QUADRATIC REGRESSION AND FACTORIAL ANALYSIS ON THE EFFECT OF CLIMATIC ELEMENTS ON GLOBAL FOOD PRODUCTION AND LAND NUTRIENTS IN AFRICA

[1] Osuolale Peter Popoola, [2] Omotola Omotayo Dawodu, [3] Olufemi Olusola Yusuf

[1] Math and Statistics Department, The Ibarapa Polytechnic, Eruwa Oyo State, Nigeria
[2] Statistics Department, McPherson University, Ogun State, Nigeria
[3] Statistics Department, University of Ilorin, Kwara State, Nigeria

Corresponding Author: Osuolale Peter Popoola, osuolalepeter@yahoo.com

ABSTRACT: The United Nation has its number one Sustainable Development Goal (SDG #1) of No Poverty Global World which is**,** Agriculture and Food Security. The question to be asked is how do we make production of food like maize, rice, and wheat (the three – world stable food) available in abundant, in the face of excessive temperature, limited or excessive rainfall, and low or sometimes high humidity? World maize, rice, and wheat production must increase by approximately 1% annually to meet the growing demand for food that will result from population growth and economic development. Global mean surface air temperature increased by ≈0.5°C in the 20th century and is projected to further increase by 1.5°C to 4.5°C this century. The seasonal and spatial variation of temperature, rainfall and humidity have been an important climatic factor determining the cropping pattern, regulates the agricultural activities and quality of food production all over the world. This research work examines the effect of these climatic elements on Food Production in Africa: establishes standard Temperature level, amount of Rainfall and relative Humidity required for the optimal yields of Maize, Rice and Wheat; Predicts the optimal yields of these global crops; Investigates degree of loss to food productions in Africa. A 3 by 3 factorial experiment was used for data analysis, further test was carried out using Duncan Multiple Range Test to detect the most significance of the various levels of climatic elements used. Multiple regression analysis was adopted to obtain the normal levels for the three main factors. Thus, the derived Quadratic regression model: $Y_i = \mu + \alpha T_i + \beta H_i + \delta R_i + \lambda T^2_i + \pi H^2_i + \tau R^2_i + \xi_i$ was used to predict yields of these crops. The result of the various data analysis shows that all the three climatic elements contributed significantly to the yields of the three crops. In some region of Africa, Temperature, Rainfall and Humidity exceed normal while in some region the three climatic elements were below normal which affected the yields of the crops. Thus, there is reduction in the food production in Africa between 2015 and 2016: Maize 9.489%, Rice 11.482%, Wheat 14.827%.

KEYWORDS: Climate Change, Global food production, Quadratic Regression Analysis and factorial Experiment.

1. INTRODUCTION

Climate change is already underway with consequences that must be faced today as well as tomorrow. Evidence of changes to the Earth's physical, chemical, and biological processes is now evident on every continent of the world. The terms "global warming" and "climate change" are often used interchangeably in newspapers and television reporting, but they are really separate. "Global warming" refers to the rise in global average temperature. It means an average temperature increase of the Earth over time. The current global average temperature is 59°F (15°C, 288K) and is projected to increase by 3 – 7°F (2 – 4°C, K) by 2100. It is generally agreed upon that the man – made increase in greenhouse gases due to the burning of fossil fuels is causing or expediting this warming. The rise in global average temperature does not mean the temperature will increase by the same amount everywhere. It does not even mean that everywhere in the world will get warmer. It just means that the average global temperature is increasing. This is where climate change comes in.

Climate change refers to the change in climatic elements around the world over time. This could be due to the effects of the increase in global average temperature, humidity, and rainfall among other things. Climate change means more than just a change in temperature, but a change in global weather patterns which could affect precipitation averages and extremes, too. This is because the increase temperatures are likely to melt large polar ice fields. Other effects could result in some locations getting more rainfall, while others are more likely to have long – term droughts. Mean global temperature, humidity, and rainfall have been increasing since about 1850, mainly owing to the accumulation of greenhouse gases in the atmosphere. The main causes are the burning of fossil fuels (coal, oil, and gas) to meet increasing energy demand, and the spread of intensive agriculture to meet increasing food demand, which is often accompanied by deforestation. The process of global warming shows no signs of abating and is expected to bring about long – term changes in weather conditions. These changes may have serious impacts on the four dimensions of food security: food availability, food accessibility, food utilization, and food system stability.

