Asian Journal of Agricultural Extension, Economics & Sociology
3(1): 23-36, 2014; Article no. AJAEES.2014.003

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The Effects of Climate Change on Agricultural Sustainability in Southeast Nigeria – Implications for Food Security

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Authors' contributions

This work was carried out in collaboration between all authors. Author IUON designed the survey, analysed and reported the result and was involved in every part of the work, author DOO Crosschecked analyses and results, authors JSO and UCI proof read the work, authors SUOO and AHU proof read the galley proof, and authors MNO and CMT assisted in data collection and collation. All authors read and approved the final manuscript.

Original Research Article

Received 9th August 2013
Accepted 24th September 2013
Published 20th November 2013

ABSTRACT

Considering the alarming predictions of researchers and policy makers concerning the natural phenomenon climate change, this study "Effects of Climate Change on Agricultural Sustainability – Implications for Food Security" was carried out in southeast Nigeria to untie some of the dangers associated with it as a prelude to the final solution. Data for the study were mainly secondary time series data collected from institutions. Statistical data on climate elements for forty years between (1972-2011) were collected from the Agro-metrological unit of the National Root Crop Research Institute (NRCRI) Umudike while input/output data in physical and value terms concerning cassava production were collected from government ministries and agencies. Data were analysed using descriptive statistical tools like mean frequency, percentages, frequency polygon or line graphs. Furthermore, multiple regression analytical tools were used to determine the effects of climate change on agricultural sustainability. Results showed an increasing

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trend in temperature, rainfall and sunshine duration while number of rain-days and relative humidity showed a decreasing trend. It was observed that the major climate elements that strongly and significantly affected agricultural sustainability were temperature and rainfall. The negative effects of climate change on sustainability requires urgent intervention by government at all levels to ensure sustained increases in food production to ensure food security.

Keywords: Climate change; sustainability; food security; temperature; rainfall; regression.

1. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC), refers to climate change as any change in climate over time, whether due to natural variability or as a result of human activity [1]. It may also be referred to as any significant change in measures of climate (such as temperature, precipitation, or wind) lasting for an extended period (decades or longer). Climate change can also mean any long-term change in the patterns of average weather of a specific region or the Earth as a whole. It reflects abnormal variations to the Earth's climate and subsequent effects on other parts of the Earth, such as in the ice caps over durations ranging from decades to millions of years.

Climate change has been observed to have varying negative effects on agricultural production by reducing the growth and yields of crops and debilitating the health status of animals and man which seriously affects agricultural productivity. According to [2] climate change is predicted to have adverse effects on the agricultural sector of the poorer parts of the world especially sub-Saharan Africa. Most of the crop production in that part of the world are low-technology based and are therefore heavily susceptible to environmental factors. A significant effect of climate change due to increased levels of CO_2 would be reflected in the production of both C_3 crops (Cassava, Yam, Cowpea, Wheat, Soybean, Rice, and Potatoes) and C_4 crops (Millet, Sorghum, Sugar cane and Maize) [3]. Increases in CO_2 can lower crop water requirements by reducing transpiration per unit leaf area [4]. High temperatures may result in accelerated physiological development, leading to hastened maturation and reduced yield. It also may accelerate the rate at which plants release CO_2 in the process of respiration leading to less than optimal conditions for net growth. When temperatures exceed the optimal for biological processes, crops often respond negatively with a steep drop in net growth and yield [5].

