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CLIMATE VARIABILITY IMPACTS ON FOOD CROP PRODUCTION IN KIENI WEST SUB-COUNTY, KENYA

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ABSTRACT

Climate change and variability has hampered global agricultural growth and is anticipated to have a notable impact on crop production owing to the high reliance of agricultural activities on weather. The study examined impact of climate variability on production of major food crops (maize, beans and Irish potatoes) in Kieni West sub-County, Kenya. Mixed methods research design was used. Pearson's coefficient of correlation (r) was used to assess the relationship between climate variables and the major food crops. Multiple Linear Regression (MLR) was employed to assess the effect of rainfall and temperature variability on major food crops. Analysis of quantitative data was done using descriptive and inferential statistics while analysis of qualitative data was done thematically. Data presentation was by use of figures, tables and verbatim quotes. Correlation results revealed a positive relationship between rainfall and bean ($r = 0.46$) and maize production ($r = 0.33$) and a negative relationship between rainfall and Irish potatoes production ($r = -0.056$). A negative relationship between maximum temperatures and production of bean ($r = -0.89$) and maize ($r = -0.56$) was observed while a positive relationship between maximum temperatures and production of Irish potatoes ($r = 0.02$) was reported. Also, correlation results revealed a negative relationship between minimum temperatures and production of maize ($r = -0.35$), beans ($r = -0.43$) and Irish potatoes ($r = -0.38$). Coefficient of Determination (R2) value of 0.11, 0.18, 0.003 for maize, beans and Irish potatoes respectively against rainfall was reported. R2 values of 0.32, 0.80 and 0.00 was reported for maize, beans and Irish potatoes respectively against maximum temperatures while R2 values of 0.12, 0.18 and 0.14 was reported for maize, beans and Irish potatoes respectively against minimum temperatures. The study concludes that climate variability had differential impacts on production of maize, beans and Irish potatoes in the study area.

Keywords: Climate variability, Crop Production, Kieni West sub-County

1. INTRODUCTION

Climate change and variability have significant impacts on crop production exceptionally due to high dependence of agricultural production on climate variables for instance rainfall, temperatures, speed of wind together with relative humidity Aggarwal et al. (2019), Ali et al. (2017), Belay et al. (2017), Saguye (2016). It is projected that climate change and variability will continue to have deleterious effects on crop production both directly and indirectly (FAO, 2016, Ochieng et al. (2016).

In several regions of the world, crop production has been impacted by climate variations Agba et al. (2017), Akinbobola et al. (2015), Mangani et al. (2019), Matji (2015), Okringbo et al. (2017), Porter et al. (2014) with most of the impacts being negative. In Arid and Semi-Arid Lands (ASALs) of the world for example, crop production is faced with challenges which include extremely low rainfall, soil moisture stress along with unavailability of nutrients Yazar and Ali (2016). Agricultural productivity of most vulnerable areas of the world is anticipated to be remarkably affected by rising temperatures coupled with unpredictable rainfall patterns Martinez-Feria and Basso (2020).

In Africa, most smallholder farmers have not only reported substantial reductions in yields quantity but also in quality due to climate change and variability Adeosun et al. (2021), Asare-Nuamah (2021). In particular, Sub-Saharan Africa have already experienced reductions in yields in some of the major crops. For instance, climate variability has caused a decline of an average of 5.8% in maize and 2.3% of wheat yields Trisos et al. (2022). Indeed, it is predicted that climate variability will have a considerable effect on agricultural productivity in developing nations where most farmers practice agriculture that largely depend on rain Huong et al. (2018), Kahsay and Hansen (2016), Kontgis et al. (2019), Masson-Delmotte et al. (2018). The effects will be exacerbated by the fact that most of Africa's farmers do farming in areas with low soil fertility, have low incomes, lack adequate farm equipment, have restricted access to climate related information besides lacking basic know how on agricultural production Thamaga-Chitja and Morojele (2014), Ubisi et al. (2017).

In Kenya, climate change and variability has affected patterns of weather causing change in seasons with notable consequences for instance reduction in food production along with productivity for communities and households involved in farming Aryal et al. (2021), Kabubo-Mariara and Mulwa (2019), Mburu et al. (2015), Musafiri (2021), Lagat and Nyangena (2018) opines that, rising variations in rainfall are anticipated to affect food production as crops like maize will be conspicuously affected if the trend continues. Datta et al. (2022) and Del Pozo et al. (2019)remarks that future climatic predictions supported by Intergovernmental Panel on Climate Change (IPCC) show that this trend will continue resulting to unpredictable rainfall, change in planting seasons, as well as extreme climate events negatively impacting on agricultural production in the country. Kogo et al. (2021) observed that climate variability is already detectable with considerable impacts including intensified floods and drought, and it is predicted that it will consequentially affect agricultural yields together with their patterns across a number of localities in Kenya. Nevertheless, there is a dearth of research on effects of climate variations and crop production especially at local level areas producing food crops. The aim of this study was to examine effects of climate variability on maize, beans and Irish potatoes production, listed major food crops in Kieni West sub-County, Kenya.

2. LITERATURE REVIEW

Climate change and variability has slowed down global agricultural growth especially in the last two to three decades Food and Agriculture Organization. (2015) and it is projected that it will have a significant impact on crop production as a result of high dependence of agricultural activities on weather (IPCC, 2022). Studies have recorded severe impacts of global climate on crop production with constant decline on crop yields around the world Bednar-Friedl et al. (2022), Trisos et al. (2022). While positive effects are anticipated in some cases for instance rise in yields of maize and sugar beet in higher latitudes Bednar-Friedl et al. (2022), in general, it is expected that most climate change and variability impacts will be negative with detrimental impacts from extreme weather events, changes in precipitation patterns as well as reduced yields of most crops Field et al. (2015). Leisner (2020) observes that warmer temperatures along with varied precipitation patterns have impacts on crop yields in agricultural production regions. Similar observations were made by Ali (2017) who noted that climate warming, unpredictable precipitation patterns and extreme weather events have negative effects on food production.

About 60% variation in global crop yield is attributed to climate change and variability and it is therefore a crucial factor in affecting food production together with farmers' income in the world Aryal et al. (2019), Ray et al. (2015). Aggarwal et al. (2019) points out that climate change and variability, both in the short-term that is during the growing season and in the long-term contributes to the success of crop production. According to Adams et al. (1998), the determinants of crop production are climatic (for example, rainfall and temperature) and extreme weather events (for example, floods and droughts). Khanal et al. (2018) posits that global moisture stress coupled with changes in temperatures have adverse impacts on global food production. Similarly, Zhao et al. (2017) opines that variations in precipitation patterns in addition to increased temperatures could have a noticeable impact on food production.