It may also have effect on land nutrients, animals, human health, livelihood assets, food production and distribution channels, as well as changing purchasing power and market flows. Its impacts will be both short term; resulting from more frequent and more intense extreme weather conditions, and long term; resulting in changing temperatures and precipitation patterns.

Agriculture is the basic activity by which humans and animals live and survive on earth. Assessing the impacts of climate change on agriculture is a vital task. In both developed and developing countries, the influence of climate on crops and livestock persists, despite irrigation, improved plant and animal hybrids, and the growing use of chemical fertilizers. The continued dependence of agricultural production on light, heat, water, and other climatic elements, the dependence of much of the world's population on agricultural activities, and the significant magnitude and rapid rates of possible climate changes all combine to create the need for a comprehensive consideration of the potential impacts of climate on global agriculture. The Climate Hot Map arranges current and future climate impacts into five main groups: Human health, Food, Aquatic animal, Land nutrients, and Animals.

This research work focuses on the effect of three climatic elements; temperature, humidity, and rainfall on the: Food production, Land nutrients and Animals. In recent times, the issue of climate change through extreme temperature, frequent flooding, drought and increased salinity of water used for irrigation has become a recurrent subject of global debate. The intensity of the debate is on the increase due to the enormity of the challenge posed to global food production. Maize, Rice, and Wheat provide two – thirds of the world human caloric intake. Wheat is the most widely grown crop in the world, along with rice, followed by maize, and are consumed both by humans and animals. These three crops are sensitive to the said climatic elements. Some studies explained that among the climatic elements, temperature increase has the most likely negative impact on crops yields. The impacts of increasing temperature, humidity, and rainfall on major global crops show substantial risks for agricultural production.

Among the three crops: maize, rice, and wheat, loss in yield for each degree Celsius increase or decrease in global mean temperature is largest for maize. Each increase or decrease in global mean temperature, humidity, and rainfall are estimated to reduce average global yields of maize, rice, and wheat by six percent. Humans and animals get two – thirds of their calories on the three of the four staple crops. According to *Proceedings of the National Academy of Sciences*, a peer – reviewed US journal, yields of wheat are expected to decrease by 6%, rice by 3.2%, maize by 7.4%, and soybean by 3.1%.

Food Security and Climate Change

Agriculture is important for food security in two ways: it produces the food people eat; and it also provides the primary source of livelihood for 36 percent of the world’s total workforce.

In May 2007, at the 33rd Session of the Committee on World Food Security, Food and Agriculture Organization (FAO) issued a statement to reaffirm its vision of a food – secured world: *“FAO’s vision of a world without hunger is one in which most people are able, by themselves, to obtain the food they need for an active and healthy life, and where social safety nets ensure that those who lack resources still get enough to eat”* [FAO17].

Also, the united Nation has its number one Sustainable Development Goal (SDG #1) of No Poverty Global World which is, Agriculture and Food Security. The question to be asked is how do we make production of food like maize, rice, and wheat (the three – world stable food) available in abundant, in the face of excessive temperature, limited or excessive rainfall, and low or sometimes high humidity? World maize, rice, and wheat production must increase by approximately 1% annually to meet the growing demand for food that will result from population growth and economic development. Global mean surface air temperature increased by ≈0.5°C in the 20th century and is projected to further increase by 1.5°C to 4.5°C this century.

