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REVIEW ARTICLE

CLIMATE CHANGE EFFECTS ON MAIZE (ZEA MAYS) PRODUCTION IN NIGERIA AND STRATEGIES FOR MITIGATION

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ABSTRACT

Although Nigeria is the leading producer of maize in Africa, effects of climate change especially high temperature, and irregular changes in precipitation are critically limiting its crop yield. In order to sustain high crop yield of maize in spite of the climate change and the rapid increasing population in the country, there is urgent need to study the responses of maize crop to variables of climate change so as to design effective coping strategies. The objective of this study therefore was to study the impacts of key climatic variables on maize production in Nigeria and to identify effective mitigation and coping measures. Secondary data on the trend of maize production and maize yield responses to changes in climates across five agro-ecological zones in Nigeria were studied. The result showed that the predicted maize yield at current CO_2 level decreased with increase in temperature in all the agro-ecological zones. The reduction in yield was more pronounced in the humid forest and semi-arid agro-ecological zones with 18% and 13% yield reduction, respectively while the least was observed in the derived and southern guinea savannas with 7% yield reduction. Doubling the current level of CO_2 showed increases in yields at low temperature change of between 1-2^oC, but the yield was consistently reduced in all the zones with higher temperature changes of between 3-4^oC. Changes in rainfall amount of $\pm$20% when the current CO_2 was doubled did not have any significant impact on maize yield. Increase in temperature showed reduction in the days to flowering and maturity across the agro-ecological zones. The simulated yields and days to physiological maturity of the four maize cultivars (early, medium, late and very late maturing varieties) under the current and doubled CO_2 using UKMO (United Kingdom Meteorological Office) scenario showed that the varieties with longer days to maturity recorded higher crop yield consistently in all the agro-ecological zones. This suggests that the yield reducing tendencies of maize in a hotter climate as in Nigeria could be mitigated through appropriate choice of cultivar, adjustment of management practices and time of planting, provision of adequate irrigation facilities among other recommendations made in this study.

INTRODUCTION

Climate change is one of the most serious environmental threats facing mankind worldwide; it affects mankind in several ways, including its direct impact on food production (Enete and Amusa, 2010). Evidences from literature and past studies have revealed that the recent global warming has influenced agricultural productivity leading to declining food production (Kurukulasuriya and Mendelsohn, 2006; IISD, 2007; Lobell *et al.*, 2008). In the quest to support the rapidly growing population, humans are negatively exploiting the environment leading to rapid depletion of fertile soils, groundwater, biodiversity, and numerous other non-renewable resources (Abrahamson, 1989; Ehrlich and Ehrlich, 1990). The most serious of human impacts is the injection of greenhouse gases into the atmosphere that distort the global climate system.

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There is a growing concern that in the coming decades the world will experience higher temperatures and changes in precipitation levels both in terms of distribution and patterns even in regions that rarely experience such harsh climates. Many countries in the tropical and sub-tropical regions, of which Nigeria is included, are expected to be more vulnerable to warming (Mendelsohn *et al.*, 2000) because of their low level of coping capacities (Nwafor, 2007; Jagtap, 2007). Dinar *et al.* (2006) further reported that many African countries such as Nigeria that have their economies largely based on weather-sensitive agricultural production systems are more vulnerable to climate change. Estimation by FAO (2005) is that by 2100, Nigeria and other West African countries are likely to have agricultural losses of up to 4% due to climate change. Researches have shown that Nigeria is already being plagued with diverse ecological problems, which have been directly linked to the on-going climate change (Odjugo, 2001; 2005; Odjugo and Ikhuoria 2003; NEST 2003; Mshelia, 2005; Ayuba *et al.*, 2007).

Agbola and Ojeleye (2007) specifically revealed that there is already an observed decline in crop yield and food crops production due to reduction in rainfall and relative humidity and increase in temperature in Nigeria. Previous research strongly suggests maize growing regions of sub-Saharan Africa will encounter increased growing season temperatures and frequency of droughts (IPCC, 2007b). Maize is an important cereal crop which ranks third after wheat and rice in the world (David and Adams, 1985), and is grown widely in many countries of the world (Onasanya, R.O *et al*., 2009). Nigeria is the 10^{th} largest producer of maize in the world, and the largest producer in Africa (FAO, 2013; Oyelade and Anwanane, 2013). It is one of the most important cereal crops in Nigeria where over 150 million people consume it on an average of 43 kg per year (Olayide *et al*., 1980; Olayemi and Ikpi, 1995; FAOSTAT, 1999). It is becoming the miracle seed for Nigeria's agricultural and economic development (Onuk *et al*., 2010). Unfortunately, climate change is seriously reducing maize production in the country. IPCC (2007a) predicted that by 2020, between 75 and 250 million people in Sub-Saharan Africa will be exposed to increased water stress caused by climate change, hence agricultural production and access to food in many African countries may be further threatened.

