***Octa Journal of Environmental Research***
International Peer-Reviewed Journal
***Oct. Jour. Env. Res. Vol. 4(3): 181-197***
Available online http://www.sciencebeingjournal.com

***Jul. – Sept., 2016***
ISSN 2321 3655

**Research Article**

Octa Journal of Environmental Research
(Oct. Jour. Env. Res.) ISSN: 2321-3655
Journal Homepage: http://www.sciencebeingjournal.com

# TREND ANALYSIS OF CLIMATE CHANGE AND ITS IMPACTS ON CASHEW NUT PRODUCTION (*Anacardium occidentale* L.) IN BENIN

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**Received**: 19th Jul. 2016 **Revised**: 12th Aug. 2016 **Accepted**: 1st Sept. 2016

**Abstract:** The study aims to analyze the past and future climate trends and their impact on cashew nuts yield in Benin. The linear adjustment with the time series analysis was conducted to assess trends of climatic factors and their effect on nut yields. Future climate has been generated using the downscaling method based from General Circulation Models (GCMs); CCCMA-CGCM3 and CNRM-CM3. A correlation analysis between the climatic data of the last 10 years and the cashew nut yields obtained was performed to assess the effect of each climatic factor. The results indicate that rainfall and temperature are marked by very remarkable inter-annual fluctuations. The last three five-year were significantly warmer than previous. The evolution of the average rainfall and temperature between 1970 and 2015 shows an increasing trend with rates ranging from 0.02% to 24%. The studied GCMs predict a decrease in the amount of rain up to 12% especially in the period from August to October by 2050. All GCMs agree on the occurrence of an increase in mean temperature to the order of 20% or even 30% *viz.* 4.02°C by 2100. the cashew nuts yields obtained on the last ten cropping seasons show a regressive trend in Centre, South and North -West with a regression rate ranging from 1.33% to 9.14%, while it exhibits an increasing trend in North–east with a growth rate of 0.11%. The rainfall did not influence the annual nuts production in Southern zone but the mean temperature of August and Potential Evapotranspiration (PET) of April have negative influence. The R square varies from 64% to 92%. From these results we can conclude that, rainfall from August to September (except South region), mean temperature and PET are the main factors that determine cashew productivity ($P<0.01$ to $P<0.001$). The implementation of adaptation strategies is essential.

**Keywords:** Benin; Cashew; Climatic variability; GCMs; Nuts yield; Trend analysis.

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## INTRODUCTION

Although global food production has been rising, the world still faces persistent food security challenge (Pretty *et al.*, 2003). By 2050, the world will need to increase crop production to feed a projected nine billion people, in the face of changing consumption patterns, the impacts of climate change and growing scarcity of water and land (Beddington, 2010). Sub-Saharan Africa (SSA) is often cited as one of the most vulnerable regions to climate change (Slingo *et al.,* 2005). According to Schlenker and Lobell, (2010) since it maintains the highest proportion of malnourished populations in the world; and national economies are highly dependent on agriculture. Farming techniques are also relatively primitive, the majority of the continent is already arid and the smallholder systems that dominate the agricultural landscape have very limited capacity to adapt (Muller *et al.,* 2011). According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the average rate of warming over the past fifty years, in the order of 0.13°C per decade, almost doubled compared to that of the last hundred years (IPCC, 2007). For illustration, IPCC (2007), indicates that Africa is one of the most vulnerable regions to climate change although the continent emits less greenhouse gas, responsible for global warming. West Africa which includes Benin, recorded a drastic drop of 20 to 40% of the precipitation in the periods 1931-1960 and 1968-1990 and a drop in the flow of the main running water of 40 to 60% since 1970 years (IPCC, 2007). Researches on climate change and particularly on rainfall variations show that Benin had a bad distribution of rainfall pattern resulting in a 40% reduction of flows (Gnanglè, 2012). Projections made by the international scientific community give the extent of the risks of climate change on agriculture and ecosystems. According to several climate scenarios, these risks include decrease in yields of crops in rainfed agriculture up to 50% by 2020 and an increase in, arid and semi-arid area from 5 to 8% by 2080 (IPCC, 2007a). According to Yaï *et al*. (2014), the diagnosis of effects of climate change shows that agro-ecological zones of central and northern Benin; very favorable areas for cashew growing, are the most vulnerable to climatic risks including drought, late and heavy rainfall and floods.

In fact, Cashew is among the first nut crops exported in the world with 5.35 million hectares of plantation in 2011 (FAO, 2014). Its production can significantly contribute to solve the economic, social and environmental problems in the world (Dwomoh *et al*., 2008; Hammed *et al.,* 2008; Yabi *et al.,* 2013). In Benin, cashew cultivation started in years 1960s when it was introduced as afforestation tree. This role evolved and cashew nut trees are not planted and exploited for the economic value of the nuts but the cashew sector which based entirely on the production of cashew nuts; really exists since 2000 in Benin (Lacroix, 2003). This sector now accounts for a great share in the country export products just behind cotton (Tandjiekpon, 2010; Yabi *et al.,* 2013; Balogoun *et al.,* 2014). Despite the importance of this crop for millions of people and households in Africa and Benin in particular, and despite an increase in cashew production, the sector is subjected to negative effects of combined climatic factors (Balogoun *et al.,* 2014). Climate variability which is of great concern for farmers in general and especially for cashew nut producers, adversely affects crop yields through its impact on growth and development of plants (Adesiji *et al*., 2012; Luka Yahaya, 2012). The study of the impacts of climate change on the cashew tree was made in Côte d'Ivoire and Ghana to anticipate the consequences of its disturbance on tree productivity (Weidinger and Tandjiekpon, 2014). But in Benin, no study has been conducted yet to assess the effects of climate variability on cashew nut productivity (Balogoun *et al.,* 2016) in order to implement adaptation strategies to the effects of climate change on cashew trees. This study aims to analyze the past and future climate trends and their likely impact on cashew nuts yield in Benin. Specifically, it aims i) analyze past trends (1970-2015) and future and inter-annual variability of climatic factors (temperature and rainfall) in the major production areas of cashew in Benin; and ii) investigate probable impacts of observed recent and predicted future climate change on cashew nuts production in Benin.

## EXPERIMENTAL

### Study Area

The study was conducted in the area favorable to cashew production as described by Tandjiekpon, (2010). According to the author, cashew is cultivated in four areas in Benin, namely the high favorable production zone located primarily in the Department of Colline and the Southern parts of Borgou Department, the medium favorable production zone represented by North Borgou, North Donga and South of Collins Department, the low favorable production zone including Zou and Plateau

Department, and southern Alibori and the marginal production zone accounted for extreme north and extreme south of Benin. The high favorable production area has a Sudano-Guinean climate with two rainy seasons, from April to July and from October to November. It is a transition zone between the climate of the South and the North (Balogoun *et al.,* 2014). This area is fully occupied by leached tropical ferruginous soils or depleted (INRAB, 1995). We also find black and waterlogged soils in the valleys of rivers and streams that cross the area. South-Benin area (low production area) belongs to the Guinean zone (6 ° 25'-7 ° 30'N) (Gnanglè *et al.,* 2012). This area is characterized by a bimodal rainfall with an annual average of 1200 mm; the average temperature varies between 25 and 29 ° C and relative humidity between 69 and 97%. Lateritic soils are either deep with marginal quality. As for the Northwest region (medium favorable production area) and the Northeast (fairly favorable production area), they have a Sudanese climate type. These areas are mainly dominated by tropical ferruginous soils with highly variable agronomic characteristics. These soils have fine clay-sandy texture. Lateritic soils and waterlogged soils are also found in these areas (INRAB, 1995).

**Climatic data Collection**

Meteorological data (maximum and minimum temperature (°C), Rainfall (mm) and potential evapotranspiration (PET) were collected at the synoptic station of the ASECNA (Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar) located at Bohicon (Southern zone: low favorable production area); Savè (zone centre: high favorable production area); Natitingou (Northwest zone: medium favorable production area) and Kandi (zone northeast: low favorable production area). The Figure 1 presents the geographic map and the distribution of rainfall toward the climatic gradient. According to the World Meteorological Organization (WMO), the recommendations of climate analysis are taken into account when the data collected on climate series exceed 30 years (Robson *et al.,* 2000). Climate data were therefore collected over four decades, from 1970 to 2015.