The continued quest for sustainable development encouraged by propagating sustainable agricultural development is being bedeviled by the highlighted menace of climate change especially from the perspective of Sub-Saharan farmers whose agriculture is mainly dependant on natural climate factors. According to [6] sustainable development is that which meets the needs and aspirations of the present without compromising the ability of future generations to meet their own needs. [7] defined sustainable agriculture as one that involves the successful management of resources for agriculture to satisfy human needs, while maintaining or enhancing the quality of the environment and conserving natural resources. In his own view, [8] defined it as agricultural systems that are environmentally sound, profitable and productive and that maintain the social fabric of the rural community. Putting all these together, it is obvious that sustainability as a subject matter has both the spatial and temporal dimensions. By spatial we look at the availability and use of natural resources to achieve maximum economic needs, while the temporal dimension looks at possibility of use of available resources to provide for the present and future generations in a fair manner. Since sustainable agriculture became the watch word for encapturing society's desire to better preserve the natural resource base for future generations, there have been debates about how to define and measure sustainable agricultural systems [9]. It is now widely agreed that there are different dimensions of sustainability ranging from the biophysical dimensions to economic and social dimensions [10]. The biophysical dimensions of sustainability relate to the long-term maintenance or enhancement of the productive capacity of the resource base. Economic and social dimensions relate to the long-term economic viability of farming and rural communities. In order to develop a single unambiguous measure of biophysical sustainability, economists have proposed the use of an index of total factor productivity (TFP), since it explicitly accounts for changes in agricultural production in relation to changes in inputs [11]. Many recent studies have used TFP to analyze the sustainability of specific agricultural systems [12], or crops [13,14]. 'TFP is defined as the value of all outputs produced by the system during one cycle divided by the total value of all inputs used by the system during one cycle of the system'. In normal economic practice, the outputs and inputs would be confined to those attributes, such as purchased inputs, labour cost and value of the harvest [11]. The researcher adopted the total factor productivity approach as an index of sustainability in this study. It is accepted that if the TFP shows a constant or upward trend over a period of time, then the system is sustainable otherwise that system is unsustainable if the TFP is decreasing.[11] It could be inferred from this decision criterion about sustainability that a sustainable production system is one that guarantees consistent increases in food production. Therefore when the system is sustainable, it portends a potentially food secure economy.

Food security is one of the major challenges worldwide in the years ahead, with global food demand forecast to rise by 70% by 2050 (FAO), accompanied by a steep increase in the demand for feed, fibre, biomass, and biomaterial [15]. However, this challenge is accompanied by a slowdown in productivity growth – in good part because of a reduction in investment in agricultural research – and increased pressure on the environment and our natural resources. For example, 45% of European soils face problems of soil quality. Around 40% of agricultural land is vulnerable to nitrate pollution and, over the last 20 years, farmland birds have declined by 20-25% [15]. These are grave effects on biodiversity and therefore portends an imminent doom for the world food security status. [16,17,18] defined food security as access by all people at all times to enough food for active and healthy life. FAO also in (1989) defined it as the physical and economic access to adequate food for all household members without undue risk of losing the access. In view of these meanings and challenges associated with food security and the direct linkage between total TFP (sustainability) and food production, effort is required on the side of researchers and policy makers to innovate and institute policies that will ensure increases in agricultural productivity. This should also be achieved in environmentally sustainable manner. Consequent upon this quest for sustainable increases in agricultural production, this study is aimed at untying the effects of climate change on agricultural sustainability as a panacea to the dwindling agricultural productivity and food security challenges of the world.

2. MATERIALS AND METHODS

The study was carried out in the Southeast Zone of Nigeria. Southeast Nigeria is located within latitudes 5ºN to 6º N of the equator and longitudes 6ºE and 8ºE of the Greenwich (prime) meridian [19]. The zone occupies a total land mass of 10,952,400 hectares with a population of 16,381,729 people[20]. Southeast is a rainforest zone in Nigeria having a belt of tall trees with dense undergrowth of shorter species dominated by climbing plants. The prolonged rainy season, resulting in high annual rainfall above 1,800mm, humidity of above 80% during the rainy season, and temperature of 27ºC annually in this area; ensures adequate supply of water and promotes perennial tree growth (Http://www.onlinenigeria.com/links/adv.asp?blurb=69). The inhabitants of this area are farmers producing mainly food crops like cassava, yam, and maize. Data for this study were mainly secondary time series data collected from institutions. Climate data on temperature, rainfall, relative humidity, number of rain-days and hours of sunshine for a period of forty (40) years (1972-2011) were collected from the Agro-metrological unit of National Root Crop Research Institute Umiudike (NRCRI). Input and output data in physical and value terms concerning cassava production over corresponding number of years were collected from the Federal Ministry of Agriculture and Natural Resources (FMANR), National Bureau of Statistics (NBS) and State Agricultural Development Projects (ADPS). Data were analysed using the descriptive statistical tools like mean, frequency distribution, standard deviation, frequency polygon or line graphs and the ordinary least square multiple regression tools. The sustainability level of agricultural production was determined using the Total Factor Productivity of the system per annum as an index of agricultural sustainability. Many recent studies have used TFP to analyze the sustainability of specific agricultural systems [12] or crops [13,14]. It is accepted that if the TFP shows a constant or upward trend over a period of time, then the system is sustainable otherwise that system is unsustainable if the TFP is decreasing [11]. In this study TFP is computed per annum using the following model

