

Effect of Climatic Factors on Cashew (*Anacardium occidentale* L.) Productivity in Benin (West Africa)

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Abstract

Cashew production is affected by variability of climatic factors. The present work aims to study the effect these climatic factors on cashew productivity in the Central and North-West areas of Benin. Data related to plant phenology, nut and apple yields were collected in three villages (Adourékoman and Gobé in the Centre and Founa in the North-West) during two production seasons (2013-2014 and 2014-2015). In addition, socioeconomic survey was conducted among 80 experienced producers (over 50 years aged and over 10 years' experience in cashew plantation). Quantity of rainfall, temperature, number of rain days, potential evapotranspiration and wind speed from a period of 1981 to 2010 were also collected at the synoptic stations of ASEENA of Savè in the Centre and Natitingou in North-West. The average rainfall and temperature of both areas revealed an upward trend while, wind speed was less violent in the North-West and potential evapotranspiration was high in the Centre. The season and the area of production did affect significantly (from $P < 0.05$ to $P < 0.001$) appearance of flowers and fruits and also nuts and apples production. In general, cashew trees had produced more in the North-West than the Centre. Furthermore, apples and nuts production were higher in 2014-2015 (6.48 ± 0.05 and 50.72 ± 5.86 kg/tree respectively for nut weight and apple weight) than in 2013-2014 (3.95 ± 0.55 and 39.20 ± 6.63 kg/tree respectively for nut weight and apple weight). The agro-climatic stress index and amount of rainfall in September and October (in both areas), and the number of rainy days (at the Centre only) were main factors determining cashew trees' production.

Keywords: Climatic variability; Agro-climatic stress index; Phenology; Perennial crop; Benin

Introduction

Cashew (*Anacardium occidentale* L.) is among the first nut crops exported in the world with 5.35 million hectares of plantation in 2011 [1]. Its production can solve the economic, social and environmental problems in the world [2]. About 950.375 tons of cashew nuts were exported in 2011, which were estimated at 1.12 billion US dollars [1]. Cashew is an important cash crop owing to its nuts, balm and cashew nut shell liquid.

In Benin, cashew represents a great agricultural export opportunity, behind cotton [2]. Cashew tree is an economic crop grown in small farms because of its easiness. Despite the importance of this crop for millions of people and households in Africa and Benin in particular, cashew production is subject to many constraints including the combined effect of soil fertility management and climate change characterized by paucity and poor distribution of rains, increase temperature and violent winds. These factors reduce considerably cashew trees' productivity as cause abortion or drying of the flowers, fall of the leaves and the immature fruits. Even, [2] observed from the field that these climatic factors when they are severe caused the unproductiveness of the cashew trees.

Much effort has been invested in assessing effects of climate change on agricultural production at global and regional scales [3,4]. Recently, studies was carried out on the impacts of climate change on agricultural production regarding plant responses to extreme weather events [5], adaptation measures developed and their limits [6]. Therefore, it appears that, effect of climate change regarding crops response depends

on the most pronounced change in the meteorological elements, land use types, soil types, water availability and crop management [3]. However, meteorological elements are unpredictable, difficult to manage and plants are sensitive to their variation. Studies conducted on the "impact of climate change on cashew" by the Directorate of Cashew Research of India indicated that the rainfed cashew crop is highly sensitive to changes in climate and weather vagaries, particularly during reproductive phase [7]. Thus, high temperature ($>34.4^{\circ}\text{C}$) and low relative humidity ($<20\%$) during afternoon cause drying of flowers which lead to yield reduction. In addition, unseasonal rains and heavy dew during flowering and fruiting period aggravated the incidence of pests and diseases. All of this resulted in yield reduction up to 50 to 65% [7].

In Benin, no study has been done yet on the impact of variation of the meteorological elements on cashew trees' productivity. The present study will contribute to determine the optimum growing conditions

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within the context of climate change and to suggest adaptation measures to improve cashew production. It aims in general to study the effect of climatic factors on cashew trees' productivity in order to determine the optimal growing conditions in Benin. Specifically it aims to 1) compare the spatial and temporal variability of climate parameters (temperature, rainfall, annual rainy day number, wind speed and potential evapotranspiration) in the Centre and North-West regions of Benin using meteorological data between 1981 and 2010, 2) evaluate the effect of climatic factors on plant phenology and quantity of apples and nuts of cashew produced in the Central and North-West regions of Benin regarding the morphotypes and, 3) identify climatic factors that influence the most the productivity of cashew trees in the last decade.

Materials and Methods

Study area

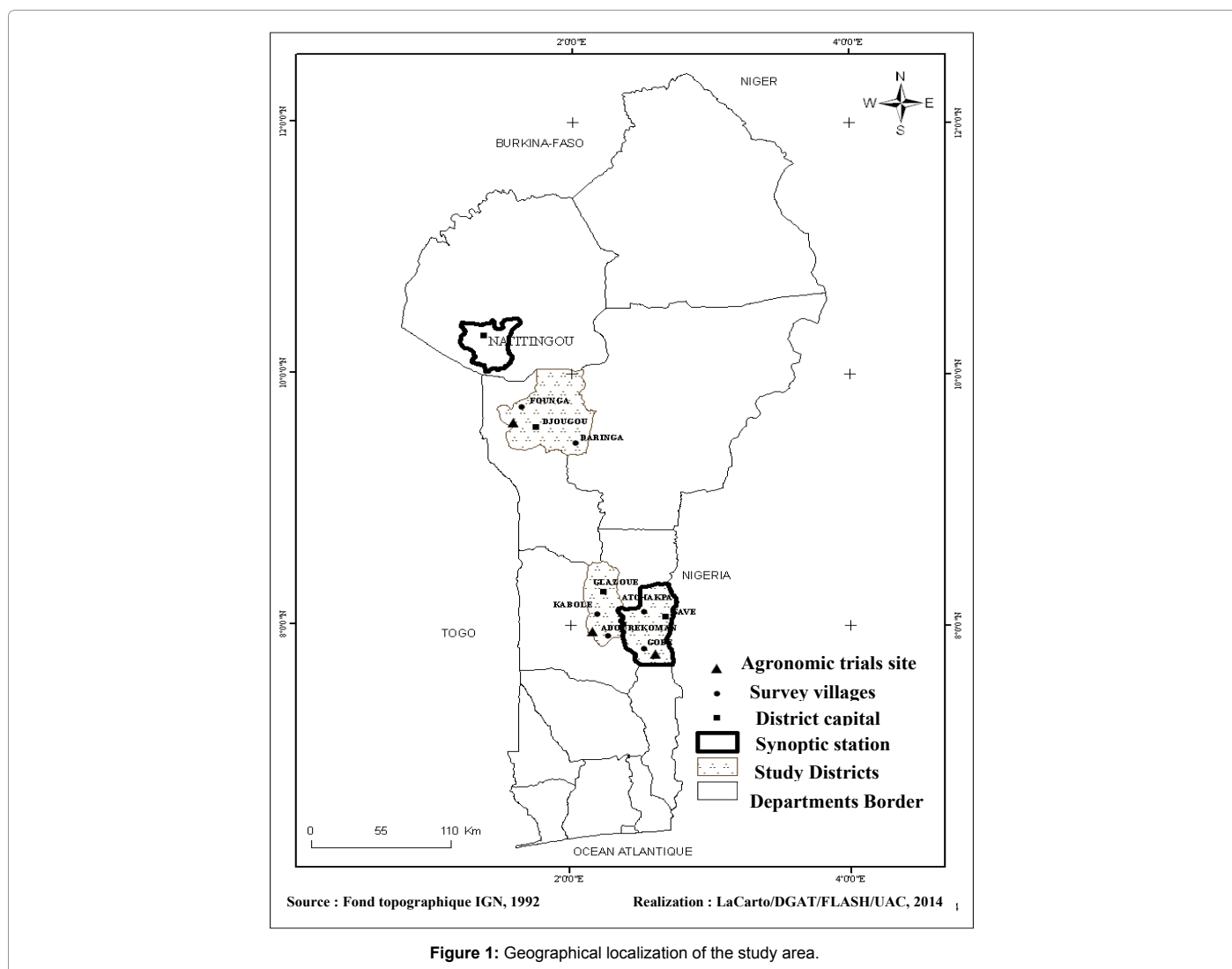
This study was carried out on the two cashew production areas in Benin namely the Centre and the North-West zones (Figure 1). In the Centre, data were collected in Savè and Glazoué districts, while in the North-West they were collected in the district of Djougou. The villages of Adourékoman in the district of Glazoué, Gobe in the district of

