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Farmers' perspectives

Impact of climate change on African indigenous vegetable production in Kenya

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Received 30 July 2017
Revised 29 December 2017
23 March 2018
Accepted 23 March 2018

Abstract

Purpose – Understanding farmers' perceptions of how the climate is changing is vital to anticipating its impacts. Farmers are known to take appropriate steps to adapt only when they perceive change to be taking place. This study aims to analyse how African indigenous vegetable (AIV) farmers perceive climate change in three different agro-climatic zones (ACZs) in Kenya, identify the main differences in historical seasonal and annual rainfall and temperature trends between the zones, discuss differences in farmers' perceptions and historical trends and analyse the impact of these perceived changes and trends on yields, weeds, pests and disease infestation of AIVs.

Design/methodology/approach – Data collection was undertaken in focus group discussions (FGD) (N = 211) and during interviews with individual farmers (N = 269). The Mann–Kendall test and regression were applied for trend analysis of time series data (1980-2014). Analysis of variance and least significant difference were used to test for differences in mean rainfall data, while a chi-square test examined the association between farmer perceptions and ACZs. Coefficient of variation expressed as a percentage was used to show variability in mean annual and seasonal rainfall between the zones.

Findings – Farmers perceived that higher temperatures, decreased rainfall, late onset and early retreat of rain, erratic rainfall patterns and frequent dry spells were increasing the incidences of droughts and floods. The chi-square results showed a significant relationship between some of these perceptions and ACZs. Meteorological data provided some evidence to support farmers' perceptions of changing rainfall. No trend was detected in mean annual rainfall, but a significant increase was recorded in the semi-humid zone. A decreasing maximum temperature was noted in the semi-humid zone, but otherwise, an overall increase was detected. There were highly significant differences in mean annual rainfall between the zones. Farmers perceived reduced yields and changes in pest infestation and diseases in some AIVs to be prevalent in the dry season. This study's findings provide a basis for local and timely institutional changes, which could certainly help in reducing the adverse effects of climate change.

This work was financially supported by the German Federal Ministry of Education and Research (BMBF) and the German Federal Ministry for Economic Cooperation and Development (BMZ), through the Horticultural Innovations and Learning for Improved Nutrition and Livelihoods in East Africa (HORTINLEA) project (Ref. FKZ 031A248A). The HORTINLEA project is part of the GlobeE – Global Food Security programme. Kenya Meteorological Services (KMS) are also thanked for providing climate data from 1980 to 2014.

International Journal of Climate Change Strategies and Management
Vol. 10 No. 4, 2018
pp. 551-579
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-07-2017-0160

Originality/value – This is an original research paper and the historical trends, farmers' perceptions and effects of climate change on AIV production documented in this paper may also be representative of other ACZs in Kenya.

Keywords Kenya, Farmers, Perceptions, Climate change, African indigenous vegetables, Agro-climatic zones

Paper type Research paper

1. Introduction

Sub-Saharan Africa (SSA) has been identified as one of the regions that are most vulnerable to the impacts of climate change (CC) (Bryan *et al.*, 2013; IPCC, 2014). CC is seen as one of the major factors limiting Africa's efforts to achieve food security because of the continent's dependency on rain-fed agriculture and the low capacity of smallholders to adapt to CC (IPCC, 2014; Phirri *et al.*, 2016). Furthermore, widespread poverty, inequitable land distribution and the declining size of farmland make the region more vulnerable (IPCC, 2014). It is projected that SSA will witness increases in temperature, changes in rainfall intensity and distribution and a rise in incidences of extreme weather events (e.g. droughts and floods), pests, weeds and disease epidemics (FAO, 2015; Connolly-Boutin and Smit, 2015). In Kenya, for example, since the early 1960s, the mean temperature has been increasing and rainfall patterns have become irregular and unpredictable, with the country experiencing an increased number of extreme events such as droughts and floods (GoK, 2013a; Thompson *et al.*, 2015). As the full effects of these changes are yet to be felt, there is evidence in the literature that these changes are already having an impact on agricultural production. For instance, combined infestations of pests and diseases in plants have been reported to result in losses of over 50 per cent of the yield of major crops. Plant diseases are also estimated to cause up to a 20 per cent reduction in the yield of principal food and cash crops worldwide (Gautam *et al.*, 2013; West *et al.*, 2015), while weeds have been found to contribute the greatest potential yield losses of up to 34 per cent compared with those caused by pests and diseases (Oerke, 2005). According to Thornton *et al.* (2014), changes in climate variability and the frequency of extreme events may have a substantial impact on the prevalence and distribution of pests, weeds and crop diseases. Additionally, increases in minimum temperatures have negative impacts on rice yields by up to 10 per cent for each increase in temperature by 1°C in the dry season. Furthermore, increases in maximum temperatures lead to reduced yields of maize by 1.7 per cent for each day above 30°C under drought conditions (Thornton *et al.*, 2013). Research shows that the impact of CC on agricultural production is likely to intensify in future because of an expected further increase in temperature. This increase is predicted to cause a yield decline of 14 per cent (rice), 22 per cent (wheat) and 5 per cent (maize) in SSA. The consequence of this is increased poverty and vulnerability of the people who primarily depend on rain-fed agriculture for their livelihoods (IPCC, 2014; Kabubo-Mariara and Kabara, 2015; Adhikari *et al.*, 2015).

Agricultural production in Kenya contributes about 25.4 per cent of the country's gross domestic product directly and another 27 per cent indirectly through its links with agro-based industries and the service sector (FAO, 2015). In Kenya, the majority of the population lives in rural areas, with smallholder rain-fed agriculture as their key economic activity (Bryan *et al.*, 2013; Barasa *et al.*, 2015b). According to the Nutritional Action Plan 2012-2017, the country is facing the challenges of food and nutrition insecurity. Additionally, the prevalence of micronutrient deficiencies in the population is becoming a matter of concern to the government. The most common include vitamin A deficiency, iron deficiency anaemia, iodine deficiency disorders and zinc deficiency (GoK, 2012). African indigenous vegetables

(AIVs) have been identified as an important component in providing food and nutrition security and compensating for nutrient deficiencies (Habwe *et al.*, 2009; Abukutsa-Onyango, 2010; Chagomoka *et al.*, 2014). Apart from their nutritional importance, they also provide opportunities for generating a higher income and other livelihood gains such as employment opportunities (Prasad and Chakravorty, 2015). AIVs are recognised for their superior provision of micronutrients, particularly iron, zinc, vitamins C and A and protein compared to other widely consumed exotic vegetables such as tomatoes, cabbages and onions (Abukutsa-Onyango, 2010; Kamga *et al.*, 2013; Luoh *et al.*, 2014). This is especially important for a country like Kenya, which is characterised by a rapidly increasing population and high poverty levels and where multiple burdens of malnutrition-persistent hunger and undernutrition are becoming increasingly prevalent (Kenya National Bureau of Statistics-KNBS and Society for International Development-SID, 2013; United Nations Children's Fund (UNICEF), 2013).

There is considerable literature on how farmers perceive CC. Some of the perceptions presented in the literature include intense rainfall; changes in the timing of rainfall; frequent droughts; and changes in temperature, landslides, crop pests, thunderstorms, hailstorms, winds and floods (Babatolu and Akinnubi, 2016; Limantol *et al.*, 2016; Sanogo *et al.*, 2016; Elum *et al.*, 2017; Stöber *et al.*, 2017; Mkonda and He, 2017; Mutunga *et al.*, 2017; Fadina and Barjolle, 2018; Williams *et al.*, 2018). Furthermore, this growing body of literature has also focused on evaluating the impact of CC on major food crops (wheat, maize, rice, millet, sorghum and cassava (Rurinda *et al.*, 2015). Notably, their observations are based on projections and CC crop model simulations, which have concentrated on the impact of CC on cereal crop production, with very little reference to horticultural crops such as vegetables. Some studies based on experiments and crop simulation models have, however, documented the effect of various climatic conditions on vegetable crops. For instance, Luoh *et al.* (2014) found that the fresh edible weight/yield of three AIVs is reduced in water-stressed conditions. Additionally, drought tolerance has also been documented for indigenous vegetables such as amaranth (Van den Heever and Slabbert, 2007). Other studies have focused on monitoring the sensitivity of some exotic vegetables to different climate variables. For example, cabbage and spinach were exposed to water stress and elevated CO_2 conditions in India, and the authors found that heat and water stress reduced the quality of cabbages, while an increased yield was reported for spinach (Jain *et al.*, 2007; Moretti *et al.*, 2010; Choudhary *et al.*, 2015). In other studies, tomatoes were evaluated under conditions of rising temperatures, double CO_2 and water deficiency in Nepal and Macedonia. A yield reduction of 72-84 per cent for tomatoes was found in water-deficient conditions. Decreased ripening and increased productivity by 51 per cent were however reported when CO_2 conditions for tomatoes were doubled (Malla, 2008; Domazetova, 2011).