$$\text{TFP (Ss)} = \frac{V_{T_O}}{V_{T_n}} = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n} P_{qij} Q_{ij}}{\sum_{j=1}^{m}\sum_{t=1}^{n} P_{xtj} X_{tj}} \quad \ldots\ldots\ldots\ldots \quad 2.1$$

Where V_{T_o} = Value of Total Output of cassava in naira/annum

V_{T_n} = Value of Total Input used in cassava production in naira/annum.

P_q = Price of output of cassava in naira

Q = Quantity of cassava Output

i = Type of output (i ranges from 1- n^{th} output type) in this case, cassava

j = Farmers (j ranges from 1 - m^{th} farmer)

P_x = Price of input

X = Quantity of input

t = Type of input (t ranges from 1 – n^{th} input type) in this case land, labour, and chemicals/fertilizer,

Adopted from [11,21,12,13,22,14]

Following the determination of the sustainability of the system per annum for the period of 30 years (1982-2011), the multiple regression model given in equation 2.2 was used to check the effects of climate change on agricultural sustainability.

$$\text{TFP/Ss} = f(\text{Ts, Rf, Rh, Sh,T, e}) \quad \ldots\ldots\ldots\ldots \quad 2.2$$

Where Ss = Agricultural Sustainability (measured as Total factor productivity estimated per annum for a period of 30 years from 1982-2011)

- Ts = Annual mean temperature of the system for 30 years period in ^{0}C from 1982-2011
- Rf = Annual mean rainfall for 30 years period in mm from 1982-2011
- Rh = Annual mean relative humidity for 30 years period in % from 1982-2011
- Sh = Annual mean number of hours of sunshine also for 30 years period in (in hours) from 1982-2011
- T = Time trend variable measuring the number of years involved (1, 2, 3, 4, …30)
- e = the stochastic error term.

The a priori theoretical expectations of the coefficients are as follow;

Ts = temperature is hypothesized to be negatively and significantly related to sustainability. The basis of this is that if temperatures continue to increase beyond a specific threshold, a crop's productive summer growing season could become shorter, thus reducing the yield and productivity [23]); [24].

Rf = precipitation is theorized to affect sustainability positively. The basis for this theoretical expectation is justified with the fact that precipitation increase affects crop yield positively ([25]; [26]; [27] by readily dissolving the nutrients for easy soil absorption by plants.

Rh = relative humidity should be positively related TFP. The basis for this assumption is that crops tend absorb soil nutrients for optimum yield when there is sufficient humid air [3].

Sh = sunshine duration is expected to be positively related to TFP. The basis for this *a priori* expectation lies in the fact that tropical crops require higher photoperiods (day lengths) for their vegetative and reproductive growth and development [3].

3. RESULTS AND DISCUSSION

3.1 Describing the Trend of Climate Variables

Table 3.1 shows the analysis of climate records in southeast Nigeria between the periods of 1972 through 2011.

Table 3.1 Analysis of climate Records from 1972-2011

Climate element	Mean	Standard deviation	Range	Trend	Correlation coefficient
Temperature(ºC)	26.77	0.444	25.95-27.65	1.192*	0.425*
Rainfall(MM)	2158.89	288	1511.4-2751.9	2.09	0.091
Number of rain-days (days)	141.80	10.99	110.00-167.00	-6.717*	0.497*
Relative humidity (%)	71.98	1.44	68.50-74.00	-0.900	0.138
Sunshine duration (HRS)	4.35	0.35	3.80-5.20	0.008	0.253

**Significant at 1%*
Source: [28]

According to the statistical records of temperature in southeast Nigeria as recorded by the Agromet unit of the NRCRI, Umudike from 1972-2011, temperature shows an increasing trend with the highest temperature occurring in 2009 at 27.65ºC and the lowest occurring in 1975 at 25.95 ºC (Table 3.1 and Fig. 3.1a). Also the mean and standard deviation of the temperature record are 26.77 ºC and 0.441 ºC respectively (Table 3.1). This shows that there is a very small variability in temperature from year to year. The trend coefficient is 1.192 and is statistically significant at 1% level (Table 3.1). The correlation coefficient is 0.425 and is statistically significant at 1% level implying that temperature has a significant positive relationship with time. This therefore indicates that climate with respect to temperature is really changing and increasing, hence there is indeed global warming.

