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The Influence of Solar Activity on Food Security in Nigeria

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Abstract: *Solar activity is regulated by the sun's dynamo; a non-linear system with deterministic turbulent features. A natural consequence of this instability is evident in the phase deviance of the solarcycle. This variability could be linked to terrestrial phenomena including agricultural systems. For this reason, the influence of solar activity on food security in Nigeria for a period of 22 years (1996 - 2017) was investigated using statistical approach. Second-order Polynomial regression in 2 variables was used to relate crop yields to the solar activity cycle. Sunspot Number SSN (R_I) with time (years) and the yields (hg ha^{-1}) of six major crops (cassava, yam, maize, rice, sorghum and millet) were employed in the regression analysis to obtain parametric coefficients, which were used in predicting the yields of the crops. The predictions when compared to the observations show a good fit. The solar cycle produced cyclic patterns characterized by annual variations in yields. It was found to have a negative outcome on the yields of the crops and the joint effect of the parameter with time on the yields varied between 31% (Sorghum) and 78% (Maize). This influence on the value of food crops in quantity produced per unit area of land from the location of the study during and around periods of solar maxima indicates food security threat.*

Keywords: *Solar Activity; Sunspot Number; Food Security; Crop yield; Nigeria.*

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I. Introduction

There is a consensus that in the coming decades, the effects of solar activity will cause drastic transformations in the biophysical systems that will lower food production with widespread implications [1,2]. The Food and Agriculture Organization (FAO) estimated that 868 million people worldwide still live without adequate food supply [3]. Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life [3]. In Nigeria, the National Special Programme on Food Security (NSPFS) was implemented to assist farmers in increasing and sustaining food productivity [3]. The 5-year programme (2002-2006) funded by the Nigerian government also covered other dimensions of food security. However, as to whether Nigeria has reached a status of food security is still a debate. Although other variables (e.g., land area, weather/climate, pests and diseases, etc.) may determine yields of crops; modern data still suggest an underlying association between crops yields and the solar cycle [4-7]. One essential property of solar activity is its quasi-cyclic variability [6]. This is characterized by high and low number of sunspots which tends to repeat itself on an average of 11 years [8, 9, 10]. It is now well known that the full dynamo cycle of the sun takes ~22 years (Hale cycle), since the polarity of the solar magnetic field is reversed approximately every 11 years [11, 12]. The potential effects of solar activity are global. Evidently, the driving force of atmospheric circulation is the uneven distribution of solar heating across the globe [4, 5, 6, 13], which can either be beneficial or detrimental to agricultural systems depending on seasons and geographical locations. For instance, rise in solar activity could sufficiently amplify the sun's effects on Earth's atmospheric temperature at the latitudinal degree of the Hadley circulation [13]. Consequently, extreme temperatures over extended periods can adversely affect crops [6, 7]; and a significant decrease in yields could pose food security threat. Therefore, anticipating and calculating the impact of solar activity on agricultural systems of countries/regions is imperative for adaptive strategies.

Some empirical works have been carried out to investigate the link between solar activity and different components of food security at different levels using a number of research methods. In what follows, Garnett *et al.* [5] assessed the impact of sunspot activity and large-scale atmospheric features on regional seasonal weather along with implications for agriculture. The atmospheric variables analyzed were the stratospheric quasi-biennial wind oscillation (QBO), El Niño/Southern Oscillation (ENSO) and North American Snow cover (NAS) on Canadian summer rainfall. The analysis was based on 55 years of atmospheric, crop yield and climatic data for more than 50 weather stations over the Canadian Prairie region. The findings of their study showed that high sunspot numbers led to low summer fall and a plummet in crop yields.

Pustil'nik and Din [6] also presented the results of the study of a possible relationship between space weather and agricultural markets. They described 4 possible scenarios of the market response to the modulations of local terrestrial weather through solar activity along with the behavior of 22 European markets during the Maunder Minimum (1650-1715). Their analysis of the statistics of depopulation in the 18th and 19th century Iceland, induced by the famine due to a sharp livestock reduction and lack of foodstuff owning to the local weather anomalies found a high statistical significance of temporal matching of these events with the periods of extreme solar activity.

