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Review on Climate Change Impacts on Sustainable Maize (*Zea mays* L.) Production in Africa

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Abstract

Maize (*Zea mays* L.) is one of the commonly grown grain crops and remains a source of staple food and food security for most countries in Africa. However, in recent decades the natural system of maize production by farmers has been influenced by severity of climatic changes. Climatic change is the biggest threat for experts, scientists and higher governmental leaders. This issue is dramatically increasing due to rise causes of global green house gas emitted from industries and intensive agricultural. Different crop models reported that at the end of this century, the atmosphere and oceans have warmed and the amounts of snow and ice have diminished, the sea level has risen, and the concentrations of greenhouse gases have increased. The world's average temperature will rise by 4-6°C, which may make maize un productive if there is no intervention. The production zone for maize is projected to decrease due to the rise in temperature and rainfall variability. Maize performs well in a range of agro ecological settings, but is highly responsive to water availability and temperature. This review showed that new areas increased by 1.3–2.5% in Northern Ethiopia, Eastern and Southern Africa whereas suitable maize cultivation areas in Central and Western Africa may reduce by 1.2–1.4% and in some cases even a complete loss of cultivable land that are suitable for maize production especially, surround the Sahara Desert and the coastal areas of Angola. Suggested IPCC (2007), rice yield will reduce by 10% when the temperature increases by 10 ^{o}C and thus, it is estimated that by 2050 rice yield will be reduced by, at least, 10%, maize yield will be reduced 3-6%. Therefore, agronomic practices such as convectional tillage, intercropping, climate smart agriculture and soil conservation practices the best option for sustaining maize production and mitigating the direct and indirect impacts of climatic changes. Since climate change is an inevitable phenomenon, policy makers should introduce adaptation measures to sustain the economic growth observed in the last few years.

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Climate change, maize production, agriculture, Africa, chlorofluorocarbon.

Introduction

Climate change is rapidly emerging as a global critical development issue affecting many sectors in the world and is considered to be one of the most serious threats to sustainable development. Globally, an unprecedented increase in greenhouse emissions has led to increased climate change impacts. Agricultural activities have been shown to contribute immensely to climate change as they rank third after energy consumption and chlorofluorocarbon production in enhancing green house emissions. In fact, emissions from agricultural sources are believed to account for some 15% of today's anthropogenic greenhouse gas emissions. Agriculture is both subject to and responsible for climate change, while also being part of the solution. It is the most sensitive and vulnerable to climate change (IPCC, 2014).

Climate change is now a leading issue on the environmental and socioeconomic agenda worldwide (Cairns *et al.,* 2013). It is the primary determinant of agricultural production and hydrologic balance (Adams *et al.,* 1998). There is testimony from the scientific community of the globe that there is climate change now and 97% of climate scientists agree that it is being driven primarily by human activity (IPCC 2001; Wang *et al.,* 2019). Climate change, however, is expected to make agricultural development in Africa more challenging in many places (Blanc, 2012).

African countries are vulnerable to climate change due to increasing stresses such as human population, water scarcity, land degradation, and food insecurity (IPCC 2012; World Bank 2010). Climate change can affect the sustainability of agriculture systems and will therefore challenge vulnerable people who depend on local food production (Wheeler and Von Braun 2013; Müller *et al.,* 2011; Boko *et al.,* 2007). Agriculture is the economic mainstay in most African countries, except in oil-exporting countries, contributing 20–30% of Africa's gross domestic product (GDP) and 55% of the total value of African exports, with 70% of the continent's population depending on the sector for their livelihood (Organization for Economic Cooperation and Development, 2009).

In most African countries, crop farming is mainly subsistence and rain-fed, but due to climate change, frequent and untimely raining affects the harvest of produce and, thus, food production. This makes Africa particularly vulnerable to the impacts of climate change.

The vulnerability of the region is further worsened by the fact that the climate is already too hot as it is tropical in nature. With reference to Africa, there is growing interest in the likely impacts of climate change on agriculture, economic growth, and sustainable development.

This is because the region has been experiencing increased drought in recent times due to increased temperatures and reduced rainfall. Incidents of climate change include changes in soil moisture, soil quality, crop resilience, timing and length of growing seasons, yield of crops and animals, atmospheric temperatures, weed insurgence, flooding, unprecedented droughts, sea level rises, and many more (Ozor and Nnaji, 2011).