Savè and Founnga in the district of Djougou were considered based on their proximity to the meteorological stations to conduct agronomic experiment. In addition to these villages, Kabole (Glazoué), Atchakpa (Savè) and Daringa (Djougou) were selected for a survey.

Data collection methods

Data were collected following three phases. Firstly, meteorological data from 1981 to 2010 were collected at the synoptic station of the ASECNA (Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar) located at Savè and Natitingou. The climatic data collected were: minimal and maximal temperature, rainfall, number of rain days, potential evapotranspiration (PET) and wind speed.

The second phase has consisted in monitoring data on the phenology and productivity of cashew trees during two cropping seasons (2013-2014 and 2014-2015) in the villages of Adourékoman, Gobe and Founnga. The cashew trees were identified based on a forest inventory carried out from June to July 2013. These cashew trees were selected according to the agro-morphological characteristics of the two cultivars (trees producing regularly large apples and nuts with long shape and trees producing small apples and nuts with kidney form)



identified in Benin [8]. In total, 36 trees (18 per cultivar) per site were sampled for data collection.

The plant phenology parameters measured were: flowers emergence period, period of apples and nuts formation, duration of flowering and fruiting periods, number of male flowers per panicle, number of hermaphrodite flowers per panicle, number of abnormal flowers per panicle and total number of flowers per panicle. Five panicles bearing flower buds according to the four cardinal points (a total of 20 panicles were selected per tree) were selected for counting types of flowers. The average rate of the different flowers types was determined per tree. Yield parameters measured were: number of apples and nuts per tree, weight of apples and nuts per tree, length and width of apples and nuts per tree. To estimate the yield per tree in each period, nuts were weighed until the end of trees' production period in order to have the total weight of nuts per tree. The apple weight / nut weight ratio was calculated from 10 fruits selected at random to determine the apples weight from the nuts weight as farmers do not harvest the apple. This ratio was used to estimate amount of apple produced in the past ten years.

The third phase consisted to carry out socioeconomic survey with experienced producers (50 years old) able to estimate the annual average yields of cashew nuts during the last ten years (2003 to 2013). Due to the no availability of statistic data on the cashew nuts production in Benin, this procedure was used. In this context, the choice of producers was based on the following considerations: 50 years and above; at least 10 years' experience in the production and management of cashew plantation; knowledge of the exact age of the growing cashew plantation; knowledge of the area of the plantation and the quantity of cashew nuts harvested (producers having written materials to record their production were primarily retained) during the last ten years. After a "focus group", 40 producers were selected in the Centre and the North-West to obtain reliable data. In each of the selected villages, the data were collected using questionnaire during individual and group surveys, as well as visiting fields. The individual survey was done according to the method described by [9] and it involved 80 producers. The main data collected were: the areas of cashew plantation in hectare and amount of cashew nuts produced per year. The real areas considered were those corrected by the gap between declared data and measured data with Global Position System (GPS mark Garmin eTrex 20) from a sample of five producers per village.

Statistical analysis

In order to study the stationary characters of the time series from 1981 to 2010 for each of the climatic parameters per zone, the linear adjustment with the time series analysis, and precisely the trend analysis were done according to the method described by [10]. This trend analysis was done with the software Minitab 14 by 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.

Concerning plant phenology and apples and nuts production, data of the agronomic trial were subjected to three-way analysis of variance (ANOVA) with season, zone and cultivar characteristics as main factors. Statistical Analysis System (SAS v 9.2) package was used to perform the analyses. The Student Newman-Keuls test was used for mean separation considering 5% level of probability. To obtain normal distributions (ANOVA hypothesis), the counted data (periods of emergence of plant organs) were transformed by $\log_{10}(n)$ while the rate

of the different types of flowers were transformed by $2\text{Arcsin}\sqrt{n}$ [11], where n was the real value.

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 [12]. 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 Student Newman-Keuls test was used for the separation of the mean. The significance level was set at 5%.

Estimation of agro-climatic stress index

The agro-climatic stress index (ASI) was used to appreciate whether the study area is suitable for cashew cultivation considering the pedoclimatic parameters. This index was also used by [12-14]. Determination of ASI is so important as its calculation takes into account not only the climatic parameters (rainfall and potential evapotranspiration) but also soil parameters (useful soil water reserve, easily usable soil water reserve and soil survival reserve). The mathematical formula of the agro-climatic stress index (ASI) developed by [13] and used by [12] is:

$$ASI = \frac{(PET - RET)}{PET} \times 100$$

With PET=potential evapotranspiration and RET=real evapotranspiration.

-If $P \geq PET$, then $RET = PET$ and it will remain a quantity of water equal $P - RET$ which will be used in the reconstitution of soil water reserves;

-If $P < PET$, then evapotranspiration will be realized not only on the total rainfall (P), but also on soil reserves: $RET + EUWR$ (easily usable water reserve).

Value of useful soil water reserve (USWR) depends on soil particle size, soil depth and soil organic matter content. Deep is the soil, high is the value of USWR and vice versa. In the present study, considering the soil type of the study area (tropical ferruginous soils with medium depth of 3 m due to the presence of laterite) we used 80 mm as proposed by [12] for the value of the USWR. The EUWR was estimated at 40% of the USWR [12].

