Original Research Article

EFFECT OF RAINFALL AND TEMPERATURE VARIABILITY ON GREEN GRAM YIELD IN THARAKA SOUTH SUB COUNTY, THARAKA NITHI COUNTY, KENYA

ABSTRACT

Globally, green gram is a significant legume particularly in Arid and Semiarid Lands (ASALs), as a source of food, income, and soil enhancement. Despite this importance, green gram yield in Tharaka South Sub County is still too low at 0.56 mt/ha far below the crop's estimated national potential of 1.5 mt/ha and compares unfavorably with the global and national average of 0.73 mt/ha and 0.67 mt/ha, respectively. Green gram production is mainly constrained by rainfall and temperaturevariability which affects the ideal conditions favourable for the crop growth which is primarily rain-fed. This study aimed at analysing the effect of rainfall and temperature variability on green gram yield in Tharaka South Sub CountyTharaka Nithi County, Kenya for the period 2001-2021. Secondary data on seasonal rainfall, temperature, and green gram yield was collected from the Meteorological Services and County department of Agriculture. Data was analysed using qualitative and quantitative methods by use of coefficient of determination, Analysis of Variance (ANOVA), correlation, and regression analysis.The study found that rainfall variability explained 30.4% of the variables affecting green gram yield. The findings of the model showed that a 1% increase in rainfall in March-April- May (MAM) season increasedyield of green gram by 49.3% but no effect was observed in OND (October-November-December) season. Temperature variability explained 28.5% of the variables affecting green gram yield. Further, the model findings revealed that a 1% increase in temperature in OND season decreased yield of green gram by 48.5% and no effect in 0ND season. A combination of rainfall and temperature variability explained 34.2% of the variables affecting green gram yield. The model coefficients showed that a 1% increase in rainfall and temperature during the OND season increased yield of green gram by 16.2%. In addition, it was noted that a 1% rise in temperature and rainfall during MAM season reduced the output of green grams by 13.2%. The study concluded that rainfall and temperature had an effect on green gram yield and recommended that green gram farmers need to adapt to the changing climate to lessen the effects of climate change and for sustainable green gram production.

Comment [H1]: For what objective?

Key words: Green gram; Rainfall;Temperature;Variability;Yield

1. INTRODUCTION

Green gram (*Vigna radiata* L.) is an important legume as a source of food security and income in Arid and Semiarid Areas (ASALs)[1] The crop is commonly grown for the seeds which are rich in nutrients especially protein and other micro nutrients such as iron, calcium, magnesium, foliate, potassium and is highly palatable [2]. It is a source of cheap and highly nutritive protein commonly known as "poor man's meat," with higher content of protein at 24 grams which is higher than common beans which contains 21 grams for every 100 grams [3]. The stocks and pods are an important sources of leguminous fodder for livestock and when dry it contains, an average, 10-15% crude protein, 20-26% crude fiber, 2-2.5% ether extract, 40-49% nitrogen-free extract, and 11-15% ash [4]. Besides being a source food and nutrition security, the crop contributes significantly to improving soil quality by fixing nitrogen in the soil. Once a crop has been harvested, it can increase by up to 30 to 40 kg of nitrogen per hectare [5]. The crop is mainly cultivated in climatically marginal areas. Globally, the legume is cultivated in an area of approximately 7.3 million ha, producing an average of 0.73 mt/ha[6].

Green gram production is prominent in Asia, especially in India and China Tanzania is the leading producer of green gram in the Sub-Saharan Africa (SSA). Small-scale farmers in Kenya produce the legume in ASALs primarily under rain-fed conditions as a source of food and income [7]. About 90% of the nation's supply of green gram is produced in the drier regions of the nation, specifically in the counties of Makueni, Kitui, Embu, Machakos, Meru, and Tharaka Nithi. These regions are arid and more vulnerable to the damaging consequences of climate change [1]. The major green gram producing Counties in the Eastern region have recently promoted the crop’s farming as a source of income. For instance, in Meru County the is labelled “Ndengu Pesa” while the County governments of Kitui and Tharaka Nithi Counties have branded the campaign “Ndengu Revolution”. Though area under production continues to increase, yield and prices continues to fluctuate despite the increasing consumption nationally and world-wide resulting to imports to cater for domestic demand. The national yield average is at 0.67 ton/ha far below the country’s crop yield potential estimated at 1.5 mt/ha [8]. The national yield is also low compared with the global average of 0.73 mt/ha [6; 7]. In Tharaka Nithi County, green gram is grown by more than 70% and its availability is equated to having adequate food and income at the household level.Despite this importance, yield in the county is low (0.56 mt/ha) and compared unfavorably with the national average of 0.67 mt/ha[8].

The low yield can be attributed to numerous factors such as: rainfall and temperature variability, increased prevalence of pest and diseases, soil degradation, limited access to good quality seeds, weed infestation, inadequate agronomic technical knowledge poor land tenure systems and increased land fragmentation, unstructured marketing systems, and post-harvest losses brought about by limited primary processing as well as poor harvesting methods [9]. The World Bank [10] has acknowledged changes in temperature and rainfall as major climate indicators that negatively affect agricultural production by affecting crop growth, development and yield. Rainfall and temperature variation affect conditions necessary for crop growth resulting to reduced yield [11]. Arid and Semiarid Areas (ASALs) which are the largest part (for over 80%) of the country’s land is most affected by rainfall and temperaturevariability. Tharaka Nithi County, like other ASALs has experience climate variability through rise in temperature and decrease in annual rainfall [12]. Information on the extent of how rainfall and temperature variability affects green gram yield is inadequate among small scale farmers. This study aimed at understanding the effects of rainfall and temperature variability on green gram yield.A better understanding of the effects is important for adaptation and implementation of appropriate farming practices that may lessen the negative effects of rainfall and temperature variability and to improve green gram production.

2. RESEARCH METHODOLOGY

2.1. Study Area

The study location was in Tharaka Nithi County, Tharaka South Sub County in Eastern Kenya which is among the Kenya's ASAL counties. It shares Mount Kenya with Kirinyiga and Nyeri to the west, and borders the counties of Embu to the south and south-west, Meru to the north and north-east, Kitui to the east and south-east. The County is located between longitudes 370 19' and 370 46' East and latitudes 000 07' and 000 26' South. The County covers 2,662.1 km2 in total, including 360 km^2 of Mt. Kenya forest. The 746.1 km^2 Tharaka South Sub County has three administrative wards: Chiakariga, Marimanti, and Nkondi[13]. The population comprises of a total of 75,250 persons (36,190 male; 39,058 female and 2 intersex) in 18,603 households [14]. The Sub County experiences a bi-modal pattern of rainfall, with the long rains occurring from March to May and the short rains from October to December. About 500mm of low-quality, irregularly distributed rainfall and intermittently high temperatures of up to 40 ^oC are experienced by the Sub County [13].

