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**Research Article**

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# Determination of Climatic Responses to Crop Water Use Efficiency

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**Abstract** Several studies have been conducted on the effects of climate variability on crop water requirements and evaporative demands, but crop consumptive water use efficiency (CWE) to climatic variables is ignored in most cases. This study investigated the response of historical climate to CWE for groundnut and soybeans over Edo State, Nigeria. Referenced climatic datasets (maximum temperature, minimum temperature, precipitation) from 1986–2005 were used. Reference evapotranspiration (ETo) was computed using Tmax and Tmin from the online evapotranspiration Cal DTA Version 8.12, while crop evapotranspiration (EToj) was estimated as the product of crop factor (Kc) and ETo. However, CWE was determined as the ratio of groundnut and soybean to EToj. As a result, the CWE rose over the baseline period and peaked at Tmax of 32.3°C for groundnut and 31.9°C for soybean, respectively. These Tmax values correspond to annual CWE values of 0.8 and 39.9 tons/mm, respectively. According to the findings, soybean and groundnut are very resilient to CWE, however the maturity days could be decreased by 15 to 10 days if Tmax rose over 31.9 ºC or 32.1 ºC, respectively. The findings of this study have important implications for establishing the CWE resistance threshold level and modelling how different climate change scenarios may impact crop productivity in Edo State.

**Keywords** Crop consumptive water use efficiency, Reference evapotranspiration, Climate variability, Climatic variables, Edo State

## Introduction

In Nigeria today, meeting adequate food and water requirements for 40% of the growing population is a serious challenge. Currently, the country is being faced with food insecurity not only to general insecurity (Terrorism, Banditry, Kidnapping, and others) but unavailability of irrigation water, low water use efficiency (WUE), and climate change (CC). It is obvious that temperature and drought events are increasing as a result of climate change phenomena and this further affects crop water supply, demand, and consumption. Hence, it is indicated that the concept of yield enhancement through supplementary water application needs replacement [1]. Therefore, the knowledge and understanding of the application of crop water efficiency controlled by plants and to create insight into climate change effects on plant phenological development [1]. Crop water use efficiency (CWE) is simply the ratio of the crop biomass to evapotranspiration. [2] explained CWE as the quantification ratio between crop yield and evapotranspiration. Also, [1] described it as the amount of produced biomass per unit of crop water use (CWE). Several studies revealed that there is a difference in CWE among species crops. For instance, a CWE of 2.27 kg/m$^3$ for cereals, 0.69kg/m$^3$, 0.42 kg/m$^3$ and 0.45 kg/m$^3$ for oilseeds, legumes, and fiber crops [1]. Environmental climate-induced variables such as relative humidity, temperature, and soil moisture have significant effects on plant phenology and CWE.

An accurate harvest prediction period is significant for meeting market demand and value. Therefore, elongation and reduction in CGL due to climate could affect crop maturity and yield. Such effect could be negatively or positive beneficial to crop yield. Under a longer CGL season, a farmer could diversify crop and also achieve multiple harvest from the same field, whereas it might cause weed growth, invasive species and increase supplementary water application [3]. Adequate knowledge and understanding of how climate influences crop growing length and water use efficiency are useful to develop robust smart agricultural practices and CC mitigation strategies. [4] and [5] showed that a modeling study indicated that WUE significantly improved under wheat and decreased for maize cultivation.

In this study, the response of climatic to CWE and the growing length of the selected crops are investigated and analyzed with a 15-minute arc resolution of baseline climate (1986-2015). However, two crops, groundnut (Arachis hypogaea L) and soybean are selected for this study due to their economic importance and food value addition. These crops are widely cultivated in Edo State (the Study area) and the entire South Southern Nigeria because more than 60% of the arable land in the region supports the cultivation of selected crops.

## 2. Materials and Methods

### 2.1 Study Area

Edo State is bounded through Delta, Ondo, Kogi, and Anambra State. The Census (1991) indicated that the place has a populace density (of 109) and a complete populace 0f 2,159,848 and a landmass of 19,744 km$^2$. It lies on latitudes 05º 44'N and 07º 34'N with annual precipitation of 1300 mm and an average temperature of 26.4ºC. Fig. 1the Nigeria's map displaying South Southern Nigeria and the take a look at area (Edo State).