Water balance on monthly scale was used to determine the values of RET. Then the annual RET was used to calculate the agro-climatic stress index (ASI). The ASI ranges between 0 and 100. When it is close to 0 ($RET = PET$) meaning that conditions are optimal for cashew trees' water satisfaction. When value is close to 100 ($RET = 0$), the conditions are rather unfavorable for plant water satisfaction.

Dependence between climate parameters and cashew nuts yield

In order to identify the most relevant explicative climatic variables determining cashew nuts yield, climate data (annual rainfall, bimonthly rainfall, annual potential water balance, bimonthly water potential balance, annual average temperature, bimonthly average temperature, average of annual relative humidity, number of rainy days per year, average wind speed and agro-climatic index) were firstly submitted to logistic regression (stepwise logistic regression) using the Statistical Analysis System (SAS v 9.2). Then, these parameters were submitted

to multiple regression in order to describe the relationships between climatic factors influencing the most cashew nuts' yield.

The 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:

$$Y = a_1X_1 + a_2X_2 + a_3X_3 + \dots + a_nX_n + b$$

Where Y is the cashew nuts' yield; $X_1, X_2, X_3, \dots, X_n$ denote the explicative variables; $a_1, a_2, a_3, \dots, a_n$ 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 ($X_1, X_2, X_3, \dots, X_n$) was measured using the multiple determination coefficient R^2 . More R^2 is near to 1, more the adjustment is better, meaning that the information considered by the model is important. Then, Fisher's test was used to evaluate the degree of signification of the information explained (cashew nuts yield) by the variables in relation with the constant value for each equation. This test uses two hypotheses H_0 and H_1 . The H_0 hypothesis is validated when the simple model (only

the constant and not the explicative variables) is preferable; in opposite, H_1 is validated. The significance level was set at 5%.

Results

Progressive trend of climatic parameters

The rainfall at Savè and Natitingou was marked by very remarkable annual fluctuations with a succession of dry and wet periods (Figure 2). Evolution of the average precipitation level between 1981 and 2010 for both meteorological stations shown an increasing trend. The growth rates were 7.4 and 8.3% respectively at Savè and Natitingou. The precision parameters (MAPE, MAD and MSD) are high but the trends were more or less linear.

The evolution of the annual average temperature level for both meteorological stations (Figure 3) shows an increasing trend with growth rates of 0.04 and 0.02% respectively at Savè and Natitingou. The analysis of annual average temperature data recorded from 1993 at Savè revealed gradual rise. However, there were many fluctuations in Natitingou from 1983 to 2010 (Figure 3). The inter-annual temperature distribution recorded during the last decade (2001-2010) was warmer than the previous. The highest annual average temperatures were recorded in 2010 at both climatological stations (28.91 and 28.01°C

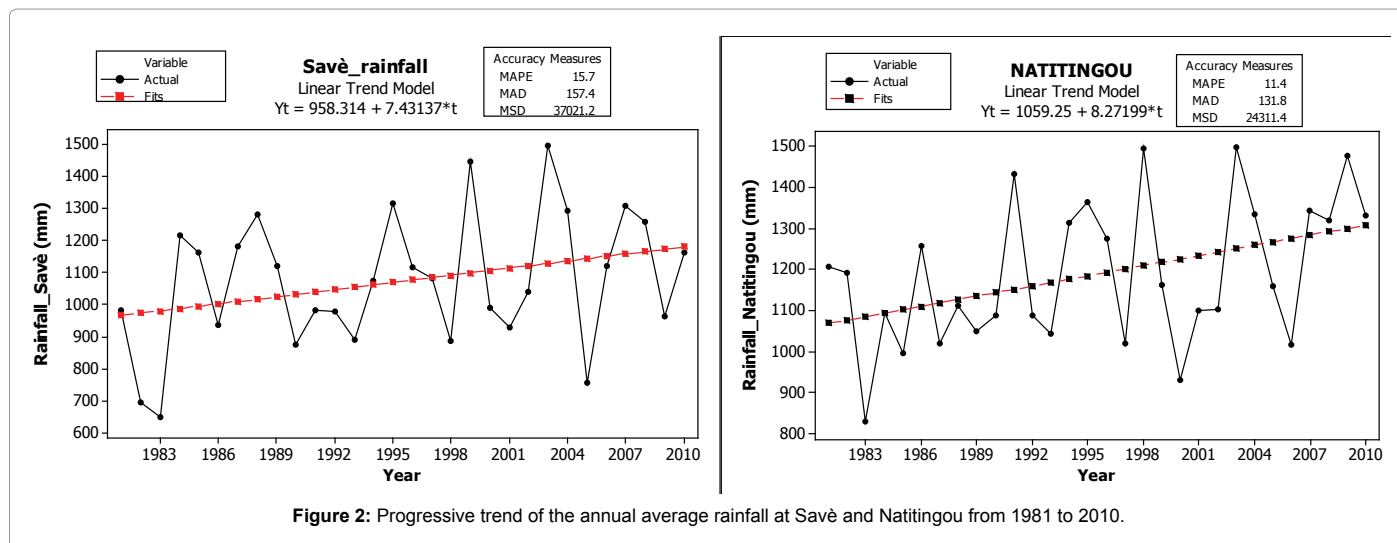


Figure 2: Progressive trend of the annual average rainfall at Savè and Natitingou from 1981 to 2010.