2.2 Research Design

The study employed a descriptive research design, which Mugenda [15] defines as a study carried out among people with the aim of determining the magnitude of difficulties and concerns that have not previously been studied. The research design was deemed appropriate for the study since it would establish the existing situation on how rainfall and temperature affect green gram yield. The benefit of this research method is that a variety of variables can be compared simultaneously or at a given period. Bhandari [16] concluded that the method was appropriate in quantitative research because it tests causal relationships and generalizes results to the whole populations.

2.3. Data Collection

The study used 20 years (2001-2020) rainfall, temperature and green gram yieldsecondary data. Seasonal rainfall and temperature data was sourced from datasets fromKenya MeteorologicalDepartment, Ministry of Environment and Forestry at Dagoretti Corner, Nairobi, while green gram yield seasonal data was sourced from Tharaka Nithi County Department of Agriculture.

2.4. Data Analysis

Data for the study was analyzed using both qualitative and quantitative methods where the 20 years' trend analysis of seasonal rainfall, temperature, and green gram yield was done using qualitative analysis. Quantitative methods were utilizedto ascertain the kind and strength of the relationship between rainfall and temperature variability on green gram yield where coefficient of determination, Analysis of Variance (ANOVA), correlation and regression analysis were used. The assessment was based on a 5% significant threshold [17].

2.4.1 Effect of Rainfall Variability on Green Gram Yield for the Years2001 to 2020

The effect of rainfall variability on green gram yield for the years 2001 to 2020 was investigated using a regression model. The following regression model was used;

$$Y = \beta_{01} + \beta_{11}X_{11} + \beta_{12}X_{12} + \varepsilon_1$$

where:

$Y_=$ green gram yield (kg/ha),
β_{01}=the constant (expected estimate of green gram yield when the effects of rainfall variability in MAM & OND seasons is zero).
β_{11}=Expected estimate of green gram yield when the effects of rainfall variability in MAM season is increased by one unit when holding X_{12} constant.
β_{12}=Expected estimate of green gram yield when the effects of rainfall variability in OND is increased by one unit when holding X_{11} constant.
X_{11}&X_{12}=rainfall variability in MAM & OND, respectively.
ε_1= Error term.

2.4.2 Effect of Temperature Variability on Green Gram Yield for the Period 2001 to 2020.

The effect of temperature variation on green gram yield for the years 2001 to 2020 was investigated using a regression model. The following regression model was used;

$$Y = \beta_{02} + \beta_{21}X_{21} + \beta_{22}X_{22} + \varepsilon_2$$

where:

$Y_=$ green gram yield (kg/ha).
β_{02} =the constant i.e. expected estimate of green gram yield when the effects of temperature variability in MAM & OND seasons is zero.
β_{21}=Expected estimate of green gram yield when the effects of temperature variability in MAM season is increased by one unit when holding X_{22} constant.
β_{22}=Expected estimate of green gram yield when the effects of temperature variability in OND season is increased by one unit when holding X_{21} constant.
X_{21}&X_{22}= temperature variability in MAM & OND seasons , respectively.
ε_2= Error term.

2.4.3 TheCombined Effect of Rainfall and Temperature Variability on Green Gram Yield for the Period 2001 to 2020.

The combined effect ofrainfall and temperature variability on green gram yieldwas investigated using a regression model. The regression model is as follows;

$$Y = \beta_0 + \beta_1X_{11} + \beta_2X_{12} + \beta_3X_{21} + \beta_4X_{22} + \varepsilon_3$$

where:

$Y_=$ green gram yield (kg/ha).
β_0=the constant i.e. expected estimate of green gram yield when the effects of rainfall and temperature variability is zero
β_1= Expected estimate of green gram yield when the effects of temperature variability in MAM season is increased by one unit when holding X_{12},X_{21}& X_{22} constant.
β_2= Expected estimate of green gram yield when the effects of temperature variability in MAM season is increased by one unit when holding X_{11},X_{21} & X_{22} constant.

β_3= Expected estimate of green gram yield when the effects of temperature variability in OND season is increased by one unit when holding X_{11}, X_{12} & X_{22} constant
β_4= Expected estimate of green gram yield when the effects of temperature variability in OND season is increased by one unit when holding X_{11}, X_{12} & X_{21} constant
X_{11}&X_{12}=rainfall variability in MAM & OND seasons , respectively.
X_{21}&X_{22}=temperature variability in MAM & OND seasons , respectively.
ε_3= Error term.

24.4 Diagnostic Test

To determine whether the data used was from normal distribution, diagnostic tests such as test for normality, multicollinearity and autocorrelation tests were conducted.

2.4.4.1 Test for Normality

Shapiro Wilk test was performed in order to determine whether the data used was from a normal distribution. The Shapiro-Wilk Test for Normality results showed that temperature in the MAM season (p-value=0.079) and temperature in the OND season (p-value=0.360) were normally distributed because the p-values were greater than 0.05, indicating that the data contained in the two variables was normally distributed. However, the null hypothesis was rejected due to yield (p-value=0.027), rainfall in MAM (p-value=0.002), and OND (p-value=0.030) seasons having p-values lower than 0.05, indicating that the variables' data was not normally distributed (Table 1).

Table 1: Shapiro-Wilk Test for Normality

Variable	Statistics	Df	Sig. (p-value)
Yield	0.890	20	0.027
Temperature in MAM	0.915	20	0.079
Temperature in OND	0.950	20	0.360
Rainfall in MAM	0.822	20	0.002
Rainfall in OND	0.892	20	0.030

The findings of Shapiro-Wilk Test necessitated log transformation of yield and rainfall (MAM and OND seasons) to convert the non-normal data to normal data. According to the results of the logarithmic transformation, the yield (p-value=0.188), the rainfall in MAM (p-value=0.201), and the amount of rain in OND (p-value=0.918) were all more than 0.05, indicating that the null hypothesis was not rejected and that the data was normally distributed (Table 2).

