Global Journal of Plant Ecophysiology, 3(2): 56-69, 2013
ISSN 2074-0891
This is a refereed journal and all articles are professionally screened and reviewed

ORIGINAL ARTICLES

Climate variability, crop-climate modeling and water ecophysiology research: implications for plant's capacities for stress acclimation, yield production and food security

J. Bayo Omotosho, S.O. Agele, I.A. Balogun and E. A. Adefisan

Department of Meteorology,
Department of Crop, Soil and Pest Management Federal University of Technology, PMP 704, Akure, Nigeria

ABSTRACT

Agricultural practices and production in West Africa have become risky and unsustainable due to the persistent and disastrous drought which started in the early 70s and only began to abate towards the end of the last milleneum. In these circumstances, it is imperative that reliable methods for relating crop yield to climate variability be developed. This paper examines the variabilities in the climate parameters and identifies the environmental factors which influence the yield of two major staple food crops in West Africa – cowpea and rice. The study uses over 80 years of rainfall, 60 years of temperature and 19 years of crop yield data for cowpea and rice for Kano state, in the Sudano-Sahelian zone of Nigeria. Significant variations are found not only in the traditional climate parameters of rainfall amount and temperature, but also in the number of raindays, the onset and cessation and, hence, the length of the rainy season. Results show that rainfall amount and number of raindays of specific heaviness in September have strong influence on the yield of both rice and cowpea. However, while June minimum temperature (with other parameters) is important only for the latter, September maximum temperature affects the yield of both crops. The crop-climate models show high skill and demonstrate that reliable annual forecasts of the yield of the crops are possible if these climate parameters could be predicted. With such crop yield models, governments would be able to plan and put in place pro-active food security measures for their people. The extremity and variability of climate and weather events has far reaching and grevious implications for agriculture and water resources and food security in the humid tropics. Although, models of soil-plant-atmosphere continuum (SPAC) integrate the influences of soil and micrometeorological conditions on plant processes, but have rarely been applied to tropical crops under rainfed agriculture. These models present relevant options which may be applied in the development of technologies for irrigation and water resources management and to ameliorate environmental constraints to crop productivity in the tropics. In circumstances of the changing climate and weather variability and droughts of the future, it is imperative to raise the efficiency of rainfall and soil water use in agriculture. Adoption of water saving/conserving technologies and identification of crop species and species-specific traits that improves crop water use efficiency of crops under rainfed, irrigated and dryland farming systems. In the wake of the growing urgency surrounding drought and a drying climate, necessary to adapt crops and rooting systems to better perform under drought/water limited situations. Improved understanding of the bases of plant adaptation to insufficient-moisture environment will offer possibilities for improving adaptation in crop plants. Therefore, the need is urgent, for tropical agriculture and farming systems to adapt and respond to the expected variable and warmer climates and droughts of the future. The conclusion emphasizes the need to strengthen knowledge and increase capacity building in soil, water and environmental management, and to develop soil, plant and agrometeorological based tools which integrate the influences of soil and micrometeorological conditions on plant processes. These tools present options useful in fine-tuning technological and agronomic interventions to protect farmers and agricultural systems from drought and consequences of extreme and hazardous climatic events. Soil, plant and agrometeorological based tools are relevant to the development of scientific base to build on sustainable agriculture and water resources management in the tropics.

Key words: *Climate variability, crop-climate modeling*

Introduction

Agriculture and water resources, which are arguably the most weather- and climate- dependent, are two very important sectors of the economy of most West African countries. This is because West African agriculture is almost completely rainfed and water availability is also totally rainfall dependent. In this region, agricultural

Corresponding Author: S.O. Agele, Department of Crop, Soil and Pest Management Federal University of Technology, PMP 704, Akure, Nigeria
E-mail: ohiagele@yahoo.com

practices and production and water resources availability and management, to a large extent, together determine food security. But these are highly dependent on weather, climate and climate variability.

Climate variability is now accepted as a serious environmental issue because it is a threat to sustainable development and food security. It has been affecting the monsoon flow which determines the start, frequency and intensity of thunderstorms and squall lines that deliver at least 80 percent of the annual rainfall in Nigeria and, indeed, the entire West Africa (Omotosho 1985). This region has been affected almost persistently by deficient rainfall and devastating droughts since the early seventies, causing hunger, starvation and crippled economies. As shown in Omotosho (1990), the variability of the monsoon, in turn, affects the rainy season onset and length, rainfall amount and number of rain days, all of which are crucial for crop production and yield. The areas north of 10N, known generally as the Sahel, are the most prone to the negative impacts of climate variability and change.

In Nigeria, the arch-type of the weather and climate of the entire West Africa, there is a large variation in the agro-climatic and vegetation zones (Fig. 1). However, these are essentially zonal: from the Guinea coast which is very humid, to the humid through the sub-humid and finally, the semi-arid extreme north (e.g. Nicholson, 1994). With this ecological set-up, a wide range of farming systems, involving a variety of crop types, are practiced. These practices depend on the climate of each eco-zone – annual rainfall and its other factors, air and soil temperatures and soil types. Jagtap (1993) showed the serious and threatening nature of the decreasing rainfall trend over Nigeria, with specific isohyetal values (e.g. 300, 1000mm and 1200mm) shifting southward from the 1960s to the 90s. This means consistently reduced rainfall availability for agricultural practices, particularly over the northern parts of the country. Southward-shifting drier zones are also pre-cursors to desert encroachment, increased temperatures and evaporation.

Moot *et al*. (1996) and Wheeler *et al*. (1996) showed that higher seasonal mean temperatures affect the yields of wheat in Europe. In Bangladesh, rice yield was found to be negatively correlated with mean temperature during the 30 days preceding anthesis (Islam and Morison, 1992). On the other hand, Rao *et al* (1997) found significant correlation between rainfall and corn yields in six of the nine states in northeast Brazil. Mollah and Cook (1996) discussed the effect of variability in seasonal rainfall amount and raindays on agricultural production in northern Australia. In the Philippines, Malabuyoc *et al* (1993) emphasized the need to identify proper cultural practices and the start of growing season date in order to minimize the effects of low rainfall and other adverse environmental conditions on the yield of upland rice.

Thus, variations in the onset, cessation and amount of rainfall, number of raindays, the length of the rainy season on which the growing season is dependent, and extreme temperatures, can together or separately have severe adverse effects on the yield of both cash and food (arable) crops. This would have serious implications for food security, particularly in the semi-arid zone of Nigeria. In particular, the onset of the rains, rainy season length and number of raindays are very critical elements in the northern parts of the country, as their variability is almost of the same order of magnitude as the mean values (Yayock and Owonubi 1986). An early onset most often leads to a longer length of the growing season and vice-versa (Sivakumar 1997).