This will adversely affect food security, thus aggravates malnutrition and increases diseases on the continent. It is very pertinent to know that over 70% of the Nigerian population relies directly or indirectly on rain-fed agriculture (IFAD, 2009). Nigerian agriculture is a key sector in the economy contributing about 41% of the nation's GDP (Aye and Ater, 2012). Hence, any change in climate patterns in the country would have a great impact on both the agriculture and economy of the nation. Thus, understanding the responses of maize, a major crop in the nation's economy to climatic variations is very crucial. This will help in designing appropriate coping strategies toward ensuring sustainable increase in yield in the face of climate change. The objective of this study therefore, is to examine global impact of key climatic variables on maize production in Nigeria and to identify effective mitigation and coping measures.

Overview of the Nigerian Climate and Vegetation

Nigeria lies on the south coast of West Africa between latitude 4-14^{o}N and longitude 2-15^{o}E; it has a total landmass of approximately 925,796 km^2 (BNRCC, 2011). The climate of Nigeria varies more than any other country in West Africa due to its great length from the south to the north (1100 km) that results in virtually all of the climatic belts of West Africa being included within Nigeria's borders (BNRCC, 2011). The Nigerian climate is humid in the south with annual rainfall over 2000 mm and semi-arid in the north with annual rainfall less than 600 mm, and there are three climatic zones which cover the north, middle and southern areas of the country: the Sahel (11-14^{o}N), Savanna (8-11^{o}N) and the Guinea (4-8^{o}N) zones (BNRCC, 2011). Rainfall commences in approximately March/April in the southern coastal zones, spreads through the middle zone in May/June, and reaches the northern zone in June/July, reaching its peak over middle and northern zones between July and September (BNRCC, 2011). The rainfall retreat period follows a reverse of this progression (Ojo, 1977).

Climate plays a significant role in the distribution of vegetation and agriculture in Nigeria. According to federal government of Nigeria report on drought management (FGN, 1999), the Nigeria landmass is divided into seven ecological zones. This classification is based on the resemblance of climatic elements and the nature of vegetation that can be supported. These ecological zones are the mangrove swamp, rainforest, montane forest/grassland, derived savannah, guinea savannah, Sudan savannah and the Sahel savannah (Sowunmi and Akintola, 2009). The mangrove swamp and rainforest zones, and part of derived savannah zone are found in the southern part of the country, and these zones are characterized by high rainfall intensity, long wet season, dense vegetation, rugged topography and temperature range of 26 – 28ºC and small farm holdings (Sowunmi and Akintola, 2009). Flood and water erosion are the major problem of crop production in these zones, and a sizeable hectare of agricultural land and farmer's properties are lost yearly to water erosion in the eastern part of the country (Sowunmi and Akintola, 2009). Maize, cassava, yam and vegetables are the major crops grown in these zones.

Conversely, the savannah zone (Derived, Guinea, Sudan and Sahel savannah) is located in the northern part of the country, which is characterized by short wet season and long dry season, high annual temperature (average) of the range 28 – 32ºC, few scattered trees and grasses, gentle slope and large farm holdings. Maize, sorghum, millet, wheat, rice, cowpea, yam, pepper and onion are the major crops that thrive in savannah (Sowunmi and Akintola, 2009). The major limiting factor to crop production in this region is water; this is because of short wet season that often commences in June and ends in September. Furthermore, the montane forest/grassland zone is located in the high altitude areas of the country, which includes Jos Plateau, Adamawa and Obudu mountains (Sowunmi and Akintola, 2009). The zone is known for low average annual temperature (20–23ºC) all year round, moderately high rainfall and rugged topography (Sowunmi and Akintola, 2009). Montane forest/grassland is exceptionally suitable for maize, exotic vegetables (carrot, cabbage, cucumber and lettuce among others) (Sowunmi and Akintola, 2009). The mountainous nature of this zone, cold weather and low concentration of oxygen are the obstacles to crop production (Sowunmi and Akintola, 2009).

Nigeria is the most populous country in Africa with over 140 million people and a population density of 138 people per square km, according to the 2006 national census. Over seventy percent of Nigerians are classified as poor and thirty-five percent live in absolute poverty (IFAD, 2009). As the increasing population puts more pressure on diminishing resources, escalating environmental problems further threaten food production. Land degradation as a result of deforestation and overgrazing is already severe in many parts of the country. Drought is a common problem in the north, while heavy rains, soil erosion and floods are major problems in the south (IFAD, 2009). Thus, effective mitigating strategies are urgently needed to ensure sustainable crop production in the country.

