CLIMATE CHANGE AND ITS IMPLICATIONS ON THE ASSESSMENT OF PLANTING OPPORTUNITIES IN THE DRY NORTHERN NIGERIA

Oluwasemire K.O.
Department of Agronomy, Faculty of Agriculture and Forestry, University of Ibadan, Ibadan, Nigeria
Corresponding author e-mail addresses: theophilus.oluwasemire@gmail.com
Tel. No. 234-703-334-9506

ABSTRACT

The shortening of the growing season and rising temperature in northern Nigeria since early 1960s has continued into the new millennium. A study was conducted on the long-term (1951-2004) rainfall data across three agro-ecological zones (northern Guinea, Sudan and Sahel savanna at Samaru-Zaria, Sokoto, Kano and Maiduguri in northern Nigeria) with emphasis on the analysis of the length of early season dry spells and their frequencies along with soil water holding capacity. Four criteria (length of dry spells between rainfall events, amount of rainfall within a given period of days, the relationship between environmental water demand and early seasonal rainfall events) were used to assess the start of planting season and for identifying planting opportunities. The occurrence of early season dry spells has increased between 1960 and 2004 by between 5 and 20 days. Early season dry spells are about 20 days at Maiduguri, 10 days at Kano and Sokoto, and less than 10 days at Samaru. Planting opportunities have reduced with resultant decrease in frequency of occurrence over time. Relatively fewer planting opportunities occur in locations in the Sahel and Sudan Savanna latitudes compared with locations in the relatively more humid Guinea savanna zone. The increase in the number of days of early season dry spell would no longer favour the production of millet in the Sahel and maize in the Sudan savanna zones thus calling for the breeding of extra early maturing varieties to adjust to the decreasing number of days in the rainfed growing season due to climate change.

Key words: Rainfall variability, dry spell, sowing opportunity, crop production, northern Nigeria

INTRODUCTION

The variability in climate and especially, the associated weather extremes are now of great concern to governments, scientists and the general community (Climate Research Committee, 1995). Although the subject of climate change is vast, the aspect of changing precipitation patterns deserves urgent and systematic attention worldwide. This is particularly so in the tropics because of its effects on regional food security (Dore, 2005).

Apart from water deficit, other climate-induced hazards that adversely affect seedling emergence and establishment of crops are high soil temperature and high soil strength, especially in soils where surface soil clay content is high (Albrecht and Bristow, 1996). Crop water use is strongly affected by temperature; hence, increases in temperature caused by global warming would accelerate plant water consumption and exacerbate the water environment for plant growth, especially in environments where water is limiting (Shigenaga *et al.*, 2005). Sivakumar (1992) had observed that the high evaporative demand in the environment of northern Nigeria is capable of reducing crop growth if dry spell period persists for more than five days.

Crop production in the Nigerian savanna zones is essentially rainfed and generally based on rainfall situation. A report of a workshop on the situation in the savanna of West Africa indicated that the standard deviation of the onset of rains is generally much higher than the standard deviation of the cessation; hence, an early onset offers the probability of a longer growing season while a delayed onset would result in shorter growing seasons (START, 1998).

Therefore, the decisions on crop choice and management are either related to the timing of planting opportunities or made at the time of planting. The start of the planting season is a key variable to which other seasonal rainfall attributes (cessation of rains and length of growing season) are related (Stewart, 1991).

The term 'planting opportunities' refers to the moisture requirements for germination and emergence of a crop. Ati *et al.* (2002) suggested the onset of the planting season in northern Nigeria as periods between May and June which usually lasts for a period of 3-4 ten-day periods with an average total rainfall of 102 mm. Potential evaporation within the same period averaged 137 mm. The excess of rainfall over evaporation is expected to be sufficient to penetrate the soil surface to a depth of 15-20 cm, thus allowing for seedbed preparation and seed germination. In the maize and soybean growing area, around Zaria, the limitation by rainfall is also considered to be days when precipitation is less than half of the potential evapotranspiration. Weather pattern, later in the rainy season also drives the time of planting maize. Planting in June allows flowering to occur during the rainy period such that this critical period, which is important for the expression of yield potentials does not experience any risk of drought stress (Sivakumar, 1992; Kamara *et al*,. 2009). Cereal crops (maize, sorghum, millet etc.) as the main crops in the agroecological zones under consideration are highly sensitive to drought stress during flowering (Heisey and Edmeades, 1999). However, early season drought impacts more negatively on crop establishment and act as severe drain on the resource of poor farmers, who may have to re-plant; and the overall food security of the community. Early season dry spells also affect soil water retention which would negatively impact on crop production in the northern Nigerian savanna. However, the frequency of poor distribution of rainfall early in the rainy season has become a common feature (Anyadike, 1992; Oladipo and Salau. 1993; Hess *et al*., 1995; Nicholson *et al*., 2000) with the resultant poor crop establishment and loss of good quality planting materials. Blench (1999) also observed that dry spells, as a serious short term drought pattern and rainfall intensity, are more important weather forecast information to most farmers than the usually available weather forecast information but that they are not readily available. The analysis of daily rainfall data for rainy season parameters of interest to agriculture will suggest the trend of changes observed in rainfall patterns and the scope of the changes. The empirical analysis of long-term rainfall data for trend of early season dry spell could provide information which could be employed as a guide in breeding crop varieties tolerant to drought and different maturity duration for different agro-ecological zones in Nigeria. Information on dry spell length can also be used in decision making with respect to supplementary irrigation that would ensure adequate plant population for optimum yield at harvest. Hence, a better scientific approach towards the assessment of planting opportunities would, therefore, impact positively on agricultural production and guarantee food security for sustainable national development.

Evidences of climate change in the dry northern Nigeria

The major climatic elements of interest in relation to climate change are rainfall, temperature, radiation and wind speed. Rainfall, however, constitutes the most important element with regard to agriculture in the dry northern Nigeria being considered in this study. Climatic change in the combined effects of elevated temperatures and drought, with consequential increase in potential evapotranspiration, constitutes the greatest risk to agriculture in many regions (IPCC, 1990). The observed trend of global and hemispheric annual variation in temperature has been a marked warming up in the sub-tropic north from the 1980s to 1990 (Boden *et al*., 1990). The trend of annual mean temperature for Samaru (1954-2004) has been on a gradual rise since 1982 as shown in Fig. 1. Some significant features have also been observed in the relationship between temperature and rainfall in the Sahelian Africa (Fig. 2). One of such relationships suggests that lower ambient temperatures are associated with higher rainfall in the West African Sahel (Landsberg, 1986). Adefolalu (1990) also suggested that effective precipitation may likely reduce in the east of

Greenwich Meridian as a result of increasing temperatures observed in the present trend of environmental warming.