The extremity and variability of climate and weather events has far reaching and grevious implications for agriculture and water resources in the humid tropics (IPCC, 1997). The sub-Saharan Africa is endowed with abundant agrodiversity, soil and water resources. However, in the past decades, variability in climate and extreme weather events had been associated with declining water resources and hence depreciating availability of moisture for agriculture. Such scenarios and its associated droughts could elicit various responses in crops, and may call for increased pressures on water resources, increases in water and heat stress situations and marginal growing environments (Nobel 1983; Hsiao 1990). There is the need to understand what may be required to adapt to significant changes in climate and their impacts on water resources and agriculture. In particular, a re-evaluation of agricultural calendar (expected planting and harvesting times and the suitability of major staple crops to different localities) is required under these ranges of climate variability. Sustainable agriculture and food security would therefore depend on making agriculture systems responsive to changing climatic and weather patterns. In addition, it is imperative to advance understanding of the range of coping or tolerance levels of crops to variable weather conditions, particularly rainfall and temperature, and to provide agrometeorological and plant based network tool to assess crop productivity. Such understanding will help to develop strategic options to mitigate the negative impacts of variable climate on agriculture and water resources and food security in the humid and sub-humid tropics. It would lead to the development of crop management guidelines and strengthen the adaptive capacities of farmers, and will contribute to productive and sustainable farming, improved agricultural livelihood and regional food security. The development of models relating various climate and weather conditions to crop performance will lead to improved and sustainable agricultural practices and production, as well as to strategies for reliable medium- and long-term agricultural planning. This will lead to the development of reliable weather advisories that could contribute to enhanced and sustainable crop yield under different climatic extremes. Information is required in order to develop strategies for improving environmental stress tolerance. Such information is important to farmers, agro-industry and policymakers in enhancing their capability to cope with, and ability to make pro-active plans against adverse climate/weather conditions.

The humid tropics is characterised by wet and dry season transitions and stressful growing environmental conditions in the wake of the changing climate and weather variabilites. The seasonality of sowing crops implies a link of crop production to the seasonally available growth resources (water and light). The maintenance of physiological functions/integrity and productivity under the circumstances of the seasonal climatic stresses would implicate adjustment of plant physiological functions (Hsiao, 1990; Kramer & Boyer, 1995). Plant water relations, xylem transport characteristics and gas exchange are driven by plant attributes, soil and weather factors (Nobel 1983; Hsiao 1990). These parameters are important determinants of physiological integrity in plants and are components of the structural-functional processes associated with the maintenance of physiological functions in plants (Kramer & Boyer, 1995; Agele, 2010).

It is obvious that, if food security and sustainable agricultural production are to be achieved, agricultural systems have to be made responsive to changing climatic and weather patterns. Unfortunately, studies that quantitatively relate agricultural production to climate variability in West African are scarce in the literature. For Nigeria, the authors are not aware of any. This paper, therefore examined the implications of the variabilities in the climatic parameters on the yield of rice and cowpea, two major staple food crops across countries of West Africa. An attempt is then made to develop crop-climate models that should be useful in estimating the expected annual yield of these crops. In addition, the paper looks at the challenges, state of the art and potentials of water ecophysiology in particular, soil-plant-atmosphere continuum (SPAC) research and its implications to crop physiological functions, stress acclimation and the attainment of increased crop productivity in the wake of the changing climate and weather varibilities.

Data sources and Analysis:

Daily rainfall data from 1916 to 2004 and June to September monthly mean maximum and minimum temperatures from 1941 to 2004 for Kano state, located within the Nigerian Sahel (Fig. 1), were obtained from the Nigerian Meteorological Agency. Annual cowpea and rice yield data were obtained mostly from the Project Coordinating Unit of the Federal Ministry of Agriculture and partially from the Federal Office of Statistics. The daily rainfall values were used to determine the onset and cessation and, hence, the length of the rainy season for each year according to Omotosho *et al* (2000). Also from the daily rainfall, annual totals were obtained and used to calculate nomalized values for each year.

The months chosen for the temperature data were dictated by the long-term (85-year) mean onset and cessation dates of the rainy season at Kano: 29 May and 28 September, respectively (Omotosho, 2006). These imply that sowing/planting usually begins from the second decade of June and crop maturation/ripening falls in September. The number of raindays of various rainfall thresholds (1.0, 10.0, 20.0, 25.0, 30.0 and 40.0mm) was summed for each year and also separately for June and September of each year. From the annual values, deviations were calculated to show interannual variability in each of these rainfall factors and temperatures. However, because of the noisiness in these variables, pentade values or 5-year moving averages were used to obtain smoother series in some cases.

2.1 Statistical Analysis:

Since only 19 years of cowpea (and 16 for rice) yield data are available, in order to allow for the testing of the skill of the resulting crop-climate models for predicting annual yields of the crops, the years 1986 to 1997 (12 years) are used for modeling while 1998-2004 are reserved for model validation. This sub-division is reasonable because the former period contains both low and high yield years.

As a first step in the statistical analysis, the set of variables that are not major factors influencing cowpea or rice yield were eliminated by considering only those with the highest variance (coefficient of multiple determination, $R^2 > 0.25$, giving correlation coefficient $R > 0.50$). It is reasonable to assume that the most important environmental factors affecting yield would be captured in 3- to 4- variable models with the highest R^2. However, because there are 10 climatic variables so identified for both cowpea and rice, further screening was carried out by retaining only 3 and 4-variable models with the highest R^2 but keeping the parameter with the single highest R^2 in such equations. This was achieved through a stepwise regression to eliminate independent variables not important at the 0.10 level. Recently, Odekunle *et al* (2005) used 2- 4 variables to develop rainy season onset and cessation models for different stations in Nigeria while Malabuyoc *et al* (1993) also developed 1- and 2-variable models for the yield of upland rice in the Philippines.

3. Variability of Environmental Parameters:

3.1 Rainfall Factors:

Since West African agriculture is essentially rainfed, it is appropriate to first study the interannual pattern of rainfall amount, raindays, the cessation and length of the rainy season. Fig. 2(a) shows the normalized rainfall anomalies over Kano from 1916 - 2004. The high interannual variability is clearly evident. It can be seen that 1930 – 1939 and much more significantly, 1996 – 2004 are wet periods while 1963 to 1990 was generally drier than normal. In particular, 1996-2004 comes out as a record-breaking period in the 89-year data with rainfall above the mean by more than twice the standard deviation. A clearer pattern is obtained by averaging data 5-yearly (pentade) as shown in Fig. 2(b).