Climate variability is projected to make worse food insecurity situation as a result of likely reduction in the yields of major crops such as maize and wheat in the tropical regions Porter et al. (2014), Trisos et al. (2022) attributable to expected increase in vulnerability of the agricultural sector, particularly among poor farmers Dasgupta et al. (2014), World Bank Group (2016). According to Arora (2019) and Ray et al. (2019), climate variations have already affected food production worldwide as productivity as well as anticipated yields of major staple food crops have reduced in all world's regions. Holleman et al. (2020) asserts that variations in temperature and precipitation is projected to account for between 30 and 50 percent of the annual variations observed in world's cereal yields. Equally, Sultan and Gaetani (2016)affirms that at the large-scale level, about 20 percent decline in major staple crops, especially cereals, and grains, have been observed, and future predictions indicate a decline of up to 50 percent.

Changing climate variables, mainly temperatures and precipitation affect crop growth and productivity El-Bially et al. (2022). However, variations in temperature and precipitation have differential impacts on crop production. For instance, Gray (2021) found out that rise in regional temperatures due to climate change exceptionally in the tropics, can result to heat stress for all crop types. According to Priya et al. (2019), the rise in mean global temperature presents significant threats to plant growth along with production. Impacts of rise in temperature are usually related to other climatic factors for example, availability of water, duration and intensity of sunlight Rehman et al. (2015). The direct negative impacts of increased temperature on crop yields could be worsened by indirect temperature impacts on these climatic factors. For example, the rise in temperature amplifies the atmospheric water demand, which can cause further moisture stress as a result of high-water pressure deficit that as a consequence result to a decline in soil water content and eventually decreases crop yields Asseng et al. (2011), Zhao et al. (2016), Zhao et al. (2017). Other indirect impacts of increased temperatures include recurrent and intense heatwaves along with pests and diseases outbreaks Lesk et al. (2016), Tack et al. (2015), Zhao et al. (2017).

On the other hand, global production of crops such as maize, wheat and rice is anticipated to reduce due to unpredictable rainfall Lobell et al. (2011), Sage et al. (2015). Skendžić et al. (2021) reported that out of total crop production, more than 80% relies on rainfall and thus variations in rainfall patterns or its total seasonal amount is important for crop production. In the same way, Emadodin et al. (2021) notes that variations in precipitation patterns have a strong effect on agriculture especially in arid and semi-arid regions including Kieni West sub-County where dry season can be a constraining factor for crop farming. This is because varied rainfall patterns do not only affect growth of crops but also cause a decline in the amount of water available for irrigation by some of the farming households Arshad et al. (2017), Mwangi and Kariuki (2015).

Apart from variations in temperature and unpredictable rainfall patterns, extreme climate events such as floods, droughts, storms and heatwaves has also impacted negatively on food production by decreasing the quality together with quality of food supplies. Extreme climate events as well as unpredictable varying patterns of seasonal climatic conditions have significantly affected rain-fed agriculture as well as home garden food production systems especially in rural areas making people to be more susceptible to food and nutrition insecurity Intergovernmental Panel on Climate Change (2014), Powell et al. (2015), Lesk et al. (2016) points out that subjection of crops to adverse climate events has resulted to loss in production largely attributed to loss in harvested areas in addition to decline in yields. Indeed, Vogel et al. (2019) posits that between 18% and 43% of variations in yields in agricultural crops is attributable to extreme climate events which does not only affect crop growth but also post-harvest losses. Chandio et al. (2020) opines that crop production highly susceptible to extreme weather events as a result of widespread spatial and temporal variations in temperature, rainfall, recurrent floods and droughts. Likewise, Reyes et al. (2021) opines that rising extreme weather events present serious threats to global crop yield and their stability.

Climate change causes variations in temperature and precipitation patterns subsequently affecting different crops in various ways and at different developmental stages. Kamkar et al. (2023) and Khan et el. (2023) asserts that the damages resulting from heat stress in crops is particularly noticed during their crucial development stage, especially the reproductive period which affects its development, productivity in addition to growth. Particularly, in potatoes crops, increase in temperature threshold as well as water shortage affect development of its various phenological phases Liaqat et al. (2022), Wang et al. (2023) usually in the formation of tubers Wang et al. (2023). Also, Lemma et al. (2016) affirms that climate change and variability affects the length of crop growing season by imposing temperature, water and heat stress in systems of agricultural production. Besides, climate change is likely to determine the kinds as well as occurrences of crop pests and diseases; affect access, timing and availability of irrigation water; along with increasing incidences of soil erosion Arslan et al., 2017, MAAIF, 2018, Ochieng (2016). For example, in the recent past, East Africa countries including Kenya faced severe swarms on desert locusts as a result of climate change Food and Agriculture Organization (2020), Salih et al. (2020).

Baya et al. (2019) and Sheng and Xu (2019) found out that crop production differs significantly with variations in temperature and rainfall amounts received in a particular area. This association is dependent on the crop type and the locality where the specific crop is grown Ayinde et al. (2017), Rötter et al. (2018). Temperature has become increasingly varied while rainfall patterns have become highly unpredictable in Kieni West Sub-County with prolonged droughts, prolonged cold seasons and increased frost incidences usually accompanied by dry spells as signs of extreme climate events (MoALF, 2016). While literature has indicated that climate change and variability has adverse effects on crop production across the globe, the impact of climate variations on crop production in Kieni West Sub-County, Kenya has not been studied. The current study sought to fill this gap by examining impacts of climate variability on crop production. A better understanding of the interplay between climate variations and crop production can contribute towards better decision-making at the household level and help policymakers to come up with sustainable policies to lessen smallholder farmers' susceptibility to the detrimental impacts of rainfall and temperature variations. This can contribute to fighting poverty, hunger as well as climate variation challenges in Kieni West sub-County, Kenya and as a result attain the United Nations Sustainable Development Goals (SGDs) exceptionally Goal 1 on reducing poverty, 2 on zero hunger, as well as 13 on climate action for a better tomorrow.