Table 2: Logarithmic Transformation of Variables for Normality

Variable	Statistics	Df	Sig. (p-value)
log Yield	0.934	20	0.188
Log Rainfall in MAM	0.883	20	0.201
Log Rainfall in OND	0.979	20	0.918

2.4.4.2 Multicollinearity Test

Multicollinearity was used to determine whether independent variables were highly collerated with each other. Linear regression makes an assumption that there exists no multicollinealiity or there is little multicollinealiity in the data set. To test multicollinealiity, the variance inflation factor (VIF) was used. The results of the VIF was 1.52, 1.154 and 1.230 for rainfall in MAM, rainfall in OND and temperature in MAMwhich was less than10 for all the variables (Table 3). A VIF of more than 10 was considered severe multicollinearlity and necessitated further investigation.

Table 3: Collinearity Statistics (Variance Inflation Factor)

Variable	Tolerance	Variance Inflation Factor (VIF)
Rainfall in MAM	0.868	1.152
Rainfall in OND	0.866	1.154
Temperature in MAM	0.813	1.230
Temperature in OND	0.891	1.122

2.4.4. 3 Autocorrelation Tests

Autocorrelation in the study was tested using Durbin Watson test statistics. Durbin Watson is a statistical test used in testing autocorrelation in regression analysis residues and it ranges from 0 to 4. A Durbin Watson value between 2 and 2.5 denotes the absence of both positive and negative autocorrelations. A range of values between 1.5 and 2.5 imply no autocorrelation and the correct model formulation of the functional form of the model can completely remove autocorrelation. The findings of the Durbin-Watson statistics was 2.228, implying that the value is within the range (1.5-2.5) indicating there was no autocorrelation.

3. RESULTS AND DISCUSSION

3.1. Trend of Rainfall, Temperature and Green Gram Yield 2002-2021

The trend of 20 years (2002 – 2021) period for rainfall, temperature, and green gram yield was analyzed.

3.1.1 Trends of Rainfall from 2002 to 2021

The study sought to analyze the 20 year (2002-2021)seasonal rainfall trends for both MAM and OND. The findings of this study observed that rainfall in Tharaka South Sub County has been fluctuating over the years for both the seasons. The trend showed that the amount of rainfall received in OND was more than the rainfall received in MAM. The highest rainfall (361.57 mm) received in OND was in 2019 while the lowest amount (80.33 mm) was received in 2010. During MAM the highest rainfall (241.4 mm) was reported in 2019 whereas 2016 saw the lowest amount (76.7 mm) [Figure 1].

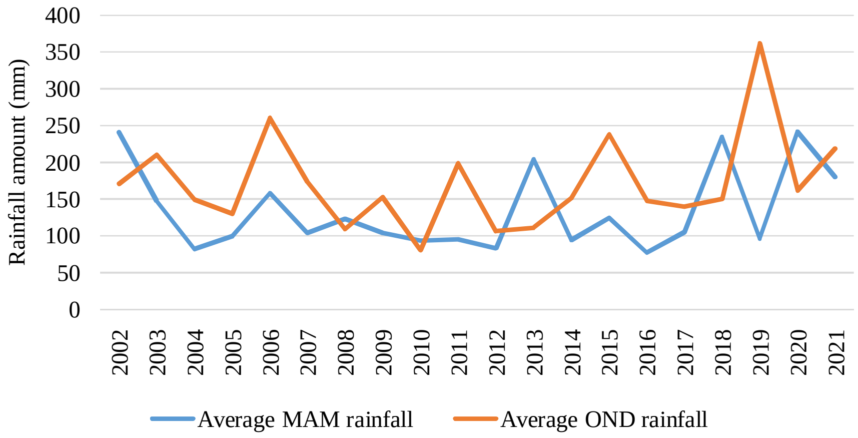

Figure 1:Trend of Rainfall from 2002 to 2021

The findings of this study concur with those of Sagero[18], who found that Kenya's OND rains displayed a rising trend and greater variation than MAM rains. Similarly, Kinyanjui [19] observed high degree of variability in rainfall seasonal trends during MAM and OND seasonsin Bahati Sub-County. Gichangi[20] also indicated high variation in seasonal rainfall in semi-arid eastern Kenya. It is possible that variability in rainfall may affect green gram production by reducing yields. Dhage [21] concluded that reduction in rainfall alone led to significant reduction in grain yield.

3.3.2 Trends of Temperature from 2002 to 2021

The trend of temperature was analyzed for both OND and MAM seasons where the findings of the study showed that average temperature during MAM was higher. During MAM season, 2011 reported the highest (26.68 ^{o}C) temperature while the lowest (24.2 ^{o}C) amount of temperature was reported in 2020. During OND season the highest (26.08 ^{o}C) temperature was reported in 2015 while the lowest (24.27 ^{o}C) amount of temperature was reported in 2003 (Figure 2).

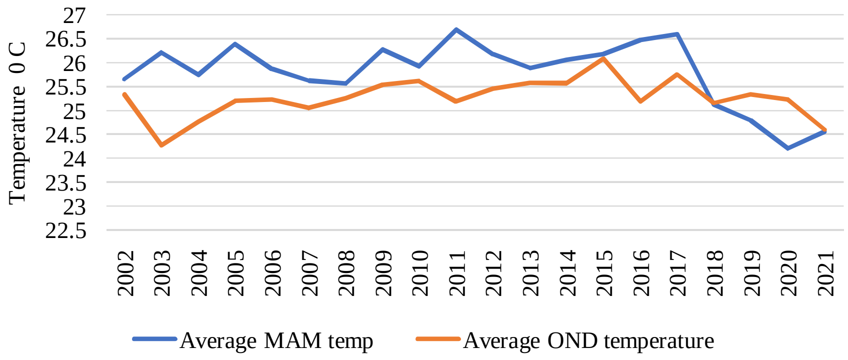

Figure 2: Trend of Seasonal Temperature from 2002 to 2021

The findings of this study concur with observations of Nouri [22] who established that during the MAM season there are usually high temperatures. The observed findings imply that farmers in the MAM season experienced high temperatures than in OND season. There are various reasons that could be attributed to the differences in temperatures and one reason may be due to the differences in the amount of daylight hours between the two seasons. There is a possibility that increased amount of solar energy warms up the atmosphere, increasing the maximum temperature in MAM. Tanu [23] found that during the MAM season, days are longer, meaning that more solar energy is able to reach the earths leading to high temperatures. Another reason that may explain the observed findings on temperature difference across the seasons may be due to the differences in the amount of moisture in the atmosphere between the two seasons.