**Cashew nuts yield data collection**

In Benin, information on cashew nut production from 1985 to 2015 is not available. Therefore, the requirement of WMO (31 years of data) in analyzing the impacts of climate change could not be met. Actually, there is no accurate and reliable data on the production of raw cashew nuts in Benin, as the available statistics data in the agricultural sector did not take into account cashew (INSAE, 2009). Thus, a survey conducted among 217 farmers of the all growing areas (Figure 1) to analyze farmers' perception on the effect of climatic factors on cashew trees and adaptations strategies adopted allowed us to estimate cashew production and area under harvesting over the last ten cropping seasons. These data were used to determine the yields per cropping season. The real areas considered were those corrected considering the gap between stated data by farmers and measured data with Global Position System (GPS mark Garmin eTrex 20) from a sample of five producers per village (Balogoun *et al.,* 2016).

**Statistical Analysis**

***Mean standardized anomaly indices and past climate trends***

To reduce errors from data related to the measures and better visualized the dry and wet periods, high and low temperatures periods, the Mean standardized anomaly indix (IP) were calculated from the formula (i) proposed by Lamb (1982):

$$IP = \frac{Xi - Xm}{\sigma} \qquad \textbf{(i)}$$

With Xi (mm) = annual rainfall or temperature in mm or °C respectively, Xm (mm) = the mean annual rainfall or temperature over the study period (1970-2015), σ = standard deviation of annual rainfall totals or annual mean temperature over the study period. Similarly, in order to study the stationary characters of the time series from 1970 to 2015 for each of the climatic variable per zone, the linear adjustment with the time series analysis, and precisely the trend analysis were performed following the method described by Bowerman and O'Connell (1993). This trend has been assessed taking into account regression equations and determination coefficient $R^2$ (Rimi *et al.*, 2011).

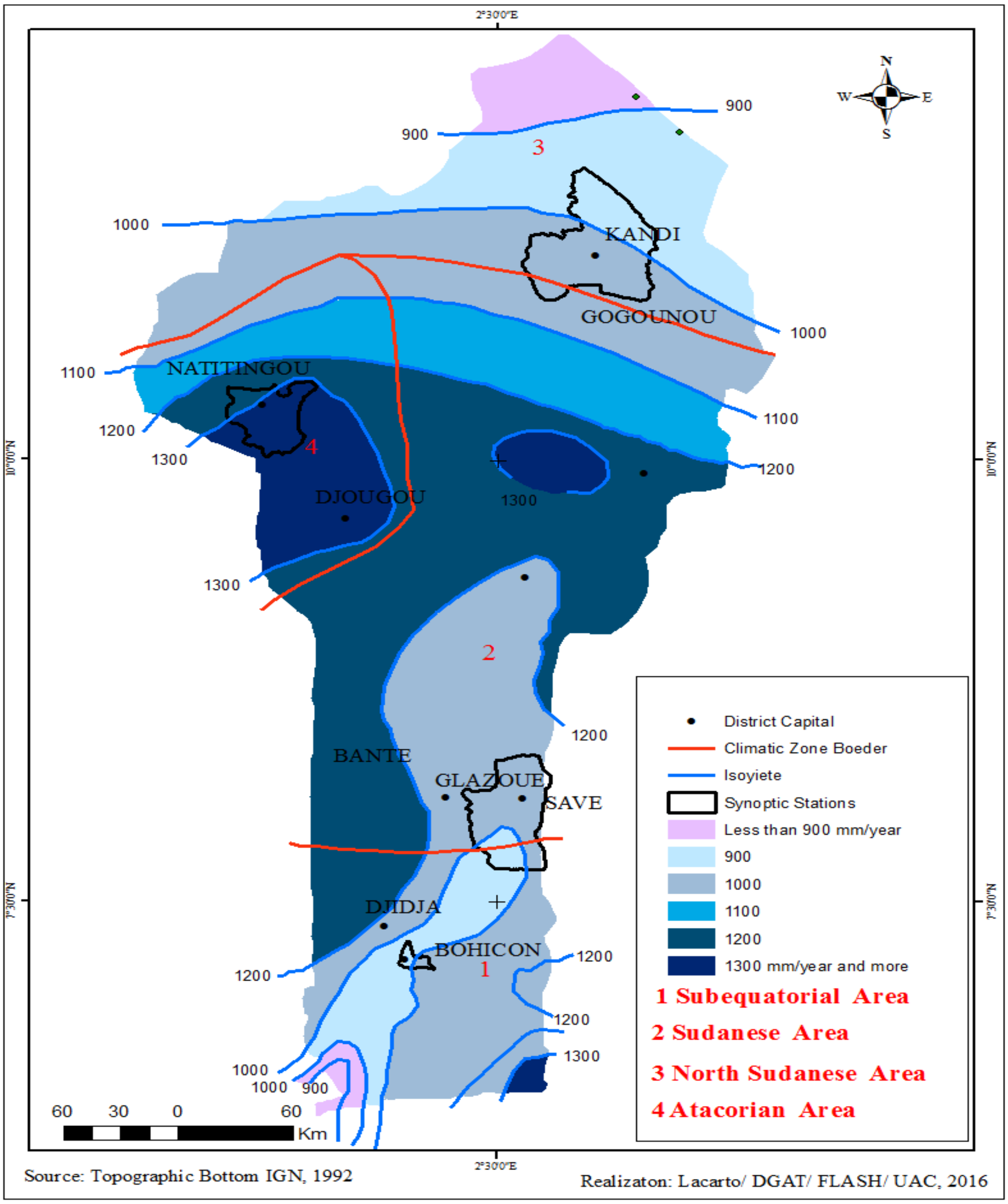


**Figure 1. Map of the Study area**

**Estimation of average yields and Investigation of Impacts of climatic variables on cashew nut production**

We investigated the probable relationship between the climate variability and change and trend of cashew nut yield over the past ten cropping seasons in order to reveal the impact of climatic variables on cashew production. The estimation of the annual average amount of cashew nuts produced was done by grouping data of each region considering each year. An average value was calculated per year and zone and values of yields of cashew nuts above 120% or below 80% of the average value were eliminated to minimize data variability (Balogoun *et al*., 2016). Then, a new means were calculated based on the selected yields and considered as average yields of the year in the zone. These yield average values were submitted to two ways analysis of variance considering the zone and the production year using Statistical Analysis

System (SAS v 9.2) package. The mean from this analysis for the ten cropping seasons were finally considered to perform a trend analysis taking into account the precision parameters such as the mean absolute error (MAPE) in percentage, the mean absolute deviation (MAD) and the root mean square deviation (MSD) series estimated and compared with the observed values and the determination coefficient $R^2$ to fully appreciate the meaning of the trend. A correlation analysis between the climatic data of the last ten years and the cashew nut yields obtained according to Oguntunde *et al.* (2014) was performed to assess the effect of each climatic factor on the nut yield in each growing area. Then, the climatic data which are correlated with cashew nut yield were submitted to multiple regression in order to describe the relationships between climatic factors influencing the most cashew nuts' yield. Multiple linear regression method assumes that the relationship is linear and the different values of the dependent variable extracted from normal distributions are independent of the same variance as the following theoretical model (ii):

$$Y = a_1X_1 + a_2X_2 + a_3X_3 + ... + a_nXn + b \quad \textbf{(ii)}$$

Where Y is the cashew nuts' yield; $X_1$, $X_2$, $X_3$, ..., Xn denote the explicative variables; $a_1$, $a_2$, $a_3$, ..., $a_n$ are regression coefficients and b is the constant value. A positive sign of the regression coefficient means that an increase in the value of the explicative variable causes an increase in the dependent variable and vice versa. The part of explicative information ($X_1$, $X_2$, $X_3$, ..., Xn ) was measured using the multiple determination coefficient $R^2$ and the adjustment determination coefficient (Adj R-Sq). More $R^2$ is near to 1, more the adjustment is better, meaning that the information considered by the model is important.