In a recent study, Chile *et al.* [7] modeled a second-order multiple polynomial regression with historical coefficients for solar activity index and crop yield data (1995-2017), using Time, Sunspot Number, and Area cultivated as input variables to predict the yields of major tuber crops (yam and cassava) in Benue State, Nigeria. The performance evaluation for the model using Willmott's d-value gave 0.92 for yam and 0.87 for cassava on a scale of 0.0 (a poor model) - 1.0 (a perfect model). The model revealed unusual yields in connection with the solar activity cycle at periods of solar maxima (decrease) and solar minima (increase).

Basic Concept

Solar activity brings the much needed energy for the metabolic processes (photosynthesis) of crops, since the heat and light [$\lambda = 0.43$ μm (blue) and 0.66 μm (green)] required by all growing crops is supplied by the sun [6, 7]. Crops intercept direct and diffuse components of sunshine; directly through solar radiation and indirectly through its effects on air temperatures [14]. However, during high solar activity as ambient temperatures increase, crops close their stoma to maximize water efficiency [14]. Consequently, this cuts off CO_2 supply, resulting in low levels of C-based molecules such as carbohydrates. Hence, a significant drop in yields can be detected during periods of solar maxima.

II. Materials and Methods

Study Location

Nigeria is a West African country sited in the Gulf of Guinea at Latitude 9°04'55.2" N and Longitude 8°40'31.0" E [15], a location of direct thermal circulation. It has a land area of 923,769 km^2 and the most populated country in sub-Saharan Africa having an estimated population of 187 million as at 2016 [16, 17]. Nearly 70% of the population engages in farming at a subsistent level [18]. Nigeria is bordered to the West by the Republic of Benin, to the North by Niger, to the North-East by Chad, to the East by Cameroon, and to the South by the Atlantic Ocean. The main rivers are Niger and Benue which have several tributaries and banks that open into the Atlantic Ocean. The climate has a wide range from semi-arid in the North to tropical and humid in the South which allows for the production of a wide variety of food and cash crops [16]. Average rainfall ranges from ~500 mm year^{-1} in the North to over 2,000 mm year^{-1} in the South [16]. The type of ecosystem and the rainfall trends in any particular region dictates the type of farming system and the people's food preference. Agriculture is expected to play an increasing role in the economy of the country. The crop sector contributes 85% of the agricultural Gross Domestic Product [17], with cassava, yam, maize, rice, sorghum and millet as the main food crops. Major cash crops include; oil palm fruit, cocoa, groundnuts, kola and ginger. However, food production is low and has not measured up with the growing population as seen in the rate of undernourishment and food importation in the country [18].

Data

The Sunspot Number offers substantial information on the state of the Sun. Some features of solar activity (such as UV, X-ray and radio emission) varies in sync with the Sunspot Number (SSN), reflecting the intensity of azimuthal fields in the solar convection zone [6, 12]. As such, the Sunspot Number is a very useful index in quantifying the activity level of the sun [11, 12, 19, 20]. For this reason, data [21] on yearly mean total Sunspot Number for 22 years (1996-2017) was accessed from World Data Center-Sunspot Index and Long-term Solar Observations (WDC-SILSO), Royal Observatory of Belgium, Brussels. On the other hand, data [22] on annual yields (hg ha^{-1}) for eight major cultivated crops (cassava, yam, maize, rice, sorghum and millet) in Nigeria was obtained from the Food and Agriculture Organization, Statistics Division (FAOSTAT), for the corresponding years as a key indicator of food security.