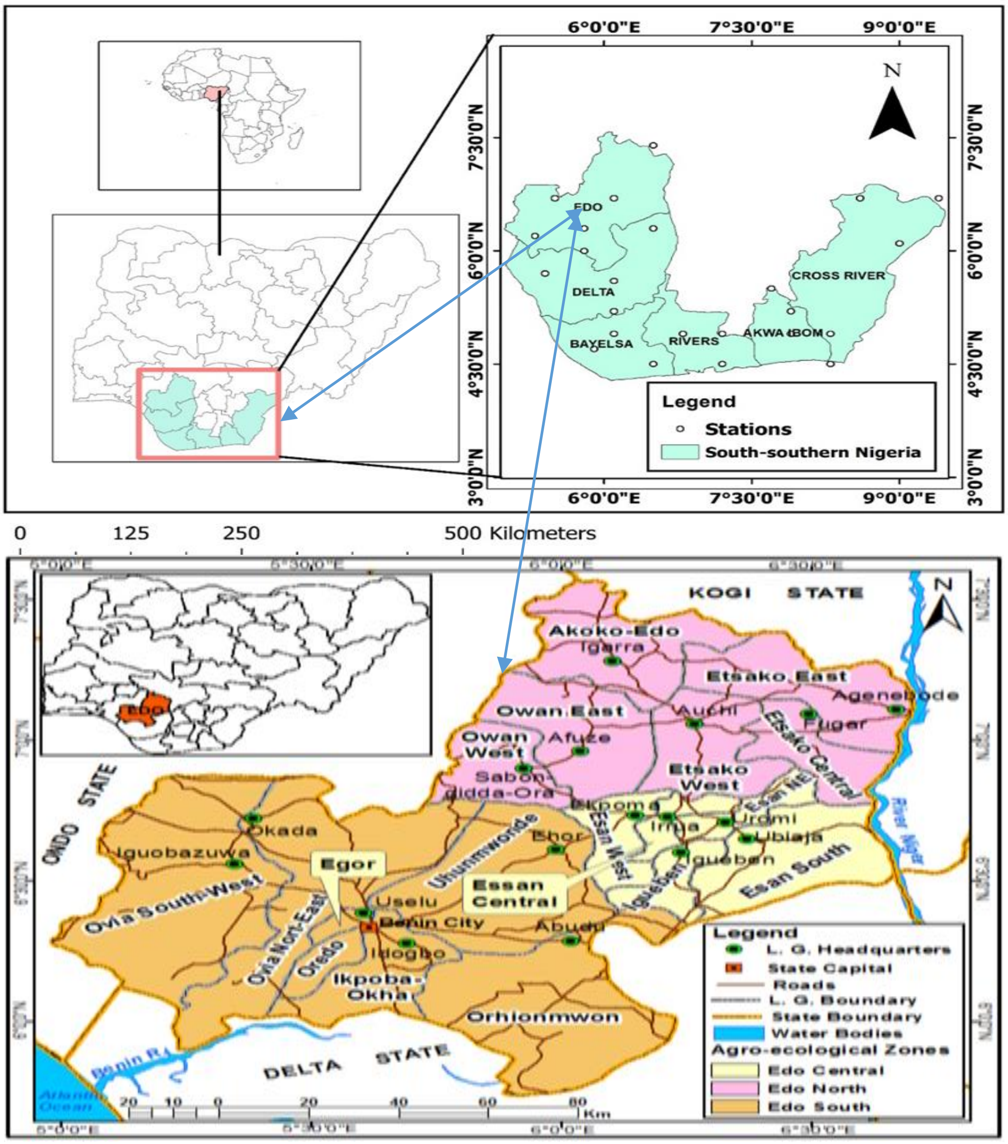


*Figure 1: The position of Nigeria in Africa, location of South Southern State in Nigeria's map and location of study area (Edo State) in the map of South Southern State*