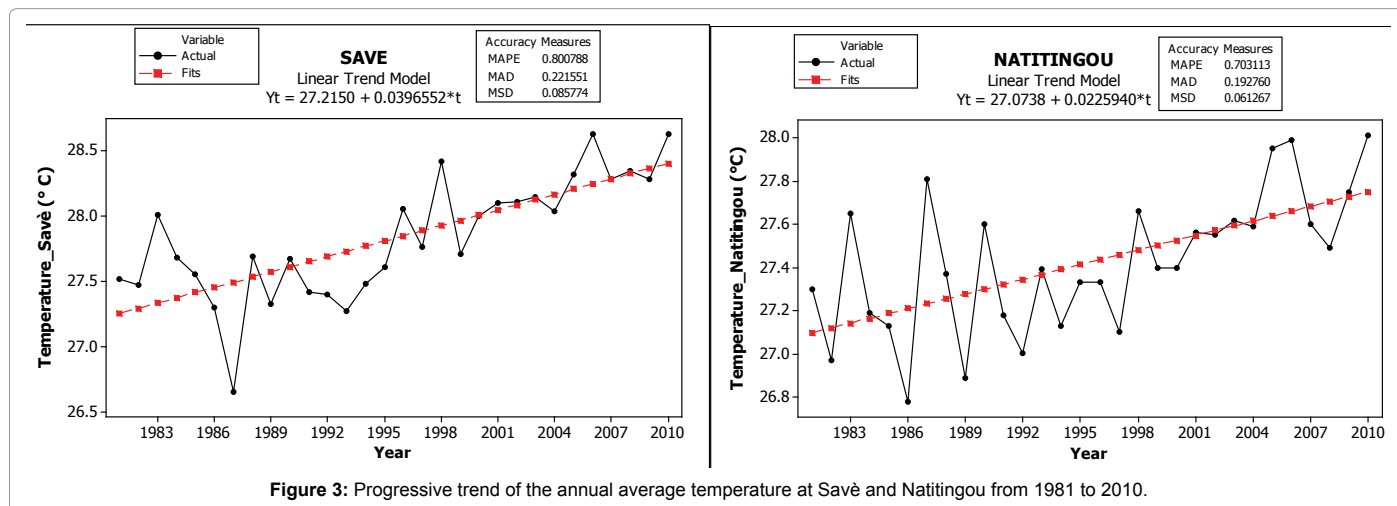
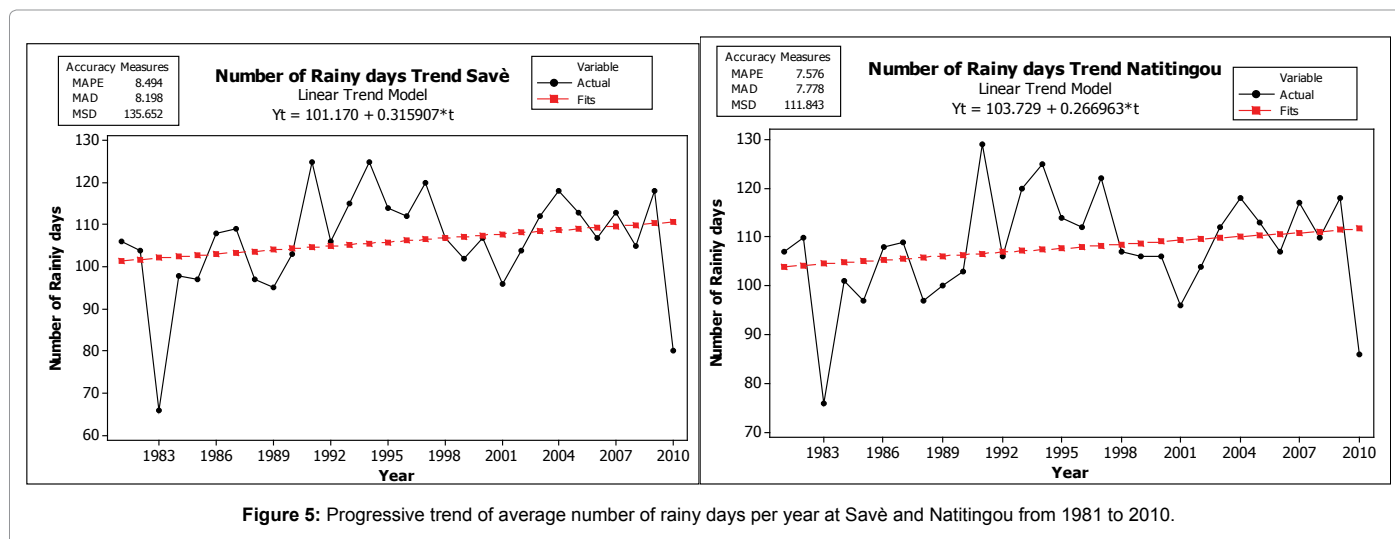
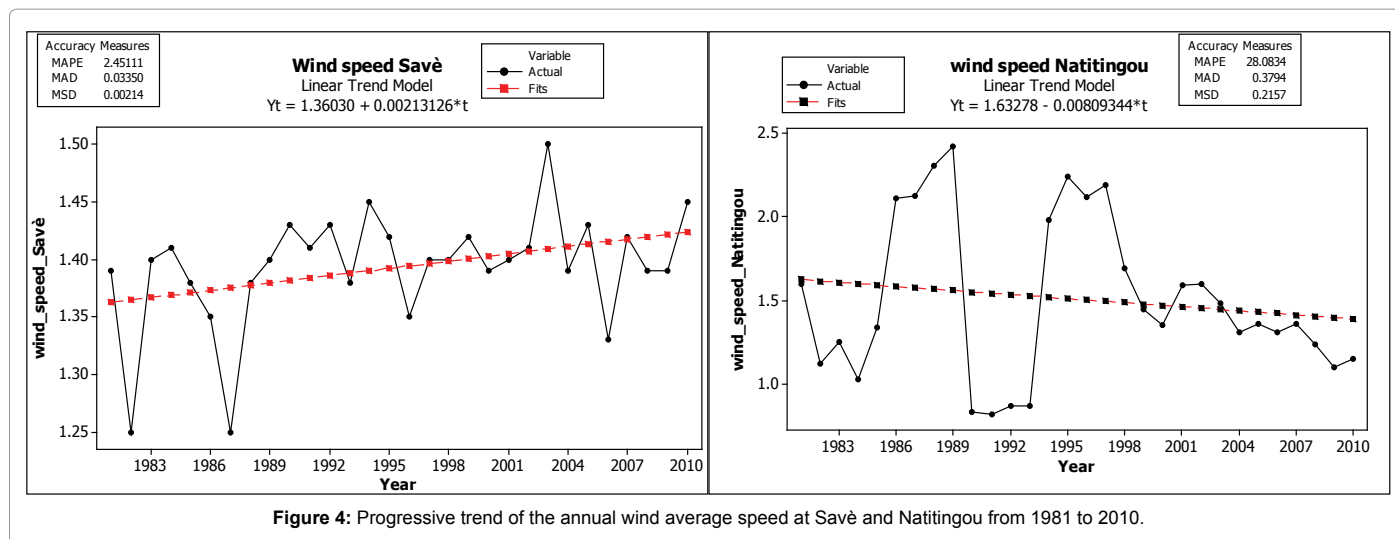


Figure 3: Progressive trend of the annual average temperature at Savè and Natitingou from 1981 to 2010.



respectively at Savè and Natitingou). In general, temporal variations indicate a high trend supported by linear lines in the two areas.

The wind speed at Savè and Natitingou was marked by remarkable inter-annual fluctuations with a succession of violent winds followed by moderate winds (Figure 4). Analysis of the trend of wind speed presented an increasing trend with a growth rate of 0.002% at Savè. In contrary, the trend was regressive with a rate of 0.008% at Natitingou.

The number of rainy days revealed also many fluctuations (Figure 5), but with an increasing trend (growth rates of 0.32 and 0.27% respectively at Savè and Natitingou). The low values of the number of rainy days were observed in 1983 and 2010 in the two zones.