### Future Climate Change Scenarios

In order to predict the future trend of climate change, the daily data of rainfall and temperature from 1970 to 2015 were used to generate the trend at two levels namely by 2050 and by 2100. The future climate has been generated using the downscaling statistical method from General Circulation Models (GCMs). This technique was developed by the CSAG (Climate Systems Analysis Group) in South Africa, and used by Muhire *et al*. (2014). In fact, the GCM were used because they have large resolutions (hundreds of kilometers) compare to Regional Climate Model (RCM) with low resolutions (about tens of kilometers) (Ilunga *et al*., 2008). The method of downscaling statistic requires data from different sources: observations, a re-analysis of all data and the data out of the MCG. Data out of the MCG in 2050 and 2100 were obtained from World Climate Research Program (WCRP) Phase 3 of the Coupled Model Inter-comparison Project (CMIP3) Multi-Model Database using the emissions scenario of greenhouse Gases (GHG) A2 of the IPCC Special Report. GCMs have been used in several recent studies (Muhire *et al.,* 2014.) and several research centers including CCCMA-CGCM3 (Canadian Centre for Climate Modelling and Analysis -Coupled Global Climate Model (Canada)) and ii: CNRM-CM3 (Centre National de Recherches Météorologiques (CNRM), Météo-France (France)). The relative difference (DR) of monthly values was calculated using the following formula (iii).

$$DR = \frac{PF - PI}{PI} * 100 \quad \textbf{(iii)}$$

Where, PF is rainfall (mm) or temperature (°C) in 2050 and 2100 and PI is the initial rainfall (mm) or initial temperature (°C) of the relevant reference 2015.

## RESULTS AND DISCUSSION

### *Temporal analysis and Progressive trend of climatic parameters*

Inter-annual fluctuations of rainfall in cashew growing areas were remarkably high with a succession of dry periods and wet periods (Figures 2-5). A long dry period was clearly observed since 2010 in Savè and Bohicon (Figure 2 and 3), the deficit was significantly more pronounced in 2013 while the wet period observed between 2007 and 2012 in Natitingou experienced a deficit in 2013 and 2015 (Figure 4). In Kandi, there was a rainfall deficit from 2012 to 2014 (Figure 5). However, over all the growing areas, the average precipitation level showed increasing trend between 1970 and 2015 for the fourth meteorological stations. However, trends were less linear and did not have defined pattern regarding the determination coefficients $R^2$ which are low in all these cases. The analysis of climate data for the annual mean temperature recorded in the synoptic stations showed a gradual rise from 1993 to the present (Figures 2-5). The last fifteen years (2000-2015) were significantly warmer than the previous periods, and this was more significant in the Center ($R^2$ = 0.62; P <0.05) and Northwest ($R^2$ = 0.55; P <0.05) of Benin (Figure 3 and 4). Climate variability and change, its impacts and vulnerabilities are growing concern worldwide (Rimi *et al.,* 2011). Rainfall and temperature are very important climatic factors affecting agricultural production in a region or even a country. Several authors also reported similar results in Sub-Saharan Africa (SSA) (Loko *et al*., 2013; Badjana *et al.,* 2014; Ezin *et al.,* 2014; Oguntunde *et al.,* 2014; Balogoun *et al*., 2016). According to Bhavnani and Vordzorgbe (2008), sub-Saharan Africa had experienced significant drought in 1986-1987 and 1991-1992 and especially Benin and Togo between 1976 and 1977. According to Hulme *et al*. (2005), rainfall and temperature are the main climatic factors which affecting agricultural production systems in Sub-Saharan Africa. Inter-annual variability of climate parameters is a major constraint for the sustainable development of rainfed agriculture in this region. Our findings revealed a significant variability rainfall deficit across cashew tree growing areas. Thus, in the South, the years 1976, 1982, 1983 and 2001, in the Centre, the years 1977, 1982, 1983 and 2005, in the Northwest, the years 1977, 1983 and 2000 and in the North East, the years 1973, 1983 1988, 1993 and 2001 experienced significant rainfall decrease. Yabi and Afouda (2012) also noted that the 1970s -1980 and 1980-1990 years recorded a significant rainfall deficit (1973, 1977, 1982, 1983, and 1984) nationwide. Moreover, in the last decade, year 2010 was particularly rainy with flooding cases. According to MEPN (2011) and Loko *et al.* (2013), the increase in rainfall combined with the reduction in the number of rainy days lead to cases of flooding in particular those observed in 2010.