Statistical Analysis

The statistical methods used in the data analysis were due to their essential functions in revealing the variation and relationship among the variables. Descriptive statistics were used in the initial processing of the acquired data and to determine the coefficients of variability. To begin with, the mean yield was calculated using Arithmetic Mean Method [23]. The standard deviation (σ) was calculated as well [23]. Coefficient of Variation (CV) is the ratio of the standard deviation to the mean, generally expressed as a percentage. It reveals the degree of variability in relation to the mean of a set of observations, even if the means are significantly different from each other. The higher the coefficient of variation, the greater the level of dispersion around the mean; it was computed using the technique reported by [23]. Subsequently, correlation and polynomial regression analyses were employed to establish the relationship as well as to show the impact of solar activity on the yields of crops. The Pearson's correlation coefficient r [23] was used. This numerical measure of correlation ranging from -1 ≤ r ≥ 1 [19, 24], measures the strength and direction of a linear relationship, while regression analysis describes how one variable affects the other in a given relationship. The link between an independent variable x and a dependent variable y is modeled as an n^{th} degree polynomial in x. It is generalized [7] as

$$y = b_0 + b_1x + \cdots + b_kx^k + \epsilon \qquad (1)$$

The polynomial regression model given in Eq. (1) can be expressed in terms of a design matrix X, a response vector $\vec{y}$, a parameter vector $\vec{b}$ and a vector $\vec{\epsilon}$ representing a random error term.. Using pure matrix notation it is written as $\vec{y} = X\vec{b} + \vec{\epsilon}$. For a second-order polynomial in two variables we have

$$y = b_0 + b_1x_1 + b_2x_2 + \cdots + b_kx_1^k + b_kx_2^k + \epsilon \qquad (2)$$

Thus, second-order polynomial in two variables with interactions is given as [7]

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_1x_2 + b_4x_1^2 + b_5x_2^2 + \epsilon \qquad (3)$$

Where;

b_0 is the intercept

b_1 and b_2 are coefficients for the linear terms x_1 *and* x_2

b_3 is the coefficient for the interaction term x_1x_2

b_4 and b_5 are coefficients for the second-order terms x_1^2 *and* x_2^2

Polynomial regression allows for the interpretation of coefficients of distinct variables. Thus, inferences could be made regarding the impact of certain variables in yield estimation. The slope coefficients measure the change in the mean of the response variable y (crop yield) for a unit change in the explanatory variables. Eq. (3) was adopted and utilized in the context of this work with the explanatory variables: x_1, x_2 representing $time$ and SSN accordingly. Polynomial regression analysis was carried out using Minitab to obtain coefficients for the parameters under consideration for each crop. The vector $\vec{b}$ is usually estimated using least square estimation [7]

$$\vec{b} = (X^TX)^{-1}X^T\vec{y} \qquad (4)$$

Although polynomial regression fits nonlinear data, statistically it is linear in the sense that the regression function $E(y|x)$ is linear in the unknown parameters to be estimated. The analysis yielded parametric coefficients and these coefficients were inputted into the model (Eq. (3)) to generate predicted outputs for the crops. The predictions were compared with observational data and the model was validated using the technique (Willmott's d-value) described by [7].

III. Results and Discussion

The results presented here are from computations based on observational data and those of the model. The values of the mean, standard deviation and coefficient of variation obtained using the crop yield data is presented in Appendix A: Table 1. The coefficient of variation which shows the relative deviation in yields among the different crops is highest for millet (30%) and lowest for sorghum (8%). This heterogeneity of coefficient of variation in the yields of the crops throughout the study period can be credited to various factors in addition to solar variability. Nonetheless, the influence of solar activity is evident as seen in the model results (Fig. 1). This could be attributed to the amplified effects of the sun owning to direct thermal circulation at the study location. The effect is most adverse as seen in the sharp decrease in yields of the crops during and around periods of solar maxima (2000, 2012 & 2014), and least at periods of solar minima (1996, 2008 & 2017) with corresponding increase in yields. The model employed aided in the understanding of the relationship between the explanatory variables and response variable. Sunspot number produced periodicities describing the annual variations in yields of the sample crops. It was found to have a negative influence (also see Appendix A: Table 2) on the yields of all the crops under investigation.

