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Rainfall and Temperature Correlation with Crop Yield: The Case of Asunafo Forest, Ghana

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Abstract: ***The paper tested the null hypothesis that there is no statistically significant correlation between rainfall and crop yield as well as between temperature and crop yield using climate and crop statistics for 14 years (1995 – 2008). The analyses involved bivariate correlation and linear regression. Annual rainfall range was 168.8 mm – 1,737.9 mm and temperature was 22.7 °C – 32.5 °C. In 83% of all rainfall cases the null hypothesis was retained and rainfall accounted for 0.000% – 18.9% variability in crop yield as against rejection of 17% in which rainfall explained about 40.9% crop yield variability. Temperature recorded 67% acceptance of the null hypothesis in which temperature explained 4.2% – 10.7% crop yield variation in contrast to 33% rejection where 35.4% - 47.4% crop yield variability was due to temperature. Largely, other factors hold more explanation to the variation in crop yield.***

Keywords: Food crops; yield; forest; rainfall; temperature

1. Introduction

Interest in the global climate is significantly growing raising awareness about anthropogenic impacts on the climate and dire consequences for human sustenance on earth. The observed trends between biophysical environment and regional climates indicate increase in number of surface run-off, fire and pests within agriculture and forestry and long dry season with detrimental effects on food security. In the tropics, food production is predicted to decrease under unfavourable climate conditions. In specific terms rain-fed agriculture in Africa is projected to suffer reduction in food production to about 50% [1:8].

In Ghana the interest in climate-natural environment nexus is very much sustained. "Rainfall patterns show great fluctuations over the years and across vegetation zones. However there is gradual decrease in rainfall distribution in all parts of the country and this will affect agricultural production levels. Generally global temperatures are observed to be changing. The trend shows rising temperatures. The general outlook is that temperatures will continue to rise" [2:1]. According to Owusu-Sekyere [3] the onset of rainfall is presently starting late than previously and that annual rainfall is decreasing and temperature increasing. In addition, utilization of water by crops (e.g. maize) has been consistent over the years; various crops show yield decline as a result of the decreasing total annual rainfall or the increasing mean temperatures or both. Actually, Ghana's crop farming is mainly rain-fed, crop productivity is highly dependent on rainfall which varies greatly over short distances, hence, it is important to use rainfall data from the site of interest [4]. To De-Graft and Kyei [5] average maize yield bears negative correlation with rainfall and temperature.

In this regard, the present paper examines local rainfall and temperature data as well as crop yield records for six major food staples for a period of 14 years. It describes cardinal rainfall and temperature (minimum and maximum) requirement for the crops and discusses whether the climate figures of Asunafo forest fall within the basic requirement. Then the analyses that follow show the correlation and regression between rainfall and crop yield as well as temperature and crop yield.

2. Literature Survey

According to [6] crop yield is influenced by farming system rather than climate. [7] agrees with [6] to the degree that when farm managements are varied crop yield respond accordingly. However, [7] reports of positive correlation between wheat kernel development and solar radiation as well as positive correlation between wheat kernel development and photothermal quotient. When temperature is varied naturally or artificially, there is linear positive correlation between wheat crop yield and solar radiation; as well as linear negative correlation with temperature. A combined variation, that is, solar radiation intercepted by wheat crops divided by mean temperature above 4.5°C gives photothermal quotient which shows linear positive correlation with wheat crop yield.

As stated by [8] there is -0.85 and -0.89 correlation coefficient between higher temperature and tree crop development such that 1°C increase in temperature results in blossoming of fruit trees 5 days earlier than the normal. In effects, the buds are likely to be destroyed by frost which may lead to possible low crop yield. Also, winter rye, sweet beet and maize responded to the increase in temperature by adjustment in crop phenophases.

With regard to rainfall, [9] found strong positive correlation between grain crop production and monsoon rainfall. Increased production in rice is explained by increased in area under cultivation as well as improved farming technology. However, annual fluctuations in rice production are as result of variability in climate. In effect, rainfall is strongly correlated with rice production. Where the crop cultivation is heavily under irrigated farming association with rainfall is less significant as happens in the case of sugar (85% under irrigation). In the case of Tanzania annual rainfall has not decreased significantly but there are frequent droughts and dry spells occurring during the raining season resulting in crop failure. When the rainfall does come, the intensity is high but duration is short. The effect is mainly on the soil loss due to erosion and the subsequent reduction in crop yield and food security [10].