Nevertheless, some attempts have been made to assess the impact of these changes on specific crops from the perspective of farmers. For instance, farmers have perceived an increase in temperatures, droughts and storms, which has led to problems of reduced yield and increased incidences of pests, diseases and failures in potato and cabbage crops in South Africa (Elum *et al.* (2017). Similarly, Ayyogari *et al.* (2014) noted that the most constraining factors in vegetable cultivation under changing climatic situations include crop failures, a decline in yields, a reduction in quality and increasing pest and disease problems. Furthermore, a general spread of pests and weeds on cropland and reduced yield have been reported by farmers (Mertz *et al.*, 2009; Apata *et al.*, 2009). Even though AIVs are known for being relatively robust to CC, water stress, pests, diseases and weed pressure pose as yet unknown risks to AIV production (Ngugi *et al.*, 2006; Luoh *et al.*, 2014; Stöber *et al.*, 2017). There is a scarcity of evidence-based research information on how CC affects smallholder production of AIVs (Stöber *et al.*, 2017). Consequently, there has always been a tendency among many researchers and practitioners to conclude that AIVs are resistant to CC, with the consequent branding of these vegetables as "hard-core" or "survivor plants". Indigenous crops including AIVs have often been recommended for use in marginal areas for coping with CC and food security because of their ability to adapt to harsh environments with various types of stresses (Abukutsa-Onyango *et al.*, 2010; Capuno *et al.*, 2015). Many also argue that they are resistant to drought and have greater resistance to pests and diseases (Muhanji *et al.*, 2011; Luoh *et al.*, 2014). For instance, slender leaf (*Crotolaria* sp.) has been identified as being particularly hardy during droughts because it quickly establishes its taproot and can survive when rainfall is low (Cernansky, 2015). In contrast, some studies point out that CC-related risks have contributed to the decline in AIV production (Masinde and Stützel, 2005; Ngugi *et al.*, 2006; Muthomi and Musyimi, 2009). However, these broad generalisations are likely to mask local farmers' perceptions of the impact of CC on production.

The production area and value of AIVs rose by 6 and 10 per cent, respectively, in 2014 (HCDA, 2014). This was because of increased awareness of their nutritional and health benefits. In addition, the role of the World Vegetable Center (AVRDC) in enhancing and promoting the AIV value chain cannot be ignored (Palada *et al.*, 2006; Ojiewo *et al.*, 2010; Ochieng *et al.*, 2016). The organisation has been instrumental in genetically enhancing local cultivars and making advances in breeding for resistance/tolerance to biotic/abiotic stresses. It is important to note that although locally adapted seeds have been developed, farmers are more likely to use their own informally produced seeds. In Western Kenya, for example, farmers have been found to produce, distribute and store their own seeds among themselves (Abukutsa-Onyango, 2007). Generally, it has also been documented that less than 10 per cent of the crop seed planted in Africa is purchased from the formal market each year (Rohrbach *et al.*, 2003). This means that farmers may not benefit from the opportunities that could be exploited by using locally adapted modified seed varieties. Additionally, previous studies on AIVs have focused on their diversity, consumption, nutritional value, demand and commercial importance (Habwe *et al.*, 2009; Yang and Keding, 2009; Oluoch *et al.*, 2009; Weinberger and Pichop, 2009; Maundu *et al.*, 2009; Pasquini *et al.*, 2009; Abukutsa-Onyango, 2010; Chagomoka *et al.*, 2014; Gido *et al.*, 2017). The present study recognises the fact that a great deal of research has been carried out to document farmers' perceptions of CC, but very few have provided evidence linking location-specific perceptions of the impact of CC on particular crops such as AIVs. This study therefore contributes new knowledge about local perceptions of CC and its impact on AIV production in light of the uncertainty around future rainfall patterns, very different agro-climatic conditions and the gap in academic literature. Knowledge of this will be important in informing institutional and policy support programmes aimed at promoting specific adaptations in Africa targeted locally and at specific crops. This may enable farmers to exploit the full potential of these AIVs in a constantly changing climate. In connection with this, four distinct questions were addressed in this study:

- *Q1.* How do AIV farmers perceive CC in three different agro-climatic zones (ACZs) in Kenya?
- *Q2.* What are the main differences between the zones in historical rainfall and temperature trends?
- *Q3.* Is there any association between farmers' perceptions and the agro-climatic location?
- *Q4.* What impact do these perceived changes and trends have on yields, weeds, pests and disease infestation of AIVs?

2. Research methodology

2.1 Study areas

The study area comprised three purposively selected ACZs in Kenya (Figure 1). Kenya is divided into seven ACZs by vegetation characteristics, the amount and reliability of rainfall and the land's ecological potential (Bryan *et al.*, 2013). The high to medium potential areas comprise ACZs I (humid), II (sub-humid) and III (semi-humid). Humid and sub-humid zones are well-watered, support arable agriculture and have a high population density, with annual rainfall above 800 mm (MAFAP, 2013). Marginal or low potential areas comprise ACZs IV (semi-humid to semi-arid), V (semi-arid), VI (arid) and VII (very arid) and constitute arid and semi-arid land or rangelands. These areas are generally hot and dry, with low and unpredictable rainfall of less than 600 mm per year (FAO, 2010).

Kakamega County (humid zone I) lies between longitudes 34° and 35° east and latitudes 0° and 1° north of the equator and within altitudes of 1,250-2,000 m above sea level (Barasa *et al.*, 2015a and b). The total area of Kakamega County is 3,020 square kilometres and it has a population of 1,660,651 (GoK, 2013b). Its climate is predominantly hot and wet most of the year, with mean annual rainfall of between 1,800 and 2,000 mm. The mean monthly rainfall trend represents maximums and minimums over the year. The maximums occur in April to June and August to November (GoK, 2013b). Generally, there are two main cropping seasons in most parts of the county that coincide with the "long rains" and "short rains". The "short rains" fall between March and May, while the "long rains" fall between October and December (Kabubo-Mariara and Karanja, 2007). The average temperature in the county is 22.5°C. January and February are generally considered dry months (Barasa *et al.*, 2015a). The county has high temperatures all year round, with slight variations in mean maximum and minimum ranging from 28°C to 32°C and 11°C to 13°C, respectively. The mean annual evaporation is high and ranges from 1,600 mm to 2,100 mm with high humidity (Ngetich, 2013).

Nakuru County (semi-humid zone III) lies within the Great Rift Valley. The county covers an area of 7,235.3 square kilometres and is located between longitudes 35° and 35° east and latitudes 0° and 1° south (GoK, 2013b). The county is between 1,520 and 2,400 m above sea level. The temperature varies between 24°C and 29.6°C. The zone is characterised by a bimodal rainfall pattern, with a high of 1800 mm and a low of 500 mm (Ogeto *et al.*, 2013;).

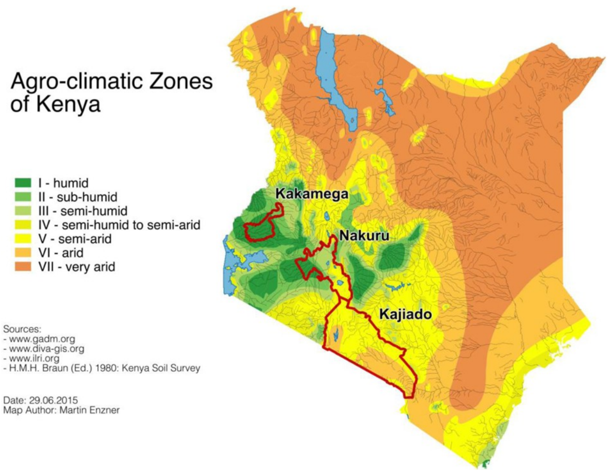

Figure 1.
Map of study areas

Kajiado County (semi-arid zone V) has a population of 687,312 and occupies an area of 21,902 square kilometres (GOK, 2009a). It is located between longitudes 360° 5' and 370° 5' east and between latitudes 10° 0' and 30° 0' south. The county has two distinct rainy seasons: a long rainy season from March to May and a short rainy season from October to December (Babadoye *et al.*, 2014; GoK, 2014). The distribution of rainfall between the two seasons changes gradually from east to west across Kajiado County. In eastern Kajiado, more rain falls during the long rains (March-May). The mean annual rainfall ranges from 300 to 800 mm (GOK, 2009b). The main characteristics of the three selected ACZs are presented in Table I.