The findings of this study observed less rainfall during the MAM season, which may imply that the atmosphere is generally dryer than during the OND season. There is a possibility that this dryness may cause less of the solar energy to be absorbed by the atmosphere, allowing more of it to reach the surface and increase the maximum temperature. Also, the other reason may be the differences in the amount of cloud cover between the two seasons. It is possible that during MAM season, there is generally less cloud cover implying that more of the solar energy is able to reach the surface without being blocked by the clouds, which increases the maximum temperature. Tanu [23] concluded that global solar radiation and cloudiness were potential indicators of Ghana's solar energy. There is a possibility that prolonged high temperatures especially in critical stages of green gram crop growth may decrease yield. Fathy [24] observed significant decrease in yield of green gram due to increased temperature during flowering stage and pod filling.

3.3.3 Trends of Rainfall from 2002 to 2021

During the study it was observed that like rainfall the trend of yield has been fluctuating over the years. It was noted that, in line with patterns in rainfall, the green gram yield obtained during the OND season was higher than the yield obtained during the MAM season. The year 2002 reported the highest yield (1.09 mt/ha) achieved in MAM season while the lowest amount of yield was achieved in 2013 and 2019 at 0.18 mt/ha. During OND season the highest yield was reported in 2006 at 1.11 mt/ha with the lowest yield reported in 2017 at 0.25 mt/ha (Figure 3).

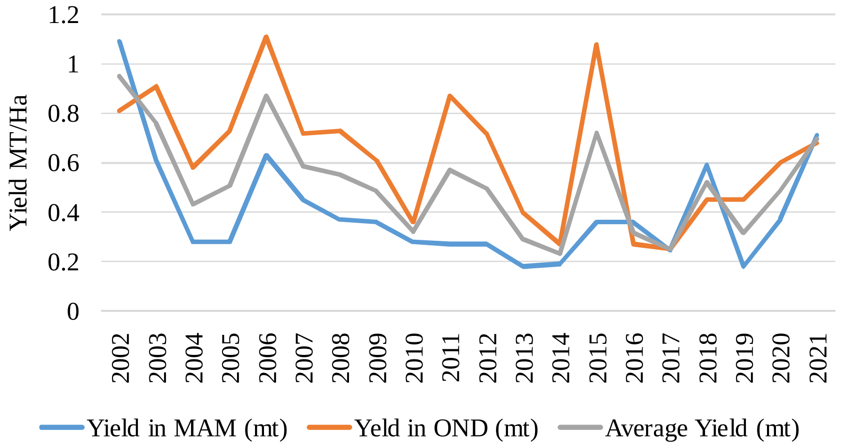

Figure 3: Trend of Yield from 2002 to 2021

The observed findings are in line with observations of Kimani[25] who found reduced and high variation of kidney beans seed yield during MAM season. Similarly, Demissie[26] projected an increase in green gram yield during the OND season while Mugo[27] observed green gram increased yield during OND. The varying yield trends may be linked to variations in rainfall that occur annually and seasonally. Mumo [28] observed that rainfall was the dominant predictor of yield variance. Mkonda[29] also found a strong relationship amongst rainfall and crop output. Similarly, Koimbori[30] reported a high correlation between rainfall patterns and maize production that is significant, favorable, and supportive. It is possible that the increased adaption to climate change through use of certified seeds, maximum soil cover, minimum tillage, crop rotation and weather advisories may have resulted in an increase in output from 2019 to 2021.Vijayasarathy [31] concluded that smallholder farmers are greatly aided by the use of climate smart technologies in their ability to continue farming in spite of the changing climate.

3.2 Effects of Rainfall Variability on Green Gram Yield for the Period 2001 to 2020.

3.2.1 Correlation Analysis for Rainfall Variability and Green Gram Yield

Pearson Correlation method was used to determine the relationship between green gram yield and rainfall variability from 2002 to 2021. The test resulted in a statistically significant correlation between the variability of rainfall and the yield of green gram, with a Pearson Correlation coefficient of 0.519 and a p-value of 0.019 less than 0.05 (Table 4). The coefficient implies that there exists moderate to strong correlation between rainfall variability and green gram yield.

Table 14: Correlation on RainfallVariability and Green Gram Yield

Model		Yield kgs/ha	Rainfall
Yields kg/Ha	Pearson Correlation	1	
	Sig. (2-tailed)		
Rainfall	Pearson Correlation	0.519*	1

	Sig. (2-tailed)	0.019

*Correlation is significant at the 0.05 level (2-tailed)

The observed findings are in line to the findings of Lukali [32] who concluded that yield variance was linked to seasonal rainfall and temperature variability especially variability in rainfall. Contrary to the findings of this study, Akano [11] reported a decline in cassava and yam yield as a result of rainfall variability. The findings of this study may suggest that a rise in rainfall variability is related to a rise in green gram production. These findings suggest that the more rainfall received in a given area varies, the higher the green gram yield. Generally, it is possible that larger levels of green gram output can only be attained with larger levels of rainfall variability. Several variables, including climate change, changes in land use and land cover, and patterns of atmospheric circulation, can have an impact on the variability of rainfall. Dakhore[33] concluded that rainfall and the amount of green gram yields were significantly and favorably correlated.

3.2.2 Regression Analysis for Rainfall and Green Gram Yield

In this study, the regression analysis for rainfall and green gram yield was established. The coefficient of determination (R squared) was calculated to assess the regression model's goodness of fit, and an ANOVA was carried out to determine the model's suitability. The regression analysis for the rainfall variability and yield of green gram obtained by the farmers was also done.The null hypothesis was;

H_{01}: Rainfall variability has no statistically significant effect on green gram yield for the period 2002 to 2021.

The regression model after the logarithmic transformation to enhance normality was given by the following:

$$logY = \beta_{01} + \beta_{11} logX_{11} + \beta_{12} logX_{12} + \varepsilon_1$$

The coefficient of determination (R squared) between rainfall variability and green gram yield was 0.3040 implying that rainfall variability explained 30.4% of the variables affecting green gram yield. The findings may further imply that the amount of rainfall, seasonality and variability have about 30.4% effect on the yield of green gram obtained (Table 5).

Table 5: Regression Model Summary for Rainfall Variability and Green Gram Yield

R	R Square	Adjusted R square	Std. error of the estimate
0. 551^{a}	0.304	0.222	0.163

F-statistic was used to assess the overall significance of the simple regression model. The ANOVA for rainfall variability and green gram yield showed that the p-value =0.046 and the F-calculated=3.705 (Table 6).