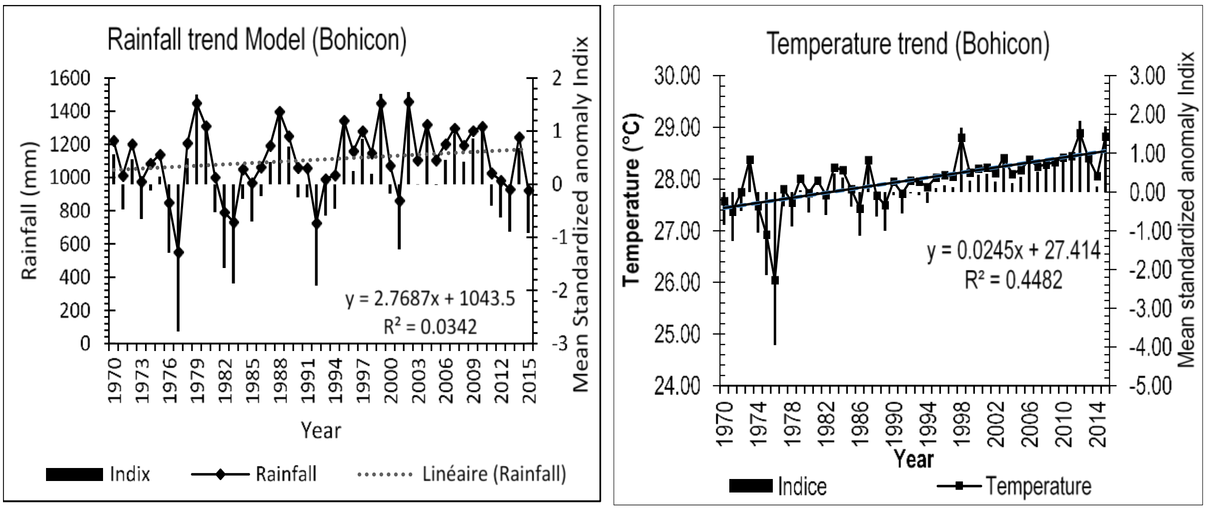


**Figure 2. Inter-annual variability and trend of rainfall and temperature at Bohicon from 1970 to 2015**

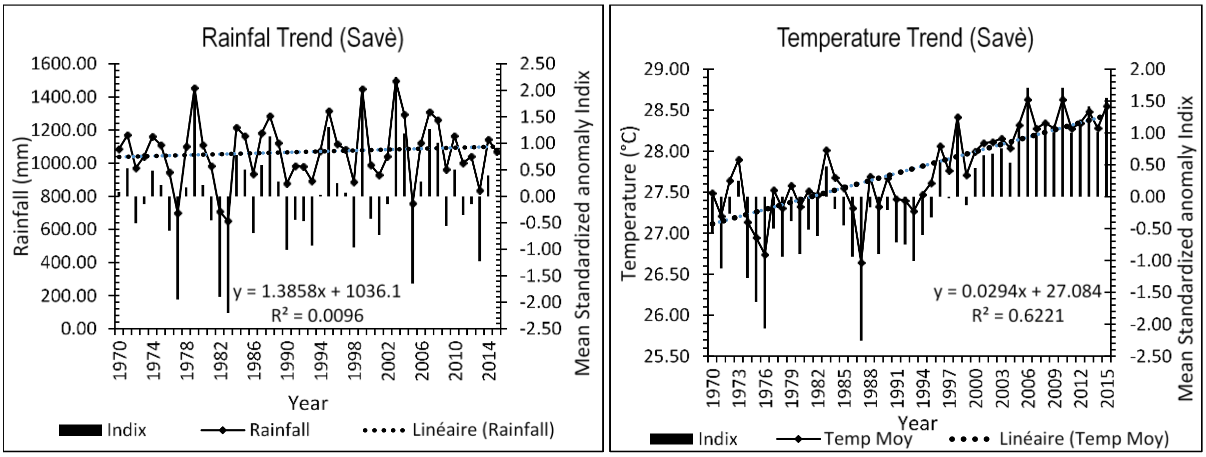


**Figure 3. Inter-annual variability and trend of rainfall and temperature at Savè from 1970 to 2015**

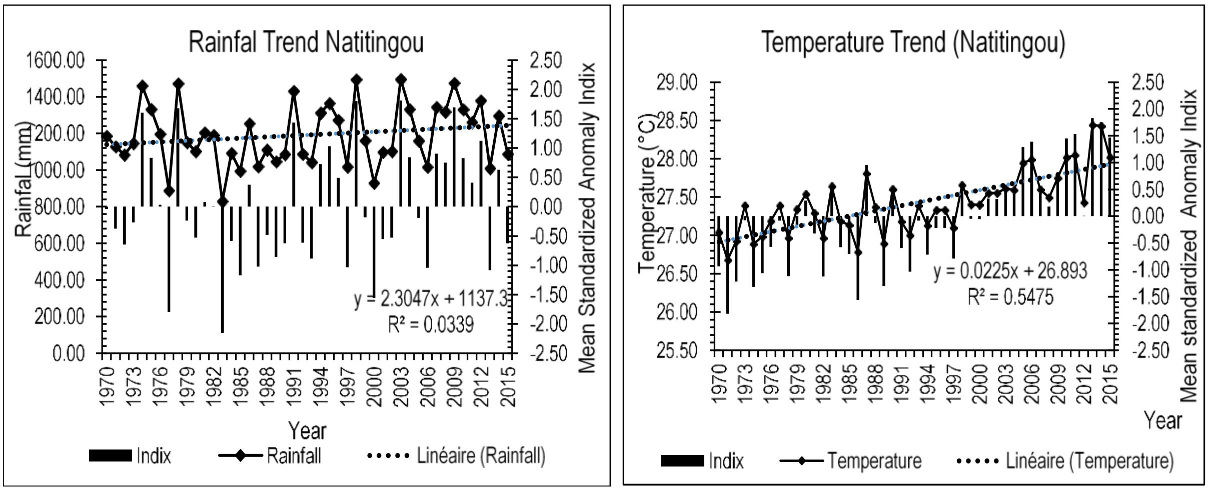


**Figure 4. Inter-annual variability and trend of rainfall and temperature at Natitingou from 1970 to 2015**

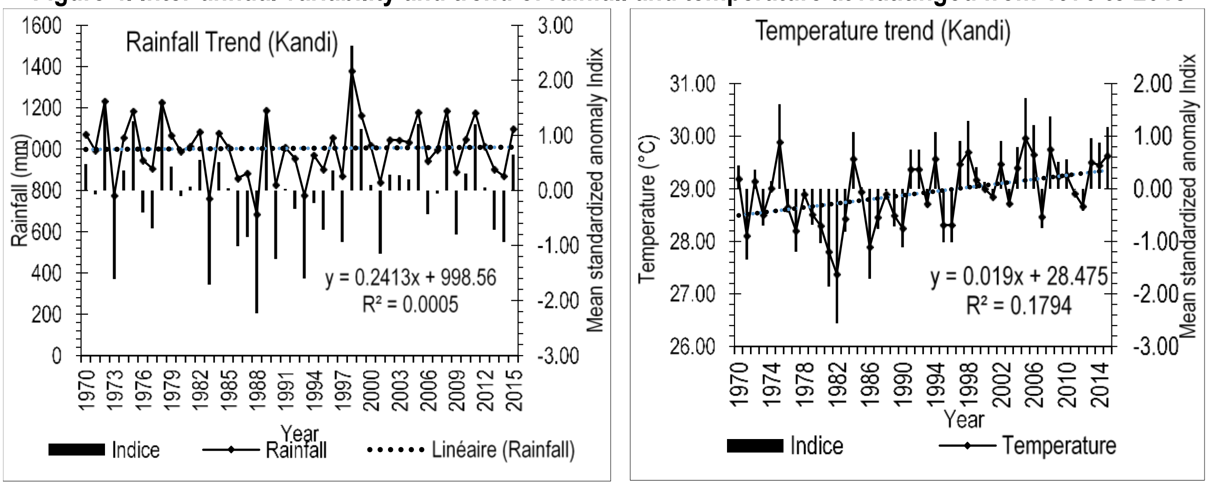


**Figure 5. Inter-annual variability and trend of rainfall and temperature at Kandi from 1970 to 2015**

## Future Climate Change Scenarios

Tables 1 and 2 show, respectively, values of relative difference in rainfall and temperature obtained for the near future (2050) and distant future (2100) from both GCMs including CCCMA_CGCM3 and CRNM_CM3 for the low, medium and high favorable cashew growing areas in Benin. All GCMs studied predict a decrease trees in the amount of rainfall especially in the period of August to October (vegetative period where cashew need more water) as well as in a near and distant future., Comparison of the two horizons, shows that the amount of water will be significantly reduced by 2050 than 2100. The annual rainfall experience a decline in the near future when in 2100, models predict an increase in the amount of water whatever the production area. Concerning the temperature, all of GCMs agree on the occurrence of an increase in mean temperature up to about 20% in the future with reference to the base 2015. In the South, the model CCCMA predicted a higher mean temperature during the period of August-September-October (8.3% and 13.1% by 2050 and 2100, respectively), while the CRNM model predicts high mean temperature during the period of May-June- July (7.9% and 15.8% respectively by 2050 and 2100). In the other growing areas, all of the models agree on the occurrence of a significant increase in the average temperature during the period of November-December-January (Tables 1 and 2). Muhire *et al.* (2014) found similar results in Rwanda using the CNRM-CM3 in their projection. Projected rainfall established by the MEPN (2011), in the southern region of Benin (at latitudes lower than 7.5°N), until 2100, there could be invariable annual rainfall compared to the reference period 1971-2000. By 2100, beyond this latitude (7.5°N), a slight increase up to more than 13% and 15% in rainfall compared to the reference period will be observed in the North West and North East Benin, respectively. A seasonal scale, changes in precipitation for the period of March-April-May during which coincides with the onset of the cropping season, would be almost negligible in both sub regions of the South by 2050. However, in the Centre and North, a slight increase in rainfall will be observed, and it can reach 16% by 2100 in the North East. According to the same report, regarding the temperatures, projections indicated an increase in all regions of Benin, by 2100. Thus, the highest increase in temperature will average 3.27°C compared to the reference period 1971-2000 while the lowest increase in temperature will average 2.6°C in the south - west. Since, the increase in temperature generally results in an increase of the potential evapotranspiration, this process could lead under certain conditions to water deficit. In Bangladesh, Rimi *et al.* (2011), obtained a temperature increase up to 2.9°C in 2070 horizon. According to Hahn *et al*. (2009), recent progressive increases in temperature, results from global warming caused by a rapid increase in the concentration of greenhouse gases since the industrial era. In early May 2013, the atmospheric concentration of carbon dioxide ($CO_2$) has reached 400 ppm causing a temperature increase ranging from 0.5°C to 1°C (Ralph, 2013). According to Davies *et al.* (2010), an increase in atmospheric concentration of carbon dioxide ($CO_2$) would force a rise in global average surface temperature of 2°C to 4°C by 2100. According to Muhire *et al*. (2014), the increase in temperature played a vital role in increasing aridity, which may lead to occurrence of drought along with land degradation, reduction in water resource and a decline in agricultural production resulting from failure and destruction of crops. However, the increase in temperature can lead to an increase in rainfall since the warming of the atmosphere could contain a lot of water (IPCC, 2007b), with high evapotranspiration rate.