As reported by [11] there is monotonic correlation between El Nino and temperature and consequential influence on potato yields in the Andes region. Low soil moisture at planting obstructs root formation of potato plant and declining soil moisture during sprouting reduces the number of stems per plant and overall potato yield. In effect, certain crops are sensitive to drought; hence, their yield is influence by rainfall and temperature.

3. Materials and Methods

Climate data was sourced from Ghana Meteorological Agency and crop statistics from Ministry of Food and Agriculture. Data was analyzed with Statistical Package for Social Scientists (SPSS 18.0 version) specifically using bivariate correlation and linear regression. Graphs were produced with Microsoft Excel 2010.

The study area –Asunafo is located within latitudes 6°27' and 7°00'N and longitudes 2°23'and 2°52'W and occupies a total surface area of 2,187.5 km^2 [12]. Asunafo is divided into north and south for administrative purpose. Both districts are located in the Brong Ahafo Region of Ghana

The study used climate and crop data for 14 years (1995 – 2008). This is supported by [13] that accumulation of crop yield and climate data for a period of 15 or more years is useful in expressing seasonal climate variability and volatility of the correlation between climate and yield.

4. Results and Discussion

Table 1 portrays cardinal requirements of rainfall and temperature for food crops grown at Asunafo. The purpose is to provide benchmark rainfall and temperature figures for comparison with the actual climatic values from the synoptic weather station at Goaso-Asunafo. According to Dickson and Benneh [14] Asunafo comes under the wet-semi equatorial climate which provides two rainfall regimes peaking during May-June and September-October. Total rainfall within the year ranges between 1,250 mm and 1,750 mm with average temperature of 26°C – 30°C. Generally, this climate type coincides with Koppen's tropical monsoonal climate (Am) with short dry season and heavy monsoonal rains in all other months. The climatic conditions are largely suitable for the growing of plantain, maize, cassava, cocoyam, rice and yam produced under local rainfall minimum (all-time-low) of 168.8 mm (drought year, 1983) to the maximum (all-time-high) of 1,737.9 mm (1995).

Table 1: Cardinal Requirements (minimum-maximum) for Rainfall and Temperature

Crop	*Rainfall (mm)*	*Temperature (°C)*
Plantain	500-2000	-30-37
Maize	500-1500	18-30
Cassava	500-1500	25-29
Cococyam	1000-5000	13-29
Rice	800-2000	20-37.7
Yam	700-8000	14-40

Source: Nelson et al., [15]; FAO [16]; Department of Agriculture Forestry and Fisheries, [17]

Figure 1 shows rain days 1979 – 2008. For the period of 27 years, the minimum number of rain days was 10 with a maximum of 129 days averaging at 90.96 (mean) with a standard deviation of 26.96 days. The drought period in 1983 and 1984 explains wide difference between minimum and maximum rain days.

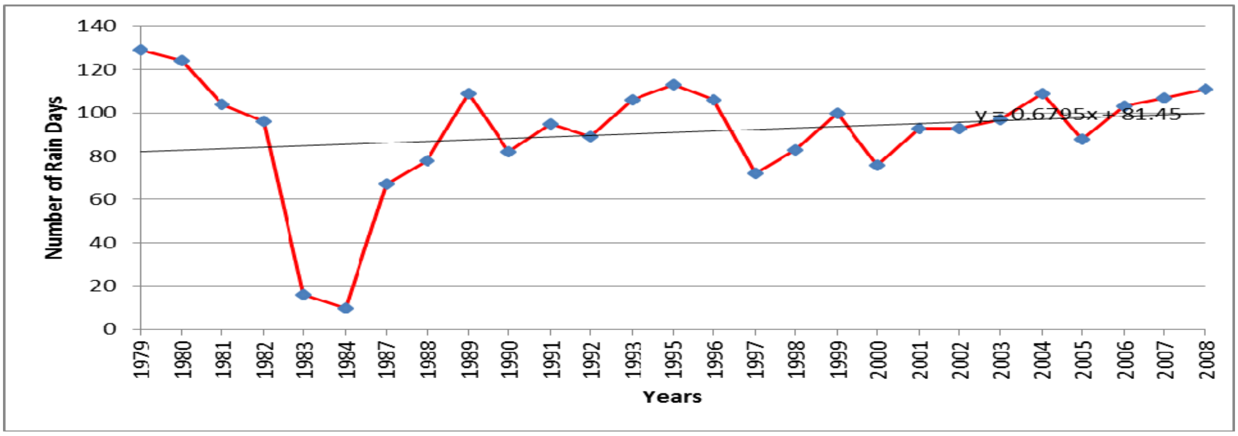

Figure 1: Number of Rain Days at Asunafo 1979 – 2008

Source: Adapted from GMet (2010)

Figure 2 portrays trend of annual rainfall from 1979 to 2008. Total annual rainfall recorded the minimum of 168.8 mm, a maximum of 1,737.9 mm, a mean of 1,241.23 mm and standard deviation of 358.40 mm. The annual mean rainfall can support growing of all the major crops under study.