### 2.2 Estimation of Consumptive Water Use Efficiency

The simulation of real crop evapotranspiration (ETc) or consumptive water use (CWU) was carried out the use of process-primarily based totally crop models (AquaCrop and EPIC) and ArcGIS- NDVI for the selected plants from the germination to adulthood stages. AquaCrop simulation version became advanced via way of means of FAO to simulate the connection among the crop yield and water, and to assess the effect of water stress (Ws) on crop yield (Cy) and CWE [9, 10]. Therefore, the crop biomass of groundnut and soybean was computed as follows:

$$CP_{sb} = NPw_{sb} * \sum Pt_{sb} \quad (1)$$

$$PCHY_{sb} = CB_{sb} * ti_{sb} \quad (2)$$

$$CP_{gr} = NPw_{gr} * \sum Pt_{gr} \quad (3)$$

$$PCHY_{gr} = CB_{gr} * ti_{gr} \quad (4)$$

Where;

CB is crop biomass (kg/ha)

NPw is Normalized productive water

Pt is Productivity transpiration

sb is soybean crop

gr is groundnut crop

Crop Water Use Efficiency (CWU) of the selected crops was estimated using the expression in equation (5).

$$CWE = \frac{Y_j}{ET_{oj}} \quad (5)$$

Where;

Yj is the yield of the crop (kg/ha) and EToj is the actual crop evapotranspiration.

### 2.3. Statistical Analysis

The crop growing cycle length (CGCL) was periodically determined using a combination of SDPT version 10.1 and TRMM imagery at 0.20º (approximately 20 km) during the crop growing period. The baseline (CGCL) from 1986-to 2015 was evaluated using an in-built algorithm of LandTrendr synchronized on GEE. Statistics metrics such as Sen's slope, R.M.S.E, $R^2$, and r was applied to analyze referenced climatic datasets. The trend in baseline CWE for the chosen crop (groundnut and soybean) was determined. The significance trend analysis was tested using LSD and Mann-Kendall.

## 3. Results and Discussion

### 3.1 Estimation of Reference and Crop Evapotranspiration

As shown in Fig. 2a and Table 1, reference evapotranspiration (ETo) was calculated using annual baseline meteorological values (minimum temperature, Tmax, and maximum temperature, Tmin) for Edo State from 1980 to 2015 using the evapotranspiration calculation version 8.14. Additionally, utilizing the relationship between the crop coefficient (Kc) and the reference evapotranspiration as shown in Fig. 2b, the yearly crop evapotranspiration was calculated. The fluctuations in ETo and EToj during the baseline were established using the log-trimester expression, as shown in Fig. 2a-b. The degree of minimum and maximum temperatures affects how much ETo and EToj fluctuate. Hence, one of the key elements influencing high or low evapotranspiration might be termed temperature. Nevertheless, ETo and EToj demonstrated a varying and ascending trend at a 0.05 significant level between 1986 and 2015. Crop and reference evapotranspiration had annual averages of 1425.7 mm and 1620.1 mm, respectively. Hence, the greatest estimated ETo value of 1787.4 mm and the corresponding EToj value of 1572.9 mm occurred in 1990, and the lowest estimated ETo and EToj values of 1422.0 mm and 1251.4 mm occurred in 1986, respectively. Therefore, the highest estimated ETo value of 1787.4 mm and the corresponding EToj value of 1572.9 mm were recorded in 1990, while the lowest ETo and EToj values of 1422.0 mm and 1251.4 mm, respectively, were recorded in 1986. The higher Tmax and Tmin values in 1990 may be responsible for the increases in these variables, but the lower ETo and EToj values may be due to lower minimum and maximum temperatures in 1986. The results are consistent with a study by [6], which found that a rise in Tmax and Tmin was responsible for the trend in reference evapotranspiration.