Records of rainfall data from the sites under consideration in this study show that annual total rainfall of 28 out of the last 40 years (1965-2004) were below the long term average, indicating a tendency towards inadequate rainfall in Kano (771.0 mm) and Sokoto (711.5 mm) areas while at Samaru and Maiduguri with mean annual rainfall of 1044 mm and 591.5 mm, in 26 and 21 years, respectively out of the same 40-year period were below the long term averages. A comparison of average decadal rainfall for 1951-1970 and 1981-2000 for all sites shows a declining trend of annual rainfall over the years which were dominated by reduction in amounts late in July and within the months of August and September (Figs. 3 and 4).

METHODS

Locations considered in this study are Maiduguri (11° 51'N, 13° 05'E; 354 m above sea level), Kano (12° 09'N, 08° 32'E; 695 m above sea level), Sokoto (13° 01'N, 05° 15'E; 351 m above sea level) and Samaru (11° 11'N, 07° 38'E; 686 m above sea level). Maiduguri is located in the Sahel savanna; Sokoto and Kano are in the Sudan savanna while Samaru is within the northern Guinea savanna zone of Nigeria.

Soil characteristics

The predominant soil type in Kano area is loamy sand, hyperthermic, Typic Ustipsamment with average surface soil bulk density of 1.50 Mg m^{-3} (Oluwasemire *et al.*, 2002). The soils at Samaru are poorly-drained, fine loams on the surface overlying clay loam and clay subsoils and classified as Typic Haplustalf with soil temperature and moisture regimes as isohyperthermic and Typic Tropustic (Uyovbisere *et al.*, 1984). Maiduguri location soils are mostly classified as Typic Ustipsamments from Aeolian sand formation (Rayar, 1984), loosely aggregated with a sandy loam texture and dry bulk density close to 1.50 Mg m^{-3} which varies little with depth. The top 0.20 m soil depth however has a lower bulk density of 1.40 Mg m^{-3} (Grema and Hess, 1994). Infiltration rate is very high with a steady state rate that varies from 72 to 220 mm h^{-1} with a mean of 135 mm h^{-1} (Folorunso, 1986). Soils in Sokoto are predominantly Kanhaplic Haplustults, fine-loamy, mixed isohyperthermic high sand fractions (Raji *et al.*. 1999). The soil's moisture regime is ustic while the clay fractions are dominated by kaolinite and sesquioxides and total porosity which vary from 396 to 464 g kg^{-1}.

Criteria for assessing planting opportunities

To quantify the occurrence of planting opportunities based on rainfall and evaporation requirements, long-term data were obtained from the Institute of Agricultural Research (IAR), Ahmadu Bello University, Zaria, Nigeria and the Nigerian Meteorological Agency, Abuja, Nigeria.

The following criteria were used for assessing planting opportunities in the study area:

i. Planting may take place when rainfall is sufficient to provide water equivalent to, or greater than, one half of potential evapotranspiration (FAO, 1996).

ii. Onset of rain is synonymous with sowing date and is defined as the date after May 1 when cumulative daily rainfall over three consecutive days is at least 20 mm and when no dry spell within the next 30 days exceeds 7 days (Sivakumar, 1988).

iii. Planting starts when daily rainfall minus Class A pan evaporation accumulated daily until it exceeded 20 mm (Monteith and Virmani, 1991).

a. $$\sum_{i=1}^{n}(Rain - Evap.) > 20mm$$

i. The beginning of the planting season is marked when the monthly total rainfall received is over 100 mm (Jagtap, 1995).

Planting opportunities for zones under consideration are only limited to periods covering months of May to July which coincide with the early part of the rainy season. Although the criteria were chosen as general in concept for defining planting opportunities, the absolute values used in the criteria will depend on soil type. Such values would be lower for coarser-textured soils e.g. Kano, Sokoto and Maiduguri location soils and higher for soils of greater clay contents (i.e. Samaru location soil). At Samaru, the soil water status at wilting point and field capacity are 12 and 19 percent respectively while in Kano, Maiduguri and Sokoto location soils, water status at wilting point is about 4 percent and 12 percent at field capacity (Grema and Hess, 1994; Oluwasemire *et al.*, 2002). The reference crop for the Sahel and Sudan savanna locations is pearl millet with an average growing period of 75 and 90 days respectively, while maize with an average growing period of 110 days was selected for Samaru in the northern Guinea savanna.

Figure 1. Annual mean temperature at Samaru, Northern Nigeria from 1954-2002.

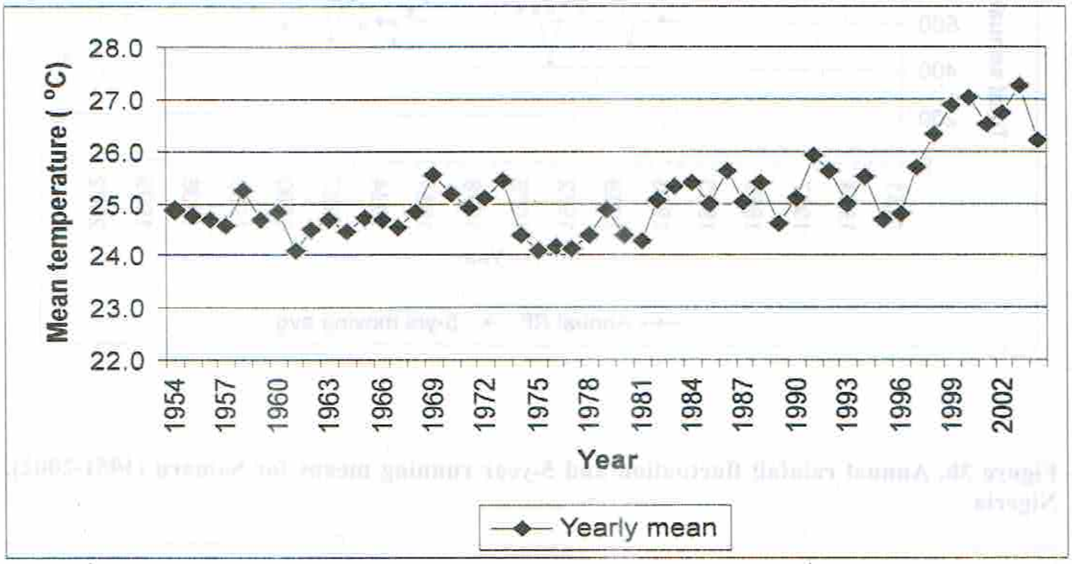

Figure 2. Annual mean temperature at Maiduguri, Northern Nigeria from 1966-2002.

