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V.I.O. Olowe*, O.A. Enikuomehin, Y.A. Adekunle, O.A. Adebimpe, O.O. Adeniregun and M. Abiala

Hydrothermal Variability and Sunflower Seed Yield in the Humid Tropical Region

Abstract: The impact of hydrothermal variability on organic sunflower seed yield in the humid tropical region of Nigeria was studied between 2001 and 2008 using rainfall and temperature as proxies for climate variability. The test variety was "Funtua", a local adapted, open pollinated, and late maturing sunflower variety. Rainfall amount during the period of study compared favorably with the long-term mean (25 years). September recorded adequate amount of rain throughout the period of study, except in 2002. Sum of effective temperature and growing degree days (GDD) ranged between 1,907.1 and 2,440.3°C and 2,435.2 and 3,634.3°C and appeared adequate for the production of organic sunflower in the region. Sunflower seed yield obtained between 2001 and 2005 ranged between 1.03 and 1.26 t/ha and were superior to the Nigerian average of 1.00 t/ha, African average of 0.81 t/ha, and a little below the world average of 1.52 t/ha. Grain yield, however, declined in 2006 and thereafter remained below 1.0 t/ha till 2008. Nevertheless, it could be concluded that despite the global increase in climatic variability a good yield of sunflower is still possible in the humid tropical region.

Keywords: growing degree days, hydrothermal variability, rainfall, sunflower, temperature

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***Corresponding author: V.I.O. Olowe,** Institute of Food Security, Environmental Resources and Agricultural Research (IFSERAR), Federal University of Agriculture, P.M.B. 2240, Abeokuta, Nigeria, E-mail: owebaba@yahoo.com
O.A. Enikuomehin, Department of Crop Protection, Federal University of Agriculture, Abeokuta, Nigeria, E-mail: adeenikuomehin@yahoo.com
Y.A. Adekunle: E-mail: adeolaadekunle59@yahoo.com, **O.A. Adebimpe:** E-mail: aoluwasemipe79@yahoo.com, **O.O. Adeniregun:** E-mail: silverview2004@yahoo.com, **M. Abiala:** E-mail: titcombemaria@yahoo.com, Department of Plant Physiology and Crop Production, Federal University of Agriculture, Abeokuta, Nigeria

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Introduction

Climate change can be described as change in climate over time whether due to natural variability or as a result of human activity, and its effects are reflected in the variation of the mean state of weather variables including temperature, rainfall, and wind (IPCC, 2007). Consequently, it is a complex biophysical process. Among the enterprises practiced in the world (agriculture, water resources, health, energy, and housing and urban development), agriculture appears to be the most vulnerable to climate change. Agriculture contributes to climate change through degradation of soil by plowing, which destroys the organic top layer of soil, pollution from fertilizers and pesticides from crop lands, intensive rearing of animals which results in the release of methane, a greenhouse gas ten times as potent as carbon dioxide, selection of high yielding crops for industrialized food production and demand for out of season exotic produce which tends to increase food miles (Altieri and Koohafkan, 2008).

In Africa, farming is mainly rain-fed, and this sector provides employment for over 70% of the population with 200 million out of 900 million surviving on one inadequate meal a day and 33 million children suffering from malnutrition. A significant and steady global increase in climate change attributable to carbon dioxide and greenhouse gas emissions has been reported (Nelson *et al.*, 2009). Unfortunately, Africa is the least prepared continent among the continents of the world for the inevitable consequences of climate change. Today, a third of Africa's population live in drought-prone regions (Fleshman, 2007). In a recent global study, decline in the production of rice, wheat, and maize was put at 15, 34, and 10% by 2050 for Sub-Saharan Africa (Nelson *et al.*, 2009). The report concluded that negative effects of climate change on crop production are especially pronounced in Sub-Saharan Africa and South Asia.