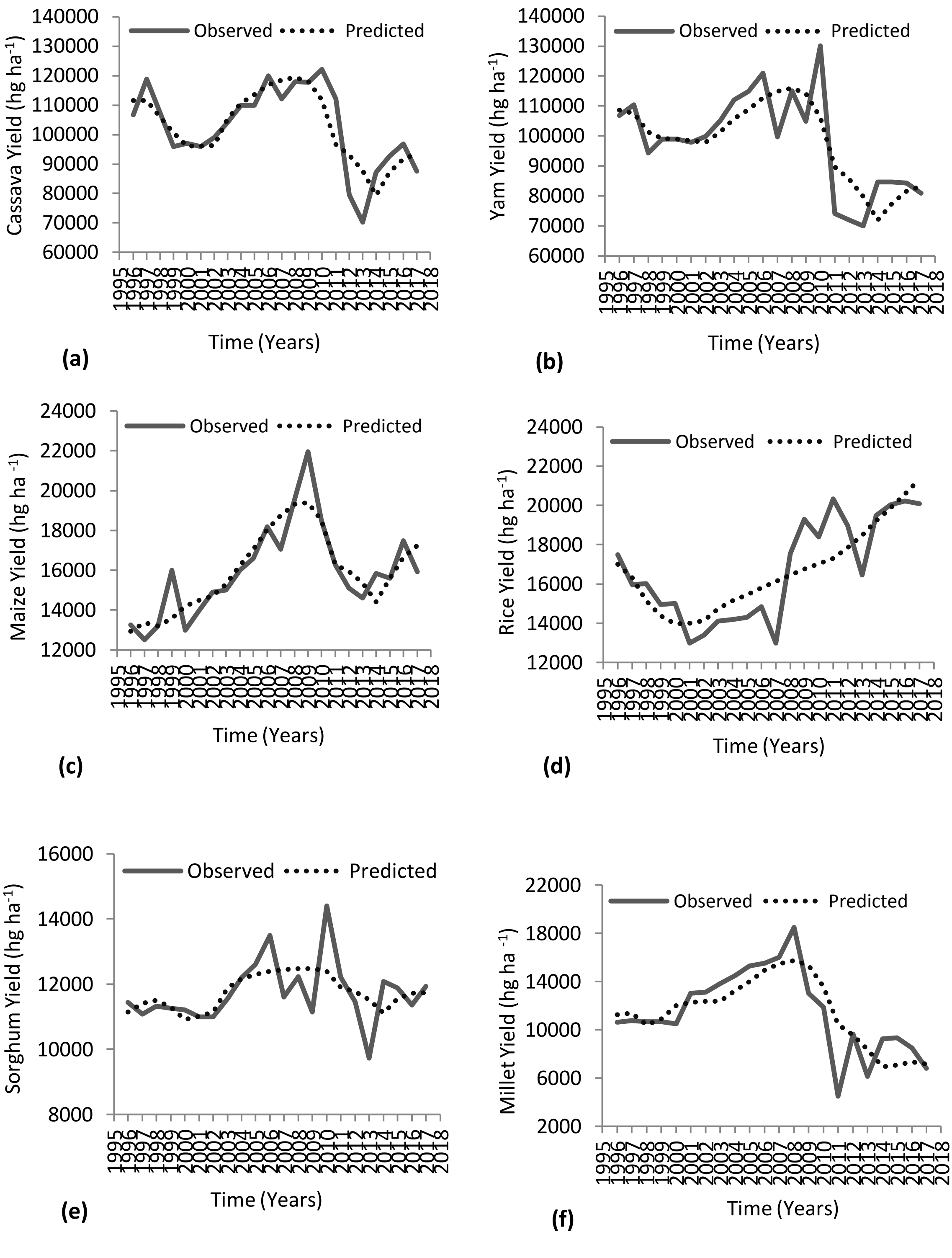

Figure1: Model results in comparison with the observational yield (hg ha^{-1}) data for **(a)** cassava **(b)** yam **(c)** maize **(d)** rice **(e)** sorghum and **(f)** millet cultivated in Nigeria, showing responses to periods of solar minima and solar maxima.