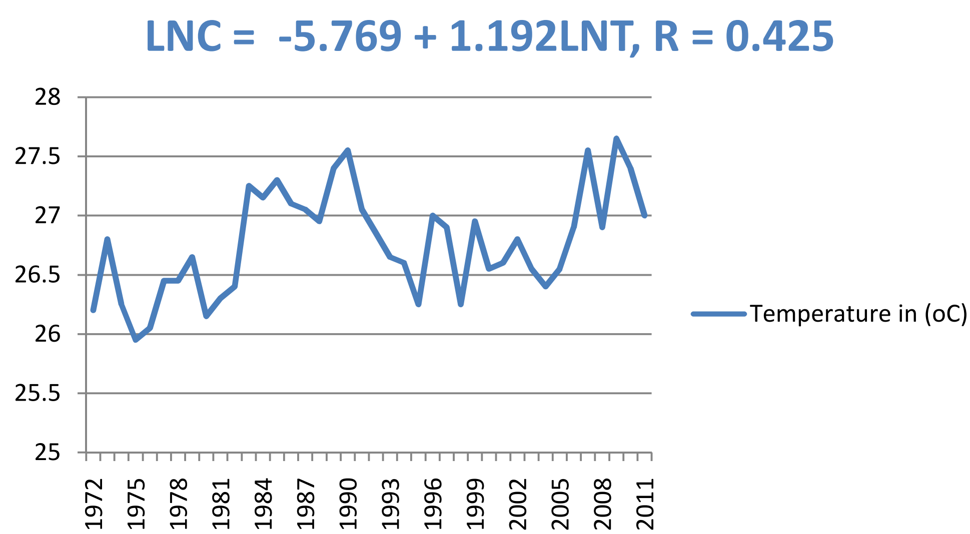

Fig. 3.1a. Trend of temperature of Southeast Nigeria between 1972-2011
Source: [28].

Statistics of rainfall volume in southeast Nigeria between the periods of 1972-2011 shows an increasing trend with the highest occurring in 1996 and lowest occurring in 1983 with values of 2751.9mm and 1511.4mm respectively (Table 3.1, Fig. 3.1b). The mean and standard deviation are 2158.89mm and 288mm respectively (Table 3.1). This implies that there is a high variability in rainfall within this period hence the observed positive trend though not statistically significant. The coefficient of correlation is 0.091(Table 3.1), which is not statistically significant also. This indicates that there exist a non significant positive relationship between rainfall and time.