Given in Fig 3 are the deviations in the number of raindays of 10, 20, 25 and 30mm or more during the same 89 year period. Meteorologically, a rainday is defined as a day with at least 0.25mm rainfall but this is hardly useful for agricultural purposes. In this study, because of crop-water requirement considerations, we regard a rainday of at least 10mm as agriculturally more important and useful (see Omotosho *et al*, 2000). The standard deviations for the 10, 20, 25 and 30.0mm raindays are 6, 5, 5 and 4 days, respectively. For the 10, 20 and 25mm thresholds, we regard $\pm 1.0\sigma$ as significant deviation from the mean since their respective mean values are 28, 15 and 12. It is thus seen that the pentade 1971-75 and particularly the decade 1981-1990 had significantly below normal while 1996-2000 had above normal agriculturally useful number of raindays of 10, 20 and 25mm or more in the 89-year period.

The variability in the rainy season onset and cessation dates is shown in Fig. 4. It is seen that the period 1926-1940, particularly 1976-80 but especially decade 1951-60 enjoyed early onset and late cessation, leading to longer rainy and, hence, growing seasons. On the other hand, 1971-75 and 1986-90 were periods of very late onset and early cessation with consequently shorter rainy seasons. These results give further credence to the statement of Sivakumar (1997) that an early onset most often leads to a longer length of the growing season and vice-versa. These pentade years have been shown to be very dry periods over the Sahel where Kano state is located (Nicholson, 1994). Fig. 4(b) depicts more clearly the onset and cessation during the crop yield available years.

3.2 Extreme Temperatures:

Extreme temperatures are known to have serious adverse effects on crop growth and yield especially at the early, anthesis and seed filling as well as late (maturation/ripening) stages of crops (Sato *et al*, 2002; Wadlaw, 2002). In the northern part of the country, planting/sowing and crop maturity/harvesting take place in June and September, respectively, months in which there is high temperature and evaporation. Therefore, it is pertinent to study the variability of the maximum temperatures in these months over a long time period. Shown in Fig. 5 are the deviations of the June and September maximum temperatures since 1941 when synoptic observations started in Kano, the state capital.

The figure shows more coherence with less noise than rainfall and its factors. The years 1942-44 and the long period 1972 – 94 had generally hotter June and September months. On the other hand, 1945- 1970 (except 1949) and 1995-1999 were cooler than normal in both months. Ferris *et al* (2000) showed through both data and modeling experiments that extreme temperatures lead to significant reductions in the yield of wheat in four sites in Europe. Incidentally, some of the crop yield years (1986-94) fall into the hotter than normal category while 1995-98 had cooler June and September months.

As will be discussed in the next section, the years 1986 – 1990, which experienced the worst of all the above environmental parameters, recorded the lowest yield while 1995-1998 with the most favourable conditions had the highest yields out of the 19 years of crop yield data. In view of the fact that Kano state is located within the West African Sahel, the serious implications for enhanced and sustainable agricultural production and food security in the entire sub-region is clear. The imperative of having reliable crop-climate models, which can be used for planning purposes by governments, is therefore obvious.

4. Crop Yield Variations:

The interannual variations in the yield of rice and cowpea are shown in Fig. 6. Yield data for rice from 1996-98 is missing. It is seen that the yield of cowpea has no particular trend. The lowest cowpea yield (251Kg/Ha) and highest (1617Kg/Ha) were recorded in 1987 and 1998, which incidentally had the lowest and highest annual rainfall, respectively. There is generally higher cowpea yield between 1995 and 2004 but significantly so from 1996-1998. However, it should be noted that crop yields depend not only on rainfall amount but also on its spatial and temporal distribution as well as on other environmental factors. Unlike cowpea, rice shows an apparently consistent increase in yield over the available crop yield years, except in 1995. Since there is no particular trend in cowpea yield, some statistics regarding the yields of these food crops are calculated (Table 1). Also, because the yield patterns for both crops differ, we discuss below the environmental factors that together or separately affect significantly the yield of each crop.

5. Crop-climate modeling:

Bearing in mind that the general planting and harvesting of crops in Kano state are in the months of June and September, the initial rejection of environmental parameters that have insignificant effect was based on their coefficient of multiple determination $R^2 < 0.25$. As previously stated and in order to avoid overfitting, further screening was carried out, resulting in only models with a maximum of 4 variables and the highest R^2 being retained, but still keeping the parameter with the single highest R^2 in such equations. The stepwise regression procedure identified September rainfall (SepRR) and maximum temperature (T_{mxse}) as the two independent variables that together have strong effect on the yield of both rice and cowpea. This may not be too surprising as this is usually the end of the rains. The absence of moderate and well spaced rainfall and extreme temperatures towards the end of the rains can cause reduced pollen viability, embryo abortion and ultimately reduced seed (kernel) yield (Zinselmeier *et al*, 1999; Wadlaw, 2002).

On crop-by-crop basis, SepRR alone produces a variance R^2 = 68% in cowpea and 55% for rice while R^2 for rice from annual rainfall alone is 64%, making it the most important single environmental factor for rice yield. The resulting empirical (best and second best 3- and 4-variable model) equations for rice and cowpea are given in Table 2. June minimum temperature (T_{mnju}) is included in the Table even though, as a single variable, it was found not to have a significant effect on both crops. This is because, for cowpea, T_{mnju} was found to increase the variance R^2 by 10-12% when it is regressed with either SepRR or with SepRR and number of raindays of at least 10mm (R_{d10}) or with SepRR and cessation date of rainfall (Julian CR). The analysis also reveals that while total annual rainfall is very important for a good rice harvest, it is of little effect for cowpea yield. Furthermore, rice is found to require days of heavier rainfall (≥ 25mm) but such heavy rainfall is inimical for cowpea especially during maturity and ripening, as the coefficient of determination R^2 reduces significantly when R_{d25} or R_{d30} were used, although a few and infrequent such falls may be useful.

6. Validation of the empirical models:

The skills of the 3- and 4-variable models with the highest coefficient of determination (R^2) in Table 2 are assessed by using each equation to predict the yield of cowpea for the years 1998-2004 and 2001-2004 for rice. The hindcasted yields (1986-97 for cowpea; 1986-2000 for rice) and predicted (1998-2004 for cowpea; 2001-2004 for rice) are shown in Fig. 7(a) and (b). They are seen to be in good agreement with the actual values except in a few years. For cowpea, there is no difference in the correlation coefficients between actual and predicted yields for all models, their values being 0.9, to one decimal place. Table 2 also shows that the variances ranged between 0.82-0.86, that is, at least 82% of the yields of cowpea and rice can be attributed to environmental parameters of rainfall factors and extreme temperatures, particularly towards the end of the rainy season. This is because the period coincides with flowering, seed filling and ripening stages of these important food crops.