3. MATERIALS AND METHODS

The study was conducted in Kieni West Sub-County, Kenya Figure 1. The sub-County extends over an area of 1230 Km2 and according to the Kenya National Bureau of Statistics (KNBS) (2019), it has a population of 88,525 people. In terms of administration, the sub-County is sub-divided into 6 locations which include Mugunda, Mwiyogo, Mweiga, Laburra, Gatarakwa and Endarasha. It is located between the equator (0o) and latitude 0o 38″ South and between longitudes 36o 38″ East and 37o 20″ East. The main physical features in the sub-County include Mount Kenya to the East at 5,199m above sea level and Aberdare ranges to the West at 3,999m above sea level. Rainfall is bimodal with long rains occurring around March-May and short rains falling around October-December (GoK) (2013). The mean annual rainfall is between 500mm and 1600mm while mean monthly temperatures range between 12.8oC and 20.8oC. The area is characterized by hot and dry climate, low and unpredictable rainfall that differs widely spatially and temporally. The main type of soil is black cotton soil which is infertile and has a poor organic matter Sombroek et al. (1982). The main food crops are maize, beans and Irish potatoes while coffee, tea, horticulture and cut flowers are the dominant cash crops County Government of Nyeri. (2018).

Figure 1

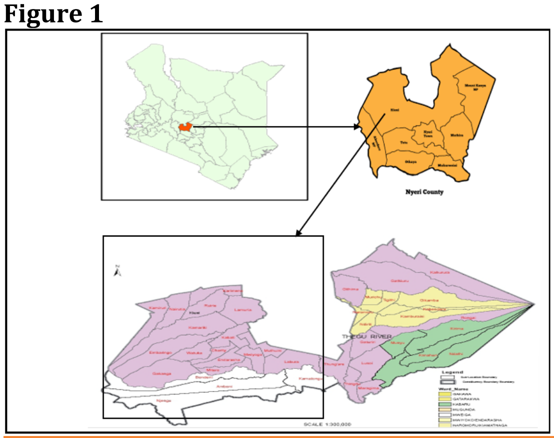

Figure 1 Map of Kieni West sub-County

Source Independent Electoral and Boundaries Commission Intergovernmental Panel on Climate Change (2022)

The sample size (n) for the study was calculated using Cochran (1977)formula at 95% confidence level for sample proportions. Bryman (2008) posits that a confidence level of 95% is most preferred because of its low variance coupled with improvement of accurateness on a higher sample size.

Thus, desired sample size (n)

$$n_o = \frac{z^2pq}{e^2} \quad \text{---} \quad (1)$$

Where,

- **no =** required sample size,
- **z =** desired level of confidence at 95% (1.96),
- **p =** proportion of an attribute in the population (0.5),
- **q =** proportion with the said characteristics (1-p) (1-0.5=0.5),
- **e =** level of precision (0.05)

Hence,

$$n = \frac{(1.96)^2 \times (0.5 \times 0.5)}{(0.05)^2} = 384 \text{ respondents}$$

Stratified technique was employed to sample administrative locations within the sub-county. So as to arrive at sampling units with proportional sizes for each location, the following formula was used:

$$ni = n/N \times 384$$

Where ni is the sample size for the location, n is the total number of households in the location and N is the total number of households in the sub-County. Sampled households were therefore 24, 30, 53, 65, 69 and 143 from Laburra, Mwiyogo, Mugunda, Endarasha, Mweiga and Gatarakwa locations respectively as indicated in Table 1. Lists of households was provided by provincial administration (area chiefs) of the sampled locations and were used as sampling frame for households' selection. A total of 384 households were randomly chosen from the six locations. Simple random sampling was used to select individual households from the six locations so to allow households to have same probability in the final sample considered.

Table 1

Table 1 Distribution of Households in Locations and Sampled Households

Location	Total Households (Hhs)	Sampled Households (N)
Laburra	1948	24
Mwiyogo	2492	30
Mugunda	4415	53
Endarasha	5433	65
Mweiga	5752	69
Gatarakwa	11905	143
Total	**31,945**	**384**

Source Kenya National Bureau of Statistics (2019)

Focus Group Discussions (FGDs) and Key Informants (KIs) were purposefully selected. FGDs and KIs were chosen on the basis of their wide experience in areas of climate variability and crop production and competent and knowledgeable on matters concerning climate variability and crop production respectively. Six focus group discussions were conducted in the six locations (1 in each location) with each focus group discussion consisting of 6-8 participants of mixed gender. This allowed gathering of a more extensive point of view as different view of men and women were taken into consideration. Nine key informants were involved in the study.

Data on climate variables (rainfall and temperatures) was obtained from Kenya Meteorological Department (KMD) while data on production of major food crops (maize, beans and Irish potatoes) in Metric Tonnes (MT) was obtained from Ministry of Agriculture, Livestock and Fisheries (MoALF) in Kieni West sub-County. Although data for climate variables was available for the period between 1998 and 2018, to ensure uniformity of years to reflect the real representation of how climate variables impacted on crop production, only the years where crop production data were available (2009-2018) were used in the analysis. A structured household questionnaire survey was used to collect data from 384 households who were randomly sampled to ascertain their perception on impacts of climate variability on crop production in the area. To triangulate the information collected from household questionnaire survey and meteorological data, focus group discussions and key informants' views and opinions were used.

Descriptive along with inferential statistics were used to analyze quantitative data where percentages and frequencies using Statistical Package for Social Sciences (SPSS) version 23 were calculated. Climatic and crop production data was further subjected to inferential statistics to identify relationships between variables. Pearson coefficient of correlation (r) was employed to assess the relationship between climate variables (rainfall and temperatures) and major food crops (maize, beans and Irish potatoes) for the period 2009-2018 using the equation:

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}} \quad (2)$$

Where r is the coefficient correlation, xi and yi are the variables being correlated whereas $\bar{x}$ and $\bar{y}$ are the means of variables x and y respectively. According to Mukaka (2012), correlation coefficient ranges from -1 to 1. When the r value is close to -1, the relationship is deemed to be negatively correlated. When the r value is close to 1, the relationship is deemed to be positively correlated. As the r value changes from either -1 or 1 and moves towards zero, the points are regarded as less correlated and in the end are uncorrelated. A p-value that is equal to or less than 0.05 is usually regarded as being statistically significant. However, a p-value that is equal to or greater than 0.05 is regarded as statistically insignificant.

To assess the effect of climate variables (rainfall and temperature) on production of major food crops (maize, beans and Irish potatoes), a Multiple Linear Regression (MLR) model was used. Using crop production as dependent variable (Y) and climate variables (rainfall and temperatures) as independent variables (X), the multiple linear regression model used was expressed using Equation 3:

$$Y = a + b1X1 + b2X2 + £ \quad (3)$$

Where Y is the dependent variable (i.e., maize, beans and Irish potatoes production), a is the constant of the model, b1&b2 is the coefficient of X1 and X2 respectively, X1 and X2 represent rainfall and temperatures respectively and £ is the error factor. Regressing the historical crop yields against climate variables is a comparatively precise method for examining the effect of climate variation on the crop production Ali (2018), Lobell and Field (2017). Likewise, in Kenya, Ochieng (2016) used multiple regressions to examine the impacts of climate variability on agricultural production.