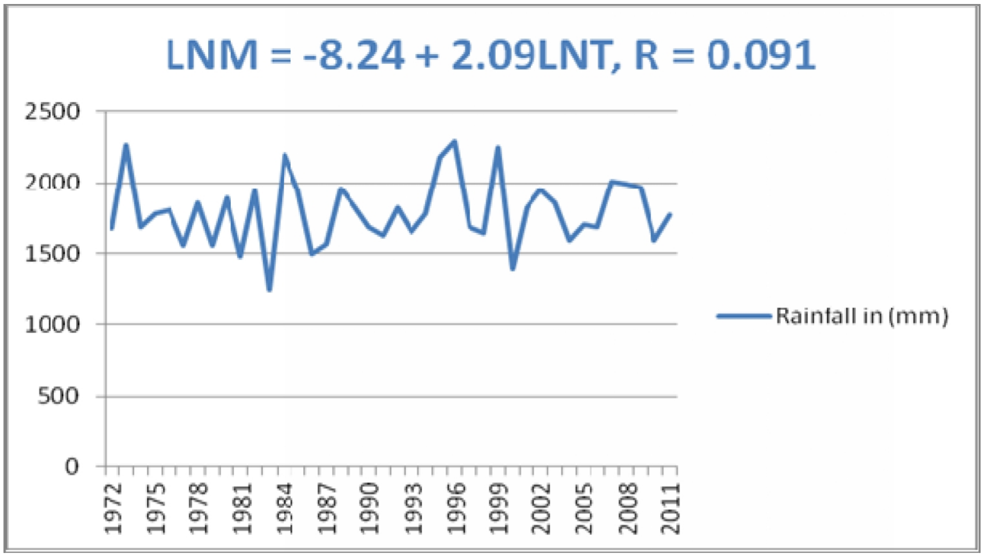

Fig. 3.1b. Trend in Volume of Rainfall of Southeast Nigeria between 1972-2011
Source: [28]

Analysis of number of rain-days as recorded by the Agromet unit of the NRCRI, Umudike shows a decreasing trend in the number of rain-days in southeast Nigeria with a trend coefficient of -6.717 which is statistically significant at 1%. The maximum and minimum number of rain-days occurred in 1976 and 1987 with the values of 167days and 110days respectively (Table 3.1 and Fig. 3.1c).The mean and standard deviation are 141.8days and 10.99days. This indicates a high variability in number of rain-days from year to year. The coefficient of correlation between number of rain-days and time is 0.497 and is statistically significant at 1% implying that the number of rain-days is strongly correlated with time and since a negative trend is observed, it means that the region and indeed Nigeria is tending toward a dryer period which portends an imminent doom for the life of the flora and fauna. Furthermore, the negative correlation between number of rain-days and time vis- a-vis the positive correlation between volume of rainfall and time provides a clearer explanation about the torrential rainfall that are usually observed in recent times.

Relative humidity records from southeast Nigeria between 1991-2011 shows a decreasing trend with a coefficient of -0.900 though not statistically significant. The highest occurred in 1996 and 1997 and the lowest occurred in 2008 with values of (74%) and (68.5%) respectively (Table 3.1 and Fig. 3.1d). The mean and standard deviation are 71.98% and 1.44% implying that relative humidity has a very small variability with time. The coefficient of correlation between relative humidity and time is 0.138. This indicates non significant relationship between relative humidity and time because the coefficient is insignificant.

Table 3.1 and Fig. 3.1e show that the hours of sunshine indicates an increasing trend with time with a coefficient of 0.008hrs. This positive trend in sunshine duration could be linked to the increasing trend in temperature as observed in Table 3.1 and Fig. 3.1a. It is agreeable that the higher the hours of sunshine the greater is the temperature. The mean and standard deviation are 4.35hrs and 0.35hrs respectively. This implies a narrow variability between sunshine duration and time over the period under review. The maximum and minimum hours of sunshine per day are 5.20 hours and 3.80 hours and were recorded in 1995 and 1978 respectively. The coefficient of correlation (r) is 0.253 and is not statistically significant. This indicates that there is no statistically significant relationship between sunshine duration and time.

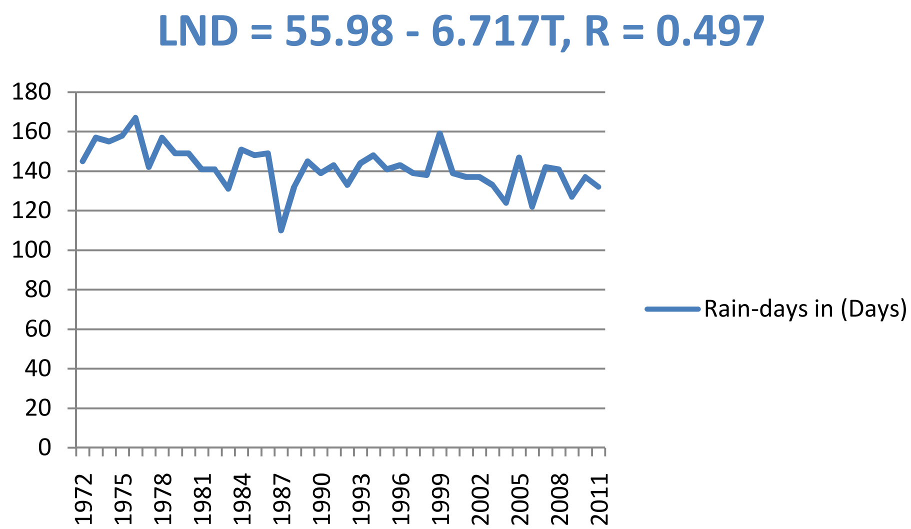

Fig. 3.1c. Trend of Number of Rain-days in Southeast Nigeria between 1972-2011
Source: [28]