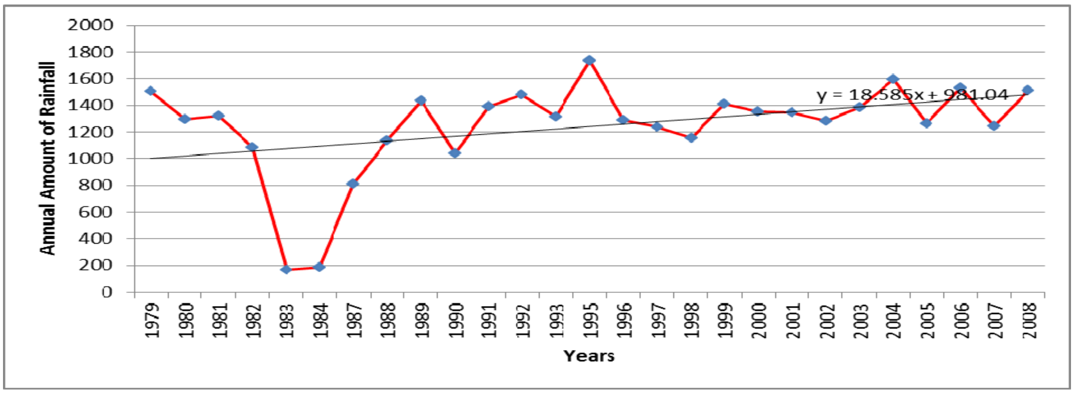

Figure 2: Annual Rainfall at Asunafo 1979 – 2009

Source: Adapted from GMet (2010)

Figure 3 reveals an ascending trend line for temperature for 1979 - 2009. There was no data for four year 1984 – 1987. For the 27 years, the lowest temperature occurred in 1988 (22.7 ^{o}C) and the highest was recorded in 1998 (27 ^{o}C) with the mean minimum temperature of 26.3 ^{o}C and the standard deviation of 0.77 ^{o}C. The mean of the minimum temperature was largely suitable for the production of the staple food crops.

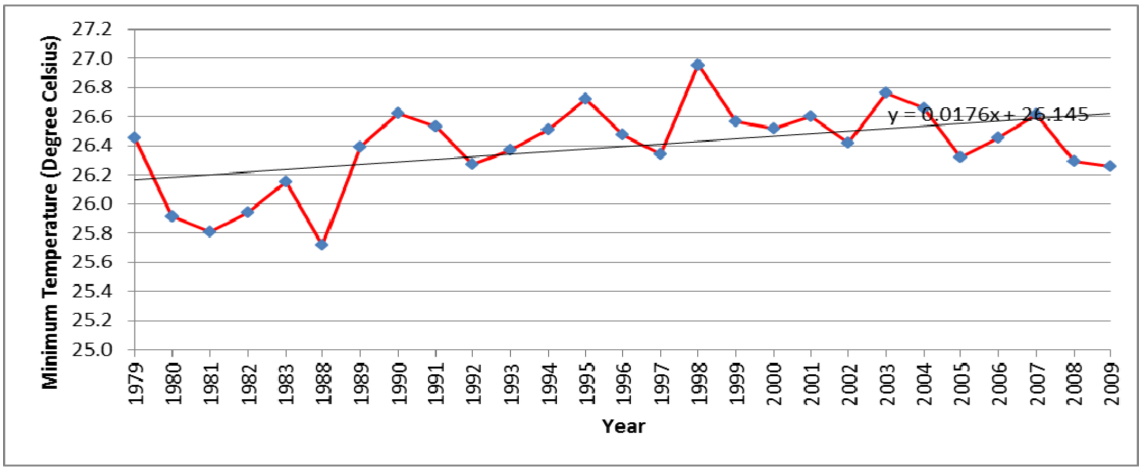

Figure 3: Minimum Temperature Graph for 1979 – 2009

Source: Adapted from GMet (2010)

Figure 4 shows the maximum temperature for 27 years (1979 – 2009) with four years missing data. The trend line indicates slightly increasing maximum temperature. The lowest maximum temperature for the period was 28.4 ^{o}C and the highest of 32.5 ^{o}C with the mean maximum temperature of 31.24 ^{o}C and the standard deviation of 0.91 ^{o}C. The mean maximum temperature is generally favourable for the growing of any of the major crops.