During the last decade (2000–2010), rainfall distribution was very erratic worldwide resulting in low yields of crops, destruction of farm lands by flood, and overall poor performance of the agricultural sector in the developing world. Food production in Africa is predominantly rain-fed and a significant proportion (>70%) of the rural populace are farmers with very limited resources even though they produce the bulk of the food consumed by the populace. Sunflower (*Helianthus annuus* L.) has been identified as a potential substitute for the traditional oilseeds (groundnut and oil palm) in Nigeria (Ogunremi, 2000) and the potential for its cultivation in the humid tropical region confirmed (Olowe, 2005a, 2005b; Olowe *et al.*, 2006). Since sunflower has a wide adaptability, different varieties and hybrids of this crop require different total number of cumulative degree days or growing degree days for growth, development, and maturity (Canavar *et al.*, 2010). A common temperature index normally used to estimate plant development is growing degree days, and sunflower varieties vary depending on their requirements for GDD (Robinson, 1971; Sur and Sharma, 1999; Qadir *et al.*, 2007; Canavar *et al.*, 2010). As reported by Olowe et al. (2013), sunflower production and total land area under it increased appreciably by 5 and 21% between 2001 and 2003, respectively, in Africa. The crop is generally considered to be drought tolerant hence it is grown mainly in the semi-arid regions including the savanna. Generally, sunflower will produce an excellent crop if rainfall is within 500–750 mm per annum.

Some studies have been carried out to investigate the impact of hydrothermal variability on yields of some cereal crops such as maize and sugarcane (Du Toit *et al.*, 2002; Deressa *et al.*, 2005; Durand, 2006; Akpalu *et al.*, 2008) and sunflower (Qadir *et al.*, 2007; Kaleem *et al.*, 2011a, 2011b). Varying results have been reported depending on the location and biology of the crops. However, there is a dearth of information on effect of hydrothermal variability on sunflower seed yield in the humid tropics. Earlier research efforts were made by Agele (2003) to study the response of sunflower to weather variations during two contrasting seasons (dry and rainy seasons) in a tropical rainforest zone, and rainfall and temperature were identified as two key factors among other weather parameters affecting sunflower productivity. Consequently, this paper investigated the effects of hydrothermal variability on sunflower yield with a view to establishing its production stability in the forest-savanna transition zone which is outside its traditional growing region using rainfall and temperature as proxies for climate variability.

Materials and methods

The field experiments were conducted at the Teaching and Research Farm of the University of Agriculture, Abeokuta, Nigeria (7°15′N, 3°25′E, altitude 140 m asl) on a sandy soil during the late cropping seasons (July–November) of 2001–2008. Traditionally, rainfall distribution in this region is usually bimodal with peaks in July and September, and a short dry spell in August often referred to as “August break”. However, this trend was not regular during the periods of experimentation due to global climate change. Land preparation involved disk plowing and harrowing of experimental site prior to planting in each year. The test sunflower variety “Funtua” is a local adapted, open pollinated, and late maturing (*i.e.* matures at about 120–130 days after sowing). The seeds of sunflower were planted in rows at a spacing of 60 cm × 30 cm. Each plot consisted of six rows and measured 5 m × 3 m (15 m^2). No agrochemicals were applied in order to simulate the usual practice of the resource poor farmers who are the major food producers in the tropics. Plots were weeded at 3 and 6 weeks after planting (WAP).

Weather data including total rainfall and average air temperature were collected from the Meteorological Station of the Department of Water Resources and Agro-climatology of the University. Rainfall and temperature were used as proxies for climate variability in the study. The long-term values for these two weather parameters were computed for 25 years. Rainfall distribution was partitioned into monthly total, late season total, annual total, number of rainy days, number of rainless days, and total rainfall during the critical water stress period (Tables 1 and 2). Mean daily temperature was recorded and

Table 1: Sunflower grain yield and monthly rainfall (mm) during the late cropping seasons, 2001–2008

Year	June	July	Aug.	Sept.	Oct.	Nov.	Late season total (mm)	Annual total (mm)	Seed yield (t/ha)
2001	155.2	279.3	11.4	149.9	56.7	26.2	687.7	989.7	1.03
2002	123.6	237.3	46.0	14.2	126.1	21.9	569.1	770.7	1.20
2003	244.2	107.5	74.3	155.5	79.0	28.0	688.5	850.4	1.40
2004	128.2	62.7	60.7	130.3	37.4	0.0	419.3	713.8	1.33
2005	259.5	122.3	68.5	198.4	38.5	0.0	687.2	991.9	1.26
2006	262.0	192.8	61.8	250.7	56.8	43.4	867.5	1153.4	0.49
2007	213.9	369.8	140.5	192.0	119.2	11.4	1,046.8	1,219.6	0.77
2008	167.2	299.2	106.7	136.3	84.5	0.0	793.9	1,007.8	0.75
LTM SE±	153.3	180.9	94.2	154.0	87.8	14.4	684.6	1,190.5	−0.115

Note: Long-term mean (LTM) of 1982–2008 (25 years).