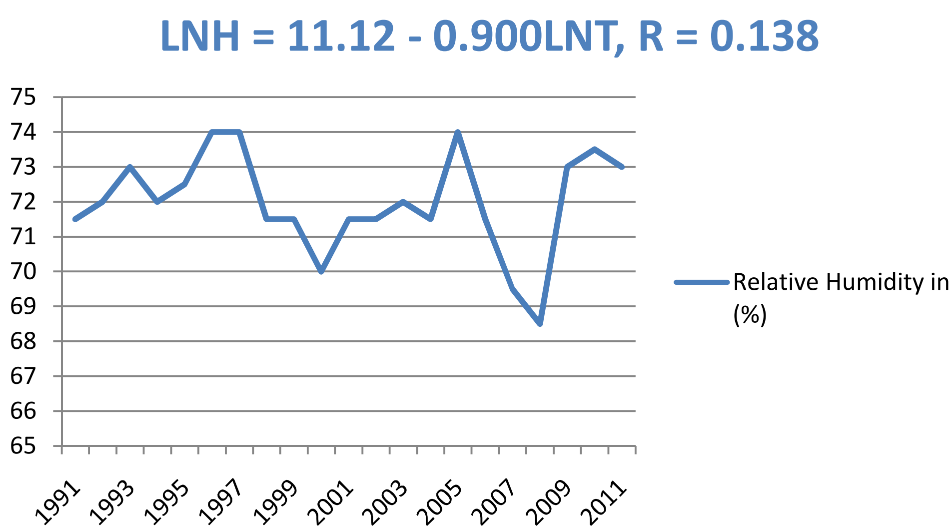

Fig. 3.1d. Trend of Relative Humidity in Southeast Nigeria between 1991-2011
Source: [28]

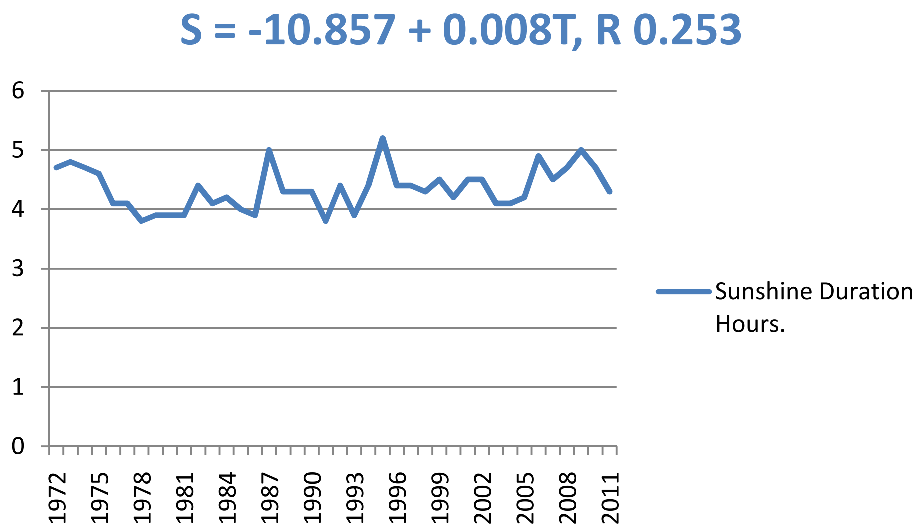

Fig. 3.1e. Trend in Sunshine Duration in Southeast Nigeria between 1972-2011
Source: [28].

Table 3.2 shows the distribution of annual sustainability/TFP of cassava production in southeast Nigeria for a period of 30 years.