Data obtained from focus group discussions was analyzed thematically where themes were identified and relevant quotes from participants were used to put more emphasis on the discussions. Presentation of data was done using graphs, tables and verbatim quotes.

4. RESULTS

4.1. CORRELATION BETWEEN RAINFALL AND CROP PRODUCTION

Results indicate that maize, beans and Irish potatoes responded differently to different amounts of rainfall Figure 2. Maize production for instance, increased despite declined rainfall between 2011 and 2012. However, there was a rise in production of maize with rise in rainfall in 2014.

Figure 2

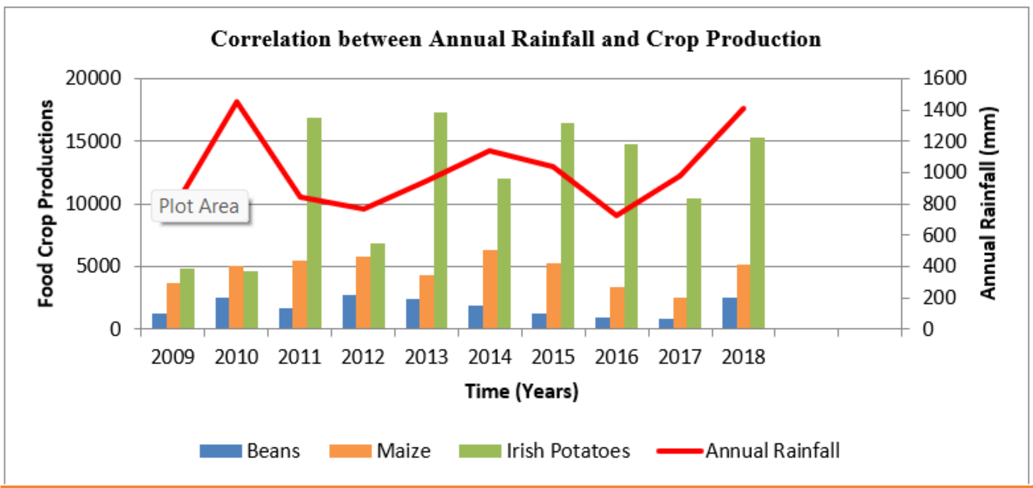

Figure 2 Correlation Analysis between Annual Rainfall and Crop Production

Source KMD and MoALF (2022)

Bean production recorded a decline with increase in rainfall in 2014 and 2015. Nevertheless, there was a decline in production of beans in 2016 and 2017 with decline in rainfall. On the other hand, production of Irish potatoes indicated a rise with decline in rainfall in 2011, 2013 and 2016.

Pearson's coefficient of correlation (r) results revealed a no significant moderate positive correlation between rainfall and maize production (r (8) = .33, p = .354). Comparably, there was a non-significant moderate positive correlation between rainfall and production of beans (r (8) = .46, p = .177). On the contrary, there was a non-significant very weak negative relationship between rainfall and production of Irish potatoes (r (8) = .06, p = .877).

4.2. CORRELATION BETWEEN MINIMUM TEMPERATURE AND CROP PRODUCTION

The findings portray a clear pattern in production of maize between 2015 and 2017 where reduced production with an increase in mean annual minimum temperature was reported Figure 3.

Figure 3

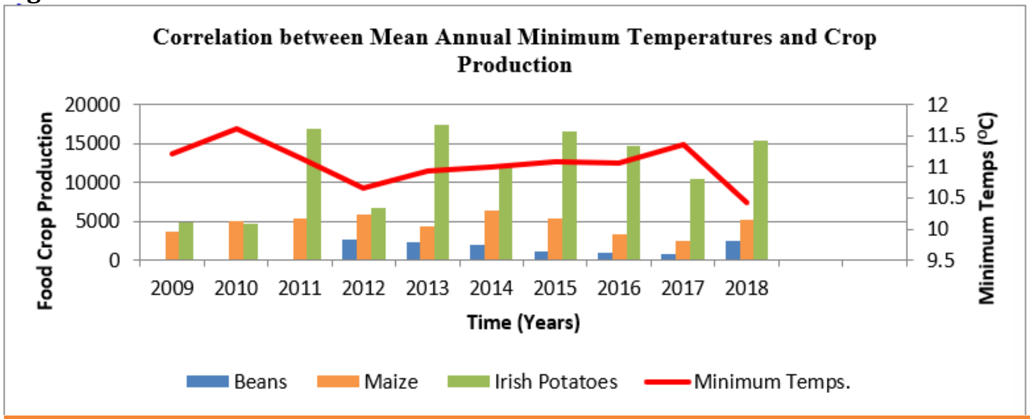

Figure 3 Correlation between Mean Annual Minimum Temperatures and Crop Production
Source KMD and MoALF (2022)

Likewise, production of beans revealed a declining trend with increase in mean annual minimum temperatures particularly in the period 2014-2017. In contrast, there was no clear pattern of the impact of mean annual minimum temperatures on production of Irish potatoes. Lowest mean annual minimum temperatures (10.42oC) in 2018 had a positive impact on production of all crops.

Pearson coefficient correlation (r) results indicated a non-significant moderate negative relationship between mean annual minimum temperatures and production of maize (r (8) = .35, p = .325). Likewise, correlation results revealed a non-significant moderate negative linear relationship between mean annual minimum temperatures and productions of beans (r (8) = .43, p= .217) and Irish potatoes (r (8) = .38, p =.280).

4.3. CORRELATION BETWEEN MAXIMUM TEMPERATURE AND CROP PRODUCTION

Results indicate that when the area experienced high mean annual maximum temperatures in 2009 at 21.20C, beans recorded the lowest production (1278 tons) compared to maize and Irish potatoes Figure 4.