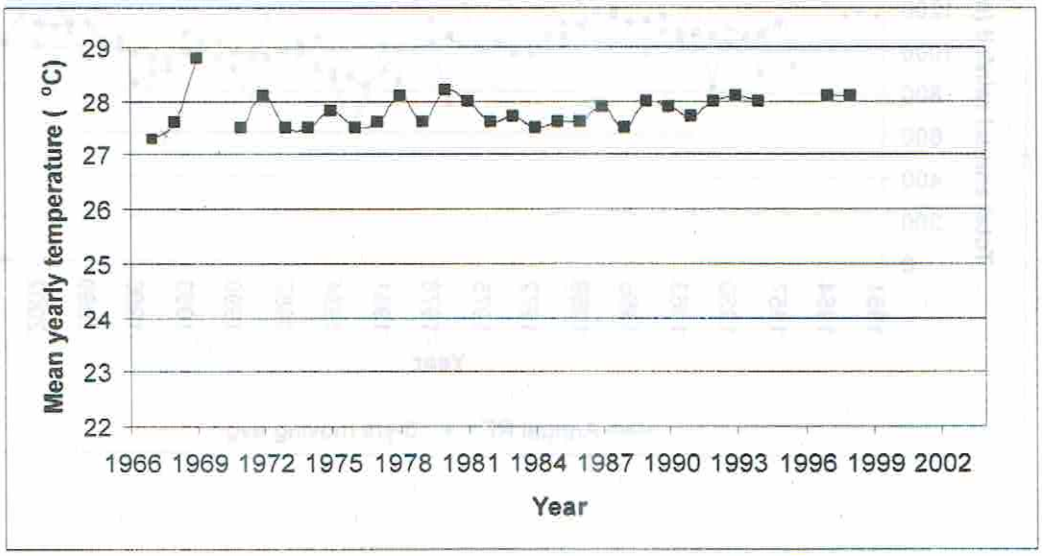

Figure 3a. Annual rainfall fluctuation and 5-year running means for Kano (1951-2002) Nigeria.

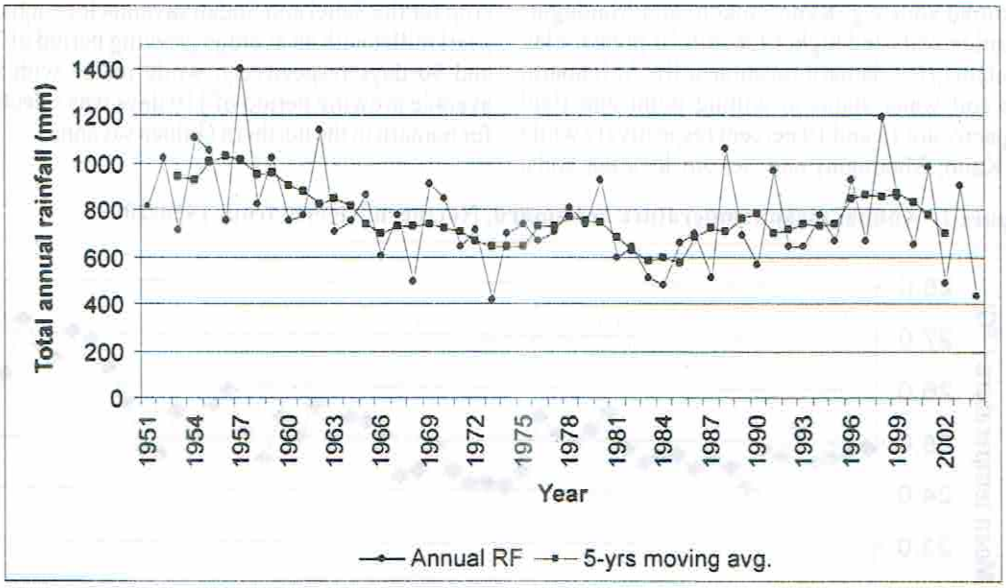

Figure 3b. Annual rainfall fluctuation and 5-year running means for Samaru (1951-2002), Nigeria

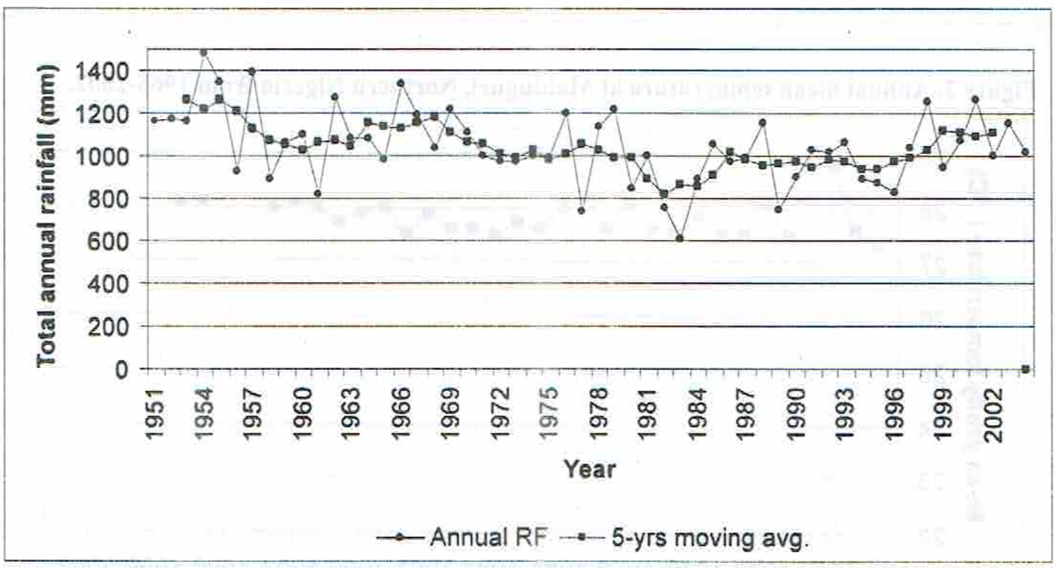

Figure 4a. Annual rainfall fluctuation and 5-year running means for Sokoto (1951-2002), Nigeria