7. Overcoming the challenges of a changing climate and weather variabilities on water resources, agricutlure and food secuirity in the tropics: Role of water ecophysiology (soil-plant-climate system) research:

The humid tropics is characterized by wet and dry season transition which define the sowing seasons while seasonal climatic stress may elicit adjustment and adaptation (plasticity) in plant physiological functions which is important to acclimation to environmental stresses. Efforts should be geared towards enhancing the coping strategies/tolerance ranges of crops to variable weather regimes especially rainfall and temperature at the present and future levels. It is also necessary to improve water productivity in crops in circumstances of greater competition and stresses on water resources and marginal growing environments under changing weather conditions. These impacts would resultantly bring about increases in crop yields at the present or worse climatic situations, and enhancing adaptive capacities of farmers and farm practices to changing climate/weather.

Although, models of soil-plant-atmosphere continuum (SPAC) integrate the influences of soil and micrometeorological conditions on plant processes, but have rarely been applied to tropical crops under rainfed agriculture. Nevertheless, water ecophysiology research and soil-plant-climate system (SPAC) models provide scientific bases to build on sustainable rainfed or irrigation agriculture. It is important to increase local capacity building for use of such soil-plant-climate models via training of local end users and fine tuning acceptable toolkits and packages for communities based on traditional/indigenous knowledge. Thus, modern ideas and scientific approaches would be presented in practical contexts that farmers can apply and benefit from thus improving links between governmental agencies and farmers and information for growers.

In addition, advanced understanding from water ecophysiology research would advanced understanding and values of weather-plant-soil based tools as useful options for the attainment of increased crop productivity and stress acclimation in plants and improved water resources management. This area of research would promote the emergence of technological tools to ameliorate environmental constraints to crop productivity in the tropics in circumstances of the changing climate and weather varibilities. It is important to strengthen (interdisciplinary) research in climate monitoring at the national and regional scale, and to strengthen knowledge of water and energy exchange processes and improve skill and manpower development in soil, plant and agrometeorological based research for improving soil and water resources management.

Advancements in weather-crop relations and drought (water ecolophysiology) research would enable the emergence of agrometeorological and plant based network tools from local climate/weather conditions. These tools would be useful and applicable to sustainable irrigation and water resources management (assessment of water requirements/irrigation needs of crops), and the amelioration of environmnetal constraints to crop productivity. Thus, improved efficiency of soil, water and plant management practices would promote adoption of technological (agricultural) interventions to ameliorate consequences of extreme weather events and variabilities on agriculture and livelihoods.

8. Water balance and crop water use models:

Soil water balance and crop water use models are derived from functional relationships among soil, water, plant and climatic factors. Water balance models enhance the quantification crop water use pattern in response to soil moisture availability and also provide information about rainy or growing season length and its variation in a region. Thus, water balance models are important for physiological studies, breeding programmes, advisory tools for agronomists and extension workers. These models have important role in drought studies, offer potential for improving water use and hence dry matter production by crops. Water balance models are thus valuable analytical tools to assess the performance of crops in relation to weather patterns and are valuable in the development of strategies to modify effects of extreme growing season weather conditions in order to tap cropping potentials of the growing seasons.

9.1. Research needs and priorities for soil-plant-atmosphere and drought research in the tropics in the wake of the challenges of a changing climate and weather variabilities:

Some key issues yet to be fully resolved in soil-plant-climate and drought research, these issues are relevant towards attainment of increased agricultural productivity, food security and livelihoods in the tropics in circumstances of variable climate and weather. Some of these issues are:

a. Development of methodologies for using climate, soil and atmospheric data to provide quantitative picture of crop available moisture under various weather variability conditions.

b. Selection of technologies to fit expected moisture patterns in order to harness resources and potentials of vast expanse of drought prone areas in the humid and sub-humid tropics.

c. Identify the possibilities of modifying technologies (management methods and crop varieties) to improve crop productivity under specific soil moisture conditions

d. Design soil and crop management systems to make productive use of available moisture and to reduce variability of crop productivity due to variations in inter and intra seasonal rainfall

e. Improve understanding of the bases of plant adaptation to insufficient-moisture environment will help in efforts and possibilities for improving adaptation in crop plants.

In this wise, it is necessary to use climatic data to put research results from experiments on soil, water and crop management practices into a larger perspective for wider adoption or application to regions of similar conditions.

9.2 Enhancing productivity of water use in tropical agriculture:

In circumstances of the changing climate and weather variability and droughts of the future, important pathways to achieving sustainable agriculture, water resources management and food security in the tropics would be to improve the efficiency of rainfall and soil water use in agriculture. These pathways may include:

i. Adopting efficient soil moisture management/conservation practices, identification of crop species and species-specific traits relevant to improved crop water use efficiency and optimizing or enhancing water productivity of crops in rainfed, irrigated and dryland farming systems.

ii. It is also necessary to identify seasons when water availability is limited, and how limited it is and help farmers to make choices about alternative crops that will use less water and attain harvest despite episodes of drought during a critical stage of growth.

iii. Understanding the pattern and probability of moisture availability under various weather conditions thus optimizing water productivity of crops in rainfed, irrigated and dryland farming systems.

iv. Studies of rainfall trends and catchment/watershed water balance useful for estimating water production functions, soil moisture adequacy for rainfed farming and necessity for irrigation (supplementary/full) should be extended. Such studies are useful for estimating rainfall capture/soil moisture availability, plant water extraction, crop water requirements and use efficiencies.

v. Screening plant species and cultivars for beneficial responses to water deficit (plant adaptation that can increase the amount of water crops can capture.)