Table 3.2 Distribution of Annual Sustainability/TFP of Cassava Production in Southeast Nigeria between 1982 – 2011

Sustainability/TFP	Frequency	Percentage
0.16-0.46	4.0	13.33
0.46-0.76	1.0	3.33
0.76-1.06	6.0	20.00
1.06-1.36	8.0	26.67
1.36-1.66	9.0	30.00
1.66-1.96	2.0	6.66
TOTAL	30	100
Mean : 1.17		
Std.dev.: 0.44		
Range : 0.16-1.94		

Source: [29,30]

According to Tables 3.2, 3.3 and Fig. 3.2, the mean sustainability of cassava production in southeast Nigeria is 1.17, with a standard deviation of 0.44. This shows that there is a relatively low variability in sustainability of cassava production over the period under review. The maximum and minimum values are 1.94 and 0.16 occurring in the years 2011 and 1986 respectively. The trend coefficient is 0.033 and is statistically significant at 1% level and positively related to sustainability. This implies that sustainability is showing a statistically significant increasing trend over the time under review. Therefore, according to[22] cassava production in southeast Nigeria is sustainable since it shows an increasing trend over time although there is observed fluctuations over the period which may be caused by such factors like annual climate challenges, pest and diseases, labour availability and efficiency, and market prices. Table 3.3 also shows that the coefficient of correlation is 0.534 and is statistically significant at 1% level. This also implies that sustainability/TFP strongly changes with time and that the time trend effect should not be ignored.

Table 3.3 Analysis of Sustainability/TFP of Cassava Production in Southeast Nigeria between 1982-2011

Sustainability/TFP	Value
Mean	1.17
Maximum	1.94
Minimum	0.16
Standard deviation	0.44
Trend	0.033*
Correlation coefficient (r)	0.534*

**Significant at 1%; Source: [28,29,30]*

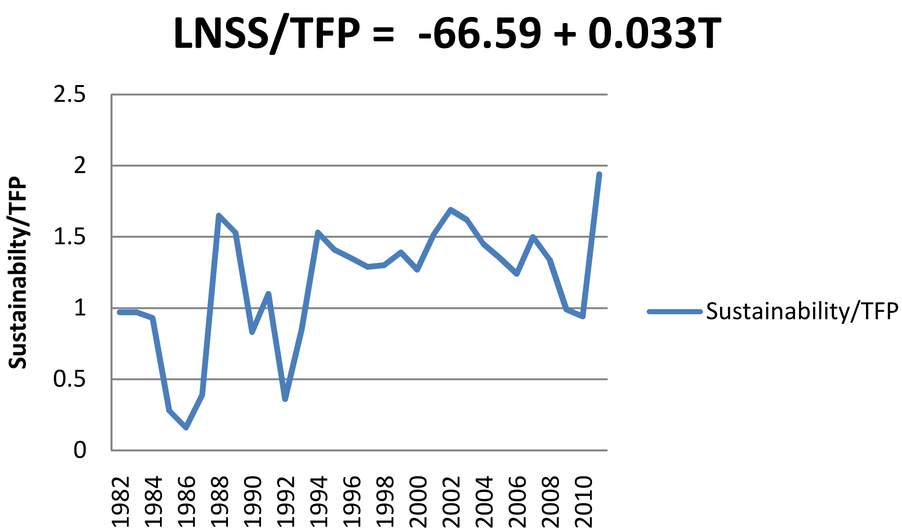

Fig. 3.2 Trend of Sustainability/TFP of Cassava Production in Southeast Nigeria between 1982-2011
Source: [29,30].

Table 3.4 shows the effect of climate change on agricultural sustainability.

According to Table 3.4 showing the effects of climate change (Temperature, Rainfall, Relative humidity, Sunshine duration) and Time trend variable on agricultural sustainability. The lead equation chosen was the semi-log functional form. This choices emanated from the fact that the outcome from the semi-log function best captures the a priori expectation. Besides, it has the second highest value of the coefficient of multiple determination R^2 with a value of 0.72. This implies that 72% of the variations in the dependent variable, agricultural sustainability is explained by the variations in the independent variables(climate elements), plus time trend variable. This is confirmed by the F-value of (12.69) which is statistically significant at 1% level with F-tab of 3.90. The coefficient of temperature and rainfall are statistically significant at 1% level with absolute t-cal of 3.18 and 5.32 respectively and t-tabulated of 2.76. Temperature is inversely proportional to agricultural sustainability which means that the higher the temperature, the lower the agricultural sustainability. It is obvious that higher temperatures reduces the yield of most crops. According to [23] higher temperatures beyond a specific threshold reduces a crops productive summer growing season and thus reduces the yield. Besides, higher temperatures reduces labour use efficiency, hence lower total factor productivity and agricultural sustainability. This results is in line with a priori theoretical expectation that temperature is negatively related to sustainability. It could be inferred from this finding that increases in temperature obviously reduces the pace at which food security is achieved since it leads to low crop yield and total factor productivity.