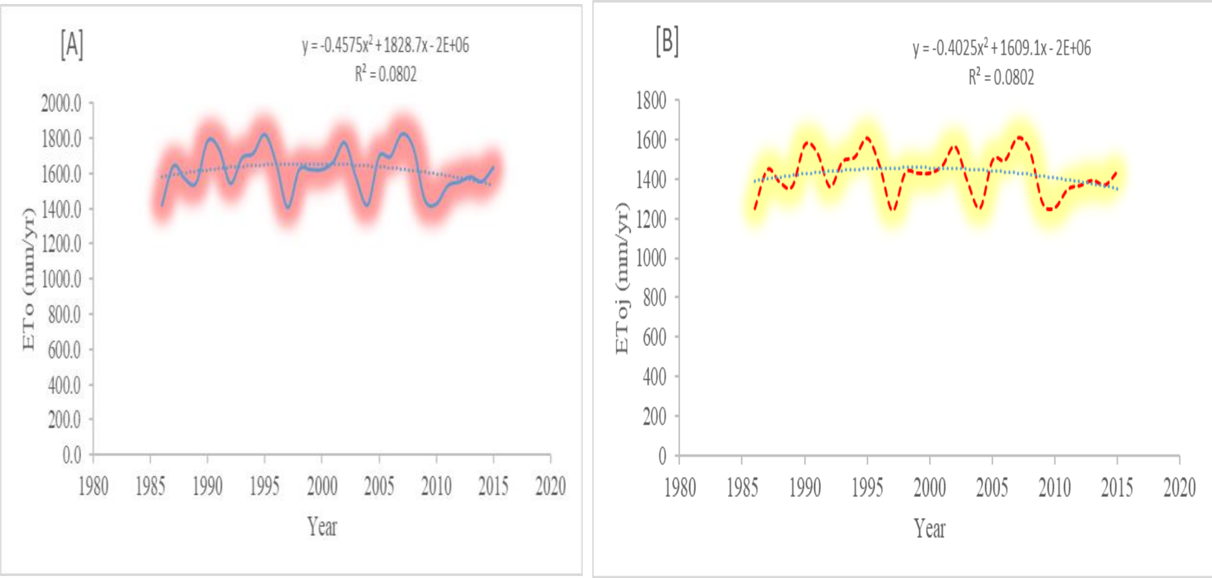


*Figure 2: Spatio-temporal variability of ETo and ETоj*

Table 1: Climatic datasets in Edo State

| N/S | Year | Tmax (ºC) | Tmin (ºC) | Prec (mm/yr) | ETo (mm/yr) | ETоj (mm/yr) |
|---|---|---|---|---|---|---|
| 1 | 1986 | 31.4 | 25.2 | 1657.4 | 1422.0 | 1251.4 |
| 2 | 1987 | 32.3 | 24.2 | 1733.4 | 1645.4 | 1448.0 |
| 3 | 1988 | 33.1 | 26.2 | 1710.3 | 1572.4 | 1383.7 |
| 4 | 1989 | 31.4 | 24.1 | 1610.0 | 1549.1 | 1363.2 |
| 5 | 1990 | 34.4 | 25.5 | 1550.4 | 1787.4 | 1572.9 |
| 6 | 1991 | 33.2 | 24.3 | 1740.3 | 1740.7 | 1531.8 |
| 7 | 1992 | 30.2 | 22.4 | 1770.6 | 1546.5 | 1360.9 |
| 8 | 1993 | 31.5 | 22.7 | 1763.6 | 1690.3 | 1487.5 |
| 9 | 1994 | 33.6 | 25.2 | 1600.3 | 1717.3 | 1511.2 |
| 10 | 1995 | 34.2 | 24.7 | 1621.5 | 1825.0 | 1606.0 |
| 11 | 1996 | 32.1 | 23.7 | 1800.5 | 1661.1 | 1461.8 |
| 12 | 1997 | 30.6 | 24.6 | 1755.7 | 1409.6 | 1240.4 |
| 13 | 1998 | 31.7 | 23.6 | 1784.6 | 1623.5 | 1428.7 |
| 14 | 1999 | 32.4 | 24.6 | 1800.6 | 1624.9 | 1429.9 |
| 15 | 2000 | 33.6 | 26.3 | 1743.7 | 1625.3 | 1430.3 |
| 16 | 2001 | 32.5 | 24.2 | 1555.4 | 1668.4 | 1468.2 |
| 17 | 2002 | 33.2 | 23.8 | 1600.4 | 1777.9 | 1564.6 |
| 19 | 2003 | 31.7 | 24.2 | 1644.2 | 1575.7 | 1386.6 |
| 20 | 2004 | 30.2 | 23.9 | 1704.6 | 1424.2 | 1253.3 |
| 21 | 2005 | 32.7 | 24.1 | 1600.4 | 1699.0 | 1495.1 |
| 22 | 2006 | 30.5 | 25.2 | 1788.9 | 1699.0 | 1495.1 |
| 23 | 2007 | 33.9 | 32.2 | 1700.2 | 1827.1 | 1607.8 |
| 24 | 2008 | 34.2 | 25.7 | 1500.3 | 1747.9 | 1538.2 |
| 25 | 2009 | 30.8 | 24.4 | 1760.3 | 1451.9 | 1277.7 |
| 26 | 2010 | 29.8 | 23.3 | 1996.8 | 1428.6 | 1257.2 |
| 27 | 2011 | 31.4 | 24.3 | 1722.3 | 1532.2 | 1348.3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 28 | 2012 | 32.3 | 25.3 | 1670.7 | 1554.1 | 1367.6 |
| 29 | 2013 | 31.9 | 24.4 | 1640.1 | 1583.0 | 1393.0 |
| 30 | 2014 | 31.4 | 24.0 | 1579.7 | 1557.0 | 1370.2 |
| 31 | 2015 | 32.5 | 24.6 | 1600.5 | 1636.6 | 1440.2 |