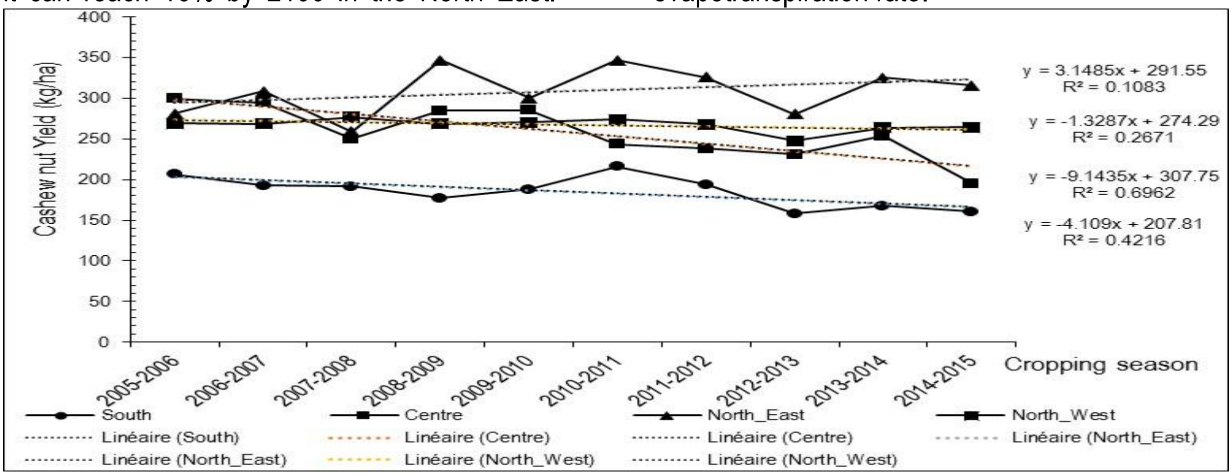


**Figure 6. Cashew nut yields trend according to production area**

**Table 1. Relative difference of low production area for temperature and rainfall generated by GCMs for 2050 and 2100 horizon through CCCMA_CGCM3_1 and CRNM_CM3**

| Global Circulation Models (Low production area of cashew) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bohicon (South Zone) | | | | | | | | Kandi (North-West Zone) | | | | | | | |
| | CCCMA_CGCM3_1 | | | | CRNM_CM3 | | | | CCCMA_CGCM3_1 | | | | CRNM_CM3 | | | |
| Mois/ | Mean Temperature (%) | | Precipitation (%) | | Mean Temperature (%) | | Precipitation (%) | | Mean Temperature (%) | | Precipitation (%) | | Mean Temperature (%) | | Precipitation (%) | |
| Période | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 |
| Jan | 6.59 | 12.54 | -100 | -100 | 6.89 | 15.67 | -100 | -25.44 | 17.36 | 24.36 | - | - | 15.37 | 27.78 | - | - |
| Fev | 2.27 | 8.94 | -91.64 | -35.70 | 4.75 | 11.91 | -77.10 | -89 | 8.73 | 24.36 | - | - | 3.63 | 14.90 | - | - |
| Mar | 2.12 | 8.28 | 39.34 | 104.20 | 3.71 | 11.02 | 32.17 | 121.69 | 7.01 | 9.65 | -22.75 | -65.13 | 4.35 | 20.94 | 44.75 | 100.28 |
| April | 6.65 | 13.70 | -40.43 | -43.84 | 8.83 | 17.31 | -61.56 | -77.78 | -2.91 | 3.15 | 109.28 | 484.70 | -2.22 | 6.75 | 88.55 | 105.23 |
| May | 2.08 | 8.30 | -9.59 | -96.95 | 4.88 | 15.70 | -40.44 | -5.96 | -16.67 | -10.65 | -9.94 | -7.89 | -12.92 | -3.40 | -32.03 | 23.04 |
| June | 4.10 | 11.74 | 8.68 | 41.85 | 8.66 | 16.75 | 40.87 | -10.84 | -15.21 | -8.38 | 63.04 | 51.90 | -11.08 | -4.12 | 74.70 | 31.06 |
| July | 6.67 | 11.93 | 76.40 | -22.58 | 10.17 | 14.80 | 98.63 | -28.32 | -8.36 | -5.18 | 51.11 | -12.22 | -7.34 | -3.91 | 124.92 | 23.86 |
| Aug | 9.88 | 13.73 | 12.23 | -67.98 | 10.82 | 15.78 | 16.61 | -73.83 | 2.23 | 4.43 | 69.35 | -55.71 | 0.51 | 5.52 | 84.85 | -50.85 |
| Sep | 8.94 | 12.88 | -73.19 | 76.85 | 6.81 | 16.55 | -68.15 | 53.66 | 0.19 | 3.90 | -25.18 | 158.01 | -3.58 | 5.85 | -23.91 | 185.73 |
| Oct | 5.96 | 12.53 | -50.83 | 39.67 | 4.52 | 8.91 | -25.60 | 84.42 | 3.21 | 8.61 | -89.46 | -54.99 | -2.04 | 22.10 | -64.88 | -15.15 |
| Nov | 1.96 | 12.61 | -100 | 109.37 | 9.17 | 16.38 | -6.22 | 54.69 | 5.98 | 26.35 | - | - | 8.64 | 25.26 | - | - |
| Dec | 0.78 | 10.23 | - | - | 0.48 | 12.87 | - | - | 20.63 | 38.90 | - | - | 18.22 | | - | - |
| FMA | 3.68 | 10.31 | -30.91 | 8.22 | 5.76 | 13.41 | -35.5 | 18.3 | 4.28 | 12.39 | 28.84 | 39.86 | 1.92 | 14.2 | 44.43 | 58.5 |
| MJJ | 4.28 | 10.66 | 91.83 | -25.89 | 7.9 | 15.75 | 66.35 | -15.04 | -13.41 | -8.07 | 91.4 | 10.6 | -10.45 | -3.91 | 55.86 | 25.99 |
| ASO | 8.26 | 13.05 | -27.26 | 16.18 | 7.38 | 13.75 | -25.71 | 21.42 | 1.88 | 5.62 | -15.1 | 1.44 | -1.7 | 11.16 | -1.32 | 9.91 |
| NDJ | 3.11 | 11.79 | -26.67 | 3.12 | 5.51 | 14.97 | -25.41 | 9.75 | 14.65 | 26.54 | - | - | 14.08 | 17.41 | - | - |
| ANN | 4.83 | 11.45 | -10.75 | 0.41 | 6.64 | 8.47 | -7.57 | 2.61 | 1.85 | 9.12 | 10.29 | 12.98 | 0.96 | 9.72 | 14.75 | 10.6 |

**FMA**: February- March-April; (Period of fruition); **MJJ**: May-June-July (Period of end of fruition and beginning of production cycle); **ASO**: August-September-October (Vegetative Period); **NDJ:** = November-December-January (Period of flowering); **ANN**: Annual

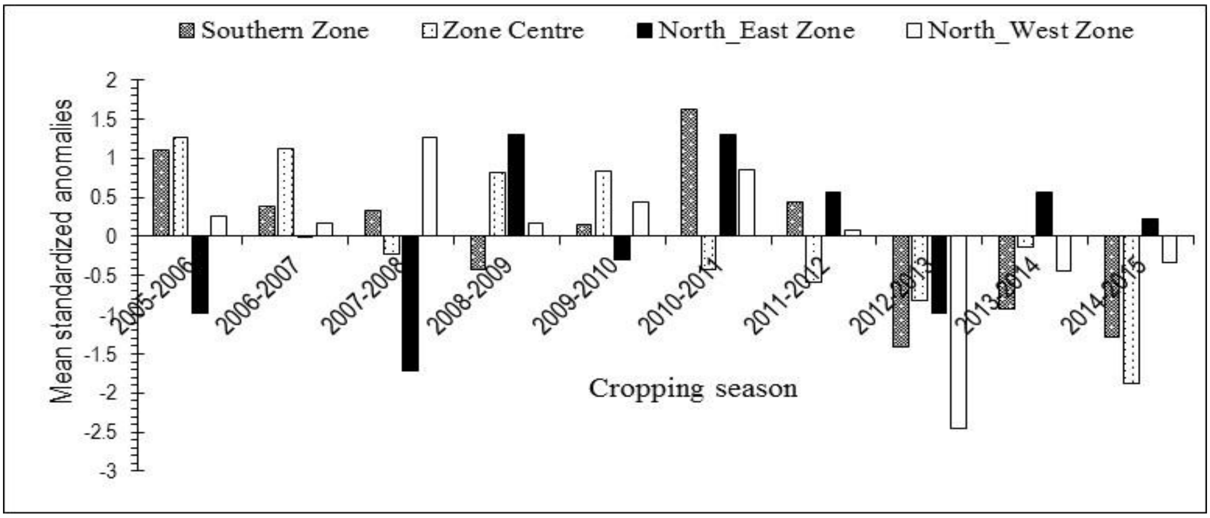


**Figure 7. Variability in cashew nuts yields according to climatic gradient**

**Table 2. Relative difference of High and medium production area for temperature and rainfall generated by GCMs by 2050 and 2100 horizon through CCCMA_CGCM3_1 and CRNM_CM3**