2.2 Sample size and sampling procedure

A multi-stage purposive sampling procedure was used to select respondents for the study. In the first stage, three counties were selected that reflected the considerable variation in climate across the country. These were Kakamega, Nakuru and Kajiado Counties. In the second stage, a purposive sampling method was used to select two sub-counties with high potential AIV production. In Kakamega, the sub-counties of Butere and Lugari, in Nakuru the sub-counties of Rongai and Bahati and in Kajiado the sub-counties of Kajiado North and Kajiado West were selected. To obtain participants for the focus group discussions (FGDs), purposive sampling was used to identify AIV farmers. Local extension workers were helpful in recruiting participants. In all, 18 FGDs were conducted involving a total of 211 farmers. Eight FGDs (four in each sub-county), six (three in each sub-county) and four (two in each sub-county) were held in Kakamega, Nakuru and Kajiado counties, respectively. FGDs generated information on farmers' perceptions of CC, the effects of climate on AIV production and the sensitivities of AIVs to climate. Each FGD lasted between 1 h and 1 h and 45 min. In the last stage, using the snowball sampling technique, 269 interviews were conducted with smallholder AIV farmers from the three selected ACZs. Interviews were conducted with 100, 107 and 62 AIV farmers in Kakamega, Nakuru and Kajiado Counties, respectively, 93 of whom were male and 176 were female. The interviews with farmers generated information about their perceptions of the changing climate. To understand the effect of CC on AIV production, the influence on yield, pests, diseases and weeds was assessed. This was because of the fact that other than having direct effects on plant productivity, the changes in climate variables also significantly influence productivity through indirect effects mediated by changes in weeds, pests and diseases (Thomson *et al.*, 2010; IPCC, 2014).

The sample summary for the study is given in Table II.

Table I.
Main features of the study areas

County	Kakamega (ACZ-II)	Nakuru (ACZ-III)	Kajiado (ACZ-V)
Agro-climatic zone	humid	semi-humid	semi-arid
No. of sub-counties	12	11	5
Rural/urban character	rural	peri-urban	peri-urban
Population	1,660,651	1,603,325	687,312
Poverty status (%)	53	40.1	11.6
Mean temperature max.	29°C	20°C	34°C
Mean temperature min.	18°C	15°C	22°C
Mean precipitation p.a.	2,000 mm	800 mm	300 mm

Source: Stöber *et al.* (2017)

2.3 Data

The study used data collected from farmers combined with climate data to assess the impact of CC on AIV production. Farmers' perceptions of CC were then compared with historical trends from meteorological data. Perception here follows the definition of Ndamani and Watanabe (2015) as the process by which organisms (humans) interpret and organise sensations to produce a meaningful experience of the world. Farmers were asked to describe the changes in CC parameters. These parameters – expressed as changes in mean temperatures, amount of rainfall, the frequency, duration and intensity of dry spells and droughts, the timing, duration and intensity of rain, the start/end of growing seasons, the frequency and intensity of storms and floods – were analysed in this study. Previous studies of such as Mertz *et al.* (2009), Kabubo-Mariara and Kabara (2015), Babatolu and Akinnubi (2016) and Dhanya and Ramachandran (2016) have followed similar approaches.

To examine trends in rainfall and temperature, climate data (rainfall and temperature) from Kenya Meteorological Services (KMS) for the respective counties were analysed. The data obtained from KMS were monthly minimum and maximum temperatures (°C) and rainfall (mm) from 1980 to 2014 for the three ACZs. The data were supplied by three reference weather stations: Kakamega town for the humid zone of Kakamega, Jomo Kenyatta International Airport (JKIA) for the semi-arid zone of Kajiado and Nakuru town for the semi-humid zone of Nakuru. These climate parameters were selected because they have the longest and widest data coverage in the country and are the most common climatic variables considered by many studies in SSA (Ochieng *et al.*, 2016). Furthermore, among small-scale farmers, rainfall is the most important climatic factor critical to their survival, particularly in relation to crop growth (AGRA, 2014). During data screening, the last-observation-carried-forward (LOCF) method was used in cases where numerical values were missing. LOCF is a common statistical approach in the analysis of longitudinal repeated measures data in which some follow-up observations may be missing. In a LOCF analysis, a missing follow-up visit value is replaced by (imputed as) that subject's previously observed value, i.e. the last observation is carried forward. The combination of observed and imputed data is then analysed as though no data were missing (Lachin, 2016). To avoid biased results, the dataset was checked for outliers. In this case, extreme data values were replaced by seasonal or annual average values.

2.4 Data analysis

2.4.1 Survey data analysis. Qualitative and quantitative data were collected in parallel and then analysis for integration of the sets of data was undertaken. Finally, the two forms of data were analysed separately and then merged (Fetters *et al.*, 2013). A statistical package for social sciences was used to analyse quantitative data. Percentages and frequencies were used to represent farmers' perceived long-term changes in temperature and rainfall.

ACZ	County	Sub-county	Farmers interviewed	No. of FGDs	No. of farmers in FGDs
Humid	Kakamega	Butere	50	4	41
		Lugari	50	4	41
Semi-humid	Nakuru	Bahati	54	3	35
		Rongai	53	3	33
Semi-arid	Kajiado	Kajiado North	31	2	14
		Kajiado South	31	2	17
Total			269	18	211

Table II.
Sample summary

Contingency tables and chi-square tests were performed to investigate whether there was any association between farmers' perception of CC and their location. The hypothesis which stated that there is no association between farmer perception and ACZ was tested at a $p < 0.05$ level of significance.

Qualitative data collected during the FGDs were analysed using qualitative content analysis. The transcription of the audio recordings of the FGDs in the sample areas was translated from Kiswahili into English. The transcriptions were studied repeatedly to develop an analysis structure. A systematic process described by Hsieh and Shannon (2005) involved the development and identification of themes and patterns identified through a series of coding cycles. In accordance with Newing (2011), data from FGDs were illustrated by direct quotations, recounting particularly relevant experiences and the views of smallholder farmers, which are essential for the findings' authenticity. Samples of quotations from the interviews and FGDs depicting the differences and similarities between the changes in climate perceived by farmers from the study sites are presented in tabular form.

2.4.2 Trend analysis.

2.4.2.1 Mann–Kendall test. The Mann–Kendall test is a non-parametric test that does not require the data to be normally distributed and has low sensitivity to abrupt breaks because of inhomogeneous time series (Tabari *et al.*, 2011). The test has been widely recommended by the World Meteorological Organization for public application (Mitchell *et al.*, 1996). Furthermore, studies of Mkonda and He (2017), Karmeshu (2012), Mavromatis and Stathis (2011), Tabari *et al.* (2011), Longobardi and Villani (2009) and many others have valued the use of this test for evaluating trends in climatic data. In this test, each value in the series is compared with others, always in a sequential order (Jaiswal *et al.*, 2015). The trend analysis of long-term climate data was performed to ascertain the changes in climate patterns and analyse the relationship between farmers' perceptions and climatic facts. Addinsoft's XLSTAT 2017 software was used to perform the statistical Mann–Kendall test in this study. The null hypothesis was tested at a 95 per cent confidence level for both temperature and rainfall data for the three ACZs. According to this test, the null hypothesis assumes that there is no trend (the data are independent and randomly ordered) and this is tested against the alternative hypothesis, which assumes that there is a trend (Longobardi and Villani, 2009).