### 3.2. Seasonal annual changes in consumptive water use efficiency and yields

As shown in Fig. 3a-3b and Table 2, respectively, the CWE and yields of groundnut and soybean were analyzed from 1986 to 2015 (30 years) to estimate and evaluate the changes in CWE and crop yields relative to the baseline consideration period. As shown in Figs. 3a and b from 1986 to 2015, respectively, groundnut water use efficiency rose at a rate of 0.94 ton/mm and soybean water use efficiency increased at a rate of 0.83 ton/mm.

**Table 2:** Estimated consumptive water use efficiency of groundnut and soybean

| N/S | Year | GrY (tons/yr) | Syb (tons/yr) | CWU-GrY(ton/mm) | CWU-Syb (ton/mm) |
|---|---|---|---|---|---|
| 1 | 1986 | 386.0 | 17000 | 0.31 | 13.6 |
| 2 | 1987 | 394.0 | 17600 | 0.27 | 12.2 |
| 3 | 1988 | 400.0 | 18200 | 0.29 | 13.2 |
| 4 | 1989 | 420.0 | 18600 | 0.31 | 13.6 |
| 5 | 1990 | 440.0 | 19000 | 0.28 | 12.1 |
| 6 | 1991 | 480.0 | 19600 | 0.31 | 12.8 |
| 7 | 1992 | 520.0 | 20000 | 0.38 | 14.7 |
| 8 | 1993 | 460.0 | 20400 | 0.31 | 13.7 |
| 9 | 1994 | 440.0 | 20600 | 0.29 | 13.6 |
| 10 | 1995 | 460.0 | 20800 | 0.29 | 13.0 |
| 11 | 1996 | 470.0 | 21400 | 0.32 | 14.6 |
| 12 | 1997 | 472.8 | 22000 | 0.38 | 17.7 |
| 13 | 1998 | 480.2 | 22600 | 0.33 | 15.8 |
| 14 | 1999 | 500.0 | 23200 | 0.35 | 16.2 |
| 15 | 2000 | 480.2 | 23600 | 0.34 | 16.5 |
| 16 | 2001 | 520.0 | 24000 | 0.35 | 16.3 |
| 17 | 2002 | 560.0 | 24600 | 0.38 | 16.7 |
| 19 | 2003 | 670.0 | 25000 | 0.43 | 15.9 |
| 20 | 2004 | 726.0 | 25600 | 0.52 | 18.5 |
| 21 | 2005 | 762.4 | 26000 | 0.61 | 20.7 |
| 22 | 2006 | 807.2 | 26600 | 0.54 | 17.8 |
| 23 | 2007 | 851.2 | 27200 | 0.57 | 18.2 |
| 24 | 2008 | 897.8 | 27600 | 0.55 | 17.2 |
| 25 | 2009 | 945.6 | 28000 | 0.61 | 18.2 |
| 26 | 2010 | 996.4 | 31240 | 0.77 | 24.5 |
| 27 | 2011 | 1052.6 | 45180 | 0.84 | 35.9 |
| 28 | 2012 | 1092.8 | 48100 | 0.81 | 35.7 |
| 29 | 2013 | 1118.4 | 52900 | 0.82 | 38.7 |
| 30 | 2014 | 1144.4 | 77160 | 0.84 | 56.3 |
| 31 | 2015 | 1162.8 | 80080 | 0.81 | 55.6 |