| | Global Circulation Models | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Natitingou (Nord-West: Medium production area of cashew) | | | | | | | | Savè (Centre : High production area cashew) | | | | | | | |
| | CCCMA_CGCM3_1 | | | | CRNM_CM3 | | | | CCCMA_CGCM3_1 | | | | CRNM_CM3 | | | |
| Mois/ Période | Mean Temperature (%) | | Precipitation (%) | | Mean Temperature (%) | | Precipitation (%) | | Mean Temperature (%) | | Precipitation (%) | | Mean Temperature (%) | | Precipitation (%) | |
| | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 |
| JAN | 25.34 | 15.30 | - | - | 24.85 | 38.55 | - | - | 4.75 | 11.41 | - | - | 5.79 | 14.89 | - | - |
| FEV | 20.26 | 31.82 | 36 | 75 | 16.37 | 27.85 | -100 | -100 | 1.66 | 9.25 | 161.11 | 200.23 | 3.95 | 10.31 | -100 | 125.23 |
| MAR | 12.27 | 23.13 | 320 | 550 | 16.22 | 29.36 | 100 | 150.23 | 1.10 | 8.20 | -10.87 | 42.89 | 4.21 | 10.32 | -44.20 | 56.34 |
| APR | 16.22 | 23.17 | -49.35 | -49.59 | 18.35 | 30.55 | -56.63 | -44.38 | 5.45 | 13.14 | -20.69 | 4.38 | 8.81 | 16.75 | -6.31 | -7.63 |
| MAI | 14.91 | 22.11 | 49.34 | 76.06 | 18.66 | 31.93 | 2.67 | 34.86 | -0.25 | 6.96 | 35.32 | 28.88 | 4.09 | 14.20 | -17.03 | 15.32 |
| JUN | 15.94 | 24.35 | -5.24 | 24.14 | 26.36 | 29.60 | 33.96 | -14.98 | 3.27 | 10.36 | 70.38 | 136.50 | 6.46 | 14.79 | 176.37 | 125.22 |
| JUL | 16.72 | 21.67 | 21.85 | 27.80 | 17.93 | 37.24 | 143.42 | 14.64 | 5.43 | 11.19 | -86.84 | 26.57 | 7.28 | 13.40 | 230.77 | -41.77 |
| AUG | 20.03 | 23.30 | 23.05 | -63.66 | 17.56 | 24.98 | 28.19 | -61.01 | 9.26 | 12.95 | 15.15 | -77.59 | 8.89 | 13.73 | 4.22 | -67.50 |
| SEP | 19.08 | 24.40 | -66.69 | -16.40 | 15.17 | 26.83 | -62.28 | -10.73 | 6.51 | 11.69 | -70.85 | 9.02 | 5.29 | 15.28 | -77.01 | 12.80 |
| OCT | 18.96 | 25.16 | -45.13 | 16.30 | 14.13 | 23.12 | -1.08 | 160.23 | 5.37 | 11.68 | -79.02 | -17.40 | 3.57 | 7.94 | -43.96 | 17.76 |
| NOV | 24.15 | 28.52 | -100 | 15.36 | 27.4 | 30.12 | 1.67 | 150.01 | 5.49 | 11.75 | -97.81 | 50.23 | 9.1 | 16.55 | -31.48 | -1.12 |
| DEC | 28.87 | 30.99 | - | - | 30.75 | 35.23 | - | - | -0.56 | 9.04 | - | - | -1.21 | 12.59 | - | - |
| FMA | 16.25 | 26.04 | 35.55 | 18.47 | 16.98 | 29.25 | -18.88 | 1.95 | 2.74 | 10.2 | 29.85 | 82.5 | 5.66 | 12.46 | -50.17 | 57.98 |
| MJJ | 15.86 | 22.27 | 21.98 | 12.67 | 20.98 | 32.92 | 60.02 | 11.51 | 2.82 | 9.5 | 6.29 | 63.98 | 5.94 | 14.13 | 70.03 | 32.92 |
| ASO | 19.36 | 24.29 | -29.59 | -1.25 | 15.62 | 24.98 | -11.72 | 16.16 | 7.05 | 12.11 | -24.91 | -28.66 | 5.92 | 12.32 | -28.92 | -2.31 |
| NDJ | 26.12 | 24.94 | -33.33 | 18.45 | 27.66 | 34.63 | 0.56 | 10 | 5.2 | 10.73 | -32.6 | 6.74 | 4.56 | 14.68 | -10.49 | -0.37 |
| ANN | 19.4 | 24.39 | -1.35 | 6.59 | 20.31 | 30.45 | 4.5 | 9.91 | 4.45 | 10.64 | -10.34 | 13.64 | 5.52 | 13.4 | -7.39 | 8.06 |

**FMA**: February- March-April; (Period of fruition); **MJJ**: May-June-July (Period of end of fruition and beginning of production cycle); **ASO**: August-September-October (Vegetative Period); **NDJ:** = November-December-January (Period of flowering); **ANN**: Annual

**Trend and variability in cashew nuts yields**

The variability and trend of cashew nuts' yields in all growing areas are presented in Figures 6 and 7. Across all the growing areas, inter-annual fluctuations of yields were very remarkable with succession of periods of good and poor production. Annual cashew nuts' yields over the last ten cropping seasons have a regressive trend in Centre, South and North - West while it showed an increasing trend in the North - East. However, the yield decline was more significant in the Centre ($R^2$ = 0.69; P <0.05) with a decreasing rate of 9.14% while trends were less linear and did not have a defined pattern in the other growing areas with regarding to parameters such as MAPE, MAD and MSD which were high and the coefficients of determinations which were all low. The lowest rate of decline (1.33%) was observed in the northwest. However, the best yields over the last ten cropping seasons were recorded during the period 2009-2011 in all the growing areas. Decline in cashew nut yield have become more noticeable over the last three or four cropping seasons in the Southern, Central, and West while the North-East zone recorded its lowest production in the first three cropping seasons (2005-2006; 2006-2007 and especially in 2007-2008). That was the consequence of climatic variability. Similar results were obtained on mango tree in Kenya (Makenzi *et al.,* 2013). In Nigeria, Ogountunde *et al.* (2014) also obtained a remarkable inter-annual fluctuations and a downward trend of cocoa's yields in Ondo State in the last 30 years. Nonlinearity trends and inter-annual fluctuations observed in the yields in the tropical regions result from the fact that the crop productivity, notably the fruit trees in this region is highly vulnerable to inter-annual climate variability and sub-seasonal (Ogountunde *et al.,* 2014). According to

Oyekale *et al.* (2009), this reduction in the productivity of fruit trees in general and cocoa and cashews in particular, result from inappropriate climatic factors.

**Association between cashew nuts yields and annual climatic variables**

The evolution of climatic parameters (temperature and rainfall) between 1970 and 2015, showed an increasing trend in all production areas and especially in the last ten years. The yields obtained in the last ten cropping seasons in response to rainfall and the annual mean temperature in southern Benin area (Figure 8, 9) revealed that, the mean temperature was negatively correlated (r = - 0.62; P <0.05 ) with yields obtained in the last ten agricultural season. This is the fact that the evolution of cashew nuts yields in this region has a downward trend. It appears that the increase of temperature is the main climate factor which affects the cashew nut yield. However, in the Center (r = 0.83; P <0.05); North East and Northwest (Figures 8, 9), the rainfall was positively correlated with yields. In these areas, rainfall amounts are not sufficient to cover plant water requirement. Therefore, adaptation strategies need to be developed in order to allow trees to manage the effects of the variability of these climatic factors. In general throughout the northern region, yield was not significantly correlated (P >0.05) with the annual climatic data. Other parameters include the correlations of cashew nuts yields with monthly rainfall data, monthly potential evapotranspiration and monthly mean of different temperatures are required to understand the most critical periods for the tree during the year.