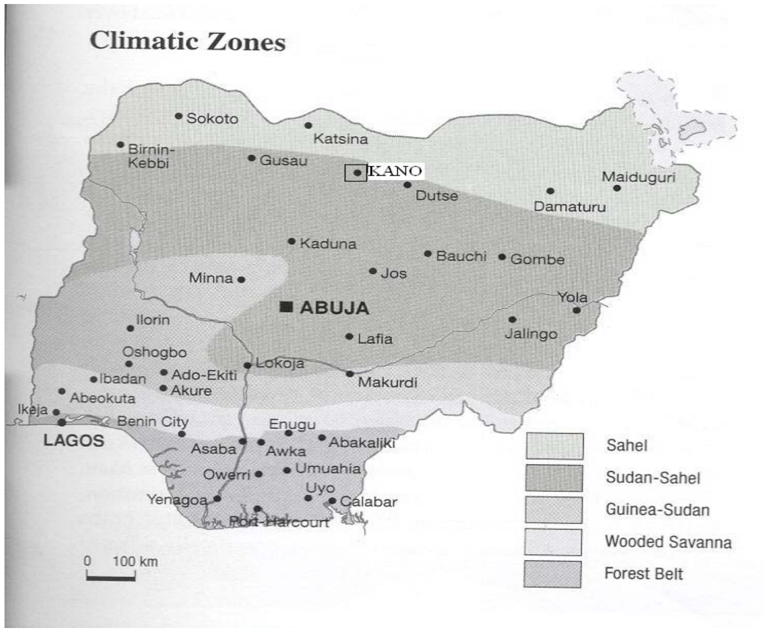


Fig. 1(a)

Vegetation Zones

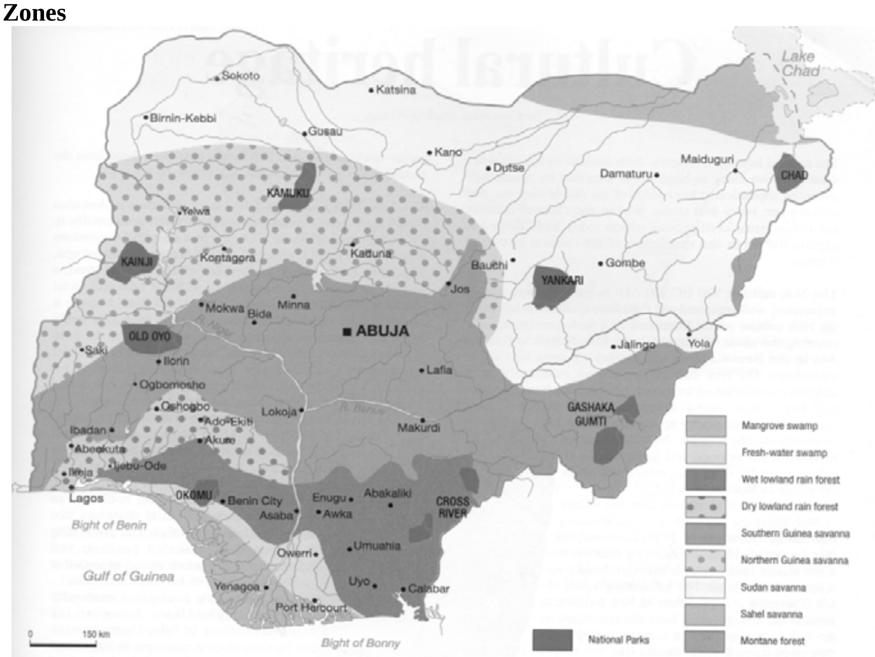


Fig. 1(b)

Fig. 1: Nigerian (a) climatic zones, (b) vegetation zones. Kano is circled.

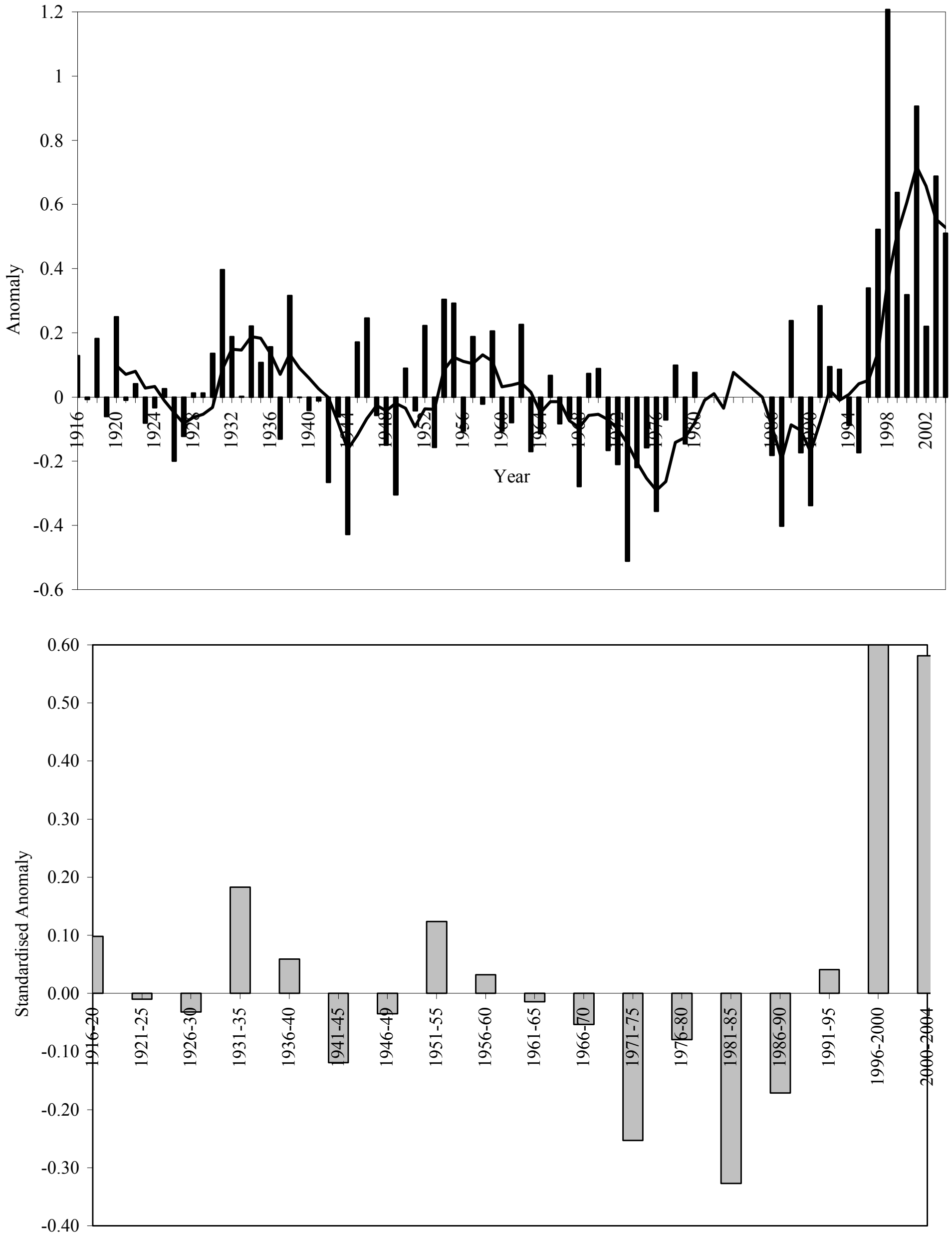


Fig. 2: Normalised rainfall anomaly at Kano between 1916 – 2004 (a) interannual variability, thick continuous curve is 5-year moving average (b) 5-year (pentade) averages