Figure 4

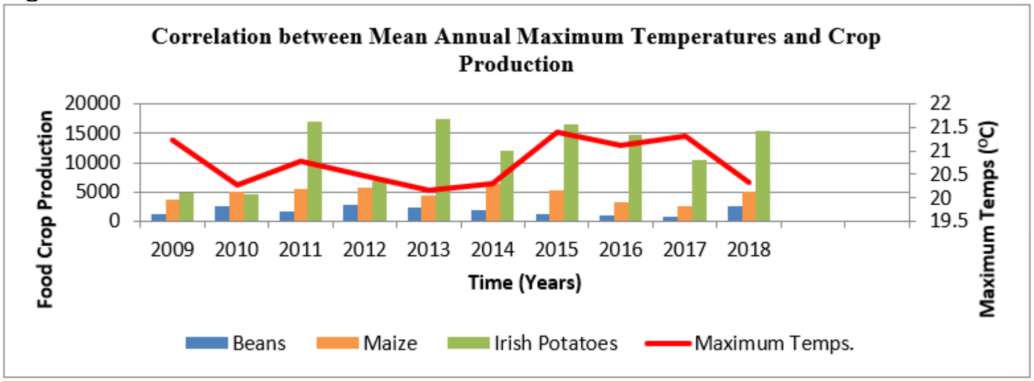

Figure 4 Correlation between Mean Annual Maximum Temperature and Crop Production
Source: KMD and MoALF (2022)

Besides, there is a clear pattern between mean annual maximum temperature and production of the three crops for the period 2015-2017. Increased mean annual maximum temperatures from 2015 to 2017 correspond with a steady decrease in production of maize, beans and Irish potatoes for the same period. On the other hand, decreased mean annual maximum temperatures correspond with increased crop production. For example, decreased mean annual maximum temperatures in 2018 (20.33oC) agreed with increased production of all crops.

Pearson's coefficient correlation (r) results demonstrated a non-significant moderate negative relationship between mean annual maximum temperatures and maize production (r (8) = .56, p = .091) was reported. Equally, there was a significant very strong negative relationship between mean annual maximum temperatures and bean production (r (8) = .89, p <.001). Contrarily, there was a non-significant very weak positive linear correlation between annual maximum temperatures and production of Irish potatoes (r (8) = .02, p = .963).

4.4. REGRESSION FOR THE RELATIONSHIP BETWEEN ANNUAL RAINFALL AND CROP PRODUCTION

The Coefficient of Determination (R2) results indicated that annual rainfall explained 21% (R2 = 0.21) of total production of beans Table 2. The degree of the relationship is revealed further by the linear regression equation (Ŷ = 520.6834+1.2585x) which denoted a positive relationship between annual rainfall and bean production.

Table 2

Table 2 Regression Analysis of Crop Productions and Annual Rainfall

Model	Dependent variable	Independent variable	R-Squared	F-value	P-value
1	Beans	Annual Rainfall	0.21	2.19	0.178
2	Maize	Annual Rainfall	0.11	0.97	0.354
3	Irish Potatoes	Annual Rainfall	0.003	0.025	0.878

Source Field Survey (2022)

Coefficient of Determination (R2) results for maize was 0.11. This revealed a very weak relationship between annual rainfall and maize Table 2. The relationship between annual rainfall and maize production is positive as depicted by regression equation ($\hat{Y}$ = 3163.6807+1.5251x). The regression analysis also reported an R2 value of 0.003 for the relationship between annual rainfall and production of Irish potatoes Table 2. A negative relationship was depicted by a trend line equation ($\hat{Y}$ = 13043.1279-1.0883x).

4.5. REGRESSION FOR THE RELATIONSHIP BETWEEN MINIMUM TEMPERATURES AND CROP PRODUCTION

Coefficient of Determination results revealed a negative relationship between mean annual minimum temperature and production of beans (R2 = 0.1832) Table 3 and further a negative association between mean annual minimum temperatures and production of beans was demonstrated by a trend line equation $\hat{Y}$ = 11669.0716-894.2694x.

Table 3

Table 3 Regression Analysis of Crop Production and Mean Annual Minimum Temperatures

Model	Dependent variable	Independent variable	R-Squared	F-value	P-value
1	Beans	Minimum Temp	0.18	1.8	0.22
2	Maize	Minimum Temp	0.12	1.1	0.33
3	Irish Potatoes	Minimum Temp	0.14	1.31	0.29

Source Field Survey (2022)

Results of Coefficient of Determination (R2) revealed a negative relationship between mean annual minimum temperature and production of maize with mean annual minimum temperatures explaining only 12% (R2 = 0.12) of maize produced Table 3. A trend line equation ($\hat{Y}$ = 18429.3075-1242.576x) also indicated that the relationship is negative. From the regression analysis, an R2 value of 0.14 was obtained between Irish potatoes and mean annual minimum temperature Table 3. Comparably, a negative relationship between mean annual minimum temperatures and Irish potato is shown by a linear equation ($\hat{Y}$ = 74245.1614-5637.1968x).

4.6. REGRESSION FOR THE RELATIONSHIP BETWEEN MAXIMUM TEMPERATURES AND CROP PRODUCTION

Regression results indicate that mean annual maximum temperature explained about 80% (R2 =0.80) of beans produced Table 4. A negative relationship between mean annual maximum temperatures and production of beans is depicted by a linear regression line ($\hat{Y}$= 28660.6422-1296.0763x).

Table 4

Table 4 Regression Analysis of Crop Production and Mean Annual Maximum Temperatures

Model	Dependent variable	Independent variable	R-Squared	F-value	P-value
1	Beans	Maximum Temp	0.8	31.82	0.00
2	Maize	Maximum Temp	0.32	3.7	0.09
3	Irish Potatoes	Maximum Temp	0.00	0.00	0.96

Source Field Survey (2022)

Results of Coefficient of Determination indicated that maize production is explained by only 3% (R2 = 0.32) of mean annual maximum temperature Table 4. The equation ($\hat{Y}$ = 33632.6278-1395.4679x) revealed a negative relationship between mean annual temperatures and maize production.

Regression results also reported an R2 value of 0.00 between production of Irish potatoes and mean annual maximum temperature Table 4. This indicated that production of Irish potatoes could not be explained by mean annual temperatures. The trend line equation however indicated an upward trend of Irish potato production with increase in mean annual maximum temperatures ($\hat{Y}$ = 8327.1478+174.6492x).

4.7. PERCEPTION OF CLIMATE VARIABILITY IMPACTS ON CROP PRODUCTION

Majority of respondents (89%) perceived reduced crop production, crop failure (73%), pests and disease infestation (57%), crop damage by wild animals (31%) and change in planting season (29%) Table 5.