Maize Yield Response to Changing Climate

Available evidence shows that climate change is global, likewise its impacts but the most adverse effects will be felt more by developing countries especially those in Africa due to their practice of weather dependent agriculture and their low level of coping capabilities (Ohajianya and Osuji, 2012; Ellen and Barry, 2005). Thus, in sub-Saharan Africa, climate models predict increased evapo-transpiration and lower soil moisture levels (Rosenzweig *et al.,* 2002). Previous research strongly suggests maize growing regions of sub-Saharan Africa will encounter increased growing season temperatures and frequency of droughts (IPCC, 2007b). This would result in some agricultural lands becoming unsuitable for cropping, and some tropical grassland becoming increasingly arid. It is projected that yield of many crops including maize in Africa may fall by 10-20% by 2020 due to climate change (Ajetumobi and Abiodun, 2010; Ajetumobi *et al*., 2010 and BNRCC, 2008). This is because African agriculture is predominantly rain-fed and weather dependent. Lobell *et al.* (2011) exploited historical data from over 20,000 field trials of maize conducted in Africa over the past decades and found out that for each ‘degree day’ that the crop spends above 30^{o}C (a unit that reflects both the amount and duration of heat experienced by the plant) depresses yields by 1 percent if the plants are receiving sufficient water. They also revealed that water availability has an important effect on the crop’s sensitivity; with yield decreasing by 1.7 percent for each degree day spent over 30^{o}C under drought conditions.

Thus, they indicated that under non-drought conditions, 65 percent of the land area in Africa that is under maize cultivation at present would experience yield losses from a uniform 1^{o}C warming increase. Under drought conditions, 100 percentage of the present cultivated area would experience yield losses, with 75 percent of this area suffering yield losses of at least 200 percent. Temperature rise will also expand the range of many agricultural pests and diseases by increasing the ability of pest populations to survive and attack crops thereby causing yield reduction. The climate change will exacerbate drought and land degradation, with estimations of 5 to 8 percent increase (60 to 90 million ha) of arid and semi-arid land in Africa (Parry *et al.,* 2007). This means that about two-thirds of arable land in Africa is expected to be lost by 2025, land degradation currently leads to the loss of an average of more than 3 percent annually of agriculture gross domestic product(GDP) in sub-sahara Africa (UNESC, 2007). In addition, decreased rainfall would impact negatively on the yields from rain-fed agriculture, with estimations of up to 50 percent in some countries by 2020. Maize production could be discontinued in some areas in the region. The current national production of maize is put at 7.0 million tonnes on an area of 3.7 million hectares (FAOSTAT, 2010). However, to meet the increasing demands of Nigeria rapidly expanding population, an estimated 50% increase in maize production is required over the coming decades (FAO, 2009), a goal that is made difficult by the declining natural resources occasioned by global climate variability. The influence of climate change on maize production in the country, only adds to an already complex problem. For this reason, an estimation of its likely impact is vital in planning strategies to meet the increased demands for maize in the next century.

Trend in maize performance across some selected countries

Table 1 shows that in Kenya, areas under cultivation are increasing but did not result in marked corresponding production increase due to either low adoption of improved varieties or vagaries of weather conditions. Bancy (2000) study on the influence of climate change on maize production in semi-humid and semi-arid areas of Kenya explained that in order to counter the adverse effects of climate change in maize production, it might be necessary to use early maturing cultivars and practice early planting. On the other hand, Nigeria, Ghana and South Africa maize production is on increase with area cultivated remaining fairly stable indicating use of improved technologies. Moreover, per hectare yield is increasing in Nigeria, Ghana and South Africa. On the other hand, per hectare yield in Ethiopia fluctuates while it is decreasing in Kenya, probably due to climatic variability. Maize yield levels are similar for Nigeria, Ghana and Kenya with average yield of about 2 tonnes per hectare. Average yield in Ethiopia stood at 2.2 tonnes per hectare, South Africa 4 tonnes per hectare, and USA 10 tonnes per hectare.