Table 6: ANOVA for Rainfall Variability and Green Gram Yield

Source of Variation	Sum of squares	Df	Mean square	F	Sig.

Regression	0.197	2	0.098	3.705	0.046 b
Residual	0.451	17	0.027		
Total	0.648	19			

The ANOVA was crucial in determining whether the model under examination was adequate. The findings of this study showed that the model was statistically significant at 5% with a p-value of 0.046, which was less than 0.05. In addition, the F-calculated was 3.705 which was greater than F-critical which equals 3.59 with 2 and 19 degrees of freedom implying that the model was useful in the prediction of how temperature variability affects the yield of green gram.The regression model showed that the constant was 1.409 with a p-value equal to 0.174 more than 0.05 implying that there was no statistical significance in the change of green gram yield when the effects of rainfall variability in MAM & OND seasons was zero. The findings of the model showed that a 1% increase in rainfall in MAM season raised yield of green gram by 49.3%. Additionally, the model demonstrated that a 1% increase in rainfall during the OND season had no discernible impact on an increase in green gram yield because the p-value (0.374) was greater than 0.05(Table 7).

Table 7: Regression for Rainfall Variability and Green Gram Yield

Variables	Unstandardized coefficients		Standardized coefficients	T	Sig.
	B	Std. Error	Beta		
Constant	1.409	0.992		1.420	0.174
Rainfall in MAM	0.549	0.228	0.493	2.413	0.027
Rainfall in OND	0.250	0.2280	0.187	0.913	0.374

The findings of this study are consistent with those of Mkonda[29] who found that rainfall and crop yields were strongly correlated. Similarly, Mugo [34] observed that increased rainfall led to higher yields, particularly during the OND season. Mumo [28] also found rainfall to be the dominant predictor of yield variance. The findings of the model imply that the null hypothesis, ‘rainfall variability has no statistically significant effect on green gram yield for the period 2002 to 2021 should be rejected. The predicted model for this study is as stipulated;

$$logY = 0.49\ 3logX_{11}$$

There is a possibility that rainfall may provide a favorable environment conducive for the green gram to thrive and increase in productivity. Rainfall may also help replenish the soil with the nutrients needed for green gram production and transport mineral nutrients from the soil to the roots of the crop plants. There is a possibility that rainfall may also help in minimizing pests and diseases that can affect green gram production and lower yields. However, excessive rainfall above the optimum amounts required by crops may be detrimental to crop growthWambua [35] concluded that heavy rainfall above 500 mm resulted to increased vegetative growth, reduced pod setting and development.

3.3Effects of Temperature Variability on Green Gram Yield for the Period 2001 to 2020.

The study sought to determine the seasonal effects of temperature variability on the yield of green gram.

3.3.1Correlation Analysis for Temperature Variability and Green Gram Yield

Pearson correlation coefficient was used to determine the association between temperature variability and yield of green gram for the period stretching from 2002 to 2021. The findings showed that the pearson correlation coefficient was -0.501 with the p-value of 0.025 which is less than 0.05 (Table 8).

Table 8: Correlation Coefficient for Temperature Variability and Green Gram Yield

Model		Yield kgs/ha	Temperature
Yields Kgs/Ha	Pearson Correlation	1	
	Sig. (2-tailed)		
Temperature	Pearson Correlation	-0.501*	1
	Sig. (2-tailed)	0.025	

**Correlation is significant at the 0.05 level (2-tailed)*

The observed findings imply that the yield of green gram had a statistically significant inverse association with temperature variation since the p-value was less than 0.05. (r=-0.501, p-value=0.025). The coefficient (r=-0.501) suggests that there is a weak to moderate negative association between temperature fluctuation and green gram yield. The observed findings corroborate those of Mkonda[29], who discovered a negative correlation between temperature and crop yields. Similar to this, Kariuki [37] demonstrated how temperature unpredictability reduced agricultural productivity. The observed findings imply that as the temperature variability increases, the yield of green gram decreases. There is a possibility that extreme temperatures may either be too hot or too cold and have negative effects on agricultural productivity and growth. It is also possible that increase in temperatures may lead to excessive evaporation, leading to water stress, while low temperatures may slow down crop growth and eventually the yield of green gram lowers. Demissie [26] established that presence of extremely cold or high temperatures led to decrease in the output of green gram obtained by the small scale farmers. It is also possible that increase in temperature may hasten the green gram growth period impacting negatively on yield. Ahmed [37]found that increase in temperature led to fast legume growth reducing the life cycle, grain filling period and reducing yield.

3.3.2Regression Analysis for Temperature and Green Gram Yield

The study sought to establish the regression analysis for temperature and green gram yield. The coefficient of determination (R squared) was used to assess the regression model's goodness of fit, and an ANOVA determined the model's suitability. The regression analysis for the temperature variability and yield of green gram obtained by the farmers was analyzed.The null hypothesis was;

H_{02}: Temperature variability has no statistically significant effect on green gram yield for the period 2002 to 2021

The regression model after the logarithmic transformation so as to enhance normality was given as follows:

$$LogY = \beta_{02} + \beta_{21} logX_{21} + \beta_{22} logX_{22} + \varepsilon_2$$

The R squared was 0.285 implying that temperature variability explains 28.5% of the variables affecting green gram yield. The amount, seasonality and variability of both the maximum and the minimum temperatures would be associated with a 28.5% effect in the yield of green gram obtained (Table 9).

Table 9: Regression Model Summary for Temperature Variability and Green Gram Yield

R	R Square	Adjusted R square	Std. error of the estimate
0. 534^a	0.285	0.201	0.1651

The overall significance of the simple regression model was evaluated using the F-statistic. The ANOVA for temperature variability and green gram yield showed that the p-value was 0.058 which was less than 0.1 and the F-calculated was 3.389 (Table 10). The findings of this study observed that F-calculated=3.389 was larger than F-critical which equals 2.644 at 2 and 19 degrees of freedom implying that the model was useful in the prediction of how temperature variability affects the yield of green gram. This led to the rejection of the null hypothesis that "temperature variability has no statistically significant effect on green gram yield for the period 2002 to 2021."