Table 5

Table 5 Perceived Impacts of Climate Variability on Crop Production

Climate variability effects on crop production	Frequency (N)	Extent of impact		
		Slight	Moderate	Significant
Reduced yields	342 (89)	46 (12)	119 (31)	219 (57)
Crop failure	280 (73)	42 (11)	108 (28)	234 (61)
Pests & diseases infestation	219 (57)	75 (19)	137 (36)	172 (45)
Crop damage by wild animals	119 (31)	73 (19)	146 (38)	165 (43)
Change in planting season	111 (29)	59 (16)	124 (32)	201 (52)

Values in Parenthesis Are the Percentage

Additionally, results revealed that more than a half of respondents (57%) observed that they were significantly affected by reduced crop production, 32% were moderately affected whereas 12% were slightly affected. With regards to crop failure, 61% of respondents reported that they were significantly affected, 28% were moderately affected whereas 11% being slightly affected. Pests and diseases infestation was noted to have affected respondents significantly (45%), moderately (36%) and slightly (19%). Respondents felt a significant change in planting season (52%) while (32%) and (16%) felt moderate and slight change respectively. Almost half of respondents (43%) reported that they were significantly affected by crop damage by wild animals, 38% were moderately affected while 19% were slightly affected.

With regard to perceived impact of diseases, pests and insects on crop production, one of the key informants indicated that:

"Diseases which never used to be there before have emerged. These includes early and late bright, potato cyst nematode, stem rot, smut, bacterial wilt, rust and maize streak. Also, we have seen an upsurge of pests and insects such as aphids, white flies, bean flies, cutworms, Tuta absoluta, stalk borers, spider mites, Fall Army Worms (FAW), millipedes, centipedes, weevils as well as thrips. Recently, we had swarms of desert locusts in our farms something we had not experienced before. These pests and diseases have been a major challenge to farmers as they result to massive destruction of crops"

Besides, deliberation during focus group discussions indicated that climate variations had caused declined crop production, increased pests and diseases infestations and sometimes total crop failures making it difficult for the smallholder farmers to continue with crop cultivation.

The perception of impacts of climate variability on crop production agrees with Pearson coefficient of correlation results which revealed a significant large negative relationship (r (8) =.89, p < .001) between mean annual maximum temperatures and production of beans Figure 3. However, the findings are in contrast with correlation results which indicated a non-significant relationship between annual rainfall and crop production.

5. DISCUSSION

Previous empirical studies have shown the influence of some variables for instance rainfall, temperature, soil moisture among others on crop production Adjei & Kyerematen (2018), Kyei-Mensah et al. (2019). The results obtained from the analysis of data spanning from 2009 to 2018 present valuable insights into the varying climate and weather patterns and their possible impacts on crop production. The findings of the study suggest that generally, the relationship between rainfall and crop production was positive while the relationship between temperature and crop production was negative.

5.1. CORRELATION BETWEEN RAINFALL AND CROP PRODUCTION

Production of crops such as maize, beans and Irish potatoes depend on the amounts of rainfall received in a particular region. Results revealed an increase in maize production in 2011 and 2012 despite decrease in annual rainfall which could be attributed to other non-climatic factors such as improved seeds as well as farming practices. Similarly, there was an increase in Irish potato production with decrease in annual rainfall in 2011, 2013 and 2016. This suggests that other than rainfall, related factors for example soil fertility, soil erosion, pests and diseases coupled within flooding could have affected the production.

Pearson's coefficient of correlation (r) results revealed a positive correlation between annual rainfall and production of beans an implication that a rise in annual rainfall resulted to an increase in bean production. This finding corroborates with Adhikari et al. (2015) who posited that bean yields in East Africa including Kenya rely on rainfall and responds more to variations in rainfall compared to temperature variations. Similarly, Pickson et al. (2020) observed a positive relationship between rainfall and bean yields where a rise in precipitation resulted to a rise in grain yields.

Comparably, a positive correlation between maize production and annual rainfall indicated that rainfall had a positive impact on maize production. The results are consistent with a study by Huang et al. (2015) who found out that there was a significant positive correlation ($p < 0.05$) between maize yields and rainfall in Eastern United States. Conversely, Liu et al. (2014) noted a negative correlation between rainfall amounts and maize yields in the northern plain of China. In addition, Adamgbe and Ujoh (2013) reported that unpredictable climatic conditions for example varying rainfall have a detrimental effect on maize harvests exceptionally in the arid and semi-arid lands. Nevertheless, Li et al. (2019) pointed out that excessive rainfall can have a negative or positive impact on maize production and with differentiated impacts across regions. Moreover, Ndamani and Watanabe (2014) observed a negative relationship between annual rainfall and maize production in northern Ghana.

On the contrary, there was a negative relationship between annual rainfall and production of Irish potatoes implying that rainfall had a negative effect Irish potato production which resonates with Naintoh et al. (2018) who reported that 63% of the farmers revealed that Irish potato bright disease and rotting were as a result of increased rainfall. Likewise, Sophie (2018) reported that in Kenya 64% of growers of Shangi variety had experienced loss owing to an increase in number of pests and diseases because of high amounts of rainfall. The findings however contradict those of Karanja et al. (2014)who reported a strong positive correlation between amounts of rainfall and production of Irish potatoes. Additionally, MoALF (2016) report revealed that, Irish potato value chain is affected by intense rainfall which becomes even more intense as a result of highly unpredictable climate. Irish potatoes are very responsive to water stress whether drought stress or waterlogged exceptionally during the growing seasons. This is because it reduces the number of tuber bulking, reducing potato grade in respect to size of the tuber, quality and generally lowers the yields of potatoes Blom-Zandstra and Verhagen (2015).

The finding that the relationship between annual rainfall and production of the three crops was not statistically significant suggests that annual rainfall did hot have adverse impacts on production of maize, beans and Irish potatoes. This finding is consistent with Aboua (2022) who pointed out that variation in temperature and precipitation patterns across West Africa had no severe impact on production of cereal, tuber and root crops. Similar observations were made by a study conducted in Chiang Mai Province Thailand by Kyaw et el. (2023) who found out that there was a statistically insignificant correlation between average annual rainfall and production of maize and rice.

5.2. CORRELATION BETWEEN TEMPERATURES AND CROP PRODUCTION

Temperatures forms a crucial climatic condition that influences production of crops. Pearson coefficient of correlation results suggested that minimum temperatures had negative impacts on all food crops. For instance, correlation results indicated a non-significant medium negative linear relationship between mean annual minimum temperatures and productions of beans ($r(8) = .43$, $p = .217$) and Irish potatoes ($r(8) = .38$, $p = .280$). This intimates that increased mean annual minimum temperatures resulted to declined production of beans and Irish potatoes. The finding is in line with that of Jovovic et al. (2016) who revealed that production of Irish potatoes is highly responsive to increased temperatures which influences not only quantity but also quality of Irish potato yields owing to high damages which includes decay of the crop, increased pests and diseases in addition to high costs of production. The finding however contradicts Blom-Zandstra and Verhagen (2015) who pointed out that higher temperatures promote development of foliar, cause delayed tuberization besides affecting Irish potato quality characteristics like higher numbers of smaller tubers in every plant along with lowering specific gravity which suggests lower dry matter contents. In the same way, Mwaura and Okoboi (2014) noted a significant increase in beans production with increased minimum temperatures.