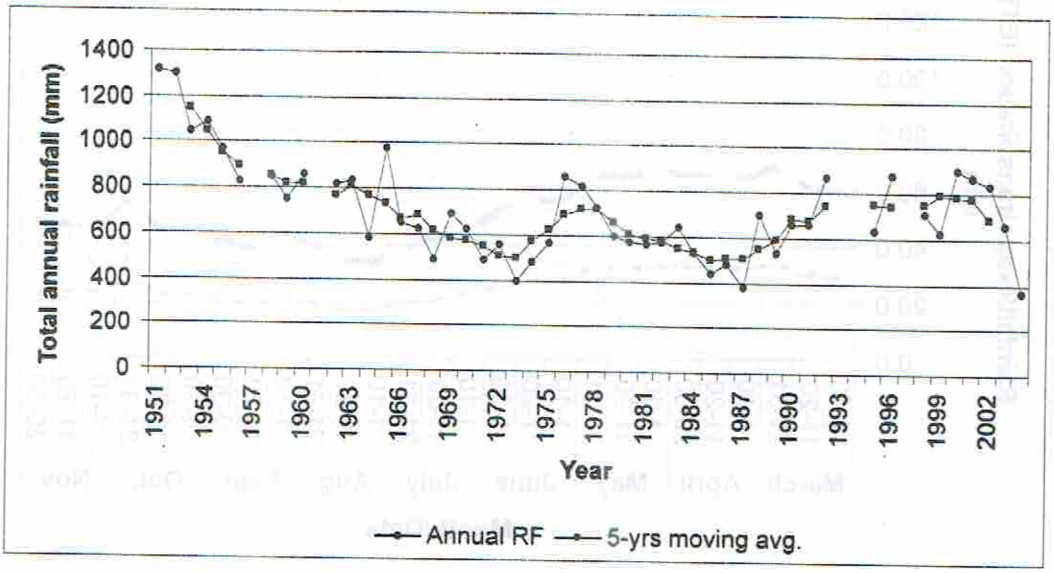

Figure 4b. Annual rainfall fluctuation and 5-year running means for Maiduguri (1951-2002), Nigeria