Table 2~~10~~: ANOVA for Temperature Variability and Green Gram Yield

Source of variation	Sum of squares	Df	Mean square	F	Sig.
Regression	0.185	2	0.092	3.389	0.058^b
Residual	0.463	17	0.027		
Total	0.648	19			

F= F-calculated; Sig=significant at 95%

The regression model revealed that the expected estimate of green gram yield when the effects of temperature variability in MAM & OND seasons is zero was 39.671. Further the findings of this study showed that since the p-value =0.011 was less than 0.05, constant was statistically significant. The findings of the model also revealed that the p-value of 0.543 was greater than 0.05, indicating that a 1% rise in temperature during MAM season had no discernible effect on the change in green gram production. Further, the findings of the study showed that a 1% increase in temperature in OND season decreased the yield of green gram by 48.5% (p-value=0.037 less than 0.05) [Table 11]. The findings of this study concur with those of Kimani [25], who predicted that higher temperature variability throughout the OND season would result in a decrease in kidney bean seed production. The results of the regression model also support the findings of Koimbori[30], who reported that maize yield decreased as temperature rose.

Table 11: Regression for Temperature Variability and Green Gram Yield

Variables	Unstandardized coefficients		Standardized coefficients	T	Sig.
	B	Std. Error	Beta		
Constant	39.671	13.828		2.869	0.011

Temperature in MAM	-3.417	1.133	-0.132	-0.621	0.543
Temperature in OND	-12.783	5.636	0.485	-2.268	0.037

T=t-test; Sig=significant at 95%

The observed findings may imply that there has been increasing temperatures in the area that may be associated with decline in green gram yield. Karimi [1] found that the high temperatures in Tharaka lowered green gram yield. There is a possibility that the area in some instances may receive temperature that is beyond the optimum temperature suitable for green gram production. Sharma [38] concluded that each degree rise or decrease in optimum temperatures reduced green gram seed yield. It is possible that an increase in temperature could lead to an increase in the number of pests, insects, weeds, and diseases, which would reduce crop productivity. Mumo [28] concluded that higher temperatures increased incidents of pests resulting to reduced quality of commodities and price. Therefore, an increase in temperature can lead to a decrease in the level of green gram yield obtained by smallholder farmers as portrayed.

$$LogY = 39.671 - 0.485 logX_{22} + 13.828$$

3.4Combined Effect of Rainfall and Temperature Variability on Green Gram Yield

The study sought to ascertain the effect of combined effect of temperatures and rainfall on the yield of green gram.

3.4.1 Regression Analysis for the Combined Effect of Rainfall and Temperature Variability on Green Gram Yield

The regression model sought to establish the regression analysis for the combined relationship between green gram production, temperature variation, and rainfall. The regression model's goodness of fit was assessed using the coefficient of determination (R squared), and the model's suitability was determined by ANOVA. The regression analysis for the temperature variability and yield of green gram obtained by the farmers was done.The null hypothesis was;

H_{03}: Rainfall and temperature variability has no statistically significant effect on green gram yield for the period 2001 to 2020.

The model used after logarithmic transformation to normalize the data was given as follows:

$$LogY = \beta_0 + \beta_1 LogX_{11} + \beta_2 logX_{12} + \beta_3 LogX_{21} + \beta_4 logX_{22} + \varepsilon_3$$

The R-square was 0.342 implying that a combination of rainfall and temperature variability explains 34.2% of the variables affecting green gram yield (Table 12). Contrarily, the observed results revealed that the model could not account for 65.8% of the variation in yield, suggesting that factors other than rainfall and temperatures may have contributed to the fluctuation.

Table 3~~12~~: Regression Model Summary for Rainfall and Temperature Variability and Green Gram Yield

R	R Square	Adjusted R square	Std. error of the estimate
0.585^a	0.342	0.166	0.1686

Further relating with the observed findings on individual effects of each variable, rainfall variability alone had 30.4% effect on the level of yield of green gram. However, the level of green gram the farmers were able to harvest was impacted by temperature by 28.5%. The study's conclusions imply that rainfall variability is greater than temperature variability for the overall effect. However, it was observed that the two variables had a much higher effect on the yield of green gram than the individual factor. The results of this study concur with those of Bekuma[39], who discovered that rainfall and temperature together had a combined influence of 46.72% on maize output. In a similar vein, Batho [40] found that rainfall and temperature throughout the growing season had an impact on maize yield in Tanzania by 65.4%.

The overall significance of the simple regression model was evaluated using the F-statistic. The ANOVA for temperature variability and green gram yield showed that the p-value was 0.055 which is less than 0.1 and the F-calculated was 1.948 (Table 13). The findings of this study observed that F-calculated (2.948) was larger than F-critical which equals 2.266 at 2 and 19 degrees of freedom implying that the model was useful in the prediction of how temperature variability affects the yield of green gram. This led to the rejection of the null hypothesis, which stated that "temperature and rainfall variability has no statistically significant effect on green gram yield for the period 2002 to 2021."

Table 13: ANOVA for Rainfall and Temperature Variability and Green Gram Yield

Source of Variation	Sum of squares	Df	Mean square	F	Sig.
Regression	0.222	4	0.055	2.948	0.055^b
Residual	0.427	15	0.028		
Total	0.648	19			

F= F-calculated; Sig=significant at 95%

The regression model revealed that the expected estimate of green gram yield when the effects of temperature and rainfall variability in MAM & OND seasons was zero is 38.606. The constant's statistical significance was established by the p-value of 0.022, which was below 0.05. The model coefficients revealed that because the p-value=0.33, which is more than 0.05, a 1% increase in rainfall throughout the MAM season is not related with a significant change in the level of yields. The observed findings revealed that during OND season, the combined effect had an inverse relationship such that a 1% temperature increases, lead to 43.9% decrease in the yield of green gram (p-value=0.066 less than 0.05). Additionally, it was found that a 1% increase in rainfall during the OND season was linked to a 16.2% increase in the yield of green gram (p-value=0.0483 less than 0.05) [Table 14].

Table 14: Regression for Rainfall, Temperature Variability and Green Gram Yield

Variables	Unstandardized coefficients		Standardized coefficients	T	Sig.
	B	Std. Error	Beta		
Constant	38.606	13.152		2.548	0.022
Rainfall in MAM	-0.291	0.290	-0.225	-1.001	0.333
Rainfall in OND	0.198	0.275	0.162	0.719	0.0483
Temperature in MAM	-2.712	3.728	-0.132	-0.727	0.0478
Temperature in OND	-11.632	5.874	0.439	-1.980	0.066

T=t-test; Sig=significant at 95%

The findings of this study demonstrated that the amount of crop yield was significantly influenced by temperature and rainfall during the MAM season. The observed findings concur with Batho [40], who revealed that the amount of maize yield that Tanzania's farmers in the Mbeya Region were able to produce was significantly influenced by temperature and rainfall. These study findings may imply that there is a possibility that during the MAM season temperature fluctuations may be very high and the short rains received does not substitute the effect of temperatures. The observed findings may suggest that rainfall received in the MAM season is lower than the temperatures and that temperatures rise may be less proportionate with the rise in rainfall. It is possible that the high temperatures in the MAM season may be due to increased heating from the sun. The sun is higher in the sky during this season, and the days are longer, resulting in more direct sunlight and more energy being absorbed by the ground. This increased energy leads to higher temperatures and Tanu [23] found that during the MAM season, days are longer, meaning that more solar energy is able to reach the earths.