Also, there was a non-significant medium negative relationship between mean annual minimum temperatures and maize production ($r(8) = .35$, $p = .325$) indicating that mean annual minimum temperatures had a negative effect on production of maize. According to Ma and Maystadt (2017), maize is one of the crops that are more responsive to variance of weather and in particular temperatures. In the northern spring maize zone of China for instance, a rise by one standard deviation in temperatures translated to a decrease of about 1.4% in maize yields. Additionally, Omoyo et al. (2015) opines that in general, increased warming can hasten loss of water from soil, therefore affecting growth of maize from the time they germinate to vegetative growth and thereafter filling of grain. Besides, a study conducted in the Shanxi Province in China by Wei et al. (2016) found out that a rise in extreme-heat-degree days coupled with consecutive-dry days by one percent led to reduction in maize yields by 0.2% and 0.07% respectively. Moreover, they reported that if all the historical temperatures were increased by 2oC, the total impacts of the extreme weather events would result to a decrease in maize yields by slightly over 30%.

The finding that beans recorded the lowest production in 2009 indicate that mean annual maximum temperatures had severe impacts on bean production compared to maize and Irish potatoes. Moreover, the finding that increased mean annual maximum temperature correlated with decreased crop production in some years while decreased annual maximum temperature agreed with increased production denotes a negative relationship between mean annual maximum temperature and crop production.

A significant large negative relationship between mean annual maximum temperatures and bean production imply that rise in mean annual maximum temperatures translated to decline in bean production. The finding is in congruence with Beebe et al. (2013) who posited that common beans are to a large extent susceptible to high temperatures as a result of their mid- to high-altitude origin, and they are also hampered by both biotic and abiotic stresses that exists in the varied environments where they are grown. Comparably, Ramirez-Villegas and Thornton (2015) observed that if adaptation is not applied, rise in temperatures will result to reduction in areas suitable for bean production in eastern Africa in the 21st Century by about 30% to 50%.

Likewise, a non-significant large negative relationship between mean annual maximum temperatures and maize production indicate that increased mean annual maximum temperature was an important variable in explaining the decline in maize production. These results validate Steward et al. (2018) who indicated that in southern Africa, temperatures of more than 30oC had a detrimental impact on maize production. Besides, in their study, Shi and Tao (2014) indicated that a rise in 1oC of mean temperatures translated to 10% loss in maize yields. The finding however is in contrast with Kyaw et al. (2023) who reported a positive relationship between mean annual temperatures and maize yields.

Conversely, a non-significant very small positive linear correlation between Irish potatoes and mean annual maximum temperatures indicated a positive impact of mean annual maximum temperatures on Irish potato production. The finding is in agreement with Naintoh et al. (2018) who reported an insignificant weak positive correlation (r = 0.02) between potato yields and temperatures. Nonetheless, the finding contradicts Lobell and Gourdji (2012) who opined that a rise in temperatures results to reduction of production besides the quality of food crops by through hastening the development of a crop thus making the duration of crop growth shorter.

5.3. REGRESSION FOR THE RELATIONSHIP BETWEEN RAINFALL AND CROP PRODUCTION

The degree of relationship between annual rainfall and bean production ($\hat{Y} = 520.6834+1.2585x$) imply that bean production will be 521 metric tons if rainfall is 0 mm. Also, it is an implication that a rise in 1millimeter of rainfall annually translated to a rise in annual bean production by 1.259 metric tons. In addition, a decline in annual rainfall would result to a decline in production of beans. Coefficient of Determination results (R2= 0.21) indicate that rainfall explained 21% of total bean production. Indirectly, 79% could be as a result of other factors that affect production of beans. Other factors that are external to the model such as application of fertilizer or manure and use of improved varieties could be attributed to the positive impact of rainfall on production of beans.

A regression line equation between annual rainfall and maize production ($\hat{Y}$ = 3163.6807+1.5251x) suggests that annual rainfall had a positive contribution in maize production. It also suggests that 1millimeter of rainfall translates to an increase of 1.525 metric tons in maize production. An R2 value of 0.11 suggest that only 11% of maize production is determined by annual rainfall. The finding is in contrast with a study conducted by Poudel and Shaw (2016) who found out that, in Nepal, there was a negative relationship between rainfall and maize yields.

The relationship between annual rainfall and Irish potato production ($\hat{Y}$ = 13043.1279-1.0883x) signifies a downward trend of Irish potato production due to an increase in annual rainfall as 1millimeter of rainfall translated to 1.084 metric tons' decline in production of Irish potatoes. Coefficient of Determination gave a value of 0.003 denoting that other factors other than annual rainfall could have influenced production of Irish potatoes. The finding support Liaqat et al. (2022) and Wang et al. (2023) who pointed out that water scarcity affects the development of various phenological phases in potatoes particularly in the formation of tubers Wang et al. (2023).

5.4. REGRESSION FOR THE RELATIONSHIP BETWEEN MINIMUM TEMPERATURES AND CROP PRODUCTION

The trend line equation ($\hat{Y}$ =18429.3075-1242.576x) between mean annual minimum temperatures and maize production implies that a rise in temperatures by 1oC translates to a decline of about 1243 metric tons in maize production. Coefficient of Determination results (R2 = 0.1211) indicate that mean annual minimum temperatures explaining only 12% of maize produced. It therefore suggests that about 88% of the annual variations in maize production cannot be explained by mean annual minimum temperatures. These variations could be as a result of other factors that affect maize production such as use of drought resistant crops, irrigation, use of improved and certified seeds in addition to application of fertilizer. The finding corroborates with previous studies Ayumah et al. (2020), Baffour-Ata et al. (2021), Epule et al. (2018) that reported that non-climatic factors for example soil fertility, farm management, pests and diseases infestation and financial factors can affect maize production.

The relationship between mean annual minimum temperatures and Irish potato production ($\hat{Y}$ = 74245.1614-5637.1968x) suggests a negative impact of temperatures on Irish potatoes. It also implies that a rise in 1oC results to a decline of 5637 metric tons of Irish potatoes produced. An R2 value of 0.1436 indicate that mean annual minimum temperatures determined 14% of Irish potatoes produced and thus about 86% of Irish potato production could have been influenced by other factors.