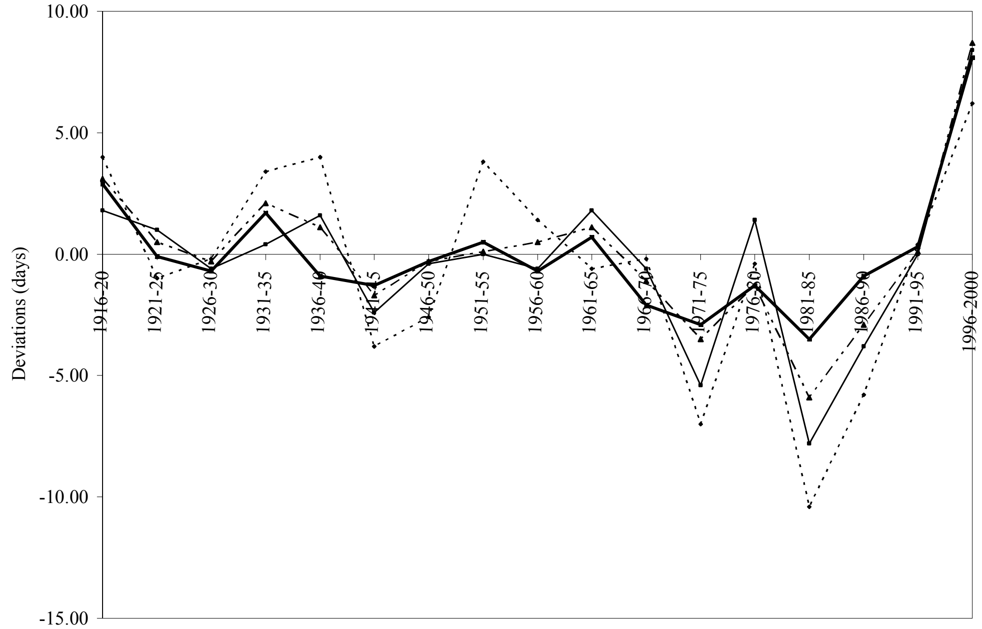
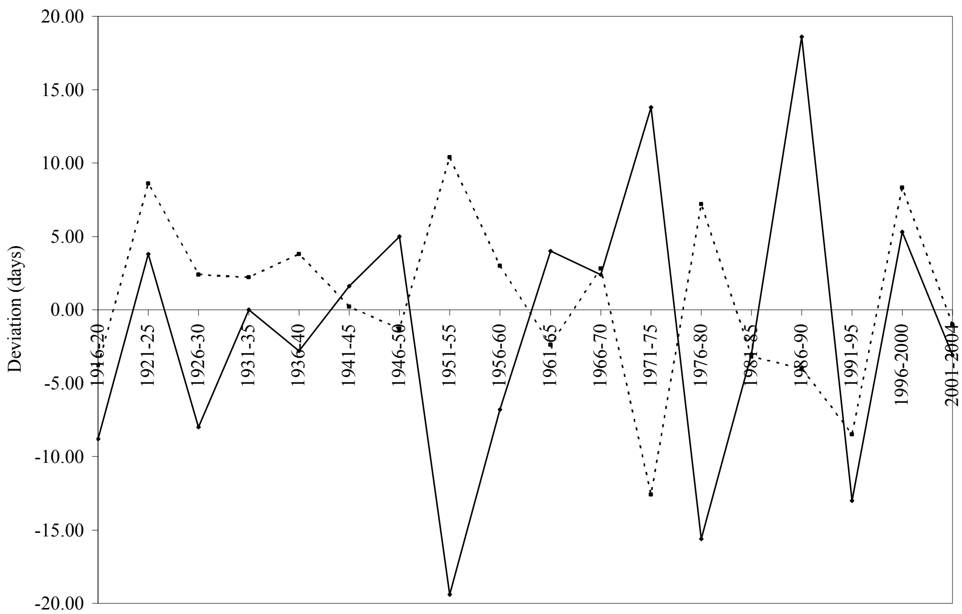


Fig. 3: 5-yearly mean deviations of raindays from their long-term averages for rainfall thresholds of (a) ≥10mm (…….), (b) ≥20mm (——), (c) ≥25mm (—-—--) and (d) ≥10mm (**▬▬**)



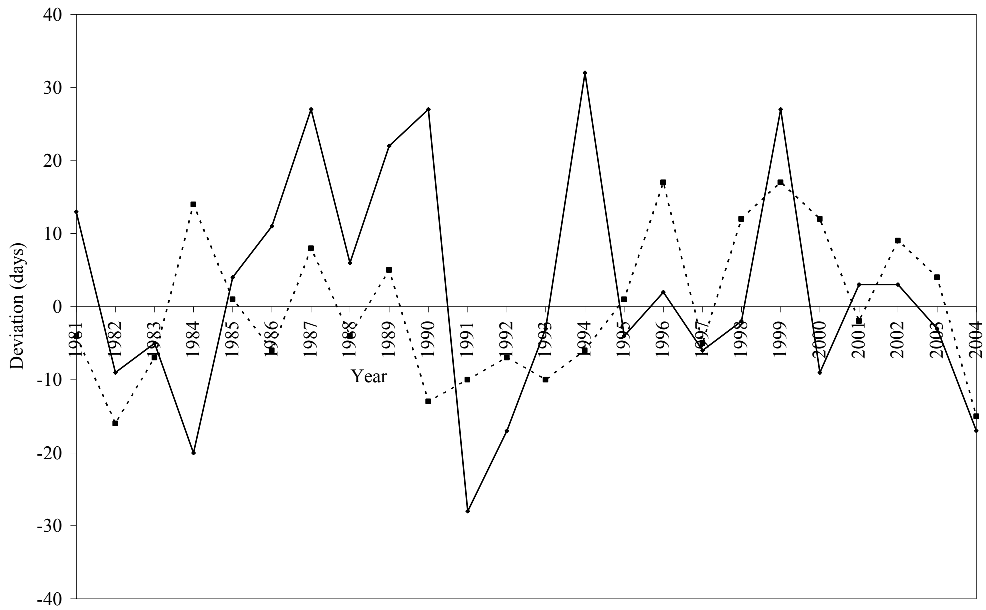


Fig. 4: 5-yearly mean deviations of onset (——) and cessation (…….) dates of the rainy season from their long-term averages 1916 – 2004 and for crop yield years 1986-2004.