According to estimates of the FAO, the global number of undernourished people is 795 million. This shows a decline of nearly 200 million over the last 20 years [FAO17]. South Asia and Sub-Saharan Africa constitute most of the world’s hungry population [V+12]. More importantly, nearly 18% of the region’s GDP is comprised of agriculture, and the industry employs more than 50% of the population [TWB17]. Studies reveal that increasing temperature and the changing pattern of rainfall have a substantial impact on food production [K+16, J+10, M+12]. A recent study anticipates that the wheat production of South Asia will decline by 50% by 2050 - equal to almost 7% of the global crop production [***17a].The Peterson Institute states that agricultural production in developing countries will further fall between 10% to 25% and global warming will decrease the agricultural capacity of India by 40% if it continues unabated [Cli07]. Hence, climate change causes serious threats to food security [Spa07, A+07, BAL05, DS02], negative impacts on productivity of different crops, the food supply [A+04, RP91], and the cost of adoption of climate change is high [KR00]. A researcher predicts that the rainfall pattern, river flows, and sea levels all over the world will be affected due to climate change over the next century [***17b]. The increase in climate change is recognized as a global anomaly with potentially long – lasting implications, corresponding with more frequent extreme weather episodes [Ste06]. The large population in South Asian countries is dependent on rural economies based on agriculture; hence, these areas are especially affected by climate changes. This causes serious threats to their social, economic, and ecological systems [AS11].

Climatic elements and crops yields

For any particular crop, the effect of increased temperature will depend on the crop's optimal temperature required for growth and reproduction. In some areas, warming may benefit particular type of crops that are typically planted there, or allow farmers to shift to crops that are currently grown in warmer areas. Conversely, if the higher temperature exceeds a crop's optimum temperature, yields will decline.

The normal temperature, humidity, and rainfall required

Maize grows where temperature is between 18°C and 27°C during the day and around 14°C during the night. It requires between 40% and 60% relative humidity. It also requires annual rainfall between 60cm and 110cm, and can also be grown where rainfall of about 40cm.

Rice grows where temperature is between 18°C and 22°C. It requires between 55% and 67% relative humidity. It also requires annual rainfall between 67.5cm and 70cm.

Wheat grows where temperature is between 21°C and 24°C during the day and around 15°C during the night. It requires between 50% and 60% relative humidity. It also requires annual rainfall between 62.54cm and 87cm, and can also be grown where rainfall of about 70cm.

3. METHODOLOGY

Numerous studies have examined the impacts of past climatic variations on agriculture using case studies, simulation models, descriptive visualization etc. This research work uses statistical methods of data analysis of designs of an experiment.

Design of Experiment is a structured, organized method that is used to determine the relationship between the different factors (Xs) affecting a process and the output of that process (Y). This method was first developed in the 1920s and 1930, by Sir Ronald A. Fisher, the renowned mathematician and geneticist. It is a method of arranging treatments in order that their effects may be meaningful tested ([Wah]). The basic concepts of the statistical design of experiments and data analysis were developed in the early part of the 20th century as a cost-effective research design tool to help improve yields in farming. Since then, many types of designed experiment and analysis techniques have been developed to meet the diverse needs of researchers.

The Factorial Experiments

Montgomery ([Mon74]) defined factorial experiments as experiment in which each complete trial or replication of the experiment and all possible combinations of the level of the factors are investigated. This is the most efficient design when an experiment requires a study of the effects of two or more factors. When factors are arranged in a factorial experiment, they are often said to be crossed.

Larsen ([Lar06]) defined factorial experiment as an experiment in which the interest is to investigate the effects of two or more factors on the response variable. According to him, a factor is a categorical variable with levels, indicating for each observation and from which populations it came from.

Data and sources and time period

This research work used data provided by the earth networks, united states of America through the United Nations on data for climate action challenge. The earth networks specialized on collecting data on Lightning and Weather. The data covers a period of two years six months (January 2015 and June 2017). Data on crops yields in Africa was extracted from the website of organization for economic co-operation and development (OECD) for 2015 and 2016.

Note that: different levels used were the average temperature, rainfall and humidity values recorded by the earth networks (data provider) for Africa between January 2015 and June 2017.Where minimum temperature, rainfall and humidity represents below, while above represents the average maximum temperature, rainfall and humidity recorded for Africa.

Research variables

In this work, we shall use a 3 by 3 factorial design model, since we have three factors to be considered at three levels each. **The three main factors are:**

Temperature (factor T), Rainfall (Factor R) and Humidity (Factor H). **The research treatments** are the sum of yields of maize, rice and wheat continent by continents.