Table 1. Trend in maize area cultivated, grain yield and production for some selected countries

Country	Maize data	2005	2006	2007	2008	2009	2010	MEAN
Nigeria	Area (Ha)	3,589,000	3,905,000	3,944,000	3,845,000	3,335,860	3,335,860	3,659,120
	Production (Tonnes)	5,957,000	7,100,000	6,724,000	7,525,000	7,338,840	7,305,530	6,991,728.33
	Yield (Hg/Ha)	16,597.94	18,181.82	17,048.65	19,570.87	21,999.84	21,899.99	19,216.52
Ghana	Area (Ha)	750,000	793,000	790,070	846,260	954,400	991,669	854,233.17
	Production (Tonnes)	1,171,000	1,189,000	1,219,600	1,470,080	1,619,590	1,871,700	1,423,495
	Yield (Hg/Ha)	15,613.33	14,993.69	15,436.61	17,371.49	16,969.72	18,874.24	16,543.18
Kenya	Area (Ha)	1,771,120	1,888,190	1,615,300	1,700,000	1,884,370	2,008,350	1,811,221.67
	Production (Tonnes)	2,905,560	3,247,200	2,928,790	2,367,240	2,439,000	3,222,000	2,851,631.67
	Yield (Hg/Ha)	16,405.21	17,197.42	18,131.55	13,924.94	12,943.32	16,043.02	15,774.24
Ethiopia	Area (Ha)	1,950,120	1,586,150	1,694,520	1,767,390	1,7681,20	1,772,250	1,746,425
	Production (Tonnes)	3,911,870	4,029,630	3,336,800	3,776,440	3,897,160	4,400,000	3,891,983
	Yield (Hg/Ha)	20,059.64	26,404.24	19,691.71	21,367.33	22,041.26	24,827.2	22,398.56
South Africa	Area (Ha)	3,223,000	2,032,450	2,551,800	2,799,000	2,427,500	2,742,000	2,629,291.67
	Production (Tonnes)	11,715,900	6,935,060	7,125,000	12,700,000	12,050,000	12,815,000	10,556,826.67
	Yield (Hg/Ha)	36,350.92	34,121.68	27,921.47	45,373.35	49,639.55	46,735.96	40,023.82
USA	Area (Ha)	30,399,000	28,586,500	35,013,800	31,796,500	32,168,800	32,960,400	31,820,833.33
	Production (Tonnes)	282,261,000	267,501,000	331,175,000	307,142,000	332,549,000	316,165,000	306,132,166.7
	Yield (Hg/Ha)	92,852.07	93,575.99	94,584.14	96,596.17	103,376.25	95,922.68	96,151.22

Source: FAOSTAT (2010)
1 hectogram=0.1 kilogram
1000 kilogram= 1 tonne

Table 2. Mean predicted changes (%) in yields of maize under different 'fixed' temperature, CO_2 and precipitation across agro-ecological zones in Nigeria for 20 years

	Temperature Increments				
330 ppm (1 x CO_2)	1°C	2°C	3°C	4°C	Mean
Humid Forest	-6.2	-15.8	-20.8	-28.6	-17.8
Derived Savannah	-2.4	-4.6	-7.7	-11.8	-6.7
Southern Guinea Savannah	-2.6	-4.3	-7.4	-11.7	-6.5
Northern Guinea Savannah	-5.6	-9.6	-14.4	-19.7	-12.3
Semi- Arid	-4.2	-9.0	-15.4	-21.6	-12.6
660 ppm (2 x CO_2)					
Humid Forest	1.5	-8.2	-13.5	-22.0	-10.5
Derived Savannah	1.6	-0.5	-2.5	-6.6	-2.0
Southern Guinea Savannah	2.5	0.9	-2.2	-5.2	-1.0
Northern Guinea Savannah	0.4	-3.5	-8.3	-13.3	-6.2
Semi -Arid	2.1	-2.8	-9.1	-14.3	-6.0
2 x CO_2 + 20% rain					
Humid Forest	1.4	-8.1	-13.2	-21.7	-10.4
Derived Savannah	1.5	-0.2	-1.8	-5.9	-1.6
Southern Guinea Savannah	3.2	1.5	-1.5	-4.7	-0.4
Northern Guinea Savannah	0.0	-3.7	-8.4	-13.4	-6.4
Semi -Arid	1.6	-3.3	-9.5	-14.6	-6.4
2 x CO_2 - 20% rain					
Humid Forest	1.6	-8.2	-13.7	-22.1	-10.6
Derived Savannah	0.0	-2.2	-4.2	-8.9	-3.8
Southern Guinea Savannah	0.9	-0.9	-3.7	-7.3	-2.7
Northern Guinea Savannah	0.5	-3.4	-8.4	-13.4	-6.2
Semi -Arid	2.5	-2.7	-9.0	-14.2	-5.9

Source: Alabi (1999)

In Nigeria, areas under cultivation are reducing while production and yield is rising steadily. This indicates adoption of maize hybrids and appropriate management practices such as use of irrigation. However, the exact knowledge of the level of impact of future climate change on maize in Nigeria is essential to aid in planning.