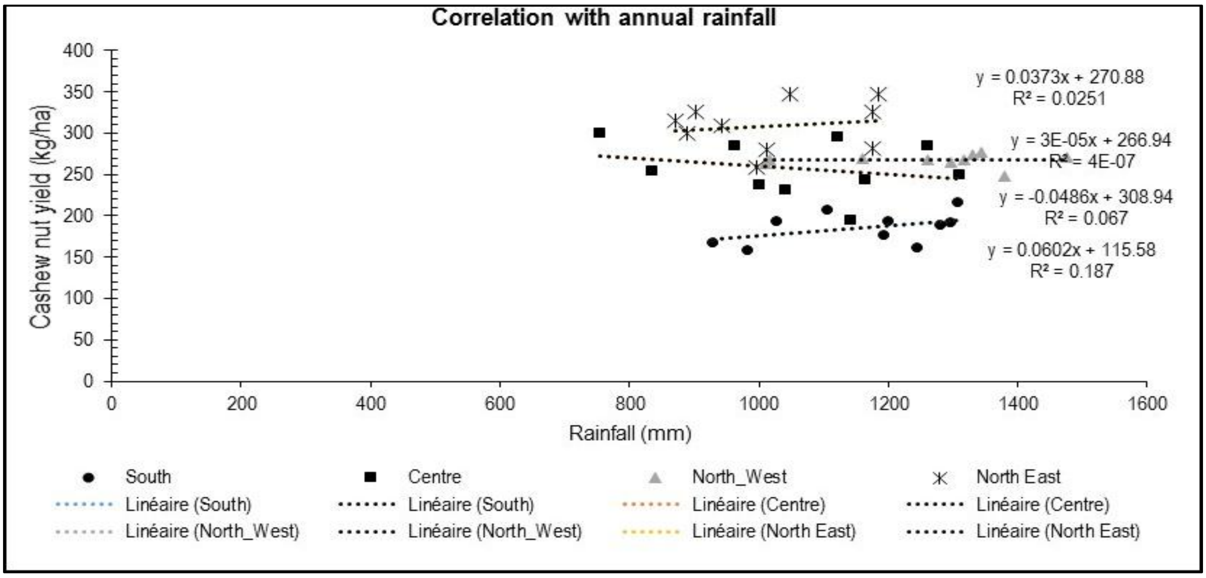


**Figure 8. Annual variation of production with response to annual rainfall from 2005 to 2015**

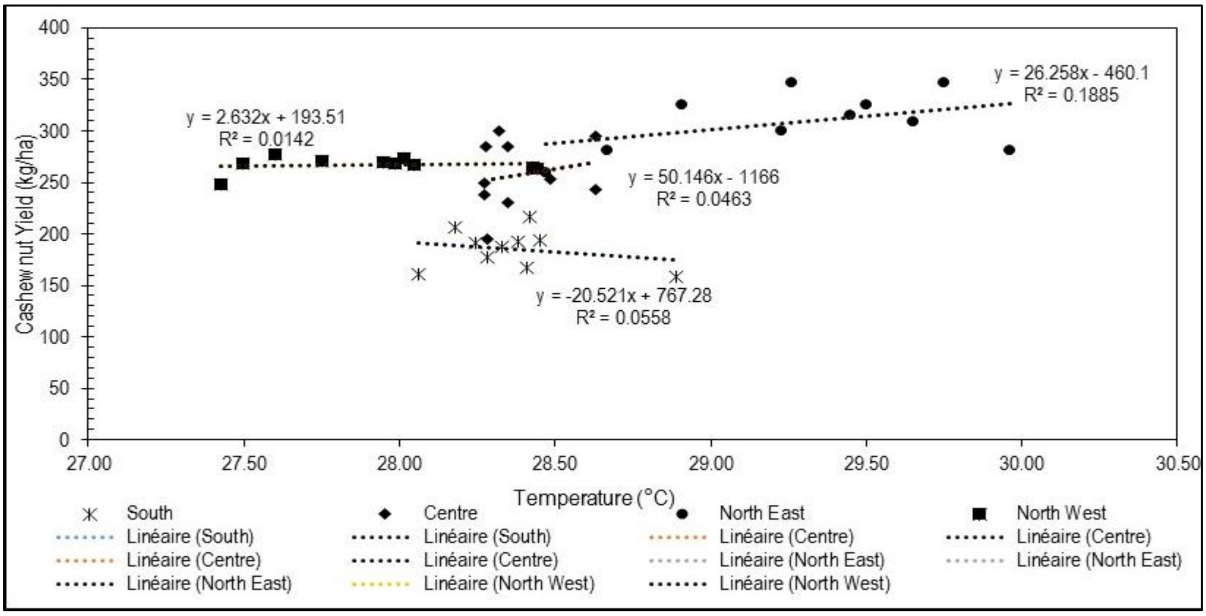


**Figure 9. Annual variation of cashew nut production regarding annual temperature from 2005 to 2015**

**Association between cashew nuts yields and monthly climatic variables**

Cashew nuts yields and monthly climatic variables from 2005 to 2014 were subjected to correlation analysis in order to determine the level of association between yields and the climatic parameters. The summary of the correlation between cashew nut yields and the climatic variables of South, Centre, North West and North East zones of Benin is presented in Tables 3, 4, 5 and 6, respectively. The analysis of these results showed that, in the South Zone (low favorable production area), the monthly minimum temperature (r = -0.80; P < 0.01) and mean temperature (r = - 0.72; P <0.05) of August of last ten cropping seasons were negatively and significantly correlated with cashew nut yields (Table 3). Similarly, the potential evapotranspiration of April, May and July (r = - 0.64; r = - 0.72; r = - 0.67, P <0.05, respectively) were negatively and significantly correlated with the cashew nuts yields. Concerning the Central Zone (Highly favorable production Area), the analysis of Table 3 indicates also that the monthly rainfall of August of each year are significantly and positively correlated (r = 0.78; P <0.01) with cashew nut yields while rainfall of November are negatively (r = -0.74; P <0.05) correlated with yields. Similarly, the minimum temperatures of February (r = -0.66; P <0.05), June (r = -0.74; P <0.05), July (r = -0.64; P <0.05) and September (r = - 0.66; P <0.05) and the potential evapotranspiration of May (r = -0.70; P <0.05) and November (r = -0.70; P <0.05) were negatively correlated with cashew nuts yields. Furthermore, in the Northwest area (medium favorable production area of cashew), the monthly rainfall during the last ten years of April was negatively correlated (r = -0.65; P <0.05) with yields while the one of September is very decisive (r = 0.76; P <0.01) for cashew. Similarly, the minimum temperature of January (r = - 0.64; P <0.05) and potential evapotranspiration of March (r = -0.66; P <0.05), April (r = -0.78; P <0.01), Mai (r = -0.72; P <0.05) and September (r = -0.72; P <0.05) were negatively correlated with the cashew nuts yields. As for the eastern zone (low favorable production area), only the monthly rainfall of August was positively correlated with cashew nut yield (r = 0.65, p <0.05) while an increase in the minimum temperature (r = -0.71, P <0.05) and mean temperature during the month of July (r = - 0.66; P <0.05) negatively affected cashew nuts yields. Similar results were also obtained by Oguntunde *et al.* (2014) in Nigeria on cocoa. In fact, a rise of potential evapotranspiration accompanied by an increase in the average temperature during the period from November to February negatively affected the productivity of the cashew and cocoa trees (Oguntunde *et al.,* 2014).