This observation might be explained by possibly favorable climatic circumstances at the time. The CWE of peanuts and soybeans significantly improved as a result of climatic change, which also slightly increased agricultural yield and production in Edo State. The results are consistent with a study by [7], which showed that a rising trend in soybean CWR in the basin is being brought on by climate change.

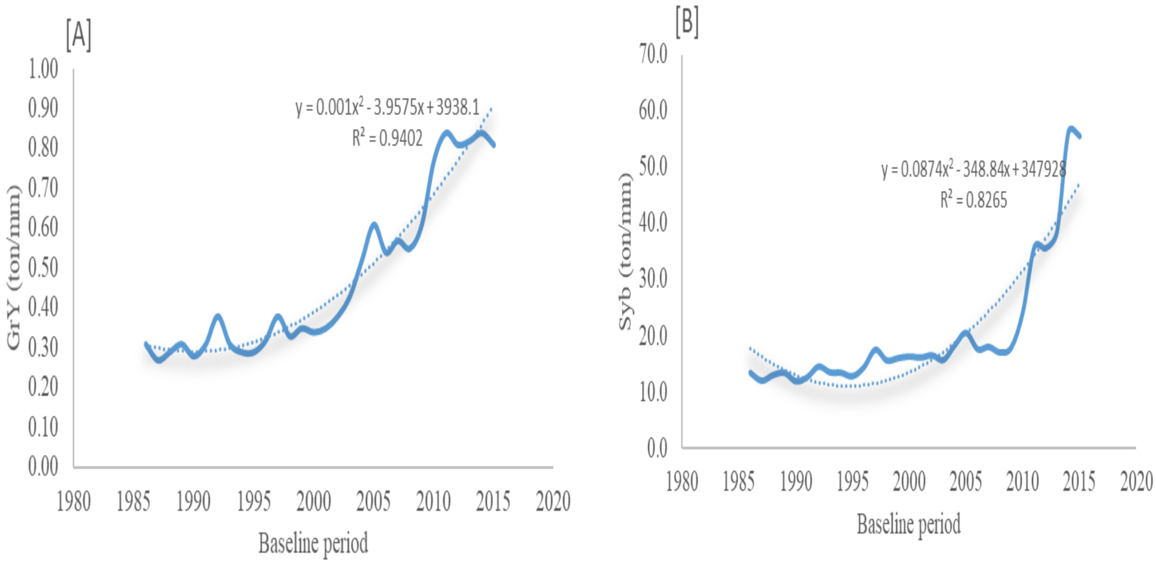


*Figure 3: Spatio-temporal variability of consumptive water use efficiency of groundnut (a) and soybean (b)*