Use of simulation model to estimate maize yield in Nigeria

In recent years, a number of controlled-environment studies have added to our understanding of the effects of increased temperature and CO_2 on crop growth and development (Baker *et al.*, 1989). The use of crop simulation models is one way in which this knowledge can be extrapolated, not only outward to a region but also forward in time. The best method available at present for evaluating the likely effect of climate change is CERES-Maize model; a dynamic crop growth model widely used to investigate the likely effects of a number of scenarios of changed climate on overall crop production. Jones and Thornton (2003) revealed that CERES- maize model is well tried, tested and reliable. CERES-Maize model (Jones and Kiniry, 1986) is a sole crop maize model that predicts growth, development and yield of maize. Its ability to predict maize growth and yield under diverse conditions all over the world has been verified and found satisfactory (Hodges, *et al.*, 1998). The model has also been improved to facilitate studies of the effect of climate change on crop performance (Hoogenboom *et al*., 1995). This model was used to simulate present and future maize yield in the five-agro ecological zones in Nigeria (Alabi, 1999).

Effect of fixed increments of temperature, rainfall and CO_2 on potential yields of maize in Nigeria

Table 2 shows the long-term mean air temperature for five agro-ecological zones (AEZ) in Nigeria and the predictions for a future climate in which CO_2 is doubled the present level. The overall effect predicted by CERES-Maize, for changes in temperature, rainfall and CO_2 levels on potential yields averaged for all agro-ecological zones (AEZ) for all available years are presented. The data revealed that increases in temperature at current CO_2 level caused a general decline in yields. These effects were more pronounced in the humid forest and Semi-arid AEZ with 18% and 13% yield reduction, respectively while least decline in yield was observed in the derived and southern guinea savannas (7%). Similarly, Sowunmi and Akintola (2009) reported that the maize hectarage as well as the output were found to be higher in the savannah than in the mangrove swamp, rainforest and montane forest/grassland zones for 22 years considered in Nigeria. They concluded that savannah (derived, guinea and sudan) zone is suitable for maize production in terms of good soil and temperature. Nevertheless, exposure to higher temperatures can significantly reduce grain yield (McDonald *et al*., 1983; Mac˜as *et al*., 1999, 2000; Mullarkey and Jones, 2000; Tewolde *et al*., 2006). A doubling of CO_2 level resulted in yield gain only at low temperature increases (1°C). At higher temperature increases, however, doubling CO_2 levels resulted in progressively yield reduction with highest reduction at temperature of 4°C.

Table 3. Mean predicted changes in days to flowering and maturity of maize under different increasing fixed temperature across agro-ecological zones in Nigeria

	Temperature 1°C	Increment 2°C	3°C	4°C	Mean
Flowering					
Humid Forest	-1.7	-2.2	-4.0	-4.4	-3.0
Derived Savannah	-1.9	-2.4	-4.2	-4.4	-3.6
Southern Guinea Savannah	-1.7	-2.3	-4.2	-4.4	-3.1
Northern Guinea Savannah	-1.6	-2.3	-3.9	-3.4	-2.8
Semi- Arid	-2.0	-1.5	-3.1	-2.5	-2.3
Maturity					
Humid Forest	-3.5	-6.0	-9.3	-9.8	-7.1
Derived Savannah	-4.1	-6.6	-10.7	-11.9	-8.3
Southern Guinea Savannah	-3.8	-6.3	-10.0	-11.3	-7.8
Northern Guinea Savannah	-3.8	-5.9	-9.3	-10.7	-7.4
Semi- Arid	-3.5	-4.8	-8.3	-9.5	-6.5

Source: Alabi (1999)

Table 4. Predicted maize yield changes in the five agro-ecological zones of Nigeria under doubled CO_2 climate using three GCM scenarios

Site	Agro-ecological Zones	(Kg/ha)	UKMO	GISS	GFDL
Benin	Humid Forest	4370	-13.9	-9.5	-6.1
Onne	Humid Forest	4426	-12	-8.1	-8.1
Warri	Humid Forest	4382	-15.9	-12.2	-7.9
Ibadan	Derived Savannah	4710	0.1	3.5	6.1
Lokoja	Derived Savannah	4314	-4.4	-1.5	0.2
Markurdi	Derived Savannah	6016	-7	-11	-4.9
Mokwa	Southern Guinea Savannah	6317	-6.7	-9.6	-4.8
Minna	Southern Guinea Savannah	5286	-11	-5	-0.7
Yola	Southern Guinea Savannah	4535	-10	-5	-0.7
Kaduna	Northern Guinea Savannah	6451	-4.7	-2.1	-0.4
Yelwa	Northern Guinea Savannah	5098	-9.7	-4.6	-0.7
Bauchi	Northern Guinea Savannah	5523	-8.7	-4.6	-0.2
Sokoto	Semi- Arid	4947	-10.8	-8.7	-4.7
Kano	Semi- Arid	6093	-11	-7.4	-4.2
Maiduguri	Semi- Arid	5825	-13.8	9.5	-6.4