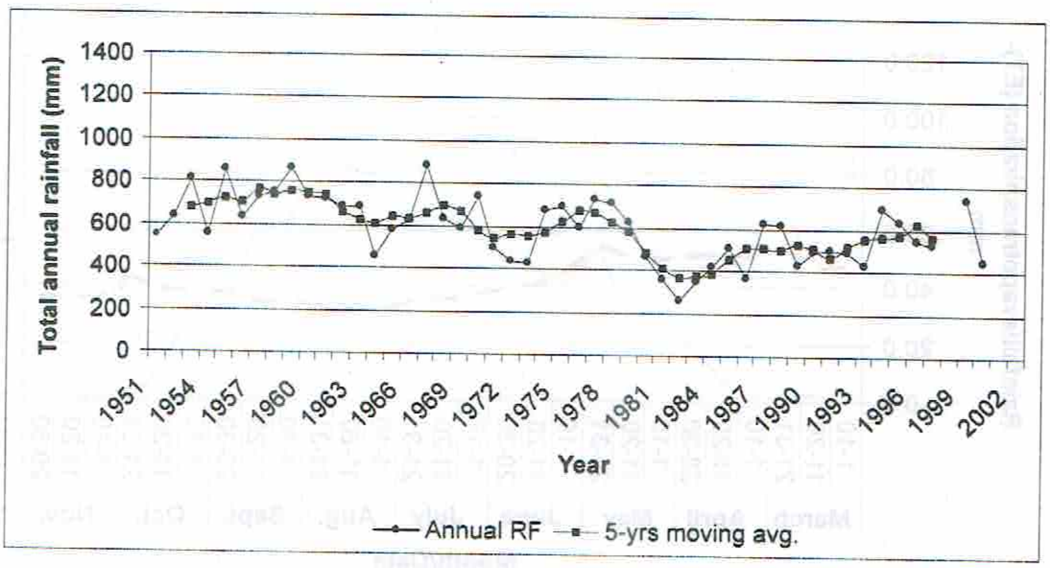

Figure 5. Water balance for determination of growing season at Kano, Nigeria

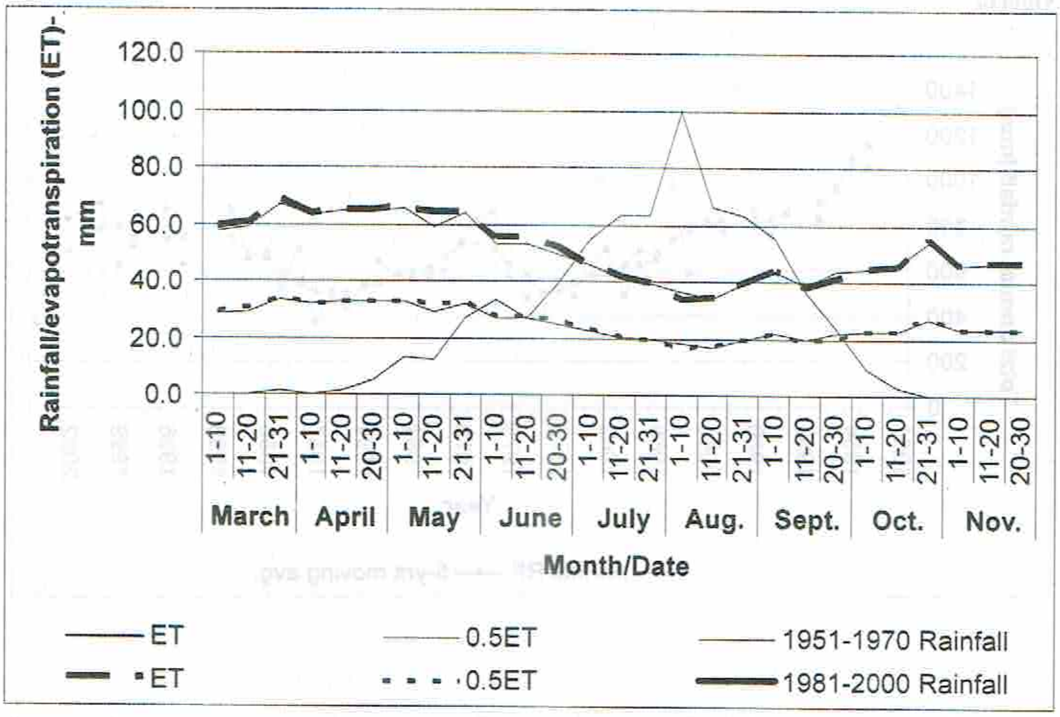

Figure 6. Water balance for determination of growing season at Samaru, Nigeria

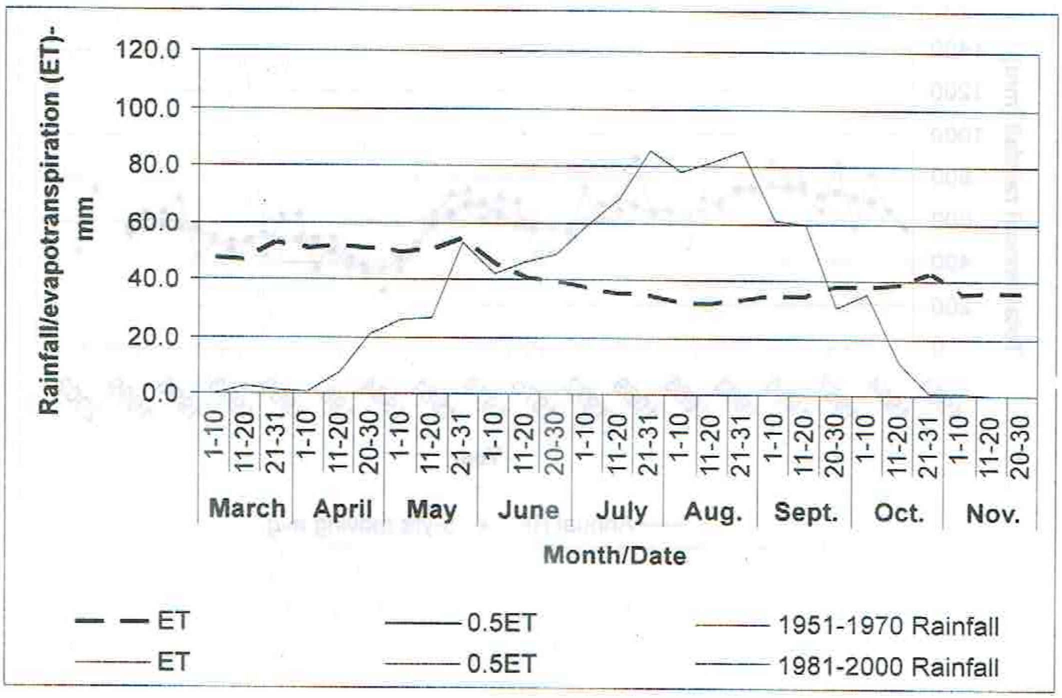

Figure 7. Water balance for determination of growing season at Sokoto, Nigeria

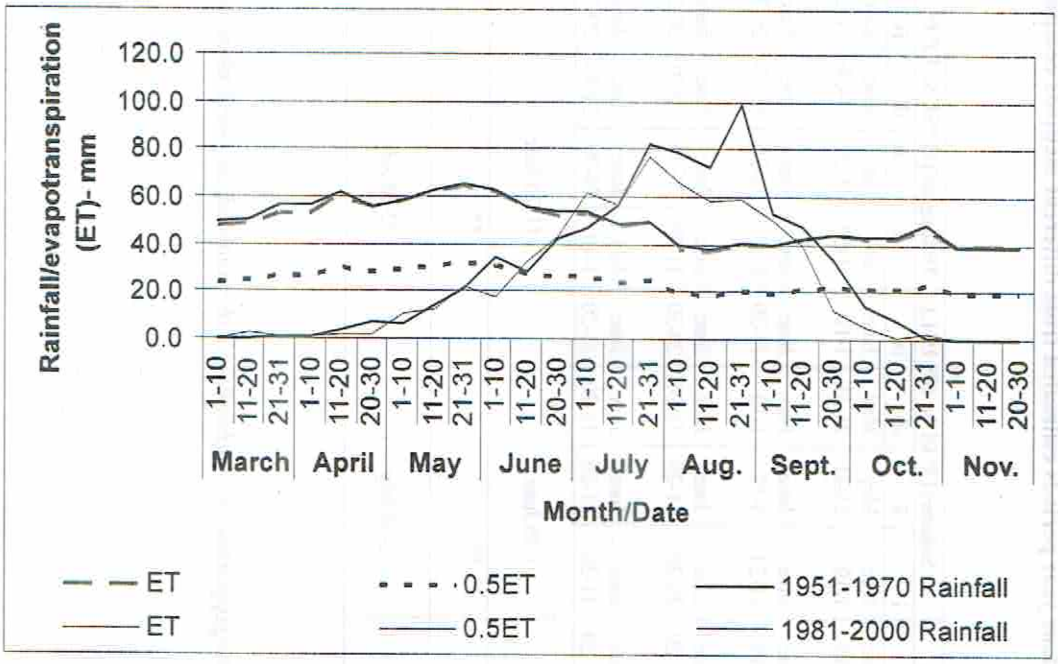

Figure 8. Water balance for determination of growing season at Maiduguri, Nigeria