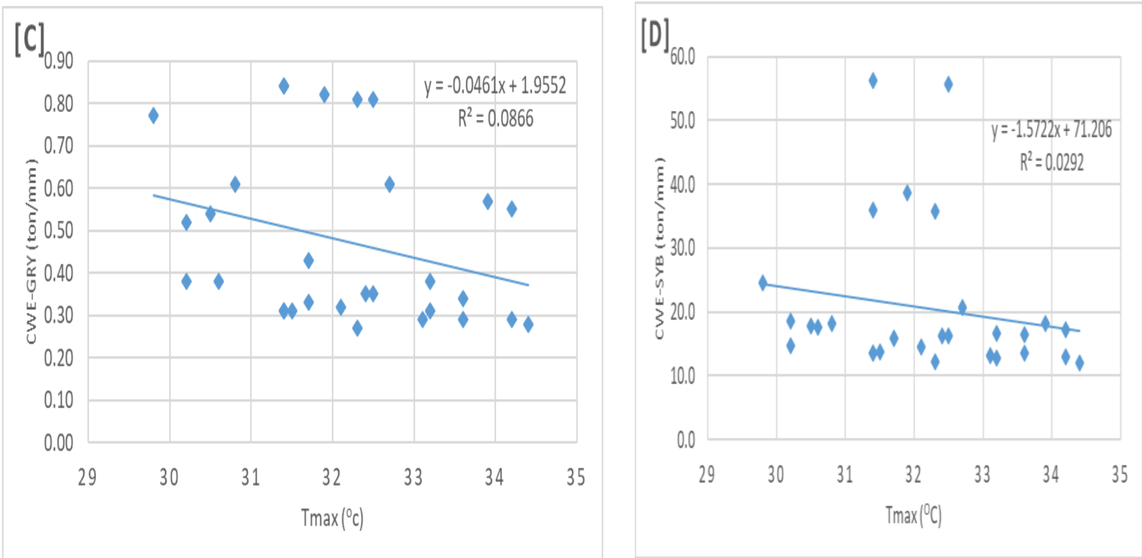


*Figure 4: Validation of relationship between groundnut consumptive water use efficiency (a) and soybean (b).*

For peanuts and soybean, the connection curves between Tmax and WUE from 1986 to 2015 showed a lagging positive trend. According to Fig. 4a-b, the Tmax thresholds for groundnut and soybean were 32.3°C and 31.9°C at CWE 0.80 ton/mm and 39.9 tons/mm, respectively. According to [8], crop WUE has grown as a result of changes in both precipitation and temperature during the past three decades. The trendlines for agricultural yield indicate that there has been an increase in yield through time. Figs. 5 and 6 depict the results, which show positive slopes of 1.185 tons per year and 114.6 tons per year for soybean and groundnut, respectively. A favorable climate may be to blame for the rising trend in soybean and ground production. This result is comparable to that of [7], who linked soybean output to $CO_2$ fertilization, which had a greater impact than fluctuating rainfall and rising temperatures.