To be tested at three levels each as follows:
Temperature for maize: Normal temperature 25^{0}C, Above normal 33^{0}C, Below normal 18^{0}C
Rainfall levels for maize: Normal 60cm, Above normal 110cm, Below normal 40cm
Humidity levels for maize: Normal 45%, Above normal 60%, Below normal 40%
Temperature for Rice: Normal temperature 20^{0}C, Above normal 22^{0}C, Below normal18^{0}C
Rainfall levels for Rice: Normal 70 cm, Above normal 93cm, Below normal 67.5cm
Humidity levels for Rice: Normal 60 %, Above normal 67%, Below normal 55%
Temperature for wheat: Normal temperature 22^{0}C, Above normal 24^{0}C, Below normal 21^{0}C
Rainfall levels for wheat: Normal 71 cm, Above normal 87cm, Below normal 62.54cm
Humidity levels for wheat: Normal 55%, Above normal 60%, Below normal 50%.

The general statistical model for a 3 by 3 factorial design is:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \delta_k + (\alpha\beta)_{ij} + (\alpha\delta)_{ik} + (\beta\delta)_{jk} + (\alpha\beta\delta)_{ijk} + \xi_{ijkl}$$

where $i = 1, 2, \ldots, a;$
$j = 1, 2, \ldots, b;$
$k = 1, 2, \ldots, c;$
$l = 1, 2, \ldots, n$
$\mu =$ Overall mean
$\alpha_i =$ Effect of i^{th} level of factor T
$\beta_j = j^{th}$ Level of factor H
$\tau_k = k^{th}$ Level of factor R
$(\alpha\beta)_{ij} =$ Effect of $(ij)^{th}$ level of interaction between Factors T and H
$(\alpha\delta)_{ik} =$ Effect of $(ik)^{th}$ level of interaction between Factors T and R
$(\beta\delta)_{jk} =$ Effect of $(jk)^{th}$ level of interaction between Factors H and R
$(\alpha\beta\delta)_{ijk} =$ Effect of $(ijk)^{th}$ level of interaction among Factors A, B, and C
$e_{ijkl} =$ Experimental error
$e_{ijkl} \sim$NID $(0, \sigma^2)$
Temperature = Factor T
Humidity = Factor H
Rainfall = Factor R
Note: In this study, we are not concern about the lower and higher interaction of the three main factors (see the objectives).

Duncan's Multiple Range Test (DMRT)
In a case where there are many effects and their interaction to be tested the objective is to know the most significant level(s) that will have maximum perception. Duncan's Multiple Range Test is the appropriate test to detect the most significant level.

Determinations of Optimum Levels of the factor effects using Multiple Linear Regressions
When regression problems involved more than one independent variable, it is called multiple linear regressions. The model is stated as:

$$Y_i = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_k X_k + e_i$$

Application of the Quadratic Regression to Determine the Optimal yields
The model

$$Y_i = \mu + \alpha T_i + \beta H_i + \delta R_i + \lambda T^2{}_i + \pi H^2{}_i + \tau R^2{}_i + \xi_i$$

4. RESULTS AND DISCUSSION

Maize yields in Africa: The results of analysis of variance using R-package shows that the three climatic elements (temperature, rainfall and humidity) contributed significantly to the yields of maize at various levels considered. Further test was carried out to determine the most significance levels using DMRT, the result shows temperature at 25^{0}C, rainfall at 110cm, and humidity at 60 % contributed most to the yield of maize in Africa. To obtain maximum levels for the optimal yields of the crops using multiple regression analysis, it shows that temperature at 20.6^{0}C, rainfall at 65 cm, and humidity at 68.7%. are normal for the yield of maize. To obtain optimum yields of maize in African at the normal levels Thus, the derived quadratic regression model: $Y_{Opt} = 15.056 + 0.331(20.636) + 0.2204(68.6604) + 0.3761(65.5494) + 0.008027(20.636^2) + 0.001605(68.6604^2) + 0.00273(65.5494^2)$ the results shows that for optimal yields **of** $\mathbf{84.3841}\boldsymbol{ton/h}$ temperature should not exceed 20.6^{0}C, rainfall should not exceed 65 cm, and humidity should be at 68.7%.