There is a possibility that rainfall during the MAM season was influenced by the sun, and the warmer temperatures resulted in more evaporation from the land, leading to increased moisture in the atmosphere. However, the atmosphere may only hold some moisture, so the increased evaporation may be offset by precipitation. As a result, there is a possibility that the rise in temperature may be much greater than the rise in rainfall during the season. Consequently, it is possible that the high temperatures may lead to a general decline in the yields obtained by the smallholder green gram farmers. Mafuru[41] established that MAM season was marked by increased temperatures than rainfall in comparison to the OND season and this had significant effects on crops yield.

Additionally, the findings of this study showed that 1% increase in rainfall in OND season was associated with an increase in yield of green gram. These observed findings show that there is high rainfall in the OND season which leads to higher yields in comparison to the MAM season. These findings may imply that the amount of rainfall during the OND season was ideal and fit for the growth of green gram. Generally, optimal rainfall may enable the crops to develop the root system to take up the necessary water and nutrients from the soil. Since green gram is a drought resistant crop, too much water may result to water logging that may cause rotting and sprouting of green gram. Rawal [42] concluded that too much rainfall especially during the grain filing stage caused premature sprouting resulting to considerable yield damage.

The findings of this study demonstrated that there was higher rainfall in OND season than that observed in the MAM season. The observed findings further showed that for the combined effect, temperature in the MAM season was observer to be high and associated with decrease in green gram yield. These findings are in line with the individual examined effects of temperature that showed that in the MAM season there was high temperatures that was associated with high crop loss. Similar to this, the results of the model showed that the combined effect in the OND season showed an inverse relationship, such that 1% increases in temperature in OND result in a 1% decrease in the yield of green gram. Demissie [26] and Makula [43] established that there was higher rainfall during the OND season than during MAM season. The combined effect of temperature and rainfall is portrayed.

$$LogY = 38.606+0.162\beta_2 \log X_{12} - 0.132 LogX_{21} - 0.439 \log X_{22} + 13.152$$

The findings may imply that although green gram has the capacity to withstand and thrive in places marked with high temperatures, extreme and adverse increases in temperature combined with reduced rains may damage the crop by hastening the crop processes. Dhage [21] concluded that the combined effects of less rainfall and higher temperatures led to a decrease in grain yield and total biomass.

4. CONCLUSION

Rainfall and temperature variability is significantly evidenced over Tharaka South Sub County. Rainfall and temperature variability has a significant influence on the green gram yield as evidenced from their seasonal relationship. Farmers shouldimplement appropriate farming practices that may lessen the negative effects of rainfall and temperature to improve green gram yield.

REFERENCES

[1]. Karimi, R., Nair, R. M., Ledesma, D., Mutisya, D. L., & Muthoni, L. (2019). Performance and participatory evaluation of green gram genotypes in the semi-arid environments of Eastern Kenya. *East African Agricultural and Forestry Journal*, *83*(2), 119-136.

[2]. Lal, G. M., Lavanya, G. R., & Udayasri, S. (2022). Estimation of Variability and Genetic Divergence in Greengram [Vigna radiata (L.) Wilczek] for Yield Characters. *International Journal of Plant & Soil Science*, 49-56.

[3]. Krishna, A. G., & Kumar, A. (2022). Efficacy of insecticides and neem oil against spotted pod borer [Maruca vitrata (Geyer)], on greengram [Vigna radiata (L.)]. *The Pharma Innovation Journal*, 425-428.

[4]. Sengupta, K. (2018). Mung Bean (Green gram). In *Forage Crops of the World, Volume II: Minor Forage Crops* (pp. 159-174). Apple Academic Press.

[5]. Marwein, Y., & Ray, L. I. (2019). Performance of rajma (Phaseolus vulgaris) cultivars under organic mulches in Meghalayan Plateau of North Eastern India. *Legume Research-an international journal*, *42*(1), 114-118.

[6]. Muchomba, M. K., Muindi, E. M., & Mulinge, J. M. (2023). Overview of Green Gram (Vigna radiata L.) Crop, Its Economic Importance, Ecological Requirements and Production Constraints in Kenya. *Journal of Agriculture and Ecology Research International*, *24*(2), 1-11.

[7]. Nair, R., &Schreinemachers, P. (2020). Global status and economic importance of mungbean. *The mungbean genome*, 1-8.

[8]. Government of Kenya (GoK) (2020). Can Green Gram Enhance Food and Nutrition Security in Kenya? Evidence from top eight Green Gram Producing Counties in Kenya: The National Treasury and Planning.

[9]. Wambua, J. M. (2021). *Analysis of factors influencing productivity and extent of smallholder commercialization of green grams and pigeon peas in Machakos County, Kenya* (Doctoral dissertation, Egerton University).

[10]. World Bank (2020). Climate Risk Profile: Kenya.

[11]. Akano, O. I., Oluwasemire, K. O., Modirwa, M. S., Aminu, O. O., Oderinde, F. O., & Oladele, O. I. (2021). Weather variability in derived savannah and rainforest agroecologies in Nigeria: Implications for crop yields and food security. *African Crop Science Journal*, *29*(4), 513-534.

[12]. Gioto, V., Wandiga, S., & Oludhe, C. (2016). Climate change detection across all livelihood zones in Tharaka nithi county. *J. Meteorol. Related. Science9* (2), 2.

[13]. County Government of Kenya (CGoK) [2018]. County integrated development plan 2018–2022. Kenya: County Government of Tharaka Nithi.

[14]. Kenya National Bureau of Statistics (KNBS), (2019). Kenya population and housing census. Population by county and sub-county. Nairobi: Government Printer.

[15]. Mugenda, A. G. (2008). Social Science Research: Theory and Principles. Nairobi: Applied Research & Training Services (ARTS) Press.