The joint effect of sunspot number with time on the yields of the crops obtained from the coefficients of determination r^2 is given in Appendix A: Table 3; the results revealed that the model accounted for 71% of variance in cassava yield, 66% of variance in yield of yam, 78% of variance in maize yield, 69% of variance in rice yield, 31% of variance in sorghum yield and 68% of yield variance for millet. The regression at 5% significance level ($p < 0.05$) was statistically insignificant for sorghum yields only with the p-value of 0.27092. This suggests that the parameters under consideration jointly had little impact on the yields of sorghum and could be attributed to non-solar factors such as insufficient farm inputs, genetic characteristics, pests and diseases etc. Interestingly, the regression was statistically significant ($p < 0.05$) with p-values of 0.00063, 0.00202, 0.00009, 0.00110 and 0.00132 for the yields of cassava, yam, maize, rice and millet respectively, indicating a connection between the yields of the crops and sunspot number with time. Essentially, the parametric quantities jointly contributed immensely to their yields. The comparisons between the observed and predicted yields of the crops suggest a good agreement; this is evident as observed from the results of the index of agreement. The efficiency test for the model, on a scale of 0.0 - 1.0 for a poor model to a perfect model yielded value of 0.91, 0.89, 0.93, 0.90, 0.67, 0.90 for cassava, yam, maize, rice, sorghum and millet respectively. This study has illustrated the utility of comprehending and measuring the relationship (also see Appendix B) between solar activity and food security in Nigeria. Solar variability has been identified as a decisive factor in food security systems and the capacity to quantify this relationship can offer considerable information required for policies towards sustaining and improving agricultural yields.

IV. Conclusion

The overall result obtained from this study suggests a negative influence of solar activity on food security in terms of food availability/stability in Nigeria. Low sunspot numbers led to increase in crop yields, while high sunspot numbers led to decrease in crop yields. Our result is in line with earlier reports by [7]. Long-held assumptions about food security must be re-evaluated since yields are not increasing fast enough to commensurate with demand in the country. The response to this will definitely include dry session farming with augmented yield growth. However, the knowledge of Solar-Terrestrial Interactions (STI) and its implications for crop yield in the study area is indispensible as it could aid in breaking the cause-and-effect chain between solar activity and food security.

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Conflicts of Interest: The authors declare no conflict of interest.

References

[1]. Yesuf, M.; Di Falco, S.; Deressa, T.; Ringler, C.; Kohlin, G. *The impact of climate change and adaptation on food production in low-income countries*: *Evidence from the Nile Basin, Ethopia,* International Food Policy Research Institute (IFPRI). IFPRI discussion paper. 2008, 828.

[2]. IPCC. *Climate Change 2014: Impacts, Adaptation, and Vulnerability.* Part A: Global and Sectoral Aspects. Contribution of working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B.; Barros, V.R.; Dokken, D.J.; Mach, K.J.; Mastrandrea, M.D.; Bilir, T.E.; Chatterjee, M.; Ebi, K.L.; Estrada, Y.O.; Genova, R.C; Girma, B.; Kissel, E.S.; Levy, A.N.; MacCracken, S.; Mastrandrea, P.R.; White, L.L. (eds.)]. Cambridge, United Kingdom and New York, USA: Cambridge University Press. 2014, pp. 1132.

[3]. McGuire, S.; FAO.; IFAD.; WFP. The State of Food Insecurity in the World 2015: Meeting the 2015 International Hunger Targets: Taking Stock of Uneven Progress. Rome: FAO. *Adv. Nutr.* **2015,** *6*(5), 623-624.

[4]. Pustil'nik, L. A.; Din, G.Y. Influence of solar activity on the state of the wheat market in medieval Europe. *Sol. Phys.* **2004,** *223*(1), 335-356.

[5]. Garnett, R.; Nirupama, N.; Haque, C.E.; Murty, T. S. Correlates of Canadian Prairie summer rainfall: implications for crop yields. *Climate Research.* **2006,** *32*(1), 25-33.