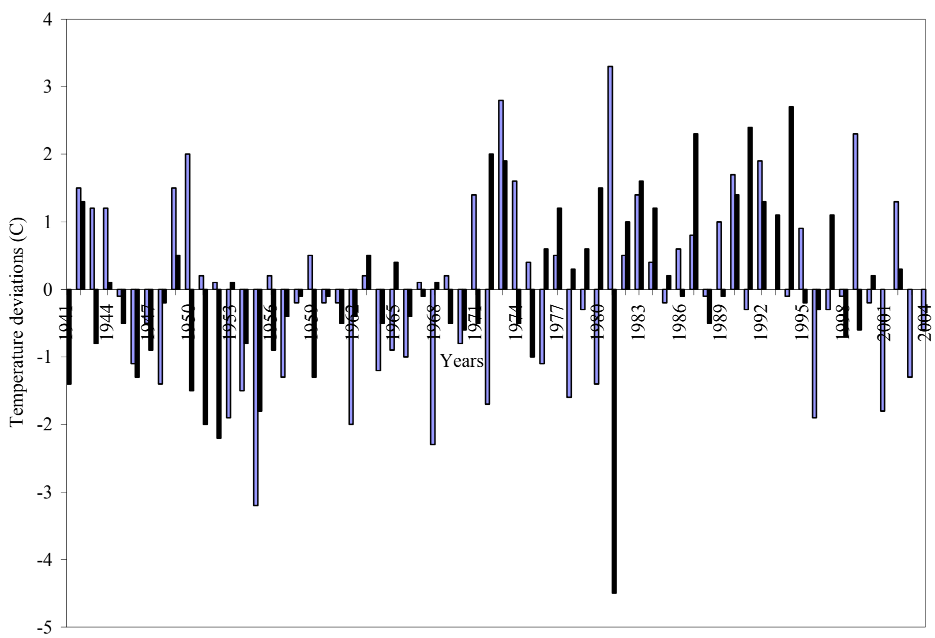


Fig. 5: Deviations of June (□) and September (■) maximum temperature from their long-term averages in (^oC).

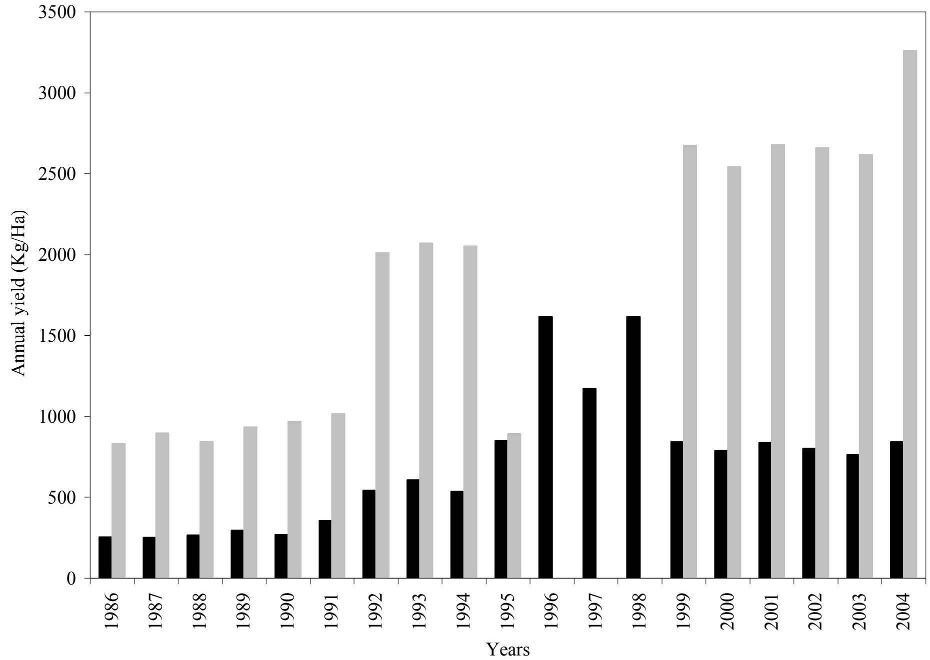
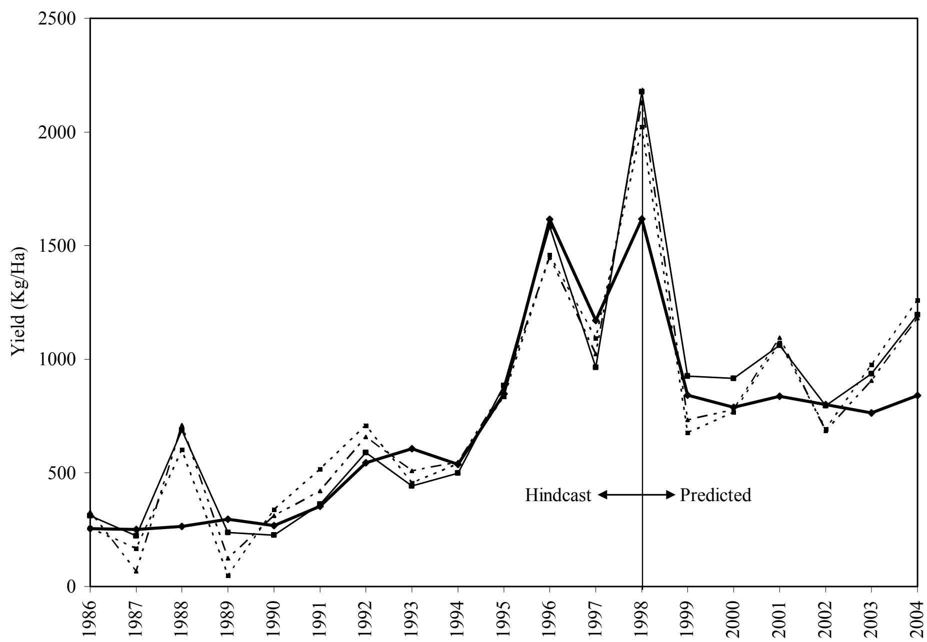


Fig. 6: Interannual variations of cowpea (■) and rice (□) yields (Kg/Ha) in Kano State.



