yield (rainfall = 0.715) and (temperature = 0.320). The results further revealed that in about 70% of the regression analysis, rainfall influenced the cotton growth and yield variability much more than temperature.

CONCLUSION AND RECOMMENDATION

There is a general declining trend of the overall cotton production levels in Zimbabwe from 1990 to 2020. The descriptive statistics did not show clear trend projections between the recorded temperature and cotton or rainfall and overall cotton production (t/year). The regression showed that rainfall explains the larger portion of the cotton yield variation than temperature in Zimbabwe during the 1990 to 2020 period. However, in some cases, the temperature had more influence than the rainfall at specific growth stages (e.g. 1st and 2nd stages) of cotton. Unlike rainfall patterns, the fluctuating temperature occurred within the favourable basic climatic requirement for the production of cotton. Hence, the variations in cotton yield could not be attributed to the effects of temperature changes but rainfall changes as supported by bivariate correlation and linear regression analyses. Further explanation for cotton yield variability should be analysed from other factors e.g. agronomic practices and selling prices.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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