Table 2: Sunflower grain yield, number of rainy and rainless days, and total rainfall during the time of critical water stress for sunflower, 2001–2008

Year	Number of rainy days	Number of rainless days	Total rainfall (mm)	Sunflower grain yield (t/ha)
2001	15	26	149.9	1.03
2002	7	34	76.4	1.20
2003	8	33	128.9	1.40
2004	8	33	52.5	1.33
2005	8	33	228.4	1.26
2006	6	35	82.5	0.49
2007	11	30	152.3	0.77
2008	14	27	137.0	0.75
SE±				0.115

partitioned into mean monthly temperature, sum of effective temperature (sum of daily mean temperature minus 5°C from sowing to maturity) as described by Weiss (2000) and growing degree days using the equation of McMaster and Wilhelm (1997) as:

$$\mathrm{GDD} = (T_{\max} + T_{\min})/2 - T_{\mathrm{base}}$$

T_{base} was taken as 7.2°C based on several studies of heat units as recommended by Robinson (1971) and adopted by Agele (2003) and Canavar *et al.* (2010). The means of yield data were compared using the standard error as described by Steel and Torrie (1980).

Results and discussion

Recently, several studies have quantified the impact of climate change on agricultural production using different models such as Generalized Maximum Entropy estimator and Maximum Entropy Leuven Estimator for maize (Akpalu *et al.*, 2008), global agricultural supply-and-demand projection model linked to a biophysical crop model (DSSAT) for rice, wheat, soybeans, and groundnut (Nelson *et al.*, 2009) and DAYSENT model as described by Del Grosso *et al.* (2002) on California cropping systems (Lee *et al.*, 2009). All the studies emphasized the need to develop community-based adaptation strategies. This study only used rainfall and temperature as proxies for climate variability.

Rainfall distribution

Data on sunflower grain yield and rainfall during the late cropping seasons of 2001–2008 compared to the 25 year mean are presented in Tables 1 and 2. The total amount of rainfall during the late cropping seasons of 2001–2008 ranged between 419.3 and 1,046.8 mm. These values compared favorably with the long-term mean of 684.6 mm and the rainfall amount (500–750 mm) required to obtain a good crop of sunflower suggesting that rainfall was not limiting during the periods of experimentation (Weiss, 2000). In this region, July and September are usually the wettest months of the year. September 2006 recorded the highest amount of rainfall (250.7 mm) and conversely the lowest yield 0.49 t/ha. This poor yield could be attributed to the devastating effect of the heavy down pour during the first decade (132.6 mm out of 250.7 mm for the month) of the month which washed away most of the stands since sunflower plants were only 2–3 weeks old. Grain yield of over 1 t/ha was recorded in 2001–2005 with September receiving substantial amount of rain, except 2002. However, the low amount of rainfall in September 2002 was compensated for by 126.1 mm recorded in October. The late cropping season received more rain than the early cropping season across the years. For sunflower plant, the critical period for water stress is the period 20 days before and 20 days after flowering. This period is approximately 40–41 days for sunflower variety “Funtua” in the transition zone. The rainy days were fewer than the rainless days across the years (Table 2). The low yield obtained in 2006 could be attributed to low rainfall during the critical period. However, the low rainfall (76.4 mm) recorded in 2002 did not reduce yield significantly because sunflower was sown on 26 July and the month was substantially wet (237.3 mm) and the rains received in October (126.1 mm) might have contributed to the comparable yield recorded.

Temperature

Data on mean monthly temperature, sum of effective temperature, and growing degree days (GDD) are presented in Table 3. According to Weiss (2000) sunflower grows well within a temperature range of 20–25°C, and the mean monthly temperature was within or even slightly above this recommended range throughout our study. Temperature affects the rate of development of sunflower particularly in the temperate countries with high temperature sometimes hastening maturity by 50%. Sum of effective temperature (daily mean temperature minus 5°C from sowing to maturity) ranges between 1,300 and 1.367°C in Japan

Table 3: Sunflower yield, mean monthly temperature, sum of effective temperature (°C), and growing degree days (GDD) during the late cropping seasons, 2001–2008