GCM=General Circulation Model, UKMO= United Kingdom Meteorological Office,
GFDL=General Fluid Dynamics Laboratory, GISS = Goddard Institute of Space Studies.
Source: Alabi (1999)

In general, crop responds directly to increase CO_2 with increased rates of photosynthesis and reduced transpiration resulting in increasing yields (Rogers *et al.*, 1983), though at favourable temperature. Similar beneficial trends of increased atmospheric CO_2 concentration have been reported by many authors in diverse ecologies (Acock, 1990, Curry *et al*., 1990, Stockle *et al.*, 1992). These trends have been confirmed with field experiments using open top chambers (Tubiello *et al.*, 1999). Their results further confirmed the ability of the generic model CERES to simulate the effects of rising atmospheric CO_2 concentrations and associated climate change on crop yields. For the future climate of doubled CO_2 and changes in rainfall amount of $\pm$20%, the present level did not have any significant impact on maize yield. This is not unexpected in most ecologies of Nigeria where seasonal rainfall is not a limiting factor to maize production. Maikasuwa and Ango (2013) indicted that crops are more sensitive to global warming associated to changes in temperature than they are to changes in precipitation. Furthermore, under an elevated CO_2, stomatal conductance and transpiration per unit leaf area is reduced. Kimball and Idso (1983) quantified average transpiration reduction of 34% for maize and some other C_3 crops. This implies that water use efficiency of maize is enhanced under an elevated atmospheric CO_2. Maize requires 400-500 mm of rainfall for optimum performance (Mornu, 1999) which is below the seasonal rainfall level of most AEZ of Nigeria, especially the savannas and the humid forest. An increase in rainfall beyond the present level may therefore lead to soil nutrient depletion through leaching and erosion. Improvement of water use efficiency in a future climate may be beneficial for dry land crops.

Temperature changes have negative influence on maize phenology Table 3. The time to the first reproductive phase (anthesis) decrease by 2-4 days for all ecologies and crop physiological maturity duration was shortened by 4-11 days. In the same vein, Rahman *et al*. (2009) reported that in response to higher temperature, there was significant reduction in the number of days to booting, heading, flowering and maturity of wheat. Reduction in duration of these phenological traits normally leads to decline in yield due to lowered grain filling duration.

Effect of predicted GCM scenarios on potential yields of maize

The simulated yield changes for all sites under the three General Circulation Models (GCMs) scenarios are presented in Table 4. Generally, the simulated yield changes for all sites under the three GCMs scenarios showed that United Kingdom Meteorological Office (UKMO) scenario predicted the highest reduction in most of the agro-ecological zones, followed by General Fluid Dynamics Laboratory (GFDL), while Goddard Institute of Space Studies (GISS) predicted the lowest values.

Table 5. Simulated yield (kg/ha) of four maize cultivars under current and doubled CO_2 Climates using UKMO scenario

Variety	Early	Medium	Late	Very Late
Agro-ecological zones		Current climate		
Humid Forest	2792	4071	4234	4547
Derived Savannah	3951	4630	4646	4542
Southern Guinea Savannah	4649	6364	6421.0	6684
Northern Guinea Savannah	4862	6417	6574	6718
Semi- Arid	4444	6042	6421	6583
Mean	4140	5505	5659	5815
		UKMO 2 x CO_2 Predicted Climate		
Humid Forest	2393	3549	3854	3968
Derived Savannah	3786	4610	4548	4571
Southern Guinea Savannah	3994	5884	5898	6488.0
Northern Guinea Savannah	4592	6077	6175	6438
Semi -Arid	3897	5591	6058.0	6042
Mean	3732	5142	5306	5501

UKMO= United Kingdom Meteorological Office
Source: Alabi (1999)

Table 6. Simulated mean days to physiological maturity of 4 maize cultivars under current and doubled CO_2 climates using UKMO scenario