[16]. Bhandari, B. (2021). Overview. Margin: *The Journal of Applied Economic Research*, 15(1), 7–21.

[17]. Mahmood, Z., Basharat, M., & Bashir, Z. (2012). Review of classical management theories. *International Journal of Social Sciences and Education*, 2(1), 512-522.

[18]. Sagero, O., Shisanya, C. & Makokha, L. (2018). Investigation of rainfall variability over Kenya (1950-2012). *Journal of Environmental and Agricultural Sciences*, *14*, 1-15.

[19]. Kinyanjui, K. J. (2019). Effects of climate variability on maize yield in nakuru county, kenya (Doctoral dissertation, Doctoral dissertation, Kenyatta University).

[20]. Gichangi, E. M., Gatheru, M., Njiru, E. N., Mungube, E. O., Wambua, J. M., &Wamuongo, J. W. (2015). Assessment of climate variability and change in semi-arid eastern Kenya. *Climatic Change*, *130*, 287-297.

[21]. Dhage, S. S., & Patil, R. H. (2022). Response of greengram to climate change in northern transition zone of Karnataka: DSSAT Model Based Assessment. *Legume Research-An International Journal*, *45*(1), 63-67.

[22]. Nouri, M., &Bannayan, M. (2019). On soil moisture deficit, low precipitation, and temperature extremes impacts on rainfed cereal productions in Iran. *Theoretical and Applied Climatology*, *137*(3-4), 2771-2783.

[23]. Tanu, M., Amponsah, W., Yahaya, B., Bessah, E., Ansah, S. O., Wemegah, C. S., & Agyare, W. A. (2021). Evaluation of global solar radiation, cloudiness index and sky view factor as potential indicators of Ghana's solar energy resource. *Scientific African*, *14*, e01061.

[24]. Fathy, N. E., Ismail, S. M., &Basahi, J. M. (2018). Optimizing mungbean productivity and irrigation water use efficiency through the use of low water- consumption during plant growth stages. *Legume Res.* 41, 108–113.

[25]. Kimani, P. N., Kumar, S. N., & Panjwani, S. (2022). Impact of climate change on kidney bean (Phaseolus vulgaris L.) in India and Kenya.

[26]. Demissie, T., Bolt, J., Duku, C., Groot, A., & Recha, J. (2019). Green gram Kenya: Climate change risks and opportunities. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS); Wageningen Environmental Research, The Netherlands.

[27]. Mugo, J.W., Opijah, F.J., Ngaina, J., Karanja, F., & Mburu, M. (2020). Suitability of Green Gram Production in Kenya under Present and Future Climate Scenarios Using Bias-Corrected Cordex RCA4 Models. *AgriculturalSciences,* 11,882-896.

[28]. Mumo, L., Yu, J., & Fang, K. (2018). Assessing impacts of seasonal climate variability on maize yield in Kenya. *International Journal of Plant Production*, *12*(4), 297-307.

[29]. Mkonda, M. Y., & He, X. (2018). Climate variability and crop yields synergies in Tanzania's semiarid agroecological zone. *Ecosystem Health and Sustainability*, *4*(3), 59-72.

[30]. Koimbori, J. K., Shisanya, C. A., Murimi, S. K., & Petterson, R. (2019). Impacts of Climate Variability on Maize Yields in Bahati Sub-County, Kenya. *Environmental Sciences*, 7(2), 45-55.

[31]. Vijayasarathy, K., & Ashok, K. R. (2015). Climate adaptation in agriculture through technological option: determinants and impact on efficiency of production. *Agricultural Economics Research Review*, 28(1), 103-116.

[32]. Lukali, A.A., Osima, S.E., Lou, Y.S., & Kai, K.H. (2021). Assessing the Impacts of Climate Change and Variability on Maize (Zea Mays) Yield over Tanzania. *Atmospheric and Climate Sciences, 11*, 569-588.

[33]. Dakhore, K. K., Kadam, Y. E., & Vijaya, K. P. (2020). Study the rainfall variability and impact of El Nino episode on rainfall and crop productivity at Parbhani. *Mausam*, *71*(2), 285-290.

[34]. Mugo, J.W., Musembi, D.K., & Kariuki, P.C. (2021). Determination of the Best Planting Season for Green Gram in Kitui County, Kenya, Using the Analytic Hierarchy Process. *Open Access Library Journal*, **8**, 1-16.

[35]. Wambua, J.M., Ngigi M., &Lutta, M. (2017). Yields of green gram and pigeon peas under smallholder conditions in Machakos County, Kenya. *East African Agricultural and Forestry Journal.*

[36]. Kariuki, G. M. (2016). Effect of climate variability on output and yields of selected crops in Kenya. *Unpublished PhD Thesis, School of Economics, Kenyatta University.*

[37]. Ahmed, M., Sameen, A., Parveen, H., Ullah, M. I., Fahad, S., & Hayat, R. (2023). Climate Change Impacts on Legume Crop Production and Adaptation Strategies. In *Global Agricultural Production: Resilience to Climate Change* (pp. 149-181). Cham: Springer International Publishing.

[38]. Sharma, L., Priya, M., Bindumadhava, H., Nair, R. M., & Nayyar, H. (2016). Influence of high temperature stress on growth, phenology and yield performance of mungbean (*Vigna radiata* (L.) Wilczek) under managed growth conditions. *Sci. Hort.* 213, 379–391.

[39]. Bekuma Abdisa, T., Mamo Diga, G., & Regassa Tolessa, A. (2022). Impact of climate variability on rain-fed maize and sorghum yield among smallholder farmers. *Cogent Food & Agriculture*, *8*(1), 2057656.

[40]. Batho, P., Shaban, N., &Mwakaje, A. (2019). Impacts of rainfall and temperature variation on maize (Zea mays L.) yields: A case study of Mbeya Region, Tanzania. *Archives of Agriculture and Environmental Science*, *4*(2), 177-184.

[41]. Mafuru, K. B., &Guirong, T. (2020). The influence of ENSO on the upper warm temperature anomaly formation associated with the March–May heavy rainfall events in Tanzania. *International Journal of Climatology*, *40*(5), 2745-2763.

[42]. Rawal, V., & Navarro, D. K., (2019). The Global Economy of Pulses. Rome, FAO.

[43]. Makula, E. K., & Zhou, B. (2022). Coupled Model Intercomparison Project phase 6 evaluation and projection of East African precipitation. *International Journal of Climatology, 42*(4), 2398-2412.