Year	June	July	Aug.	Sept.	Oct.	Nov.	Sum of effective temperature (°C)	GDD (°C)
2001	20.8	24.8	22.8	22.0	25.9	28.9	2,295.9	2,907.5
2002	25.6	26.0	26.5	26.9	26.8	27.1	1,907.1	2,435.2
2003	26.0	26.5	26.0	26.0	28.7	26.0	2,216.6	2,831.9
2004	26.4	26.3	23.0	23.0	26.0	25.0	2,440.3	2,761.2
2005	28.4	25.9	24.9	26.7	27.0	26.0	2,157.0	3,634.3
2006	25.5	26.5	27.7	25.6	26.9	25.4	2,228.3	3,498.6
2007	26.0	26.0	25.0	26.3	27.5	28.4	1,993.7	3,407.8
2008	26.3	25.3	25.5	26.6	28.5	30.0	1,990.7	2,897.9
LTM	26.4	26.7	25.9	27.1	28.2	28.5	–	–
SE±	–	–	–	–	–	–	63.33	147.78

and Australia, respectively (Anderson *et al.*, 1978). However, these values as expected are higher in the tropics ranging between 1,907.1 and 2,440.3°C in our study across the years. Similarly, summed GDD from sowing to harvest ranged between 2,435.2 and 3,634.3°C in our study were much higher than values reported for other cooler countries, 2,187.0–2,292.3°C (Germany) by Canavar *et al.* (2010) and 1,621.0–1,731.0°C (Pakistan) by Kaleem *et al.* (2011a). However, our findings compared favorably with earlier results of 3,504.5–3,561.5°C reported for sunflower in a rainforest region by Agele (2003). No clear cut relationship was recorded between grain yield and sum of effective temperature and GDD in our study. Although, temperature has been reported to largely affect sunflower rate of growth and development especially in regions where temperature is limiting (Weiss, 2000; Baydar and Erbas, 2005; Qadir *et al.*, 2007). The detrimental effects of temperature increases as a result of climate change will manifest as an interplay of increase in number of extremely hot days, reduction in rainfall and soil moisture, increased evaporation, forced ripening, and consequently lower crop yields (IPCC, 2007). Therefore, rising temperatures and changes in rainfall patterns will have negative direct effects on crop yields over time.

Seed yield

Sunflower seed yield values varied across the years ranging from 0.49 to 1.40 t/ha (Table 2). However, only seed yield above 1 t/ha recorded in 2001–2005 compared very well with the current African average of 0.81 t/ha and Nigerian average of 1.00 t/ha for sunflower as reported by Olowe *et al.* (2013). The highest yield value of 1.40 t/ha was significantly higher than 1.03, 0.49, 0.77, and 0.75 t/ha produced in 2001, 2006, 2007, and 2008, respectively, but lower than the recent world average of 1.52 t/ha (United States Department of Agriculture, 2012). The gradual decline in sunflower yield toward the end of the decade might suggest the effect of an interplay of other environmental factors such as soil temperature, air composition, and light qualities that were not taken into consideration in this study (Kaleem *et al.*, 2011a, 2011b; Onemli, 2012). Crop diversification has been recognized as one of the key mechanisms and strategies to enhance resiliency to climatic variability (Altieri and Koohafkan, 2008). Such a mechanism or strategy is multiple cropping (polyculture system) and sunflower has some favorable morphological characteristics (erect growth habit, easily harvestable head, comparable resistance to lodging, and limited ground cover) which easily qualify it as a suitable component crop in an intercropping system (Robinson, 1984). Although, the sunflower considered in this study was grown under monoculture, the above average performance of sunflower in polyculture systems in the tropics had been demonstrated (Olowe, 2005a, 2006; Olowe *et al*., 2006; Olowe and Adebimpe, 2009).

Conclusions

The results of this study demonstrate that rainfall and temperature regimes in the transition zone appear adequate for the production of a good crop of sunflower despite the global increase in climatic variability in the recent past. The gradual decline in grain yield of sunflower from 2005 to 2008 could be attributed to the effects of other climatic factors (air, soil and canopy temperatures, light interception, and soil moisture) whose effects on yield were confounded in this study since they were not measured. These limitations will be taken into consideration in subsequent studies. Notwithstanding the preceding limitations, the results have shown that sunflower is a rustic crop whose natural features could be used to mitigate climatic variability by resource poor farmers in monoculture and even polyculture systems.

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