2.4.2.2 Linear regression. Linear regression is a non-parametric test that was used to study trends in rainfall and temperature change data. Regressions are used to estimate temporal trends in rainfall records. The suitability of data for regression analysis and the interpretation of results are taken from case studies that have applied a similar approach (Longobardi and Villani, 2009; Nyatuame *et al.*, 2014). Microsoft Excel was used to conduct linear regression analysis. In the linear regression test, a straight line is fitted to the data and the slope of the line may or may not be significantly different from zero (Jaiswal *et al.*, 2015). In addition, trend lines were plotted for each of the ACZs. The value of R-squared (R^2) or the square of the correlation from the regression analysis was used to show the strength of the correlation and relationship between variables X and Y. The value is a fraction between 0.0 and 1.0. An R^2 value of 1.0 means that the correlation is strong and all points lie on a straight line, while an R^2 value of 0.0 means that there is no correlation or linear relationship between X and Y (Nyatuame *et al.*, 2014).

2.4.2.3 Analysis of variance and least significant difference. One-way analysis of variance (ANOVA) was used to determine whether there were significant differences in the mean annual rainfall between the three climatic zones in the region. Least significant difference (LSD) was used to test the variance between the means.

The hypothesis stated that:

H0. There is no significant difference in the mean annual rainfall between the climatic zones in Kenya.

H1. There is a significant difference in the mean annual rainfall between the climatic zones in Kenya.

3. Results and discussion

3.1 Farmers' perceptions of climate change

AIV farmers in Kenya have perceived a notable change in climate in recent years across the study areas (Tables III and IV). The three ACZs differ from each other with respect to ecological and climatic conditions, but also with respect to CC scenarios. Extremes in temperatures have mostly been reported by farmers. In the humid zone, for example, farmers agreed that extremes in temperature prevailed in the area both during the day and at night. For instance, farmers reported that "when it is hot, it is extremely hot and when it is cold, it is extremely cold". In the semi-arid zone, farmers particularly noted that temperatures were very high during the day and very low at night (Table III). Approximately, more than 70 per cent had observed an increase in temperatures in all the zones, while less than 23 per cent had perceived a decrease in temperatures in the past 20 years. These results are in agreement with the findings of numerous studies from Africa, which report that farmers have perceived an increase in temperatures (Babatolu and Akinnubi, 2016; Limantol *et al.*, 2016; Bobadoye *et al.*, 2016; Sanogo *et al.*, 2016; Mutunga *et al.*, 2017; Mkonda and He, 2017; Fadina and Barjolle, 2018).

Farmers in all three zones also reported a change in the amount of rainfall. In the humid zone, farmers' perceptions were that rainfall has increased, whereas in the semi-humid zone and semi-arid zone farmers perceived that the rains had generally decreased over the years and were not sufficient. Erratic rainfall patterns were also reported in all the study areas. In the humid zone (Kakamega), farmers perceived that the rains that used to come regularly during the planting season in previous years have now become more unpredictable. Similar observations were made regarding the onset and cessation of rain in the three zones. In the humid zone, the majority noted that the rain mostly started late and ended early. In the humid zone, farmers furthermore said that "in the 1980s and 90s, rainfall was regular from March to May and July to December, but now the seasons are no longer predictable". Additionally, farmers noted that "long rains are no longer long rains and short rains are no longer short rains, seasons are scattered". These results are in agreement with many studies such as those by Limantol *et al.* (2016), Sanogo *et al.* (2016), Dhanya and Ramachandran (2016), Bobadoye *et al.* (2016), Mutunga *et al.* (2017), Mkonda and He (2017), Fadina and Barjolle (2018) and Williams *et al.* (2018). These authors confirm that farmers perceived less rain, a decreased duration and of rainy seasons and unpredictable and irregular rainfall patterns.

Besides season duration, this study revealed that changes in the intensity of the rainy seasons had also been observed in the study areas. More than half perceived that the intensity of the rainy seasons had increased in the humid and semi-arid zone, while only 34 per cent had perceived this in the semi-humid zone. It is notable that many farmers observed that the rains were unpredictable/unreliable, with clear changes in rain onset. More than half of the farmers noted that rains started late. For example, in the semi-humid zone (Nakuru), the majority of the farmers agreed that "in the past, rain started in March and ended in August, but now it starts in late April and ends in June" (Table III). Other results from this study also revealed that farmers have observed clear changes in rain cessation. There was

Characteristic/ parameter	Temperature	Rainfall	Dry spell	Flood/hailstorm
Humid Zone Amount and frequency	Temperatures have generally increased	Heavy rains Rains mostly come late	Frequent dry spells	More floods and waterlogging problems
Duration/ intensity	When it is cold, it is extremely cold and when it is hot, it is extremely hot	Rainy seasons are short but intense	Dry spell intensity is high	–
Variability/ change	Higher than in the past even during rainy season High during the day and low during the night	Rain is unpredictable Seasons are scattered		–
Semi-humid zone Amount and frequency	Increase in temperatures	Delayed onset of rain and planting Rainfall is no longer predictable	Drought is very common in the area Recent drought in 2014 was severe	Floods have increased
Duration/ intensity	Very high during dry season and very low in wet seasons	Rainfall has declined in the area and has been inadequate	Increase in intensity Longer dry spells	
Variability/ change	High volatile temperature	Unreliable and unpredictable rainfall Large change in seasons		Large amounts of rain cause floods, as in 2012 and 2013
Semi-arid zone Amount and frequency	Increased temperatures Temperatures are high during the night	There is not enough rain/rainfall has decreased in recent years	Dry spells have increased Since 2000, there have been more droughts	
Duration/ intensity	Extreme temperatures	Rainy seasons are short Rain started in mid-March and ended in August, but now it ends in June	Prolonged and intense dry spell Droughts last up to one year and farming is temporarily abandoned	–
Variability/ change	Temperatures are very high, even during rainy season	Rainfall is erratic, unreliable and onset is delayed	In 2014 and 2015 the dry spell was harsh and of high intensity Unpredictable droughts	–

Table III. Statements on change in climate parameters in ACZs

an overall agreement by more than 60 per cent of the farmers that the rains ended early, while less than 26 per cent in each of the zones perceived that they ended later. Similar observations have been reported in various studies (Apata *et al.*, 2009; Gandure *et al.*, 2012; Ochenje *et al.*, 2016; Fadina and Barjolle, 2018), which confirm that farmers perceive a delayed and decreased amount of rainfall and an early cessation of it. For example, in research on farmers' awareness of climate variability in Kenya, farmers experience excessive downpours and the rainfall has become unreliable, appearing out of season

(Barasa *et al.*, 2015b). Similarly, in a study in Tanzania, farmers declared that rainfall onset has changed because they used to plant crops in October/November, but the season has now shifted to December/January (Lema and Majule, 2009). Besides changes in the start and end of the rainy seasons, the findings from the semi-humid and semi-arid zones in the present study agree with those of other studies who report farmers' observations of a general decrease in the amount of rainfall (Limantol *et al.*, 2016; Mutunga *et al.*, 2017). In line with these findings, Mugalavai *et al.* (2008) argued that early onset translates into early cessation, while for the short rains, early onset translates into a longer growing season.

The interviewed farmers notably observed an increase in the frequency, duration and intensity of dry spells. More than half of the farmers in the semi-humid and semi-arid zones perceived that the frequency of dry spells had increased, while 36 per cent from the humid zone did so. Over half the farmers in the humid and semi-arid zones perceived that the duration of dry spells had increased, while 30 per cent in the semi-humid zone did so. Evidence of the perceptions of farmers in Zambia and Benin agrees with these findings. The authors reported that farmers were experiencing prolonged and frequent dry spells (Nyanga *et al.*, 2011; Sanogo *et al.*, 2016; Fadina and Barjolle, 2018).