Potential evapotranspiration (PET) at Savè and Natitingou was marked by remarkable annual fluctuations (Figure 6). Evolution of the average PET level between 1981 and 2010 for the two synoptic stations showed an increasing trend with growth rates of 4.94 and 2.33% respectively at Savè and Natitingou.

Effect of climatic factors on the phenology of cashew trees and the apple and nut yields

Results of analysis of variance (Table 1) showed significant (from $P < 0.05$ to $P < 0.001$) effects of the geographical zone of production on the phenology of the cashew trees. We have also observed that plants phenology were not significantly ($P > 0.05$) dependent on the cultivars. Moreover, apart the rate of appearance of male flowers, significant ($P < 0.05$ and $P < 0.001$) interaction was found between the season of production and the geographical zone.

The effects of the season of production, the zone and the cultivar characteristics on the cashew plants' phenology are presented in Table 2. It was observed that all of the plant organs emerged earlier in the Centre compared with the North-West. Thus, during the season of production 2013-2014, the first floral buds emerged from 16th to 25th October 2013 in the Centre while in the North-West, they emerged late from 18th to 22th November 2013. During production season 2014-2015, they emerged from 29th August to 16th September 2014 in the Centre while in the North-West, they emerged from 9th September to 11th November 2014. In general due to climate variation, the period of the emergency of cashew plant reproduction organs after the first buds was reduced during season 2013-2014 compared with the season 2014-2015.

It is also appeared from the results of Table 2 that the highest value

Source of variation	Degree of freedom	Period of appearance				Rate of flower types		
		First flowers	Completed appearance of flowers	Cashew nut	Apple	Male	Abnormal	Hermaphrodite
Season	1	4.71 [*]	5.20 [*]	27.70 ^{***}	111.10 ^{***}	2.36 ns	12.17 ^{***}	7.21 ^{**}
Area	1	4.67 [*]	6.96 ^{**}	18.14 ^{***}	13.86 ^{***}	8.15 ^{**}	5.17 [*]	23.00 ^{***}
Cultivar characteristics	1	0.01ns	0.00 ns	0.01 ns	0.32 ns	1.77 ns	0.06 ns	0.79 ns
Season*Area	1	17.23 ^{***}	7.44 ^{**}	7.67 ^{**}	8.01 ^{**}	1.39 ns	116.54 ^{***}	147.61 ^{***}
Season* Cultivar characteristics	1	2.45 ns	0.11 ns	1.39 ns	2.17 ns	0.00 ns	0.34 ns	0.79 ns
Area*Cultivar characteristics	1	0.11 ns	0.75 ns	1.07 ns	3.50 ns	0.03 ns	0.01 ns	0.18 ns
Season*Area*Cultivar	1	2.87 ns	0.06 ns	0.02 ns	0.32 ns	0.04 ns	0.35 ns	0.01 ns

Table 1: Three way ANOVA (F values) of the cashew plant phenology regarding season of plant production, geographical area and the cultivars characteristics.

Season of plant production	Geographic area	Cultivars characteristics	Period (number of days after the appearance of the first floral buds) of the emergence of plant organs				Floral rate (%)		
			First flower emergence	Completed occurrence of flower	Cashew nut formation	Apple formation	Male flower	Abnormal flower	Hermaphrodite flower
2013-2014	Centre	Big apples and big cashew nuts	0.74 ± 0.09 a (7.43)	1.35 ± 0.03 a (23.29)	1.45 ± 0.03 a (29.43)	1.57 ± 0.03 a (38.93)	1.84 ± 0.03 a (63.38)	0.62 ± 0.03 a (9.56)	1.09 ± 0.04 a (27.07)
		Small apples and small cashew nuts	0.86 ± 0.06 a (8.00)	1.34 ± 0.04 a (23.18)	1.39 ± 0.02 a (24.81)	1.57 ± 0.03 a (38.00)	1.81 ± 0.05 a (61.67)	0.61 ± 0.04 a (9.48)	1.13 ± 0.04 a (28.85)
		Mean	0.79 ± 0.06 B (7.68)	1.35 ± 0.02 B (23.24)	1.42 ± 0.02 B (27.40)	1.57 ± 0.02 B (38.52)	1.83 ± 0.03 B (62.63)	0.62 ± 0.02 A (9.52)	1.11 ± 0.03 A (27.85)
	North-West	Big apples and big cashew nuts	1.14 ± 0.05 a (15.78)	1.72 ± 0.03 a (54.61)	1.63 ± 0.04 a (45.56)	1.79 ± 0.03 a (64.11)	2.04 ± 0.03 a (72.54)	0.55 ± 0.03 a (7.56)	0.92 ± 0.03 a (19.89)
		Small apples and small cashew nuts	0.99 ± 0.06 a (11.06)	1.68 ± 0.04 a (51.41)	1.56 ± 0.03 a (38.47)	1.71 ± 0.02 b (51.72)	2.00 ± 0.04 a (70.64)	0.52 ± 0.04 a (7.09)	0.98 ± 0.03 a (22.27)
		Mean	1.07 ± 0.04 A (13.49)	1.70 ± 0.03 A (53.06)	1.60 ± 0.03 A (42.11)	1.75 ± 0.02 A (58.09)	2.02 ± 0.02 A (71.62)	0.53 ± 0.02 B (7.33)	0.95 ± 0.02 B (21.05)
GENERAL MEAN			0.93 ± 0.03 Y (10.59)	1.53 ± 0.02 Y (38.15)	1.51 ± 0.02 Y (34.76)	1.66 ± 0.02 Y (48.31)	1.93 ± 0.02 x (67.13)	0.58 ± 0.01 x (8.43)	1.03 ± 0.02 Y (24.45)
2014-2015	Centre	Big apples and big cashew nuts	1.02 ± 0.05 a (11.21)	1.59 ± 0.04 a (41.83)	1.71 ± 0.01 a (51.50)	1.92 ± 0.02 a (84.22)	2.21 ± 0.05 a (79.23)	0.50 ± 0.03 a (6.35)	0.78 ± 0.05 a (15.10)
		Small apples and small cashew nuts	1.02 ± 0.07 a (12.82)	1.58 ± 0.05 a (42.18)	1.71 ± 0.02 a (52.29)	1.91 ± 0.01 a (82.29)	2.16 ± 0.09 a (76.31)	0.51 ± 0.07 a (7.80)	0.77 ± 0.08 a (15.89)
		Mean	1.02 ± 0.05 B (12.07)	1.58 ± 0.03 B (42.00)	1.71 ± 0.01 B (51.89)	1.92 ± 0.01 B (83.29)	2.18 ± 0.05 A (77.67)	0.50 ± 0.04 A (7.12)	0.78 ± 0.05 B (15.52)
	North-West	Big apples and big cashew nuts	1.17 ± 0.06 a (17.00)	1.72 ± 0.05 a (57.43)	1.83 ± 0.06 a (75.71)	2.01 ± 0.02 a (103.71)	1.80 ± 0.02 a (61.12)	0.46 ± 0.03 a (5.43)	1.23 ± 0.02 a (33.45)
		Small apples and small cashew nuts	1.28 ± 0.04 a (20.29)	1.75 ± 0.04 a (58.56)	1.90 ± 0.04 a (84.25)	2.05 ± 0.02 a (114.19)	1.77 ± 0.02 a (59.73)	0.49 ± 0.03 a (6.20)	1.25 ± 0.02 a (34.07)
		Mean	1.22 ± 0.04 A (18.60)	1.74 ± 0.03 A (58.03)	1.87 ± 0.04 A (80.27)	2.03 ± 0.02 A (109.30)	1.78 ± 0.01 B (60.44)	0.47 ± 0.02 A (5.80)	1.24 ± 0.01 A (33.75)
GENERAL MEAN			1.15 ± 0.03 x (16.04)	1.64 ± 0.02 x (47.53)	1.65 ± 0.02 x (47.00)	1.83 ± 0.01 x (70.69)	1.90 ± 0.02 x (66.03)	0.50 ± 0.02 Y (6.57)	1.09 ± 0.02 x (27.40)