Variety	Early	Medium	Late	Very Late
Agro-ecological zones		Current climate		
Humid Forest	84	99	104	112
Derived Savannah	92	109	114	123
Southern Guinea Savannah	94	112	116.0	125
Northern Guinea Savannah	99	116	123	131
Semi -Arid	92	106	111	119
Mean	92	108	113	122
		UKMO 2 x CO_2 Predicted Climate		
Humid Forest	75	87	93	98
Derived Savannah	79	94	99	107
Southern Guinea Savannah	81	96	100	110.0
Northern Guinea Savannah	85	101	105	114
Semi- Arid	80	94	99.0	106
Mean	80	94	99	107

UKMO= United Kingdom Meteorological Office
Source: Alabi (1999)

Specifically, in the humid forest ecology, the model that predicted the highest yield reduction (12-16%) was UKMO scenario while the lowest yield reduction was predicted by GFDL (6-8%). However, the yield predictions under GFDL were not remarkably different from that simulated under the Goddard Institute of Space Studies (GISS) conditions (8-12%). At Ibadan, a site within the derived savannah zones, simulated yield increased by 0.1-6% for the three GCM scenarios. Other sites in the derived savannah ecology displayed yield reduction of about 4-11%. Sites within southern and northern guinea savannah ecologies exhibited similar yield responses to predicted climate change scenarios by the three GCMs, the highest reduction being obtained under UKMO.

For all the sites in the semi-arid zones, simulated yields decreased in similar patterns to that observed in the humid ecology, UKMO scenario gave the highest while GFDL shows the least changes. Wang *et al.* (1996) obtained similar yield decreases with the 3 GCM scenarios while simulating maize production in China using CERES-Maize. Yield decreases of similar order under GCM scenarios were obtained for maize growing areas of Zimbabwe (Muchena and Iglesias, 1995). The results of simulated yields and days to physiological maturity of the four maize cultivars (early, medium, late and very late maturing cultivars) under the current climate using UKMO scenarios were shown in Tables 5 and 6.

As total crop maturing duration increased, simulated yields increased from a mean of 4.14 t/ha to 5.82 t/ha under the present climate conditions (current CO_2). A similar trend was portrayed under the UKMO scenario when the current CO_2 is doubled, though yields were generally reduced due to warmer climate conditions. However, it is interesting to note that the yields of the TZ-V.Late under UKMO scenario were almost similar to that of TZ-Medium under the present climate Table 5. Moreover, the duration to physiological maturity of the very late maturing variety under the UKMO climate change scenario was equivalent to that of the medium maturing variety under the present climate Table 6. This implies that for the same maturity duration, present yield level of the cultivar TZ-Medium could be maintained under a future climate if the cultivar TZ-V. Late was planted instead. The results suggest that the yield reducing tendencies of maize in a hotter climate as in Nigeria could be mitigated through appropriate choice of cultivar and adjustment of time of planting.

Mitigation Strategies for maize production in Nigeria

Singer and Avery (2007) stressed that it is impossible for man to stop the natural causes of climate change but much can be achieved in either to stop or drastically reduce the human causes of climate change.

For the developing nations like Nigeria to survive the effects of climate change, serious adaptation measures are needed (Akpodiogaga and Odjugo, 2010). Coping with or managing climate variability and change in maize production systems requires a combination of adaptation and mitigation measures (Oseni and Masarirambi, 2011). Generally, there should be effective protection, sustainable management and enhancement of terrestrial, environmental and marine ecosystem of the country, which include use of more of automobiles and industrial machines that depend on biofuels and solar energy; deforestation should be reduced at the barest minimum, while afforestation or agroforestry practices should be highly encouraged in the nation; bush burning should be discouraged especially among hunters and farmers; and more attention should be paid to preservation and conservation of our soils, forest reserves and water bodies like oceans, seas, lakes, streams, rivers that are major carbon sinks. Thus, government has a greater role to play in ensuring clean and environment friendly nation. These approaches will only slow down the rate of further increase in climate change, but will not address the immediate impacts already created by climate change.

Furthermore, in order to cope with the effect of climate change on maize production in Nigeria, there is the need to establish well-equipped and standard weather stations across the nation as against the scanty and ill-equipped ones we currently have. With these, accurate weather forecast and predictions will be possible and this will help to prevent weather-related disasters through early warning and effective response system. The Nigerian Meteorological Agency (NIMET) should issue seasonal forecasts of dates of rainy season onset and cessation, duration of rainy season and annual number of rain days each year. Considering the sensitivity of maize to these variables, farmers should be encouraged to avail themselves of these services and apply such information to enhance early planting and reduce yield losses associated with late planting. Making relevant climate change information available to relevant stakeholders could go a long way in helping farmers improve and develop their own mitigation or adaptation strategies. Agricultural Extension Officers (AEOs) should be deployed to guide farmers through routine visits, sensitization programs on variability in rainfall characteristics, use of farm inputs and monitoring of the crop-climate relationship in the area in other to achieve improved crop yield. An open trade regime, which is a way to share climate risk and information across countries in mitigating the adverse effects of climate change, should be pursued by the Nigerian government. Furthermore, risks associated with reduced maize production and yield losses caused by climate variability can be partly alleviated by government through provision of appropriate crop insurance coverage to maize farmers.