Overall, more than half of the interviewed farmers had also experienced droughts (Table IV). Approximately 30 per cent of them perceived that the frequency of droughts

	Name of ACZ				
Perceptions	Kakamega (humid) n =	Nakuru (semi-humid) n =	Kajiado (semi-arid) n =	Total $N = 269$	χ^2 (p-value)
Rain onset early	17	7	45	19.7	38.72****
Late	76	90	52	75.8	(0.000)
No change	7	3	3	4.5	
Rain cessation early	63	93	72	77.3	36.31 ****
Late	23	5	26	16.4	(0.000)
No change	14	2	2	6.3	
Duration of rain season					11.18 **
Increased	23	11	23	18.2	(0.025)
Decreased	65	84	71	74	
No change	12	5	6	7.8	
Temperature					0.421
Increased	79	81	77	79.3	(0.810)
Decreased	21	19	23	20.7	
No change	0	0	0	0	
Dry spell frequency					18.19 ****
Increased	36	57	53	48.3	(0.001)
Decreased	37	13	26	24.9	
No change	27	30	21	26.8	
Drought frequency					
Increased	30	55	34	41.8	26.05 ****
Decreased	53	13	46	34.1	(0.000)
No change	17	32	20	24.2	
Drought duration					
Increased	40	65	0	50.5	16.01 ****
Decreased	58	30	59	46.7	(0.003)
No change	2	5	41	2.7	

Note: **** and ** indicate a statistical significance at $p < 0.01$ and $p < 0.05$ respectively

Table IV. Percentage distribution and correlation between farmers' perceptions and ACZs had increased, while the remainder perceived that it had decreased. In the semi-arid zone (Kajiado), farmers agreed that the most recent drought occurred in 2014 and was very severe. The Kajiado County integrated development plan 2013-2017 agrees that Kajiado County is characterised by cyclical and prolonged droughts, which confirms the findings of this study (GoK, 2014). Furthermore, these findings are a confirmation of the perceptions of climate documented for farmers in the Sahel and Benin. According to those studies, farmers perceive less rain, longer dry spells and a reduced number of rainy seasons (Mertz *et al.*, 2009; Fadina and Barjolle, 2018). Similarly, in recent years, increased incidences of extreme droughts have also been reported in studies such as those by Sanogo *et al.* (2016), Mkonda and He (2017).

The interviewed farmers also confirmed that hailstorms were common in the humid zone. According to the farmers, the number of storms had increased over time, resulting in flash floods that wash away their crops. They mentioned that "short rains turn into hailstorms that come with strong winds and destroy our crops, including vegetables" (Table III). Barasa *et al.* (2015b) agreed that more farmers perceive an increase in the frequency of violent storms in Kakamega. In the humid zone, farmers stated that they had experienced frequent floods caused by heavy rains, leading to waterlogging problems. In the semi-humid region, only 20 per cent of farmers had experienced flooding. In the semi-arid zone, they stated that sometimes the rainfall is very high and causes floods. For instance, farmers mentioned that rainfall in 2012 and 2013 resulted in floods because it was too heavy. Similarly, hail stones, flooding and frequent droughts have also been reported by farmers in countries such as Ethiopia, Zambia, Senegal and Nigeria (Mertz *et al.*, 2009; Apata *et al.*, 2009; Mengistu, 2011; Nyanga *et al.*, 2011). The authors reported that farmers are experiencing increased frequency of floods, excess rainfall, violent rains and hailstorms. Globally, research shows that farmers' perceptions of the climate will inform their response to CC (Abid *et al.*, 2015; Fadina and Barjolle, 2018). It is therefore important to understand how farmers perceive climate in order to support effective context specific adaptations. Chi-square test results to determine the association between farmers' perceptions of CC for each ACZ are given in Table IV. The hypothesis stated that there is no relationship between farmers' perceptions and ACZ (*H0*). Except for the temperature and duration of the rainy season, the results showed a highly significant association with the ACZ at a $p < 0.05$ level of significance. This means that AIV farmers perceived different climatic parameters depending on the ACZ in which they live.

3.2 Results of the long-term average annual rainfall trends

A trend is a significant change over time exhibited by a random variable, detectable by statistical parametric and non-parametric procedures (Longobardi and Villani, 2009). Climate trends were analysed for both temperature and rainfall. Figure 2 shows graphs for 12-month precipitation accumulation observations for each of the three ACZs. A fitting of trend lines showed that there is increasing rainfall for Kakamega (humid) and Nakuru (semi-humid). The slope of the trend line was not very large in magnitude for Kakamega and Nakuru, but it was positive. Meanwhile, decreasing rainfall for Kajiado (semi-arid zone) over the 30-year period was noted. The slope of the trend line was not very large in magnitude for Kajiado, but it was negative. Based on the above results, it is of immense importance to discuss the potential impact on agricultural production if increasing and decreasing rainfall trends continue in these ACZs in future. Research has shown that excess rainfall, for instance, could lead to soil saturation, as well as to runoff, and soil erosion problems (Frunhoff *et al.*, 2007). However, it is important to note that a decrease in rainfall in future

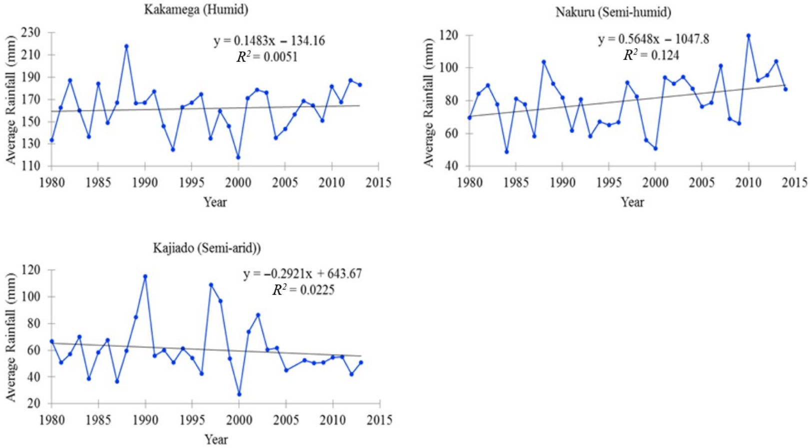

Figure 2. Mann–Kendall graphs showing average annual rainfall trends

could have repercussions on the sustainability of surface water resources and groundwater recharge (Green *et al.*, 2011).

To establish trends in average annual rainfall, the Mann–Kendall test was applied to climate data. The results in Table V were obtained for the three ACZs. If the *p*-value is less than the significance level α (alpha) = 0.05, *H0* is rejected. Rejecting *H0* indicates that there is a trend in the time series, while accepting *H0* indicates no trend is detected. On rejecting *H0*, the result is said to be statistically significant. For this test, *H0* was accepted for the three ACZs. Linear regression results, however, showed that the trend was only significant in the semi-humid zone (Table V).

3.3 Results of seasonal rainfall trends

In this study, only two seasons useful for crop production under a rain-fed system were considered. Normally, there are two cropping seasons in Kenya that coincide with bimodal rainfall regimes in which long rains fall between March and May (MAM) and the short rains between October and December (OND) [Famine and Early Warning System Network (FEWS NET, 2013)]. The Mann–Kendall trend line plotting for seasonal rainfall for the three ACZs is shown in Figure 3.

The analysis of the seasonal rainfall variations is important because of farmers' dependence on rain-fed vegetable production. The delays in rain onset, early cessation of rain and inadequate rainfall reported by farmers could mean that the seasons are getting shorter. An analysis of climate data showed that seasonal MAM mean rainfall was

Table V. Mann–Kendall test and regression analysis of mean annual rainfall data for the ACZs in Kenya

	Mann–Kendall test					Regression analysis		
ACZs	MK statistic (S)	Kendall's Tau	Var (S)	*p*-value	Test interpretation	Equation	R^2	*p*-value (slope)
Humid	65.0	0.12	4550.3	0.343	No trend	Y = 0.148 + 159.31	0.005	0.86
Semi-humid	137.0	0.23	4958.3	0.053	No trend	Y = 0.565x + 69.87	0.124	0.053**
Semi-arid	−76.0	−0.14	4165.3	0.245	No trend	Y = -0.433x + 69.25	0.036	0.36