Table 2: Effect of season of plant production, geographical area and cultivars characteristics on the cashew plant phenology (mean ± standard errors).

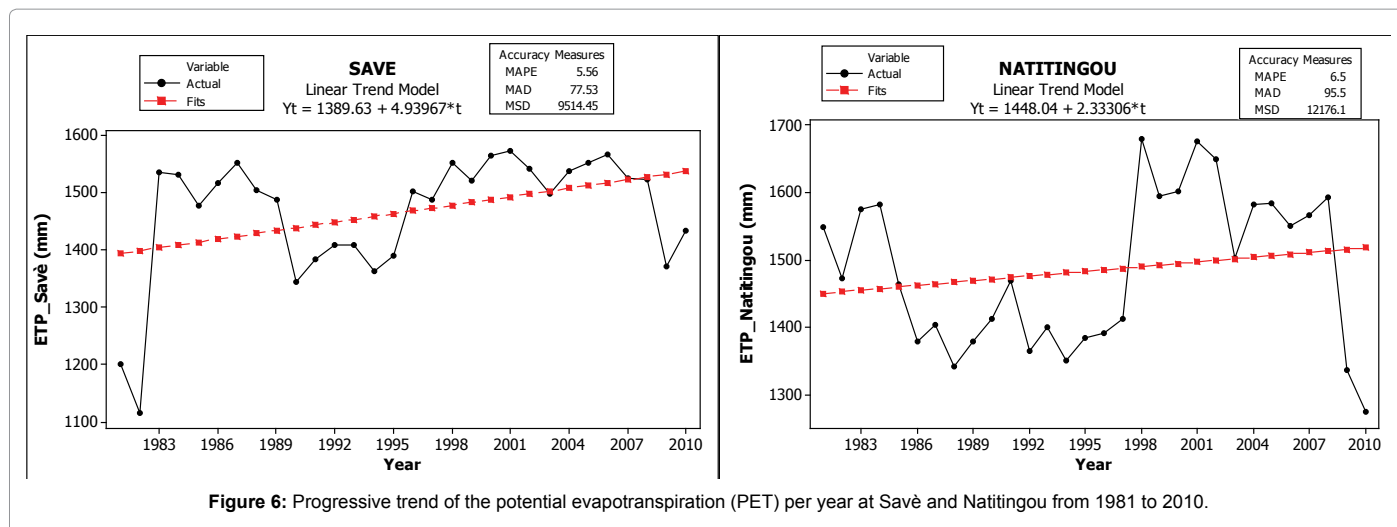


Figure 6: Progressive trend of the potential evapotranspiration (PET) per year at Savè and Natitingou from 1981 to 2010.

Source of variation	Degree of Freedom	Nut			Apple		
		Length	Circumference	Weight	Length	Circumference	Weight
Season	1	89.49***	0.03 ns	25.78***	30.33***	0.24 ns	4.51*
Area	1	1.74 ns	8.50**	50.84***	25.53***	25.85***	40.42***
Cultivar characteristics	1	4.89*	4.57*	4.17*	5.13*	5.45*	4.23*
Season*Area	1	2.13 ns	1.80 ns	1.48 ns	1.53 ns	3.83 ns	1.02 ns
Season*cultivar characteristics	1	0.58 ns	0.62 ns	0.09 ns	0.05 ns	0.15 ns	0.00 ns
Area*cultivar characteristics	1	0.79 ns	3.78 ns	1.47 ns	3.18 ns	3.78 ns	0.56 ns
Season*Area*cultivar	1	0.45 ns	3.70 ns	0.80 ns	0.06 ns	3.45 ns	0.04 ns

Table 3: Three way ANOVA (F values) of cashew nut and apple length, circumference and weight regarding the season of plant production, geographical area and the cultivars characteristics

Season of plant production	Geographical area	Cultivar characteristics	Nut			Apple		
			Length (cm)	Circumference (cm)	Weight (kg/tree)	Length (cm)	Circumference (cm)	Weight (kg/tree)
2013-2014	Centre	Big apples and big cashew nuts	3.79 ± 0.02 a	6.28 ± 0.09 a	2.70 ± 1.20 a	8.68 ± 0.19 a	16.24 ± 0.25 a	19.25 ± 2.24 a
		Small apples and small cashew nuts	3.76 ± 0.04 a	6.22 ± 0.09 a	1.60 ± 0.20 a	8.29 ± 0.19 a	15.85 ± 0.33 a	14.40 ± 2.01 a
		Mean	3.78 ± 0.02 B	6.25 ± 0.06 B	2.15 ± 0.60 B	8.48 ± 0.14 A	16.04 ± 0.21 A	16.82 ± 1.50 B
	North-West	Big apples and big cashew nuts	3.99 ± 0.08 a	6.74 ± 0.10 a	6.04 ± 1.31 a	7.42 ± 0.16 a	15.03 ± 0.25 a	69.23 ± 18.47 a
		Small apples and small cashew nuts	3.82 ± 0.08 a	6.30 ± 0.11 b	5.45 ± 1.28 a	6.98 ± 0.55 a	13.51 ± 0.46 b	53.49 ± 13.75 a
		Mean	3.91 ± 0.06 A	6.53 ± 0.08 A	5.74 ± 0.90 A	7.20 ± 0.28 B	14.29 ± 0.28 B	61.58 ± 11.52 A
GENERAL MEAN			3.84 ± 0.03 ×	6.39 ± 0.05 ×	3.95 ± 0.55 Y	7.85 ± 0.17 ×	15.18 ± 0.20 ×	39.20 ± 6.63 Y
2014-2015	Centre	Big apples and big cashew nuts	3.41 ± 0.05 a	6.39 ± 0.07 a	4.92 ± 0.39 a	7.20 ± 0.22 a	15.85 ± 0.56 a	39.68 ± 6.75 a
		Small apples and small cashew nuts	3.39 ± 0.07 a	6.30 ± 0.08 a	3.94 ± 0.41 a	7.01 ± 0.22 a	15.50 ± 0.31 a	30.37 ± 5.56 a
		Mean	3.40 ± 0.04 A	6.34 ± 0.05 A	4.46 ± 0.29 B	7.11 ± 0.18 A	15.87 ± 0.30 A	35.02 ± 4.38 B
	North-West	Big apples and big cashew nuts	3.42 ± 0.05 a	6.49 ± 0.08 a	9.04 ± 0.10 a	6.54 ± 0.27 a	15.08 ± 0.32 a	76.87 ± 13.35 a
		Small apples and small cashew nuts	3.38 ± 0.09 a	6.40 ± 0.10 a	7.34 ± 1.20 a	6.11 ± 0.26 a	14.69 ± 0.35 a	63.36 ± 12.24a
		Mean	3.40 ± 0.05 A	6.45 ± 0.06 A	8.21 ± 0.78 A	6.33 ± 0.19 B	14.89 ± 0.24 B	70.31 ± 9.02 A
GENERAL MEAN			3.40 ± 0.03 Y	6.40 ± 0.03 ×	6.48 ± 0.50 ×	6.69 ± 0.14 Y	15.25 ± 0.19 ×	50.72 ± 5.86 ×