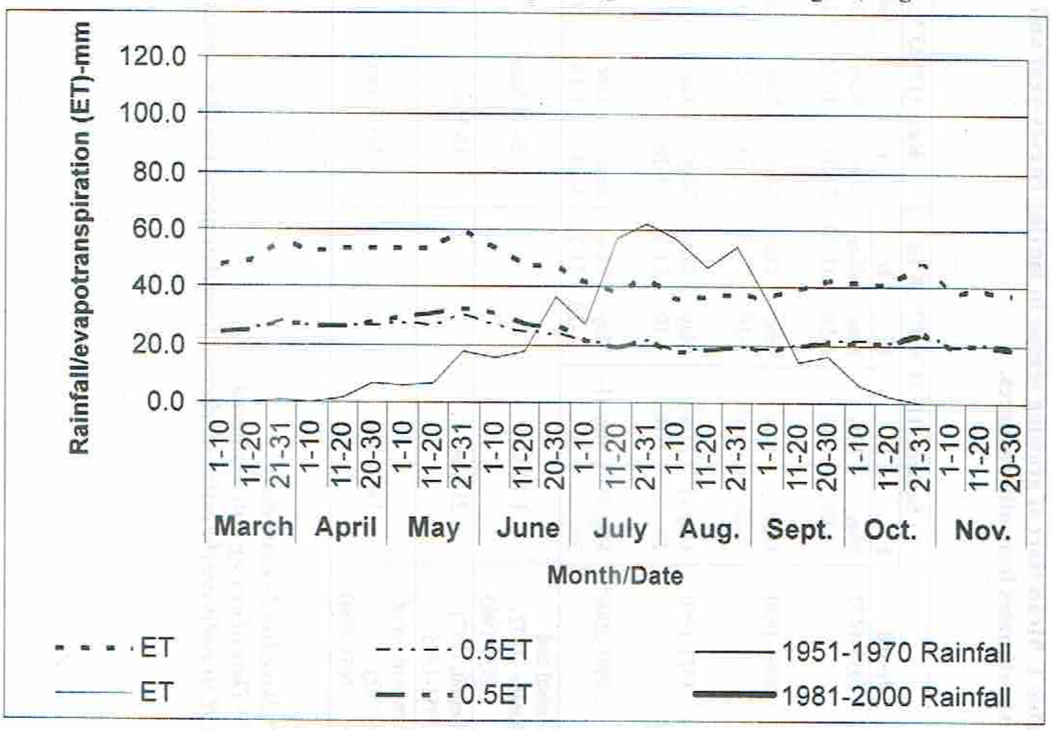

Table 1. Mean start of growing season in moving twenty-year and twenty-four year periods estimated from different methods compared with estimates from other sources.

Period	Samaru (11° 11'N; 07° 38'E)				Kano (12° 03'N; 08° 32'E)				Sokoto (13° 01'N; 05° 15'E)				Maiduguri (11° 51'N; 13° 05'E)			
	i	ii	iii	iv	i	ii	iii	iv	i	ii	iii	iv	i	ii	iii	iv
1951-1970	May 1-10	May 1-10	May 1-10	May 11-20	May 21-31	May 11-20	June 1-10	June 1-10	June 1-10	May 21-31	May 21-31	June 1-10	June 11-20	June 11-20	June 11-20	June 11-20
1961-1980	May 1-10	May 1-10	May 1-10	May 21-31	May 21-31	May 11-20	June 1-10	June 1-10	June 11-20	June 1-10	June 1-10	June 11-20	June 1-10	June 11-20	June 11-20	June 20-30
1971-1990	May 11-20	May 1-10	May 1-10	May 21-31	May 11-20	May 21-31	June 1-10	June 11-20	June 20-30	June 11-20	June 11-20	June 20-30	June 11-20	June 20-30	June 20-30	June 20-30
1981-2004*	May 11-20	May 11-20	May 11-20	May 21-31	June 1-10	June 1-10	June 11-20	June 11-20	June 11-20	June 11-20	June 11-20	June 11-20	July 1-10	June 20-30	June 20-30	June 20-30
Kowal and Knabe (1972) 1951-1965	1-10 May				21-31 May				1-10 June				11-20 June			
Benoit(1977) 1951-1975	21 May				10 June				**				**			
Owonubi *et al.* (1992) 1931-1990	14-20 May				11-17 June				02-08 July				02-08 July			

**- Based on 24 years data.*
***-Date of sowing not considered.*
i, ii, iii and iv are the estimates derived from the criteria used for assessing planting opportunities highlighted in the materials and methods section

RESULTS AND DISCUSSION

Comparison of criteria

The soils of Kano, Maiduguri and Sokoto are predominantly sandy in nature; hence they have low water holding capacities and high infiltration rates. However, the soil at Samaru, with relatively higher clay contents has the capacity to retain more water.

Table 1 shows the comparison of methods used for the assessment of planting opportunities at the sites selected for this study. At Samaru, the first three criteria were in agreement for assessing planting opportunities from 1951-1980 while the accumulation of total monthly rainfall in excess of 100 mm was the criterion that gave later (> 10) days from 1951-2004. The soil at Samaru has relatively higher clay content and so requires higher amount of soil water to sustain crop germination and emergence. As Kowal (1973) observed in the Samaru environment, the high evaporative demand is capable of serious reduction in crop growth if dry spell period persists for more than five days.

Planting dates observed with the different methods for Kano showed clear backward shifts between the periods 1951-1980 and 1981-2004. At Sokoto, there was also a backward shift in planting dates after the period 1951-1970 by about 10 days which seemed to have remained the same from around 1961-2004. The criteria gave June 11-20 planting opportunities for all the methods for the 1981-2004 period.

At Maiduguri, all the criteria used for assessment of planting opportunities gave the same period from 1951-1970 while the methods showed some differences between 1961 and 1990 (Table 1).

The planting dates estimated for 1951-1970 period agreed with results obtained by Kowal and Knabe (1972) while the later studies carried by Owonubi *et al.* (1992) showed some agreement for Samaru and Kano but much later dates for Sokoto and Maiduguri.