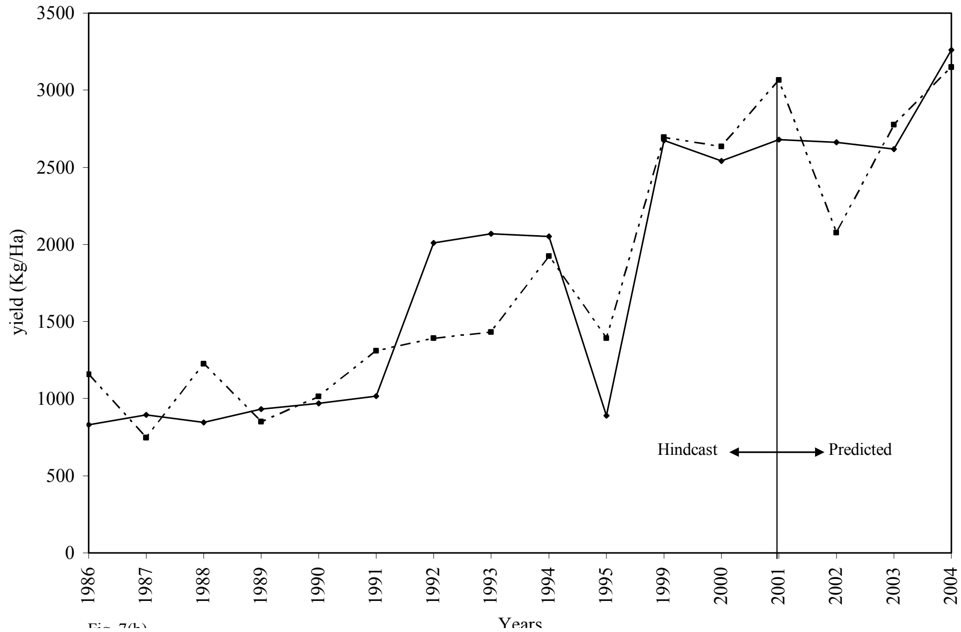


Fig. 7: (a) Actual (▬▬) and predicted cowpea yields from 3-variable (—-—--) and 4-variable [(1: ——)), (2: …….)] models (b) Actual (——) and 4-variable predicted (—-—--) rice yield (Kg/Ha) in Kano State

Table 1: Some statistics on cowpea and rice yield in Kano State.

	Cowpea	Rice
Mean yield (Kg/Ha)	711	1809
Maximum yield (Kg/Ha)	1617	3260
Minimum yield (Kg/Ha)	251	831
Standard deviation	416	870
Growth duration	70-90	>100
Mean onset date	29 May	
Mean cessation date	28 September	

Table 2: Best crop-climate model equations for cowpea and rice yield in Kano State.

Crop	Model**	R^2 (%)
	3-variable: 4871.9 + 7.0Sep RR – 132.2SepR_{d10} – 198.5Jun T_{min}	83
Cowpea	4-variable A: 2468.6 + 6.8Sep RR + 87.7Sep T_{max} – 100.5Sep R_{d10} – 221.9 Jun T_{min}	86
	4-variable B: 1668.5 + 6.5Sep RR + 10.6Julian CR – 127.3Sep R_{d10} – 181.5Jun T_{min}	87
Rice	4-variable: – 7844.5 + 15.4Sep RR + 1.7Ann RR + 209Sep T_{max} – 400.3Sep R_{d25}	75

** Sep RR and Ann RR are, respectively, September and total annual rainfall (mm); Jun T_{min} and Sep T_{max} are June minimum and September maximum temperatures, respectively, in degree C ; Sep R_{d10} and R_{d25} represent the number of raindays of at least 10mm and 25mm in September, respectively. Julian CR is the rainy season cessation date in Julian days

There is a growing urgency surrounding drought and a drying climate, necessary to adapt crops to better perform under drought/water limited situations. Therefore, the need is urgent to study adaptation strategy in tropical crops in circumstances of the expected variable and warmer climates and droughts of the future. This will enable the identification and selection of crop germplasms with drought tolerance, high water use efficiency (water productivity) traits and their choices for use in intermittent/terminal drought situations.

In plants under drought, the uptake of an extra mm of water can contribute to extra kg of grain per hectare:

The objectives of enhanced productivity of water use of tropical crop species may be achieved via phenotyping technologies. Thus the suites of traits that stand to drive water productivity gains are examined followed by correlation of these traits with value and gains in terms of water productivity.

10. Summary and Conclusion:

It is well known that adverse climate conditions have serious implications for crop yields. In this article, we have studied the interannual variability of two climatic elements – rainfall (its factors: rainy season onset and cessation, total annual rainfall, number of raindays) and extreme temperatures – and their effects on the yield of rice and cowpea in Kano state in the Sudano-Sahelian zone of West African. The yields of these food crops are found to be significantly correlated with the climate parameters. The empirical models are also shown to have good predictive skill.

However, this study raises some pertinent issues that need to be addressed if enhanced crop production and food security are to be achieved in Nigeria in particular, and West Africa in general since the weather and climate of the former is typical of the latter. First, it is quite obvious from all the above that, if the environmental parameters of rainfall, number of rainydays, onset and cessation of the rainy season as well as extreme temperatures could be reliably predicted early in the year, it is possible to make yield forecasts for these very important food crops. While it is noted here that the prediction of rainy season onset and cessation dates as well as annual rainfall, before the rains begin, has been addressed by Omotosho *et al* (2000), there is also the need for methods for forecasting the number of raindays and extreme temperatures so that the models could become fully operational. Secondly, in the light of our modeling, it is imperative that meteorologist and agriculturists in Nigeria collaborate to carry out farm experiments, in order to determine plant-critical environmental factors for many cash and food crops and their crop-tolerant limits, especially during initiation, flowering, fruiting and ripening stages of the crops. The extremity and variability of climate and weather events has far reaching and grevious implications for agriculture and water resources and food security in the humid tropics. Climate change and weather variabilities are likely to exacerbate the current vulnerability of crop yield to extreme climatic events. It means that in future climates, greater heat and drought tolerance (increases in water use efficiency) in crops will be required.

The capacities and abilities to mitigate adverse effects of extreme climate/weather events hinge on increased capacity building in soil, water and environmental management practices, good policy choices and advancement in technology. It is urgently required to enhance skills, competences and scientific techniques in soil-crop-climate research, the results would promote the emergence of technological/agronomic interventions to protect farmers and agricultural systems from drought and consequences of hazardous climatic events. The results of such efforts will provide scientific base to build on rainfed and irrigation agriculture, and appropriate water/irrigation technologies as inputs in the strategies for productive and sustainable agriculture in the tropics.

Agriculture and water resources are climate and weather dependent, this dependence is particularly critical for agriculture. However, agriculture and water resources availability and management, to a very large extent, determine food security. It is concluded that sustainable agriculture and food security would therefore depend on making agriculture systems responsive to changing climatic and weather patterns.

Acknowledgement

The authors wish to acknowledge the grant from the Dr. Kachala Research Grant in Agriculture, awarded by the Center for Research and Development, Federal University of Technology, Akure. This work was carried out partly from this grant.

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