Within column, means followed by letters of same characters are not significantly different ($P > 0.05$) according to Student Newman-Keuls test

Table 4: Effect of season of plant production, geographical area and cultivars characteristics on cashew nut and apple length, circumference and weight (mean ± standard errors).

Source of variation	Degree of freedom	F Values
Area	1	351.26 ***
Years	10	15.89 ***
Area*Years	10	11.96 ***

*** $P < 0.001$

Table 5: Two way-ANOVA (F values) of the estimated cashew nut production (from 2003 to 2013) regarding the geographical area and production year.

Years	Centre	North-West
2003	231.48 ± 13.80 a	279.49 ± 8.93 b
2004	222.92 ± 12.28 a	284.34 ± 9.53 b
2005	238.54 ± 13.45 a	286.80 ± 11.49 b
2006	226.04 ± 10.85 a	281.47 ± 9.15 b
2007	232.29 ± 10.50 a	282.06 ± 10.56 b
2008	228.05 ± 9.30 a	273.16 ± 9.42 b
2009	223.54 ± 8.73 a	289.57 ± 8.12 b
2010	200.28 ± 6.21 ab	279.31 ± 8.16 b
2011	182.66 ± 7.29 ab	299.37 ± 16.55 b
2012	143.11 ± 5.01 c	352.89 ± 18.01 a
2013	75.86 ± 3.02 d	216.28 ± 13.28 c

Means followed by the same alphabetic letter of same character and for the same factor are not significantly ($P > 0.05$) different according to Student Newman-Keuls test.

Table 6: Estimated cashew nut production (mean ± standard error) in kg/ha (from 2003 to 2013) regarding the geographic area and the years.

Parameters	Centre		North-West	
	Coefficients	$P > t$	Coefficients	$P > t$
Constant	132	0.003	490	0.000
ASI	-3.12	0.000	-5.91	0.000
RSO	0.194	0.000	0.154	0.003
NRD	1.65	0.000		
$P > F$	0.000		0.000	

ASI = agro-climatic stress index; RSO = rainfall from September to October (mm); NRD: number of rainy days; F: F values; t: Student test.

Table 7: Regression equations of the cashew nut yield and their statistical tests regarding the geographic area.

of hermaphrodite flowers rate was observed in the Centre zone in 2013-2014 ($27.85 \pm 0.86\%$ compared with $21.05 \pm 0.88\%$ in the North-West). Opposite results were found during season 2014-2015 ($33.75 \pm 0.67\%$ in the North-West and $15.52 \pm 1.66\%$ in the Centre).

The results of the analysis of variance (Table 3) showed that, apart nuts and apples circumference, the season of production affected significantly ($P < 0.05$ and $P < 0.001$) cashew's apples and nuts production. Furthermore, apart nut length, it was observed that cashew nuts and apples' length, circumference and their weight were significantly ($P < 0.01$ and $P < 0.001$) affected by the geographical area of production. The result of the table shows also that the nuts and apples' length, circumference and their weight vary significantly ($P < 0.05$) according to the cultivars.

Table 4 presents the effect of the season of production, geographical area of production and cashew cultivars on nuts and apples' length, circumference and their weight. Considering each season, big nuts and apples therefore higher production was observed in the North-West area compared with the Centre. It appears also from the results of the table that, cashew trees produced more during cropping season 2014-2015 compared with season 2013-2014. In general, 6.48 ± 0.05 kg of

nut/tree and 50.72 ± 5.86 kg of apple/tree were recorded in 2014-2015 against 3.95 ± 0.55 kg nut/tree and 39.20 ± 6.63 kg apple/tree in 2013-2014.

Cashew nut production from 2003 to 2013

Results of the two way-ANOVA regarding the geographical area of production and the years of the average estimated yield of cashew nuts per trees from 2003-2013 are presented in Table 5. Cashew nuts' yield varied highly ($P < 0.001$) from one geographical area to another and from one year to another. As presented in the previous section, cashew nuts' yields in the North-West zone were almost higher than that of the Centre. Furthermore, results of the Table 6 showed significant difference ($P < 0.05$) among yields from one year to another. Low cashew nuts' yields were estimated in 2012 and 2013 in both geographical zones.

Climatic factors determining cashew nuts production

The results of the multiple regression between cashew nuts' yields and the climatic factors from 2003 to 2013 are presented in Table 7. The agro-climatic stress index (ASI) and the bimonthly (September to October) rainfall are the most important climatic factors explaining the variation of cashew nuts' yields in both geographical areas. The average values of ASI calculated were 44.4 and 46.8% respectively for the Centre and the North-West zones. The ASI variable influences negatively the annual cashew nuts production while, rainfall during the period of September to October has positive influence on the annual cashew nuts production in both geographical areas.

In addition to these two factors, the number of rainy days also influences positively the annual cashew nuts production in the Centre. Henceforth high is the value of this climatic factor, high is the amount of cashew nuts' produced. These three variables (ASI, rainfall from September to October and number of rainy days) have together induced variation in cashew nuts' yields of 79.5% and 78.3% in the Centre and North-West respectively. From these results one can conclude that, ASI and rainfall from September to October (in both zones), and specifically the number of rainy days (only for the Centre area) are the main factors that determine cashew nuts production during a year. Results of the statistical analysis (Table 7) revealed that, the selected variables provided highly significant information ($P < 0.01$ or $P < 0.001$) for the validity of the multiple regression models.