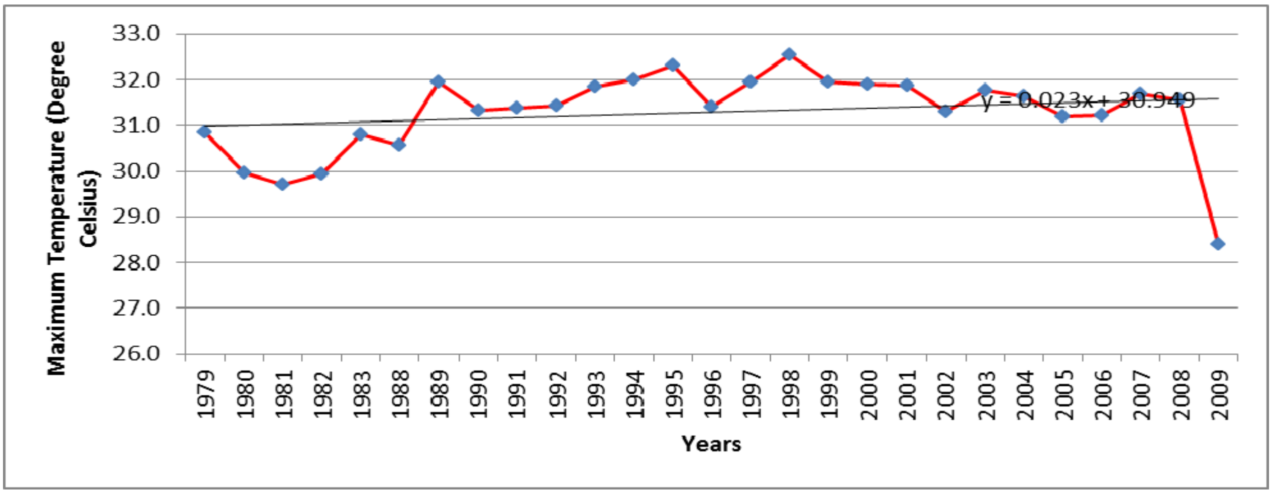

Figure 4: Maximum Temperature Graph for 1979 – 2009

Source: Adapted from GMet (2010)

Figure 5 indicates the yield of major starchy staples between 1995 and 2009. For the period of 14 years, the minimum and maximum yield of maize was 2 tonnes with the mean yield of 1.86 tonnes and standard deviation of 0.207 tonnes. The values for rice for the same period was minimum and maximum of 1 tonne, the mean of 1 tonne and standard deviation of 0.209 tonnes. Cassava recorded a minimum yield of 15 tonnes and maximum of 17 tonnes with mean yield of 16 tonnes and standard deviation of 0.821 tonnes. Yam registered minimum yield of 4 tonnes and maximum yield of 13 tonnes with the mean yield of 10.32 tonnes and standard deviation of 3.34 tonnes. Cocoyam yielded a minimum of 5 tonnes and maximum of 9 tonnes with the mean yield of 7.6 tonnes and standard deviation of 0.86 tonnes. Finally, plantain yield showed a minimum of 6 tonnes and maximum of 19 tonnes with the mean yield of 9.73 tonnes and standard deviation of 3.98 tonnes.