[6]. Pustil'nik, L.A.; Din, G.Y. On Possible Influence of Space Weather on Agricultural Markets: Necessary Conditions and Probable Scenarios. *Astrophys. Bull.* **2013,** *68*(1), 1-18.

[7]. Chile, C.A.; Ihongo, G.D.; Ikyo, B.A. Crop Yield Prediction Using Solar Activity. *IOSR Journal of Applied Physics* (*IOSR-JAP).* **2018,** *10*(6), 35-43.

[8]. De Jager, C.; Usoskin, I.G. On possible drivers of sun-induced climate change. *J. Atmos. Sol. Terr. Phys.* **2006,** *68*(18), 2053-2060.

[9]. Singh, S.; Shrivastava, D.; Lahauriya, S.; Mishra, A. Comparative study of solar cycles 22 to 24 in relation to solar output variability. *Natural Science*. **2012,** *4*(6), 349-354.

[10]. Ihongo, G.D.; Wang C.H.T. The Relationship between Galactic Cosmic Rays and Solar Wind. *Proceedings of Science*. [PoS(ICRC2015)]. **2015,** 1-8.

[11]. Hathaway, D.H. The Solar Cycle. *Living Rev. Sol. Phys*. **2015,** *12*(4), 1-87.

[12]. Usoskin, I.G. A history of solar activity over millennia. *Living Rev. Sol. Phys*. **2017,** *14*(3), 1-97.

[13]. Shaviv, N.J. The Spiral Structure of the Milky Way, Cosmic Rays, and Ice Age Epochs on Earth. *New Astronomy.* **2003,** *8*(1), 39-77.

[14]. Campillo, C.; Fortes, R.; Prieto, M.H. Solar Radiation Effect on Crop Production. In: E.B. Babatunde (ed.), *Solar Radiation.* 2012. ISBN: 978-953-51-0384-4, InTech. Available online: http://www.intechopen.com/books/solar-radiation/solar-radiation-effect-on-crop-production (accessed on 12 October 2017).

[15]. GEODATOS. Geographic coordinates of Nigeria. Available online: https://www.geodatos.net/en/coordinates/nigeria (accessed on 14 October 2017).

[16]. Merem, E.C.; Twumasi, Y.; Wesley, J.; Isokpehi, P.; Shenge, M.; Fageir, S.; Crisler, M.; Romorno, C.; Hines, A.; Hirse, G.; Ochai, S.; Leggett, S.; Nwagboso, E. Analyzing Water Management Issues Using GIS: The Case of Nigeria. *Geosci.* **2017,** *7*(1), 20-46.

[17]. Merem, E.C., Twumasi, Y., Wesley, J., Isokpehi, P., Shenge, M., Fageir, S.; Crisler, M.; Romorno, C.; Hines, A.; Hirse, G.; Ochai, S.; Leggett, S.; Nwagboso, E. Assessing the Ecological Effects of Mining in West Africa: The Case of Nigeria. *Int. J. Min. Eng. Miner. Process.* **2017,** *6*(1), 1-19.

[18]. FOS. Federal Office of Statistics. *Review of the Nigerian Economy.* FOS, Abuja. 2009, pp. 150.

[19]. Utomo, Y.S. Correlation analysis of solar constant, solar activity and cosmic ray. *J. Phys.: Conf. Series*. **2017,** *817* 012045.

[20]. Floyd, L.; Newmark, J.; Cook, J.; Herring, L.; McMullin, D. Solar EUV and UV spectral irradiances and solar indices, *J. Atmos. Sol. Terr. Phys.* **2005,** *67*(1-2), 3-15.

[21]. SILSO, *Sunspot Index and Long-term Solar Observations (SILSO)*, institutional homepage, Royal Observatory of Belgium. Available online: http://www.sidc.be/silso/datafiles#total (accessed on 18 February 2018).
[22]. FAOSTAT, *Food and Agriculture Organization Statistical Division (FAOSTAT)*, database, United Nations, Rome, Italy. Available online: http://www.fao.org/faostat/en/#data/QC (accessed on 27 February 2018).
[23]. Paul, D.; Sethi, L.N.; Deka, B.J.; Sarkar, S.; Kumar, A. Impact of climate change on yield of different crops grown in Cachar district of Assam, India. *Arch. Agr. Environ. Sci.* **2017,** *2*(4), 330-335.
[24]. Dendakari, N. Reinhold, C. Correlation and Regression. *AJR.* **2005,** *185*(1), 3-18.