Rice yields in Africa: The results of analysis of variance using R-package shows that the three climatic elements (temperature, rainfall and humidity) contributed greatly to the yields of rice at various levels considered. Further test was carried out to determine the most significance levels using DMRT, the result shows temperature at 20.0^{0}C, rainfall at 67.5cm, and humidity at 67 % contributed most to the yield of rice in Africa. To obtain maximum levels for the optimal yields of the crops using multiple regression analysis, it shows that temperature at 20.331^{0}C, rainfall at 65.3243 cm, and humidity at 67.0%. are normal for the yield of rice. To obtain optimum yields of maize in African at the normal levels Thus, the derived quadratic regression model: $Y_{Opt} = -1314.615 + 3.4734(20.331) + 3.4197(89.8975) + 8.6620(65.3243) - 0.08542(20.331^2) + 0.01902(89.8975^2) + 0.0663(65.3243^2)$ .The results shows that for optimal yields of $\mathbf{30.5868}\boldsymbol{ton/h}$, rice temperature should not exceed 20.0^{0}C,rainfall should not exceed 65.3243 cm, and relative humidity should be at 67.0%.

Wheat yields in Africa: The results of analysis of variance using R-package shows that the three climatic elements (temperature, rainfall and humidity) contributed greatly to the yields of wheat at various levels considered. Further test was carried out to determine the most significance levels using DMRT, the result shows temperature at 24.0^{0}C, rainfall at 87.0cm, and humidity at 60 % contributed most to the yield of wheat in Africa. To obtain maximum levels for the optimal yields of the crops using multiple regression analysis, it shows that temperature at 22.2439^{0}C, rainfall at 77.1326 cm, and humidity at 56.449% are normal for the yield of wheat. To obtain optimum yields of wheat in African at the normal levels Thus, the derived quadratic regression model: $Y_{Opt} = -1314.615 + 3.4734(20.331) + 3.4197(89.8975) + 8.6620(65.3243) - 0.08542(20.331^2) + 0.01902(89.8975^2) + 0.0663(65.3243^2)$. The results shows that for optimal yields of $\mathbf{30.5868}\boldsymbol{ton/h}$, rice temperature should not exceed 20.0^{0}C, rainfall should not exceed 65.3243 cm, and humidity should be at 67.0%.

Table 1. Summary of the results: AFRICA

Staple Crops	2015 Yield *(ton/ha)*	2016 Yield *(ton/ha)*	Predicted Yield *(ton/ha)*	% loss in 2016	% loss Actual to Predicted
Maize	49.400	40.838	84.384	9.489	30.320
Rice	25.881	20.550	30.5868	11.482	39.481
Wheat	52.385	28.286	20.982	14.827	31.984

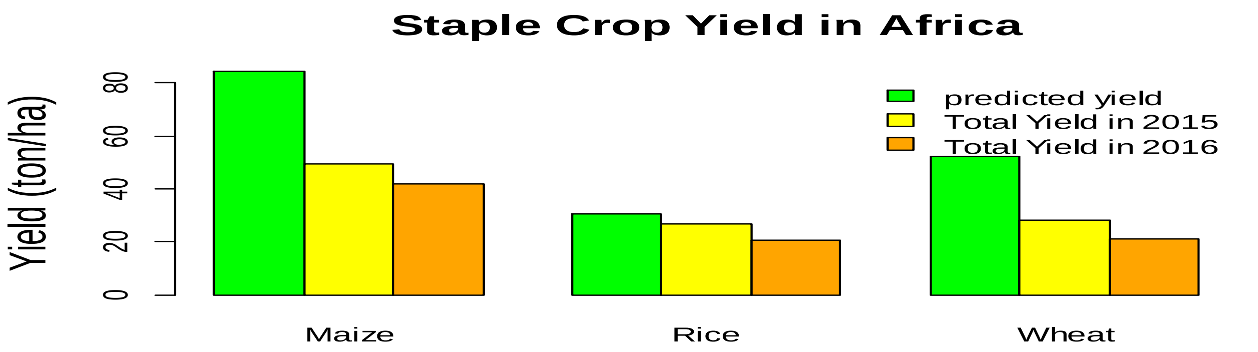

Figure 1. Summary of the results: AFRICA

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