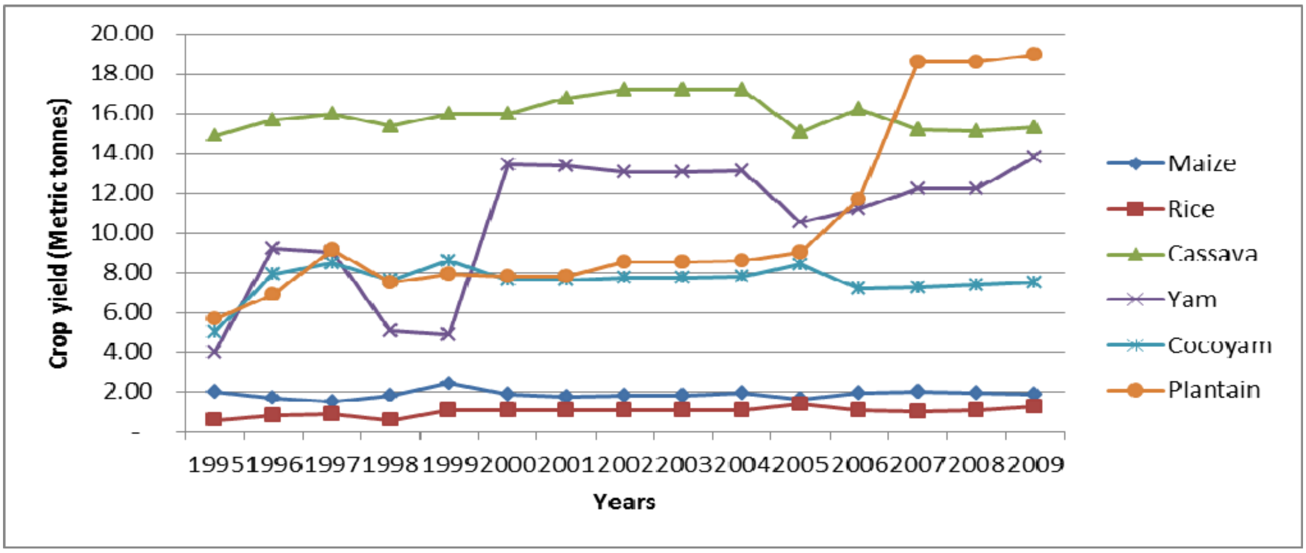

Figure 5: Yield of Major Food Crops in tonnes

Source: Ministry of Food and Agriculture 2010

The relationship between climate and the yield of major food crops is analyzed through correlation with the null hypothesis (Ho) that there is no statistically significant correlation between climate element (rainfall and temperature) and yield of the six major food crops.

With regards to rainfall and maize, the correlation coefficient of 0.435 is interpreted as strong positive relationship between the two variables. The significance 2-tailed gives p value of 0.120 which is greater than 0.05, hence, the Ho is retained, that study does not provide enough evidence to conclude that there is statistically significant correlation between rainfall and maize yield. In terms of regression, Ho is that, there is no supported relationship between rainfall and maize yield (b=0). The results give R value of 0.435 and R square of 0.189 meaning rainfall explains only 18.9% of maize yield. The regression equation is:

$$Y = a + b * X$$

$$Y = 1.083 + 0.001 * Rainfall$$

Rainfall and rice correlation provides coefficient of -0.108 representing no or negligible relationship between the two variables. The significance 2-tailed shows 0.714, hence, Ho is maintained since 0.714 > 0.05. The regression analysis indicates R value of 0.108 and R square of 0.012 implying that rainfall accounts for only 1.2% of rice yield while 98.8% variation in rice yield is explained by other factors.

$$Y = 1.195 + 0.000 * Rainfall$$

Rainfall and cassava relationship gives correlation coefficient of 0.014 explained as no or negligible relationship. The significance 2-tailed is 0.963, hence, Ho is accepted since 0.963 > 0.05. The regression results provide R value of 0.014 and R square is 0.000 meaning rainfall accounts for 0% of cassava yield variation.

$$Y = 15.904 + 7.023 * Rainfall$$

Rainfall and yam linkages by correlation provide coefficient of -0.097 interpreted as no or negligible relationship. The significance 2-tailed is 0.741, hence, Ho is retained since 0.741 > 0.05. The regression coefficients are R value of 0.097 and R square is 0.009 suggesting that only 0.9% of variation in the yield of yam is explained by rainfall.

$$Y = 13.160 + -0.002 * Rainfall$$

Rainfall and cocoyam show correlation coefficient of -0.639 indicating strong negative relationship. The significance 2-tailed is 0.014 which is lesser than 0.05, hence, Ho is rejected and Ha is accepted suggesting that unit increase in rainfall results in unit decrease in yield of cocoyam. The regression analysis indicates R value of 0.639 and R square of 0.409.

$$Y = 12.329 + -0.003 * Rainfall$$

Rainfall and plantain correlation shows coefficient of -0.041 representing no or negligible relationship. The significance 2-tailed is 0.889, hence, Ho is retained because 0.889 > 0.05. The regression shows R value of 0.041 and R square of 0.002 proposing that rainfall accounts for only 0.2% of the variations in plantain yield.

$$Y = 11.131 + -0.001 * Rainfall$$

With respect to the relationship between temperature and the six major food crops, the same Ho is assumed. The analysis uses maximum temperature values.