Discussion

Climatic variability in Benin

Results of our study show the evidence of high annual fluctuations of rainfall, wind speed, and an upward trend of temperatures followed by a decrease in the number of rainy days in both study areas. These results have also showed the succession of dry periods and wet periods. This corroborate those of [15] in Togo. These fluctuations of the rainfall and temperature were also studied in Ivory Coast by [16], in Nigeria by [17] and they made similar conclusion. According to [18], these sudden changes coincide with major droughts in sub-Saharan Africa in 1986-1987 and 1991-1992; especially in Benin and Togo from 1976 to 1977. The decrease in rainfall observed in both zones confirms results of [15] who revealed less rainfall in West Africa. The significant decrease in rainfall demonstrated by several studies in the sub-region was also reflected by the shift of the isohyets [19]. This shift did not affect Benin but only Togo and Ivory Coast. Thus, [19] have showed a shift of isohyets in the North of Benin since 1970, and this varies in space. However, in Natitingou, an increase in the height of rainfall was observed. This important rainfall observed in Natitingou area

could be explained by the influence of topography [15]. Indeed, the area is crossed by the chain of Atacora (600 m). The hills that cross the zone stop the southwestern maritime trade winds called monsoon which blows South-West to North-East and favors the formation of clouds and therefore heavy rainfall in the area. According to [20], the increase in rainfall in the area combined with the reduced number of rainy days enable to understand the reported cases of flooding in this area in the last five years. The effect of climate change may consist in an increase of rainfall in some areas or at some relief types with more intense rainfall and their late end [21]. On the whole, this may affect variation in cashew trees' phenology and yield formation as observed in our study in this area.

Influence of climate factors on the cashew trees' phenology and productivity

The low rate of hermaphrodite flowers observed during season 2013-2014 could be explained by climatic factors especially rainfall distribution and temperature. The low rainfall observed during the vegetative stage did not enable the trees to get appropriate quantity of water to sustaining the flowering stage. Yet, cashew trees prefers a rainfall between 1000 and 2000 mm per year with flowering stage duration between 4 to 6 months [22]. During the period of fruit production (mid-January), two successive rains were recorded in both sites with long period of hamattan. This phenomenon led to the drop of the flowers and consequently affected cashew fruit production [23] also revealed that rains followed by the cloudy times during flowering period affect cashew nut production. In our study, the majority of the trees did not set flowers during 2013-2014. Besides, harmattan has also caused dry off and abortion of some flowers therefore low cashew nut and apple were produced in this season. [24] stated that, from the flowering period to the beginning of fruition, climatic conditions are very decisive and of paramount importance. During this period, high temperatures, dry or violent winds can cause damage of the flowers, immature fruits and also reduction of fruit number per tree. Violent winds, drought periods and rains during January and December, have affected negatively cashew productivity by causing the drop and drying of the flowers.

The high cashew nut and apple yields obtained in the North-West area could be explained by the high rain quantities recorded due to as mentioned in the previous section the influence of the Atacora chain [15,24] showed that cashew can produce in dry season and it is especially productive when rains are regular and temperatures are moderate during the rainy season. In fact, during the rainy season, if rainfalls are irregular it will still lead to low cashew's trees productivity. Thus, good distribution of rainfall enhances cashew yield. The best climatic conditions recorded in the North-West area (sufficient rainfall and good distribution, moderate temperature and less violent wind) have ineluctably induced higher cashew yields than the Centre. This observation corroborates those of [20]. According to [25], a reduction of the quantity of rainfall follow by an increasing temperatures induce a reduction of available water in the soil, which could affect negatively crop yield. The final conclusion, as mentioned by [26], rainfall and its distribution are the most important climatic factor affecting agricultural activities in the tropics.

Climatic factors affecting cashew nut yields

The average values of the agro-climatic stress index (ASI) were 44.4 and 46.8 respectively in the Centre and North-West. These values were relatively high and not favorable for a good development of perennial

plants such as cashew [12]. Indeed, the water available in the soil for cashew production in the two zones is lesser than that required by cashew tree to reach potential production. Values obtained were almost similar with those obtained by [12] (48% in the Centre). Agro-climatic conditions also affect crop management options and the suitability of crops for a specific regions [5]. These factors affect crop yields both directly (the plant) and indirectly (e.g. via soil conditions and crop management) and should be considered in long-term.

The amount of rainfall from September to October shows positive influence on cashew yield in both zones. This result corroborates those obtained by [12] on cashew in Benin. In fact, the rainfall during the period from September to October was a valuable water resource for cashew plantation especially during the period of flowering and fruiting and for plant survival during the dry period. In that period cashew plantation mostly makes suitable water reserve to pass the dry season and also to sustain the production. However, [27] have already shown that irregular and unpredictable rainfall and sunshine hours (albedo and photoperiods) affect many crops production. Thus, cocoa, cashew, oranges, kola nut, oil palm, rubber, cotton and coffee, suffer severe setbacks under reduced photoperiods and rainfall with flower and fruit abortion consequently, it shots down the annual yields by 5.5 tons/ha.

The number of rainy days has influenced positively cashew nut yield only in the Centre. This can be explained by a normal distribution of rain during the period from September to October even if the quantity recorded is lower in this zone than in the North-West. A normal distribution of rainfall may create good condition for plant growth and fruition.

Furthermore, several studies revealed that climate change can affect inter-annual crop yield variability [28]. This confirms our finding. Therefore, crop management strategies must comply with these climatic conditions in order to enhance plant productivity. Thus, water supply and fertilization management techniques may play a crucial role in maintaining the potential production of crops [4]. This is not the case of cashew plantation in Benin. The plants are cultivated without fertilizer application and water management strategy [2] as consequence cashew trees are subject to climate variability. Several measures that reduce evapotranspiration will be increasingly crucial for cashew trees. Number of management options are available to improve water availability and water use efficiency including irrigation, soil cultivation, fertilization and crop rotation [29]. Implementing these management strategies will contribute to enhance cashew trees' productivity.

Conclusion

The present study shows that from 1981 to 2010 the climatic parameters in the Centre and North-West zones of Benin were marked by significant inter annual fluctuations. Thus, rainfall and temperature revealed an upward trend in the two zones while wind was less violent in the North-West and the potential evapotranspiration was high in the Centre. The emergence of cashew trees' flowers and fruition occur earlier in the Centre than the North-West zone. The amount of cashew nuts and apples produced per tree were higher in the North-West than the Centre. High quantity of cashew nuts and apples were recorded in 2014-2015 than the cropping season 2013-2014. In general, the agro-climatic stress index (ASI) and the quantity of rainfall in the period from September to October in both zones, and the number of rainy days (especially in the Centre), are the main climatic factors determining cashew plantation production in the study area. The study suggests

suitable rainfall water management strategies during this critical period in order to enhance cashew trees production.

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