Appendices

A) Tables

Table 1: Descriptive statistics of the yield (crop) data

Crop	Mean Yield (hg ha^{-1})	σ	CV (%)
Cassava	102779	13866	13.49
Yam	98215	16258	16.55
Maize	15937	2274	14.27
Rice	16686	2578	15.45
Sorghum	11734	945	8.05
Millet	11447	3431	29.97

Table 2: Multiple correlation showing the nature of the relationship between the parameters

Crop	r	
	Time	SSN
Cassava	-0.378	-0.501
Yam	-0.496	-0.311
Maize	0.479	-0.533
Rice	0.685	-0.370
Sorghum	0.175	-0.403
Millet	-0.373	-0.217

Table 3: The joint effect of sunspot number with time on crops yield

Crop	r^2	p-value
Cassava	0.713	0.00063
Yam	0.664	0.00202
Maize	0.779	0.00009
Rice	0.690	0.00110
Sorghum	0.307	0.27092
Millet	0.683	0.00132

B) Established relationship based on polynomial regression analysis

$yield_{cassava} = -555295369.159719 + 554238.590339307\,\mathbf{t} + 17305.0443722243\,\mathbf{SSN} - 8.72608538956371\,\mathbf{t}\times\mathbf{SSN} - 138.265528401836\,\mathbf{t^2} + 0.063741932916266\,\mathbf{SSN^2}$

$r^2 = 0.713$, Adj. $r^2 = 0.623$, $d = 0.9101$

$yield_{yam} = -656481062.21222 + 655413.902325001\,\mathbf{t} + 16260.8227867885\,\mathbf{SSN} - 8.24993823754746\,\mathbf{t}\times\mathbf{SSN} - 163.557135476044\,\mathbf{t^2} + 0.736257914658123\,\mathbf{SSN^2}$

$r^2 = 0.664$, Adj. $r^2 = 0.559$, $d = 0.8881$

$yield_{maize} = -121110672.292015 + 120483.049542651\,\mathbf{t} + 3510.66994381216\,\mathbf{SSN} - 1.77197434809846\,\mathbf{t}\times\mathbf{SSN} - 29.9597895811597\,\mathbf{t^2} + 0.123147995083572\,\mathbf{SSN^2}$

$r^2 = 0.779$, Adj. $r^2 = 0.709$, $d = 0.9337$

$yield_{rice} = 114416602.228228 - 114225.622190633\,\mathbf{t} - 1911.97075099862\,\mathbf{SSN} + 0.948272351597039\,\mathbf{t}\times\mathbf{SSN} + 28.5126752844517\,\mathbf{t^2} + 0.0193172758506156\,\mathbf{SSN^2}$

$r^2 = 0.690$, Adj. $r^2 = 0.594$, $d = 0.9003$

$yield_{sorghum} = -35029758.0940683 + 34890.6455770189\,\mathbf{t} + 1121.72955053401\,\mathbf{SSN} - 0.559048987688934\,\mathbf{t}\times\mathbf{SSN} - 8.68492769417756\,\mathbf{t^2} - 0.051138119824629\,\mathbf{SSN^2}$

$r^2 = 0.307$, Adj. $r^2 = 0.090$, $d = 0.6670$

$yield_{millet} = -221034167.311537 + 220485.115303983\,\mathbf{t} + 1859.20053183526\,\mathbf{SSN} - 0.960143677210379\,\mathbf{t}\times\mathbf{SSN} - 54.9802612543469\,\mathbf{t}^2 + 0.251535706575799\,\mathbf{SSN}^2$

$r^2 = 0.683$, Adj. $r^2 = 0.584$, $d = 0.8968$

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