Planting opportunities

The seasonal water balance analyses for the four study sites are shown in Figs 5, 6, 7 and 8 (FAO 1996). The water balance indicates five, four and three-month periods of cropping season for Samaru, Kano/Sokoto and Maiduguri respectively. The actual cropping season started from 11th to 20th May (1981-2000) as against 1st to 10th May between 1951 and 1970 at Samaru. The commencement of the cropping season shifted from 21st to 31st May (1951-1970) to 11th to 20th June (1981-2000) at Kano, while at Sokoto the shift in the start of cropping season was from 1st to 10th June (1951-1970) to 11th to 20th June (1981-2000). The magnitude of the shift in the commencement of cropping season was greatest at Maiduguri by about 30 days in the Sahelian zone from 1st to 10th June (1951-1970) to 1st to 10th July (1981-2000) (Fig. 8).

Planting opportunities in the Sudan savanna were more affected by reduction in early season monthly rainfall amounts induced by climate change than at the northern Guinea savanna location (Table 1). Planting opportunities were about 10 days later within 1981-2004 compared with 1951-1990 period at Samaru. At Kano, the magnitude of the backward shift and reduction in planting opportunities varied from 10 to 20 days.

The backward shift in planting dates at Maiduguri were more drastic, being > 20 days reduction in a rainfed cropping season of about 80 days. This has far reaching implications for sustainable crop production and calls for a serious adjustment in cropping pattern, choice of crop varieties and general livelihood of the people of this zone. At these relatively low-rainfall locations of the dry northern Nigeria, the long period of early season dry spell have implications on the length of the growing season. The varieties of the reference cereal crops (millet, maize and sorghum) commonly grown mature at about 90, 110 and 130 days, respectively. The reduction in the length of growing period from about 110 days to 80 days, has reduced the traditional millet varieties to a marginal crop that would only fully mature with soil water reserves. In the Sudan savanna (Kano and Sokoto), maize may experience drastic reduction in yield potentials with a reduction of growing season period from about 125 days to 105 days. Reduction in yield or out-right crop failure may be experienced if mid-season drought occurs at any other stage of maize growth and development during the season (Sivakumar, 1992; Kamara *et al.*, 2009). Sorghum would face a more serious threat to its productivity by this trend in the Sahel and the Sudan savanna because of its longer duration of growth. The major challenge to this trend of reducing growing period is a threat to regional food security that could be solved through the breeding of early maturing varieties of these crops with potentials for high yield, drought tolerance and acceptable qualities by farmers (Ainsworth, 2010; Baron *et al.*, 2010).

The sandy nature of the soils in Maiduguri area and high ambient temperatures also make soil water retention for crop production a major challenge. The adverse effects of prolonged early season dry spells with the resultant effect of shortened growing season period on the production of arable crops can be lessened by the use of early maturing high-yielding hybrids. Other possible adaptation strategies may be achieved by increasing plant density and fertilization levels (Cuculeanu *et al.*, 1999).

CONCLUSIONS AND RECOMMENDATIONS

Production risk varied with location, soil water storage and length of planting season. The prevalence of extended period of dry spell during the early part of the rainy season and rising temperature have resulted in accelerated potential evapotranspiration that reduced the planting opportunities, which are generally unreliable over cropping seasons. A good assessment of planting opportunity could, therefore, be used as a guide for breeding crop varieties of various maturity durations for different locations. This would guide against the mismatch of the phenology of existing crops and rainfall regime and so reduce the possibility of crop failure, which could cause social and economic dislocation of farmers.

The results of this study suggest that information on seasonal rainfall onset should be disseminated as an integral part of an extension package that includes the potential response strategies and risk management. An operational advisory team consisting of the Nigerian Meteorological Agency (NIMET), National Agricultural Research Institutes (NARIs), governmental agencies at the states (Agricultural Development Programmes and Ministries of Agriculture) and local government (Agriculture Departments) levels should be formed with the aim of arriving at appropriate onset of planting season that would be provided on-line and through radio/television programmes for every cropping season in a participatory approach with farmers. Such information provided must also include a means of greater access to basic agricultural technologies by farmers. These would include the adoption of water conservation tillage practices, the use of drought tolerant crop varieties and drought mitigation strategies. Integrated management practices must emphasize good quality planting materials, planting early-maturing varieties, innovative land preparation and planting techniques, conservation of moisture and appropriate cropping systems. Farmers' should be guided against the problems associated with the loss of improved crop varieties (with the attributes stated above), but lost through poor management practices such as dry planting, mixture of crop varieties (impurity in genetic materials and the unorganized seed production sector of the Nigerian agricultural enterprise). These would minimize risk of planting when variability in onset of rainfall is high.

ACKNOWLEDGEMENT

The supply of daily weather data used for this study by the Nigerian Meteorological Agency (NIMET) and the Meteorological Services Unit of the Institute of Agricultural Research (IAR), Ahmadu Bello University, Zaria, Nigeria is hereby acknowledged. The support for this academic work by the University of Ibadan is also appreciated.

REFERENCES

Abrecht, D.G. and Bristow, K.L. 1996: Coping with soil and climatic hazards during crop establishment in the semi-arid tropics. *Australian Journal of Experimental Agriculture* 36 (8): 971-983.

Adefolalu, D.O. 1990: Desertification Studies. In: Vaughan (Ed.), Microwave Remote Sensing. Kluwer Publishers. Pp. 278-305.

Ainsworth, E.A. and Ort, D.R. 2010: How do we improve crop production in a warming world? *Plant Physiology* 154: 526-530.

Anyadike, R.N.C. 1992: Regional variation in fluctuations of seasonal rainfall over Nigeria. *Theoretical and Applied Climatology* 45: 285-292.

Ati, O.F., Stigter, C.J. and Oladipo, E.O. 2002: A comparison of methods to determine the onset of growing season in northern Nigeria. *International Journal of Climatology* 22: 731-742.

Baron, J., Enfors, E., Cambridge, H. and Moustapha, A.M. 2010: Coping with rainfall variability: dry spell mitigation and implication on landscape water balances in small-scale farming systems in semi-arid Niger. *International Journal of Water Resources Development* 26 (4): 543-559.

Benoit, P. 1977: The start of the growing season in Northern Nigeria. Agricultural Meteorology, 18: 91-99.

Blench, R. 1999: Seasonal climate forecasting: who can use it and how should it be disseminated? Natural Resources Perspectives, London ODI, 4 pp.