Regression results also indicated a negative association of mean annual minimum temperatures and production of beans ($\hat{Y}$ = 11669.0716-894.2694x) which suggested that an increase in 1oC in temperatures translated to a decline in 894 metric tons of beans produced. Coefficient of determination gave a value of 0.1832 denoting that mean annual minimum temperatures only explained 18% of beans produced. It can therefore be concluded that 82% of bean production was influenced by other factors other than mean annual temperatures. The finding corroborates with previous studies Ayumah et al. (2020), Baffour et al. (2021), Traore et al. (2013) which reported that climatic factors such as temperatures, rainfall onset and cessation, humidity among others influenced yield of staple food crops in Ghana and other parts of Sub-Saharan Africa.

5.5. REGRESSION FOR THE RELATIONSHIP BETWEEN MAXIMUM TEMPERATURES AND CROP PRODUCTION

A regression line equation (Ŷ= 28660.6422-1296.0763x) between mean annual maximum temperatures and production of beans intimates that a rise in 10C in maximum temperatures translates to a reduction of 1296 metric tons in production of maize. An R2 value of 0.7992 indicate that mean annual maximum temperatures explained about 80% of bean produced and that production of beans depended to a large extent on mean annual maximum temperature. Sultan and Gaetani (2016) posits that negative impacts of climate variability on crops can be explained partly by the severe effect of higher temperatures which shorten the duration of crop cycle in addition to increasing evapotranspiration requirements.

The degree of relationship between mean annual maximum temperatures and maize production (Ŷ = 33632.6278-1395.4679x) implies that 1oC increase in maximum temperatures resulted in a decline in production of maize by about 1395 metric tons. Coefficient of determination results (R2 = 0.3158) indicated that maize production is explained by only 3% of mean annual maximum temperature. This suggests that a high level of maize production relied on other factors other than the mean annual maximum temperature. The finding is in line with studies conducted in Ethiopia Moges and Bhat (2021) and the US Midwest Liu and Basso (2020) which revealed a negative correlation between rising temperatures and maize production. Comparably, previous studies Al-Masud et al. (2014), Awotoye and Matthew (2010), Rowhani et al. (2011) found out that high temperatures have a deleterious effect on maize yields. Moreover, a study by Lobell et al. (2011) noted that heat stress resulted to approximately 1.0 - 1.7% loss in maize yield per day for every rise in temperature above 30°C. Nevertheless, the results are in contrast with Sazib et al. (2020) who opined that there was an increase in production of maize by 11% in Southern Africa attributable to La Niña.

The trend line equation (Ŷ = 8327.1478+174.6492x) between mean annual maximum temperatures and production of Irish potatoes indicate that an increase in 1oC resulted into an increase of about 175 metric tons of Irish potatoes. Coefficient of Determination value of 0.0002 indicated no relationship between mean annual maximum temperature and production of Irish potatoes. It therefore intimates that production of Irish potato was significantly influenced by other factors other than maximum temperatures. Jarvis et al. (2012) observes that tuber crops are usually considered less vulnerable to climate change and variability compared to other staple crops in sub-Saharan Africa. Comparably, Srivastava et al. (2015) opines that many tuber crops have a higher optimal temperature range that are favorable for plant growth and as a result they are less vulnerable to the negative impacts of warming.

5.6. PERCEPTION OF CLIMATE VARIABILITY IMPACTS ON CROP PRODUCTION

The finding that climate variability significantly reduced crop production in the area could be attributed to variations in rainfall patterns as well as increase in temperatures. It implies that respondents were highly vulnerable to climate variability and as a consequence they could perceive effects associated with climate variations. MoALF (2016) reported that in Kieni, variations in agricultural productions are attributable to adverse effects of climate conditions including unpredictable rainfall and diseases for instance the Maize Lethal Necrosis (MLN). Likewise, Kariuki (2022) posited that crop damage by wild animal species which include elephants, monkeys and baboons was significant among farmers in Kieni West Sub-County exceptionally in areas that borders the Aberdare National Park. Moreover, El-Bially et al. (2022) noted that variations in rainfall and temperatures affect crop growth as well as productivity. According to Kuzucu et al. (2016) climate variations inhibit agricultural production and largely affect crop production. For instance, direct impacts of high temperatures including frequent and intense heat waves as well as pests and diseases outbreaks Lesk et al. (2016), Tack et al. (2015), Zhao et al. (2017) are likely to cause a decline in quantity of desirable crops Jasper et al. (2020)whereas variations in rainfall patterns will result to likelihood of short-term crop losses along with long-term damage of crop yields Raza et al. (2019). Similarly, previous studies Abdul-Rahman (2018), Agom-Ucha and Nwodeh (2020), Manap and Ismail (2019), WHO (2019) indicate that variations in climate for instance increasing temperatures, unpredictable rainfall patterns together with pest and disease infestations, pose serious challenges on crop production.

Respondents' perception of climate variability impacts on crop production resonates with Pearson's correlation results between mean annual maximum temperatures and crop production while it contradicts correlation results between annual rainfall and crop production. It therefore suggests that whereas respondents were able to accurately perceive the impact of mean annual maximum temperatures on crop production particularly beans, they were unable to accurately perceive impacts of annual rainfall on food crops in Kieni West sub-County.

6. IMPLICATIONS OF THE STUDY

The findings of this study are important both for practice and policy. The finding that annual rainfall has a general positive impact on crop production while mean annual minimum and maximum temperatures has a general negative impact on crop production will help smallholder farmers in developing better climate change adaptation mechanisms to deal with challenges posed by climate change and variability. The study also provides good insights on the crucial role played by non-climatic factors on crop production. It underscores the importance of smallholder farmers taking into account other non-climatic factors that influence crop production while at the same time acknowledging existence of climatic factors for maximum benefits from cultivation of crops. The obtained results will also be useful as they will serve to inform policy and decision makers in formulating policies on climate change adaptation options especially to temperature variations so as to minimize negative impacts of changing temperatures on crop production and agricultural production in general. This will consequently enhance sustainable crop production.

7. CONCLUSION

Climate variables (rainfall and temperatures) have impacted on production of maize, beans and Irish potatoes although the impacts differ across the crops. Climate variability has both negative and positive impacts on crop production with the general observation that annual rainfall has a positive impact on crop production while annual mean temperatures has a general negative impact on crop production. Nonetheless, the impacts were not significant except for mean annual maximum temperatures which has a statistically significant impact on bean production. It can therefore be concluded that whereas climate variability has negative impacts on crop production, other non-climatic factors have also played part in explaining crop production in the area. Non-climatic factors for instance, pests and disease infestation, low soil fertility, low quality of seeds, lack of farm inputs, inaccessibility to extension services, poor farming practices in addition to land fragmentations could have influenced on crop production in the area.

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CONFLICT OF INTERESTS

None.

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