**Table 3. Correlation between cashew nuts' yield and monthly climatic variables**

| | | Cashew production Area | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Climatic factors** | **Month** | **North East** | | **North West** | | **Centre** | | **South** | |
| | | r | Prob | r | Prob | r | Prob | r | Prob |
| Rainfall (mm) | April | - | - | -0.65 | 0.04 | - | - | - | - |
| | August | 0.65 | 0.04 | - | - | 0.78 | 0.008 | - | - |
| | September | - | - | 0.76 | 0.01 | - | - | - | - |
| | November | - | - | - | - | -0.74 | 0.01 | - | - |
| Maximal (°C) Temperature | July | - 0.71 | 0.02 | - | - | - | - | - | - |
| | December | - | - | - | - | -0.77 | 0.009 | - | - |
| Minimal (°C) Temperature | January | - | - | -0.64 | 0.04 | - | - | - | - |
| | June | - | - | - | - | -0.74 | 0.01 | - | - |
| | July | - 0.71 | 0.02 | - | - | -0.67 | 0.02 | - | - |
| | August | - | - | - | - | - | - | -0.80 | 0.01 |
| | September | - | - | - | - | -0.66 | 0.04 | - | - |
| Mean (°C) Temperature | February | - | - | - | - | -0.66 | 0.04 | - | - |
| | July | - 0.66 | 0.04 | - | - | - | - | - | - |
| | August | - | - | - | - | - | - | -0.72 | 0.02 |
| ETP (mm) | March | - | - | -0.66 | 0.04 | - | - | - | - |
| | April | - | - | -0.78 | 0.007 | - | - | -0.64 | 0.04 |
| | May | - | - | -0.72 | 0.02 | -0.70 | 0.02 | -0.72 | 0.02 |
| | July | - | - | - | - | - | - | -0.67 | 0.04 |
| | September | - | - | -0.72 | 0.02 | - | - | - | - |
| | November | - | - | - | - | -0.70 | 0.02 | - | - |

r = Pearson correlation ; *Correlation significative at $\alpha$ =0.05 ; ** Correlation significative at $\alpha$=0.01

## Climatic factors determining Cashew nuts production

The results of the multiple regression analysis between cashew nuts' yields and the climatic factors from 2005 to 2015 are presented in Table 4. The August monthly rainfall and the mean temperature of July are the most important climatic factors explaining the variation of cashew nuts' yields in North East region. The September monthly rainfall and the PET of March are the most important climatic factors explaining the variation of cashew nuts' yields in North West region. In regard to Centre region, the rainfall of August and the minimal temperature of September had positive influence on the annual cashew nuts production while the rainfall and PET of November had negative influence on the annual cashew nuts production. The rainfall have not influence the annual cashew nuts' production in Southern zone but the mean temperature of August and PET of April had negative influence on the annual cashew nuts' production. The R square varied from 64% to 92% (Table 4). From these results, we can conclude that, rainfall from August to September (except South region), mean temperature and PET are the main factors that determine cashew nuts production during a year. Results of the statistical analysis revealed that, the selected variables provided highly significant information ($P<0.01$ or $P<0.001$) for the validity of the multiple regression models. Our findings revealed that climatic factors that the most affect the productivity of the cashew are rainfall, temperature and PET. In the central region the month of August is critical while that September in the northern zone is very critical. Balogoun *et al.* (2016) reported similar results in the central and northern areas of Benin. However, the rainfall of November significantly affected the performance of cashew. According to the IPCC report, the increase in temperature can lead to an increase in rainfall since the warming of the atmosphere could contain a lot of water but this with a strong evapotranspiration rates. Projections by the various global circulation models indicated a decrease in rainfall from August to October (cashew tree vegetative period) where cashew tree need more water according to Ricau (2013) by 2050 and an increase in temperature by 2100. In the absence of a simulation model which can predict cashew nuts' yields taking into account soil and climatic conditions, it is urgent to implement adaptation strategies especially in the month of August in the central area and in September in the northern area and in April in southern area that will contribute to maintain soil moisture content and to reduce evapotranspiration during periods of fruiting. Climate change is threatening livelihoods of the rural poor in Africa, particularly where soils and climate are already marginal for production and where farmers have limited access to agricultural knowledge and technology. These situations hamper their ability to adapt (Lobell *et al*., 2008). According to Tidjani and Akponikpé, (2012), adaptation strategies are now the only means through which farmers can manage the effect of climatic variability. In India, Rupa *et al.* (2013) have shown that several strategies can be used to reduce the vulnerability of the cashew tree to climate change. These include adoption of soil and water conservation strategies, mulching, supplemental irrigation, drip irrigation, fertigation and carbon sequestration. When the availability of moisture is very low, mulching is useful to conserve soil moisture for a long period. Green leaves, dry leaves, early weeding and black polythene can be used as mulch and they are proven to be useful in conserving of soil moisture (Nawale *et al.,* 1985). According to Rupa *et al.* (2013), mulching, irrigation and green manures have beneficial effects on the moisture and temperature of the soil and on cashew productivity. Dugué (2012) recommend the use of mulch when rainfall is erratic, or in small amounts or in great intensity. In addition, thicker is the spread mulch more is the residue left on the fields and higher is the soil organic carbon (SOC) accumulation rate. Mulching increases the water infiltration rate. Especially in dry areas, mulching has an important role in water conservation. This also reduces the temperature, thereby slowing the rate of mineralization of the organic matter (FAO, 2002). Mulching would then be a copping strategy to yield reduction in cashew nut in response to the decline in rainfall and increase in temperature.

**Table 4. Multiple regression result and their statistical test showing the effect of climatic factors on cashew production in Benin regarding the Geographic area**

| Climatic factors | Month | Cashew production Area | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | North East | | North West | | Centre | | South | |
| | | Coefficient | Pr > \|t\| | Coefficient | Pr > \|t\| | Coefficient | Pr > \|t\| | Coefficient | Pr > \|t\| |
| Constant | - | 451.14 | 0.01 | 185.73 | 0.04 | 656.73 | 0.03 | 511.03 | 0.035 |
| Rainfall (mm) | April | - | - | 0.48 | 0.05 | - | - | | |
| | August | 0.44 | 0.02 | - | - | 0.41 | 0.0001 | - | - |
| | September | - | - | 0.13 | 0.001 | - | - | - | - |
| | November | - | - | - | - | -2.74 | 0.01 | - | - |
| Maximal (°C) Temperature | July | -12.31 | 0.52 | - | - | - | - | - | - |
| | December | - | - | - | - | -19.70 | 0.05 | - | - |
| Minimal (°C) Temperature | January | - | - | 13.56 | 0.18 | - | - | - | - |
| | June | - | - | - | - | 17.20 | 0.10 | - | - |
| | July | -10.23 | 0.06 | - | - | -58.27 | 0.10 | - | - |
| | August | - | - | - | - | - | - | -38.72 | 0.06 |
| | September | - | - | - | - | 1.20 | 0.04 | - | - |
| Mean (°C) Temperature | February | - | - | - | - | 41.68 | 0.30 | - | - |
| | July | -22.89 | 0.04 | - | - | - | - | - | - |
| | August | - | - | - | - | - | - | -10.26 | 0.0001 |
| ETP (mm) | March | - | - | -0.29 | 0.002 | - | - | - | - |
| | April | - | - | 0.74 | 0.36 | - | - | -0.13 | 0.04 |
| | May | - | - | 0.46 | 0.66 | 4.55 | 0.06 | 0.82 | 0.72 |
| | July | - | - | - | - | - | - | 0.43 | 0.65 |
| | November | - | - | - | - | -8.71 | 0.02 | - | - |
| R-Square | - | 0.78 | | 0.90 | | 0.95 | | 0.84 | |
| Adj R-Sq | - | 0.70 | | 0.70 | | 0.92 | | 0.64 | |

## CONCLUSION

In conclusion, the present study revealed that rainfall and temperature from 1970 to 2015 varied from a growing area to another and from one year to another. The last fifteen years were particularly warmer than the previous periods and there is an increase trend in temperature regardless of the production area. Projections of climate simulation models predict a decrease in the amount of rainfall by 2050, especially in the period from August to October and an increasing of the temperature by 2100. Cashew nut yields during the last ten cropping seasons experiencing a downward trend in the Centre, South and Northwest. Similarly, rainfall, temperature and potential evapotranspiration are the major climatic factors which positively or negatively correlated with cashew nuts produced in the last ten cropping seasons. In this context, the implementation of adaptation strategies and mitigation of the effect of the variability of temperature and rainfall on cashew productivity in the major growing areas in Benin is essential. For further research, it is planned to test the effect of mulching and the contribution of organic fertilizer on the cashew trees productivity as adaptation strategy. In addition, the contribution of plantations of cashew in carbon sequestration should be evaluated.

**Acknowledgements**: The authors wish to thank START department and the International Development Research Center (IDRC) through the ACCFP (African Climate Changes Fellowship Program) for funding this research and to Unit of Soil Physics and Environmental Hydraulics (SPEH) at the University of Parakou in Benin for hosting the fellow for this research. Authors are also grateful to people who review and improved the quality of the manuscript.

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**Source of Support:** African Climate Changes Fellowship Program (ACCFP Phase III)
**Conflict of interest:** Nothing, Declared.