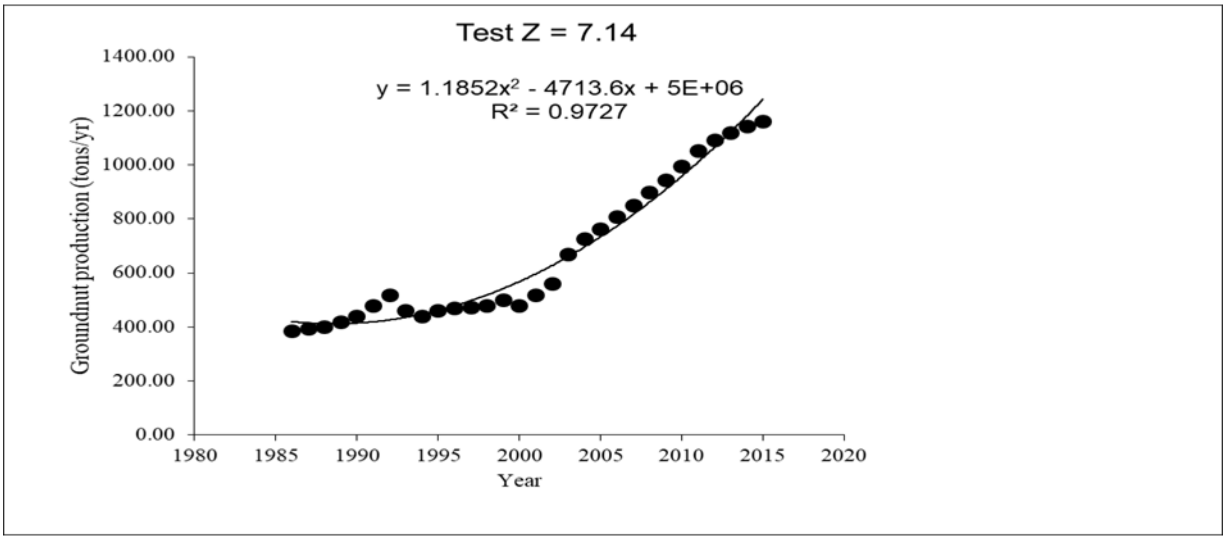


*Figure 5: Spato-temporal of groundnut yield*

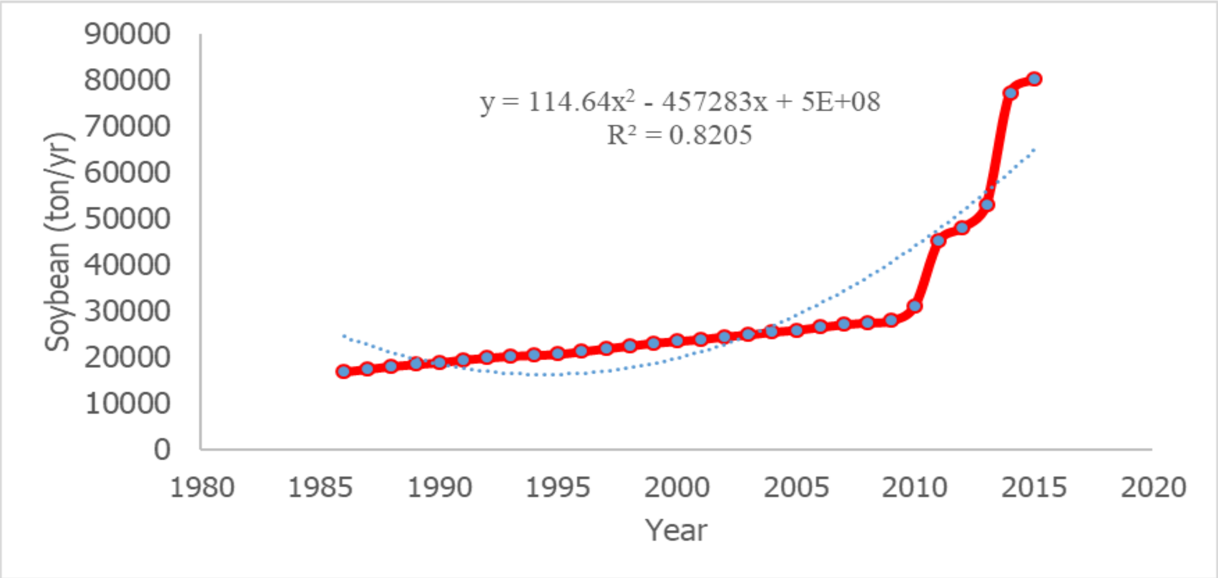


*Figure 6: Spatio-tempora of soybean yield*

**4. Conclusion**

Groundnut and soybean seasonal crop consumptive water use efficiency (CWE) in Edo State using historical climatic datasets from 1986 to 2015. The study found that the crop's CWE increased steadily over the baseline period. However, due to the increased evaporative requirement, a rise in maximum temperature above 32.3 ºC and 31.9 ºC could reduce the maturity days of groundnut and soybean by 10 and 15 days, respectively. The study's findings are verifiable because they offer pertinent data for analyzing and simulating how different climate change scenarios may affect crop productivity.

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**Conflicts of Interest:** None.

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