Temperature and maize provide correlation coefficient of 0.222 interpreted as weak positive relationship. The significance 2-tailed is 0.446, hence, Ho is retained since 0.446 > 0.05. The regression indicates R value of 0.222 and R square of 0.049 indicating that temperature accounts for only 4.9% of variation in maize yield.

$$Y = -1.841 + 0.117 * \text{Temperature}$$

Temperature and rice correlation gives coefficient of -0.688 denoting strong negative relationship. The significance 2-tailed is 0.006 which is lesser than 0.05, hence, Ho is rejected. The regression results show R value of 0.688 and R square of 0.474 meaning temperature explains 47.4% of yield variation in rice.

$$Y = 12.621 + -0.336 * \text{Temperature}$$

Temperature and cassava show correlation coefficient of -0.204 representing weak negative relationship. The significance 2-tailed is 0.484, hence, Ho is maintained because 0.484 > 0.05. The regression model gives R value of 0.204 and R square of 0.042 implying that temperature is responsible for only 4.2% of variation in yield of cassava.

$$Y = 29.511 + -0.426 * \text{Temperature}$$

Temperature and yam linkages provide correlation coefficient of -0.595 representing strong negative relationship. The significance 2-tailed is 0.025 which is lesser than 0.05, hence, Ho is rejected. The regression analysis indicates R value of 0.595 and R square of 0.354 suggesting that temperature accounts for 35.4% of the variation exhibited by yam yield.

$$Y = 173.367 + -5.139 * \text{Temperature}$$

Temperature and cocoyam indicates moderate negative relation with the correlation coefficient of -0.318. In this instance, Ho is retained since significance 2-tailed of 0.268 > 0.05. The regression model reveals R value of 0.318 and R square of 0.101 meaning temperature explains only 10.1% of the variation in cocoyam yield.

$$Y = 29.657 + -0.695 * \text{Temperature}$$

Temperature and plantain record correlation coefficient of -0.328 representing moderate negative relationship. The significance 2-tailed is 0.253 > 0.05, hence, Ho is retained. The regression analysis registers R value of 0.328 and R square of 0.107 suggesting that temperature is responsible for only 10.7% variation in yield of plantain.

$$Y = 114.977 + -3.317 * \text{Temperature}$$

The increase in temperature found by [8] 1.4^{o}C between 1961 and 2000 which compares with global estimates shows that the rising temperature in Asunafo is minimal. It is therefore not surprising that temperature did not explain much of crop yield variation. Rainfall has been generally good at Asunafo. The annual variability in rainfall has not been very phenomenal to explain crop yield variation as reported in the case of India by [9].

The correlation analysis indicates coefficient of:

- maize (rainfall = 0.435) and (temperature = 0.222),
- rice (rainfall = -0.108) and (temperature = -0.688),
- cassava (rainfall = 0.014) and (temperature = -0.204),
- yam (rainfall = -0.097) and (temperature = -0.595),
- cocoyam (rainfall = -0.639) and (temperature = -0.318), and,
- plantain (rainfall = -0.041) and (temperature = 0.328).

The study further reveals that in about four of the six cases (67%) of the regression analysis, temperature influences crop yield variability much more rainfall. For instance:

- temperature explains (47.4%) and rainfall (1.2%) of rice yield,
- temperature accounts for (4.2%) and rainfall (0%) of cassava yield,
- temperature is responsible for (35.4%) and rainfall (0.9%) of yam yield, and,
- temperature explains (10.7%) and rainfall (0.2%) of plantain yield.

In about 33% of the regression analysis, rainfall showed higher influence in the explanation of variation in crop yield than temperature. For instance:

- rainfall accounts for (18.9%) and temperature (4.9%) of maize yield, and,
- rainfall is responsible for (40.9%) and temperature (10.1%) of cocoyam yield.

5. Conclusion

The study concludes that temperature explains the larger portion of the crop yield variation than rainfall. However, in the specific cases of maize and cocoyam, rainfall holds higher influence than temperature. Cocoyam has higher rainfall requirement than all the other crops (1000 – 5000 mm). Furthermore, the investigation of crop yield under the wet-semi equatorial climate shows climate variability in rain days, annual rainfall and temperature trends. However, the fluctuating rainfall and temperature occur within the favourable basic climatic requirement for the production of plantain, cassava, cocoyam, maize, rice and yam. Hence, the variations in crop yield could not be attributed to climatic conditions as supported by bivariate correlation and linear regression analyses. Further explanation for crop yield variability may be sought from other factors.

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