Boden, T.A., Kanciruk, P. and Farell, M.P. 1990: "TREND '90"- A compendium of data on global change. ORNL.CDIAC-36, 257 pp.

Climate Research Committee 1995: National Climate Variability on Decade-to-Century Scales. National Research Council. National Academic Press, Washington, DC.

Cuculeanu, V., Marica, A. and Simota, C. 1999: Climate change impact on agricultural crops and adaptation options in Romania. *Climate Research* 12: 153-160.

Dore, M.H.I. 2005: Climate change and changes in global precipitation patterns: What do we know? *Environment International* 31: 1167-1181.

FAO, 1996: Crop forecasting: The model. www.fao.org/sd/EIdirect/agromet/model.htm

Folorunso, O.A. 1986: Distribution of steady state infiltration rate for Borno soil. *Ann. Borno* 3: 193-204.

Grema, A.K. and Hess, T.M. 1994: Water balance and water use of pearl millet-cowpea intercrops in north east Nigeria. *Agricultural Water Management* 26: 169-185.

Heisey, P.W. and Edmeades, G.O. 1999: Maize production in drought-stressed environments: technical options and research resource allocation. *CIMMYT 1997/98 world maize facts and trends; maize production in drought-stressed environments: Technical options and research resource allocation*, Part 1. CIMMYT, Mexico D.F. Available at: http://www.cimmyt.org/research/economics/map/facts_trends/maizeft9798/pdf/Maizef&t9798.pdf (accessed 29 June 2012).

Hess, T.M., William Stephens and Maryah, U.M. 1995: Rainfall trends in the North East arid zone of Nigeria 1961-1990. *Agricultural and Forest Meteorology* 74:.87-97.

Hills, K.C. and Morgan, J.H.T. 1981: Rainfall statistics: An interactive approach to analyzing rainfall records for agricultural purposes. *Experimental Agriculture* 17:1-16.

IPCC (Intergovernmental Panel on Climate Change), 1990: Climate Change: The IPCC Impact Assessment. W.J McG Tegart, G.W. Sheldon and D.G. Griffiths (Eds.). Australian Government Publishing Service, Canbera.

Jagtap, S.S. 1995: Changes in annual, seasonal and monthly rainfall in Nigeria during 1961-1990 and consequences for agriculture. *Discovery and Innovation* 7:337-348.\

Kamara, A., Ekeleme, F., Chikoye, D. and Omoigui, L. 2009: Planting date and cultivar effects on grain yield in dryland corn production. *Agronomy Journal* 101: 91-98.

Kowal, J.M. 1973: Water use, energy balance and growth of maize at Samaru. Agromet 12, No. 3.

Kowal, J.M. and Knabe, D.T. 1972: *An Agroclimatological Atlas of the Northern States of Nigeria-With Explanatory Notes.* Ahmadu Bello Unversity Press, Ahmadu

Bello University, Samaru-Zaria, Nigeria. 111 pp.

Landsberg, H.E. 1986: Potentialities and limitations of conventional climate: Data for desertification monitoring and control. *Climate Change* 9: 123-128.

Monteith, J.L. and Virmani, S.M. 1991: Quantifying climatic risk in the semiarid tropics: ICRISAT Experience. In Climatic Risk in Crop Production: Models and Management for the Semiarid Tropics and Subtropics, Muchow, R.C. and Bellany, J.A. (eds.). C.A.B. International, Wallingford. Pp. 183-204.

Nicholson, S.E., Some, B. and Kone, B. 2000: An analysis of recent rainfall conditions in West Africa, including the rainy seasons of the 1997 El Niño and the 1998 La Niña years. *Journal of Climate* 13:2628-2640.

Oladipo, E.O. and Salau, S. 1993: Spatial and temporal variation of rainy days and mean daily rainfall intensity in northern Nigeria. Mausam 44 (1): 85-92.

Oluwasemire, K.O., Stigter, C.J., Owonubi, J.J. and Jagtap, S.S. 2002: Seasonal water use and water productivity of millet based intercropping systems in the Nigerian Sudan Savanna near Kano. *Agricultural Water Management* 56 (3): 207-227.

Owonubi, J.J., Odiwo, A.E., Asiribo, O.E. and Abdulmumi, S. 1992: Rainfall probability estimates for agricultural production in the Nigerian Savanna. *Samaru Journal of Agricultural Research* 9:3-18.

Raji, B.A., Esu, I.E. and Chude, V.O. 1999: A pedological characterization of soils of Sokoto sand plains of Northern Nigeria. *Journal of Arid Agriculture* 9: 47-59.

Rayar, A.J. 1984: Soil Survey Report. University of Maiduguri Teaching and Research Farm, Maiduguri, Nigeria (unpbl.). pp 20.

Shigenaga, H., Matsumoto, Y., Taoda, H. and Takahashi, M. 2005: The potential effect of climate change on the transpiration of Sugi (*Crptomeria japonica* D. Don) plantations in Japan. *Journal of Meteorology* 60 (5): 451-456.

Sivakumar, M.V.K. 1988: Predicting rainy season potential from the onset of rains in the Sahelian and Sudanian Climatic zones of West Africa. *Agriculture and Forest Meteorology* 42:295-305.

Sivakumar, M.V.K. 1992: Empirical analysis of dry spells in agricultural application in West Africa. *Journal of Climate* 5(5): 532-539.

START (SysTem for Analysis, Research and Training), 1998: Climate variability prediction, water resources and agricultural productivity: Food security issues in Tropical Sub-Saharan Africa. In: M.V.K. Sivakumar (ed.), Report of the Joint START/WCRP/SCOWAR/ORSTOM Workshop held at Cotonou, Benin between 22-25 July 1997. Pp 66.

Stewart, J.I. 1991: Principles and performance of response farming. In: Climatic Risk in Crop Production. Models and Management for the Semi-Arid Tropics and Sub-Tropics, Ford W., Muchow R.C., Bellamy, Z.A. (eds.), CAB International, Wallingford.

Uyovbisere, E.O., Kparmwang, T. and Møberg, J.P. 1984: Profile description: Samaru Profile No.1. Department of Soil Science, IAR, ABU, Zaria (Unpubl.) pp.2