Table 3.4 Multiple Regression Result Showing the Effect of Climate Change on Agricultural Sustainability

Predictor Variables	Linear	Semi-log	Cobb- Douglas	Exponential
Constant	12.27	23.14	13.89	11.25
	(2.829)*	(1.3187)	(0.5248)	(1.64)
Temperature(X_1)	-0.4741	-11.3572	-10.264	-0.4918
	(-3.73341)*	(-3.118)*	(-1.8704)***	(-2.452)**
Rainfall (X_2)	0.0011	2.004	2.4942	0.0013
	(5.3693)*	(5.321)*	(4.3940)*	(4.0234)*
Rel.Hum.(X_3)	0.0048	0.2924	0.5132	0.0045
	(0.1389)	(0.1161)	(0.1352)	(0.0835)
Sunsh. dur.(X_4)	-0.2173	-0.7991	-1.0389	-0.2443
	(-1.3378)	(-1.0971)	(-0.9467)	(-0.9519)
Time (X_5)	0.0150	0.1367	0.2440	0.0239
	(2.5748)**	(2.170)**	(2.572)**	(2.5906)**
R^2	0.73	0.72	0.63	0.61
R^{-2}	0.675	0.67	0.564	0.53
F-Value	(13.10)*	(12.69)*	(8.50)*	(7.58)*
Standard error	0.2504	0.253	0.381	0.395
TSS	5.62	5.62	9.69	9.69
N	30	30	30	30

**Significant at 1%; **Significant at 5%; ***Significant at 10%*

Source: SPSS Analysis of the Field Survey Data, (2012).

Furthermore, the Table showed that coefficient of rainfall is directly proportional to agricultural sustainability. This implies that the higher the volume or amount of rainfall, the more sustainable the agricultural production system or sustainability. This is also in line with the a priori theoretical expectation that the coefficient of rainfall (Rf) >0. This finding agrees with[31] who opined that availability of rainfall is the major limiting factor in the growth and production of crops worldwide. This goes to suggest that the movement to drier condition as epitomized by the observed decreasing number of rain-days (Fig. 3.1c) has severe consequences on food production and food security.

Although not statistically significant, relative humidity is positively related to sustainability, which implies that the higher the relative humidity, the higher the sustainability of the production system. Similarly, sunshine duration is not statistically significant but is inversely related to sustainability. Finally the time trend variable is statistically significant at 5% level with t-cal of 2.17 and t-tab of 2.05. It is also positively related to sustainability. However, the time trend effect is usually viewed in a similar way to a dummy variable as a shifter of the constant term [32]. In this regard the constant term (bo) which is 23.14 autonomously increases by 0.1367 per annum while the coefficients of temperature, rainfall, relative humidity and sunshine duration remains unchanged. Finally, factors which affects agricultural sustainability positively encourages sustainable food security, therefore climate changes which are adverse to sustained food production worsens the potentials to achieving food security by the present generation and generations to come.

4. CONCLUSION

The foregoing brings to the fore the fact that there is really environmental degradation, low food production and imminent doom for life on earth as a result of climate change. Among the climate parameters of greatest concern are temperature and rainfall which have been found to be significantly related to agricultural sustainability. Since increases in temperature negatively affects food production and sustainability, climate change abatement and adaptation measures which discourages anthropogenic activities that lead to emission of dangerous green house gases into the atmosphere should be instituted. Besides, increases in rainfall volume positively affects food production and sustainability, but the result indicated that due to the changing climate, number of rain-days is decreasing. Consequently, more effort is required on the side of government and all stake holders to ensure that appropriate policy measures that will mitigate the menace of climate change are made and implementation strictly adhered to.

COMPETING INTERESTS

The authors do hereby declare that there are no competing interests.

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