Note: **Shows statistical significance at $p < 0.05$

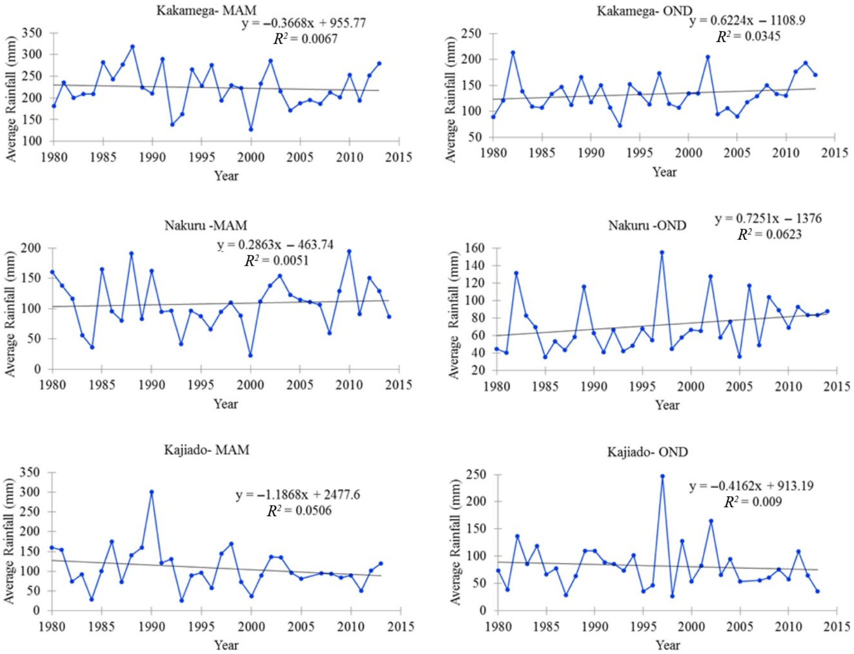

Figure 3.
Mann–Kendall graphs showing average annual seasonal rainfall trends

decreasing for the humid and semi-arid zones; however, it was increasing in the semi-humid zone. The OND mean rainfall was increasing for the humid and semi-humid zone but decreasing in the semi-arid zone. However, the Mann–Kendall test was statistically significant only for OND rains in the semi-humid zone. Otherwise there was no trend in either the MAM and OND rains in all three zones. However, the MK test result showed no trend in MAM and OND in the humid and semi-arid zones, and in MAM in the semi-humid zone since *H0* was accepted. Although the MAM and OND rainfall was increasing for the humid and semi-humid zones, and decreasing for the semi-arid zone, the regression analysis results showed that the change was not significant in the three zones (Table VI). Differences in mean annual rainfall between the three ACZs were tested using ANOVA (Table VII). Highly significant differences in mean annual rainfall were detected (F = 247.7944,

Table VI.
Mann-Kendall and Regression Statistics Results for the ACZs in Kenya

	Mann–Kendall test			Regression analysis		
ACZs	MK statistic (S)	*p*-value	Test interpretation	Regression equation	R^2	*p*-value (slope)
Humid						
MAM	−21.00	0.767	No trend	Y = -0.3668x+229.8	0.01	0.548
OND	77.00	0.260	No trend	Y = 0.6224x+122.85	0.04	0.293
Semi-humid						
MAM	41.000	0.570	No trend	Y = 0.2863x+102.84	0.01	0.741
OND	155.000	0.029	Trend detected	Y = 0.7251x+58.98	0.06	0.169
Semi-arid						
MAM	−80.000	0.221	No trend	Y = -1.2195x+129.11	0.05	0.189
OND	−66.00	0.314	No trend	Y = -0.7931x+102.98	0.02	0.565

P = 1.79E-39). The hypothesis that there is no significant difference in the mean annual rainfall between the climatic zones in Kenya over the 30-year period was therefore not accepted (*H0*). To determine which of the zones actually differed in terms of mean annual rainfall, multiple mean comparisons were performed using LSD. The results in Table VIII indicated that the mean difference in annual rainfall between the zones was highly significant for all the ACZs.

3.3.1 Results of the coefficient of variation in seasonal rainfall for the selected agro-climatic zones. This study also investigated variability through annual and seasonal meteorological time series. A coefficient of variation (CV) of 30 per cent or more is considered high (Thornton *et al.*, 2014). Rainfall in the two growing seasons was highly variable, with a CV ranging from 31 to 105 per cent (Table IX). This was shown in all three zones except in May and October (29 per cent) in the humid zone. These climate data confirmed farmers' perception that the rainfall in the study areas was highly variable. According to Mamba *et al.* (2015), an analysis of farmers' perception of CC in Swaziland shows that rainfall variability presents a great challenge to farmers. It makes rainfall highly

Source of variation	Sum of squares	df	MS	F	*p*-value	*F* crit
Between groups	191329.7	2	96164.85	247.7944	1.79E-39****	3.09
Within groups	38808.32	100	388.08			
Total	231138	102				

Table VII. Analysis of variance of mean annual rainfall between ACZs in Kenya

(I) Zone	(J) Zones	Mean difference (I-J)	Std. Error	Sig.	95% confidence interval Lower bound	Upper bound
Semi-arid	humid	−99.6*	4.8	****	−109.1	−90.1
	Semi-humid	−17.7*	4.7	****	−27.1	−8.3
Humid	Semi-arid	99.6*	4.8	****	90.1	109,.1
	Semi-humid	81.9*	4.7	****	72.5	91.3
Semi-humid	Semi-arid	17.71*	4.7	****	8.3	27.1
	Humid	−81.9*	4.7	****	−91.3	−72.5

Note: ****Shows significance at $p < 0.001$ level

Table VIII. LSD Multiple comparisons of mean annual rainfall in the ACZs in Kenya from 1980 to 2014

	Mean			SD			CV (%)		
	Humid	Semi-humid	Semi-arid	Humid	Semi-humid	Semi-arid	Humid	Semi-humid	Semi-arid
March	163	66	74	77	50	54	47	75	73
April	259	134	132	81	68	69	31	51	52
May	248	124	120	73	74	116	29	60	96
October	163	85	54	47	40	57	29	47	106
November	150	86	115	66	42	70	44	49	61
December	89	45	80	62	39	56	69	87	70

Notes: SD = standard deviation; CV = coefficient of variation

Table IX. MAM and OND seasonal variability of rainfall unpredictable and tends to confuse farmers. Increased rainfall variability will affect agricultural growth and economic development. CC and increased climate variability, through their impact on food production, will have a negative impact on the prevalence of undernutrition, increasing severe stunting by 62 per cent in southern Asia and 55 per cent in eastern and southern Africa by the 2050s (Lloyd *et al.*, 2011).

3.4 Results of temperature trends in the selected agro-climatic zones of Kenya

Figure 4 shows graphs for the 12-month average maximum and minimum temperatures for each of the ACZs of Kakamega (humid), Nakuru (semi-humid) and Kajiado (semi-arid). The results showed an increase in both the maximum and minimum temperatures by 0.02°C and 0.08°C in the humid and semi-arid zones, respectively. The climate data agreed with farmers' perceptions in the two zones. Even though the farmers in the semi-humid zone perceived increased temperatures, the climate data showed a decreasing trend in the annual maximum temperature.

For the temperature data, the Mann–Kendall test was statistically significant for all three ACZs, except the maximum and minimum temperatures in the semi-humid and semi-arid zones respectively (Table X). In this case, *H0* was rejected, thereby implying that there was a trend in the data for the two zones. With temperature showing an increasing trend for the three ACZs over the 30-year time period, it is essential to understand how this may affect AIV production if such a trend continues. It also confirms recent findings by Bobadoye *et al.* (2016) and Mulinya *et al.* (2016).