There should be a greater commitment by governments at all levels to significantly invest on irrigation infrastructures to reduce dependence on rain-fed agriculture currently being practiced in Nigeria. Rain-fed agriculture is highly unreliable due to its unpredictable nature. Additionally, investment on improved agricultural technology, which should include the manufacturing and establishment of storage and processing facilities are very necessary. This will help to store excess agricultural produce or convert farm produce to long lasting forms to ensure consistent maize supply in the nation especially in the time of food scarcity occasioned by climate change. Adoption of important abiotic and biotic tolerant maize varieties with short duration of maturity would be ideal for the nation. These early maturing variety will employ escape means to avoid prolonged terminal heat and water stresses that occur at the end of cropping seasons. Use of genetically modified maize for abiotic stresses may also be encouraged. Governments may support the breeding of maize for biotic and abiotic stresses tolerance such as high tolerance to drought, heat stress, salinity, acidity or flooding. Adjusting the cropping calendar to synchronize crop planting and the growing period with soil moisture availability based on seasonal climate/ rainfall forecast will be crucial. Sustainable soil management practices like minimum tillage, use of mulches and cover crops, organic manuring, crop rotation, bush fallowing, and other soil cultural practices are very important in mitigating effects of climate change on maize production in Nigeria. Other possible socio-economic coping strategy is for farmers to diversify their livelihoods since not all sources of income are affected by climate change (e.g off-farm employment). Property rights such as land use need to be in place so that farmers can secure loan easily and confidently implement long term water management and other environmental mitigation measures in their farmlands.

Conclusion

Numerous literatures have shown that Nigeria is among the developing countries that will be highly vulnerable to climate change especially in respect to crop production. This is because of the geographical location of the country (tropics), low climate change mitigating strategies and weather-sensitive crop production systems associated with the country's agricultural practices. Although Nigeria is the leading producer of maize in Africa, effect of climate change is seriously limiting its crop yield. Increase in temperature, and irregular changes in precipitation amount, duration and intensity are the major aspects of climate change that affect maize production in the country. In order to maintain high crop yield in spite of the climate change in Nigeria, there is need to study the responses of maize crop to variables of climate changes. Such information will be useful in predicting yield losses under different changing climates and to design appropriate coping strategies to ensure sustainable increase in maize productivity in the face of Nigerian's rapid increasing population.

In this study, the predicted maize yield at current CO_2 level decreased with increase in temperature in all the agro-ecological zones in Nigeria. These effects were more pronounced in the humid forest and semi-arid with 18% and 13% yield reduction, respectively while least decline in yield was observed in the derived and southern guinea savannas with 7% yield reduction. Doubling the current CO_2 levels only gave increases in yields at low temperature change of between 1-2^{o}C, but higher temperature changes of between 3-4^{o}C tended to counteract effects of a double CO_2 in all the five major maize growing regions of the country. For the future climate of doubled CO_2 and changes in rainfall amount of $\pm$20%, the present level did not have any significant impact on maize yield. However, increase in temperature showed reduction in the phenological traits (days to flowering and maturity) across the five agro-ecological zones studied.

The simulated yield changes for all sites under the three General Circulation Models (GCMs) scenarios showed that United Kingdom Meteorological Office (UKMO) scenario predicted the highest reduction in yield in most of the agro-ecological zones, followed by General Fluid Dynamics Laboratory (GFDL), while Goddard Institute of Space Studies (GISS) predicted the lowest values. The simulated yields and days to physiological maturity of the four maize cultivars (early, medium, late and very late maturing varieties) under the current climate (current CO_2) using UKMO scenario showed that the varieties with longer days to maturity recorded the higher crop yield consistently in all the agro-ecological zones.

The same trend was maintained when the current CO_2 was doubled, though there was more reduction in yield for all the varieties than when they were under current CO_2 condition. Although early maturing varieties are being bred for abiotic stressed environments, the result shows that late maturing varieties can still be useful especially when planting is done early enough. This suggests that the yield reducing tendencies of maize in a hotter climate as in Nigeria could be mitigated through appropriate choice of cultivar, adjustment of management and time of planting, provision of adequate irrigation facilities among other recommendations earlier made in this study.

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