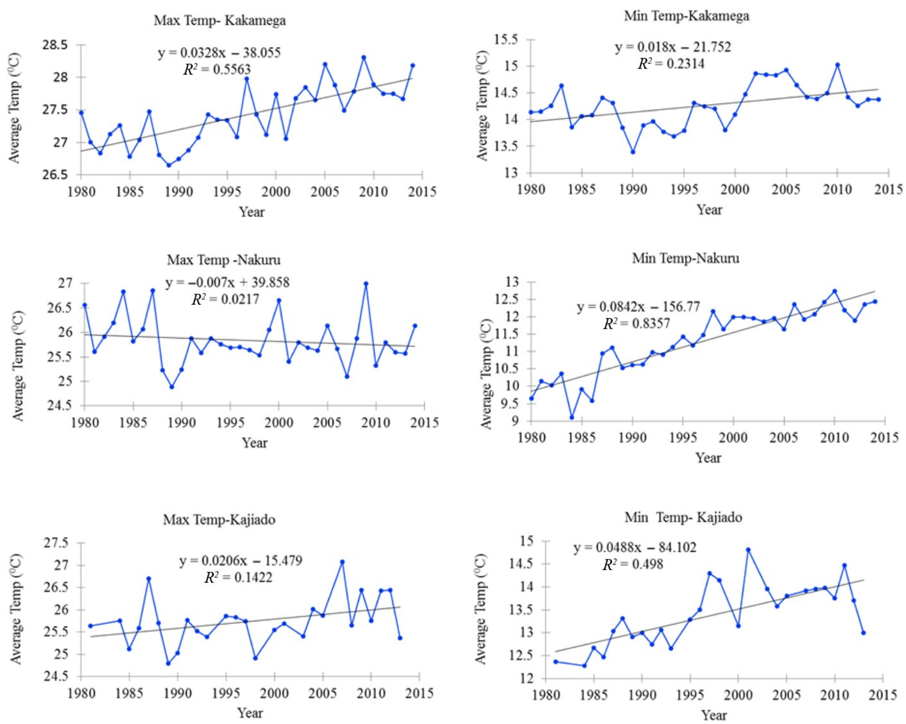

Figure 4.
Mann–Kendall graphs for annual maximum and minimum mean temperatures

3.5 Farmers' perceptions of the effect of changing climate on African indigenous vegetable production

The most common AIVs produced across the study areas included cowpea *(Vigna unguiculata)*, jute mallow, African nightshade (*Solanum villosum*), pumpkin leaves (*Cucurbita moschata)*, amaranth (*Amaranthus* sp.) and spider plant (*Cleome gynandra*). The least produced included Ethiopian kale and African spinach and slender leaf (*Crotolaria* sp.). It is worth noting that the impact of CC on AIV production is both positive and negative. The findings of this study clearly revealed that AIV farmers in the study areas had noted that the climate is indeed changing. Farmers' perceptions discussed in this paper show that the humid, semi-humid and semi-arid zones of Kenya already face a range of CCs that include more frequent, heavy or inadequate rainfall events, erratic rainfall and unpredictable onset/retreat of rain and change in the duration of dry spells characterised by increasing temperatures. The negative effects on these CCs described by AIV farmers that are predicted to have implications on AIV production cannot be ignored. The two major parameters of CC that have far-reaching implications on agriculture in general, and horticulture in particular, are more erratic and inadequate rainfall patterns and unpredictable high temperatures (Datta, 2013). According to Thornton *et al.* (2013), CC is already affecting the amounts, distribution and intensity of rainfall in many places in the tropics. This has direct effects on the timing and duration of crop-growing seasons, with related effects on plant growth. Research has shown that farming activities rely on favourable climate conditions and are at risk from a changing climate (Porter *et al.*, 2014). Changes in yields, weeds, pests and diseases of AIVs in two different conditions, the rainy season and the dry season, are discussed in this study.

Table XI: Changes in the pests and diseases of AIVs because of CC.

An understanding of the impact of CC conditions on the distribution and intensity of plant pests and diseases is important in informing decisions that will lead to better ways of managing them in a changing climate. Perceived changes in the severity and frequency of attacks by pests and diseases varied with the seasons and also with the type of AIVs. There was uniform agreement among farmers that AIVs, for instance, cowpea, were affected by some pests, which included aphids and whiteflies *(Bemisia tabaci)*, with increased incidences of disease such as rust *(Uromyces anthyllidis)* during the dry spells, while in the wet season farmers noticed that cowpea was affected by a number of pests and diseases.

	Mann–Kendall				Regression analysis			
ACZs	MK (S)	*p*-value	Sig.	Test interpretation	Equation	R^2	*p*-value (slope)	
Kakamega (Humid)								
Max	312.0	0.0001	****	trend	Y = 0.0032x + 26.83	0.56	0.0007	****
Min	182.0	0.010	***	trend	Y = 0.0394 + 27.08	0.23	0.0657	
Nakuru (Semi-humid)								
Max	−73.0	0.306		no trend	Y = -0.007 + 25.96	0.022	0.020	***
Min	454.0	0.0001	**	trend	Y = 0.04x + 9.9.78	0.84	1.15E-13	****
Kajiado (Semi-arid)								
Max	83.0	0.087		no trend	Y = 0.0239x + 25.41	0.12	0.5423	
Min	184.0	0.000	****	trend	Y = 0.598x + 12.564	0.51	0.000	****

Notes: ****, *** and ** indicate significance at $p < 0.001$, $p < 0.01$ and $p < 0.05$ respectively

Table X. Mann–Kendall and regression statistic results for annual maximum and minimum temperatures for ACZs

Table XI. Comparison of the changes in sensitivities of common AIVs to changes in rainfall

AIVs	Changes in sensitivities of AIVs because of too much rain			Changes in sensitivities of AIVs because of dry spell/drought/no rain		
	Yield	Pests and diseases	Weeds	Yield	Pests and diseases	Weeds
Cowpea	Heavy unpredictable downpours reduce yield and quality (turns yellow)	Changes observed – many pests. High severity of black spot on the leaves	Increased weeds	No changes	Many pests and diseases have occurred	Weeds remain low (no changes)
Nightshade	No change in yield (yield remains high)	Changes observed – high severity of blight, Frequent pests such as spider mite Frequent moderate infestation of diseases such as bacterial wilt and powdery mildew	Emergence of new weeds that farmers do not recognize	Moderate yield reduction Tough leaves	Sudden dry spells and drought cause moderate to high severity of pests such as spider mite and white flies observed Frequent high severity of diseases such as bacterial wilt and powdery mildew	no observed changes
Spider plant	Not affected by too much rain if germination has occurred	Changes occur but few pests and moderate severity of diseases have been observed		Moderate yield if dry spell/drought is not prolonged Tough leaves	Few pests and moderate severity of diseases have been observed	No observed changes in weeds
Amaranth	Not affected No change reported	No changes on pests and diseases		Yield change to moderate	No changes	No observed changes in weeds
Pumpkin leaves	No change in yield	No changes observed		Reduced yield	No changes observed	No observed changes in weeds

Source: Focus group discussion, 2015

Increased infestation of pests and diseases was also reported in nightshade during the dry season. Pests reported in this period included red spider mites (*Tetranychus urticae*), which cause yellowing of leaves, while aphids (Aphis spp.) affect quality because they cause leaves to curl and shrink. Importantly, farmers agreed that attacks by aphids had become more common in recent years. Thus, continued droughts and dry spells coupled with high temperatures caused by CC are expected to alter the manifestation of pests and diseases for some AIVs. In agreement, Abang *et al.* (2014), noted that aphids are the most recurrent insect pests in vegetable crops. Findings from this study also revealed that increased wilting of nightshade caused my nematodes has been recurrent in recent years. During the rainy season, some pests, for example, spider mites, are reported with a moderate recurrence of diseases such as bacterial wilt (*Ralstonium solanacearum)* and powdery mildew (*Erysiphe polygoni, Laveillula taurica*), which affect the yield and quality of nightshade. Furthermore, farmers have observed frequent and severe attacks by bacterial blight (*Clavibacter michiganense pv. michiganense)* in African nightshade in recent years because of too much rain. A moderate to high severity of pests such as spider mites and whiteflies in African nightshade is reported during dry spells and droughts. Farmers noted that changes in attacks by these pests in spider plants were higher during dry season as opposed to the rainy season. In agreement, Stöber *et al.* (2017) noted that a lack of rainfall and extreme heat cause wilting, attract pests and reduce yields. Overall, a high attack of blight, mildew and wilt are the most serious diseases in AIV production noted by farmers in the recent past. This could be because high moisture caused by frequent and extreme rainfall events creates favourable environments for diseases, destroying fields and causing nutrient leaching (Stöber *et al.*, 2017). Datta (2013) confirmed that more extreme weather may make certain diseases (such as rust and powdery mildews) more sporadic and encourage those that develop quickly in warm conditions.

Farmers also agreed that no clear changes in pests and diseases for amaranth and pumpkin leaves had been detected either during the dry or the wet seasons. Abang *et al.* (2014) confirmed that insect pest attacks are more numerous in the dry season and diseases are more problematic in the rainy season. Crop resistance and pest dynamics are altered by CC, creating more complex challenges for the management of pests and disease (Keatinge *et al.*, 2010). Rain, heavy dews, warm temperatures and dry climates have been identified as causes of increased pests and diseases (Abang *et al.*, 2014). Research has shown that pests and diseases are important constraints to vegetable production in the tropics. Plant pests and diseases are one of the important factors that have a direct impact on global agricultural productivity, and CC will further aggravate the situation. Further changes in temperature could directly affect the spread of infectious diseases and their survival between seasons (Gautam *et al.*, 2013). Overall, CC is predicted to have a direct impact on the occurrence and severity of diseases in crops, which will have a serious impact on food security (West *et al.*, 2015; Gautam *et al.*, 2013). Similarly, Gregory *et al.* (2009) noted that CC is already altering the distribution and intensity of weeds and plant pests and diseases.

3.5.1 Changes in weeds in African indigenous vegetable production because of climate change. Besides altering yields, pests and disease infestation, CCs also influence the manifestation of weeds in vegetable production. Weeds are undesirable, unattractive or troublesome plants, not intentionally grown, especially when they grow where they are not wanted, such as in gardens or agricultural fields (Prakash *et al.*, 2015). For all the common AIVs grown by the farmers in the study areas, weeds grew and spread more quickly in the wet season than in the dry season. High weed growth during the rainy season has led to competition and more pest and disease incidence because of CC for some AIVs (Table X). One exception to this was pumpkins which, according to AIV farmers, do not allow weeds to grow, as they have large leaves that cover the ground entirely (Tables XI). The emergence of new persistent weeds was also reported by farmers in semi-humid and semi-arid zones. However, they stated that they were not knowledgeable about the names of the weeds. Although labour intensive, farmers in this case are forced to regularly weed their gardens. According to the farmers, this is necessary, as most AIVs only do well in weed-free plots and gardens. Research has also found that crops and weeds alike respond to elevated CO^2 concentrations or an increase in temperature in the atmosphere. As the weeds are found in the same agricultural fields in which crops grow, any change in weed behaviour will directly or indirectly depend on the relative advantage or disadvantage crops have because of CC (Prakash *et al.*, 2015). Weeds affect crop cultivation in many ways by reducing crop yield, stealing water, light, space and soil nutrients, producing substances that are toxic to crop plants, often serving as hosts for many crop diseases, and also providing shelter for insects and disease pests during their off-season (Prakash *et al.*, 2015).

3.5.2 Changes in the yield of African indigenous vegetables because of climate change. All the farmers agreed that there had been changes in terms of vegetable yield because of the combined effects of climate conditions (Table XI). It was apparent that rainfall and temperature changes had already posed some challenges to AIV production in Kenya.

Cowpea performs better with little rain. Farmers agreed that it germinates well with little water and the yield is good. However, farmers expressed concerns about unexpected heavy downpours and hailstones, which result in cowpea crops being lost. There was overall agreement that cowpeas are more sensitive to heavy rains. They turn yellow and are often completely destroyed. However, other vegetables, such as the spider plant, African nightshade, pumpkin leaves and amaranth, record high yields even in the heavy rainy season. In particular, farmers noted that the spider plant requires a lot of water and the yield is high during the wet seasons. However, the frequent prolonged dry spells and droughts experienced in the recent past have been the main challenge faced by farmers. They agreed that the spider plant is stunted during the dry season, and turns yellow and flowers early, therefore producing low yields. Farmers agreed that timing in the planting of AIVs such as spider plants was very important as heavy rains limit their germination. This means that the frequent and increased intensity of dry spells and droughts reported by farmers was a hindrance in their production. Farmers also mentioned that pumpkin leaves have thick succulent stems that store water to be used by the plant during dry spells. Overall, farmers agreed that they experienced yield reduction for all AIVs during the dry season but could generate a fair amount of money at the same time. In the humid zone, farmers experienced frequent hailstones that completely destroyed their vegetables. AIV farmers were aware of the type of vegetables that thrive under certain climatic conditions. Amaranth, jute mallow and pumpkin leaves were identified as most resistant to changes in yield reduction, pests and diseases. According to Stöber *et al.* (2017), AIVs thrive better in rainy seasons. This implies that as a matter of priority, to respond to these threats caused by CC, farmers need to combine adaptation strategies that address water, pests and disease problems in production. According to Thornton *et al.* (2013), changes in agricultural inputs and the way farmers use them may be able to more than offset projected yield declines by using adaptation options. These strategies may include, but are not limited to, a combination of more drought and pest-tolerant varieties of AIVs, water harvesting, irrigation, mulching and intercropping.

The most tolerant AIVs grown across all the ACZs were pumpkin leaves, wild amaranth, slender leaf, jute mallow and Indian spinach. In general, farmers agreed that AIVs register low sensitivities to climate variables compared to other vegetables. Luoh *et al.* (2014) confirmed that some indigenous vegetables are considered to have stronger water-stress adaptation mechanisms than common, commercially available vegetables. Additionally, Stöber *et al.* (2017) confirmed that many AIVs tolerate a wide spectrum of climate variability and are therefore considered less sensitive to climate variations. Despite this, farmers agreed that a high reduction in yields was observed whenever there was a prolonged dry spell or drought. Besides yield reduction, high temperatures also caused yellowing of leaves for some vegetables such as spider plant and African nightshade. For most AIVs, the leaves become tough during droughts. In the FGDs the majority of the farmers mentioned that they temporarily abandon AIV farming whenever there is a prolonged drought/dry spell because of a lack of water for irrigation. Additionally, theft of vegetables, which mostly occurs at night, was also reported by some farmers in the humid and semi-humid zones. This was attributed to the scarcity of the vegetables during the season. According to the farmers, AIVs are tastier during the dry season and they can be sold for a good price in markets. There is no doubt that AIV farmers in Kenya are more concerned now with the rising temperatures, heavy and or unpredictable rainfall patterns, prolonged droughts, frequent and prolonged dry spells, together with increased pests and disease problems. Even though the impact is not severe for AIVs, the findings of this study are in agreement with those of Ayyogari *et al.* (2014) and Mattos *et al.* (2014) who found that vegetables are generally sensitive to environmental extremes. Therefore, high temperatures and limited soil moisture are the major causes of low yields since they greatly affect several physiological and biochemical processes. Within the scope of this study, it was not possible to ascertain the extent of yield losses caused by the climatic conditions.

4. Conclusions and recommendations

Most of the research that has been carried out on AIVs has ignored and downplayed the range of potential effects on production caused by CC variables. AIV farmers are aware that their area is getting warmer and drier. Increased temperatures, an increased frequency of droughts and dry spells, late onset, early cessation and decreased rainfall, are among the major climate hazards reported. Climate data revealed no trends in the mean annual rainfall in the selected ACZs in Kenya, but the mean annual rainfall in the semi-humid zone is increasing significantly. The main constraining factors identified in AIV production were increased temperatures, erratic rainfall patterns and inadequate rainfall caused by frequent dry spells and droughts. Farmers were aware of the moderate effect of climate on AIVs. The current volatility in rainfall patterns has made it difficult for farmers to plan their cropping calendar to suit the changes. Therefore, CC adaptation programmes need to provide accurate projected weather patterns to farmers. This study also revealed that farmers' perceptions were significantly associated with their ACZs, while there are highly significant differences in the mean rainfall of the three ACZs. Severity of pests and disease are more prevalent in the dry season than in the wet season. Too much rain and frequent dry spell conditions caused by CC alter the infestation of pests and manifestation of diseases as well as growth of some new weeds. This has resulted in lower yields for AIVs. Changes in the manifestation of pests, diseases and weeds in some AIVs could imply that farmers may be pushed into applying pesticides and herbicides on their vegetables. There is therefore a need to make farmers aware of the need to use pesticides and herbicides sustainably, including integrated pest management practices, to reduce environmental damage. The changes in the severity of pests and diseases in spider plant and African nightshade calls for a development of more resistant cultivars of these AIVs. This could be designed within programmes aimed at ensuring that farmers benefit from opportunities offered by engaging in AIV production. To achieve this, it is important to ensure that farmers gain access to good quality and affordable resistant seed varieties. Farmers' perceptions and observed trends should be communicated to policy makers at local, national and international levels. This will provide a pathway for effective planning of context-specific adaptation options and climate communication programmes. However, further research is recommended to ascertain the quantity of yield losses because of pests, disease and CC.

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