This adversely affects agricultural activities, which are the mainstay of most African economies. The situation is made worse due to factors such as widespread poverty, over dependence on rain-fed agriculture, inequitable land distribution, limited access to capital and technology, inadequate public infrastructure such as roads, long term weather forecasts, and inadequate research and extension by the Intergovernmental Panel on Climate Change (IPCC, 1998). The second (IPCC, 1996) report predicted that tropical and subtropical regions would experience higher losses in crop production, while temperate climates might gain in productivity with climate warming. Issues of hunger and famine in Africa are associated with low cereal crop production like maize as a result of poor rainfall, which is happening nowadays in Africa once again. It is apparent, therefore, that tropical and subtropical parts of the nation wholly rely on rainfed farming. Africa's food production could be greatly impacted by climate change.

According to Muller *et al.,* (2011), climate change impacts on agricultural crop production vary from place to place and from crop to crop (Tubiello *et al.,* 2002). Higher temperatures can reduce crop production in parts of the world (Gohari *et al.,* 2013), although crop yield could increase with warm-wet climate change in some areas (Chavas *et al.,* 2009). Crop yield reduction has long-term implications for food security (Ringler *et al.,* 2010), socioeconomic stability (Burke *et al.,* 2009), and ecological integrity (Walker and Schulze, 2008). These risks are especially high for impoverished countries that are less resilient (Muller *et al.,* 2011). By the end of this century, growing season temperatures will exceed the most extreme seasonal temperatures recorded in the past century (Battisti and Naylor, 2009). Using crop production and meteorological records, Thomson (1966) showed that a 6 °C increase in temperature during the grain filling period resulted in a 10% yield loss in the US Corn Belt. A later study in the same region showed maize yields to be negatively correlated with accumulated degrees of daily maximum temperatures above 32 °C during the grain filling period (Dale, 1983). Lobell and Burke (2010) suggested that an increase in temperature of 2 °C would result in a greater reduction in maize yields within sub--- Saharan Africa than a decrease in precipitation by 20 %. A recent analysis of more than 20,000 historical maize trial yields in Africa over an eight year period combined with weather data showed for every degree day above 30 °C grain yield was reduced by 1 % and 1.7 % under optimal rainfed and drought conditions, respectively (Lobell *et al.,* 2011). These reports highlight the need to incorporate tolerance to heat stress into maize germplasm. However, relatively little research has been conducted on heat stress compared to other abiotic stresses in maize (Paulsen, 1994). The vast majority of heat stress research has been conducted on temperate maize germplasm for high production areas. Therefore, limited breeding progress has been made in the development of improved maize germplasm with specific tolerance to elevated temperatures.

To stabilize maize yields under elevated temperatures, it is necessary to understand the mechanisms responsible for yield loss. Maize yields in Sub-Saharan Africa remain low and highly variable between years, at 1.6 t ha^{1}, barely enough to achieve self-sufficiency in many areas (Banziger and Diallo, 2004; FAOSTAT, 2010). The world population is expected to surpass 9 billion by 2050, with population growth highest within developing countries. Harvest at current levels of productivity and population growth will fall far short of future demands due to climate change, which will further exacerbate the ability to ensure food security within many maize producing areas. The development of improved germplasm to meet the needs of future generations in light of climate change and population growth is of the utmost importance (Easterling *et al.*, 2007).

Past experience has demonstrated that the use of new varieties alongside improved management options can offset yield losses by up to 40% (Thornton *et al.*, 2009). Many more examples of the use of molecular tools to quickly develop improved germplasm with resilience to major abiotic and biotic stress are beginning to emerge.

As the impacts of climate change will vary regionally and given the time lag between the development of improved germplasm and adoption in farmers' fields, there is an immediate need to identify future breeding target environments, climate smart agriculture, well-agronomic practices, mitigation, and adaptation practices and reduce uncertainty within climate change to allow priority setting for both researchers and policy makers.

Based on extensive justification information studies or investigations and modeling scenarios, the idea of climate change is accepted and real. Most scientists and government bodies now believe that the warming trend is largely growth right up, without any descending (Baker and Haggar, 2007). Therefore, the objectives of this reviews are; To know the current status of climate change and its impact on sustainable maize production and productivity in Africa.

Maize origin and Agro ecologies

Although maize was domesticated and diversified mostly in the Meso-American region, at present it is cultivated mainly in warm temperate regions where the conditions are best suited for this crop (Norman *et al.*, 1995). Maize is an annual plant and the duration of the life cycle depends on the variety and on the environment in which the variety is grown (Hanway, 1966). Maize is typically grown in temperate regions due to the moisture level and number of frost-free days required to reach maturity. The number of frost-free days dictates the latitude at which corn varieties with different life cycle lengths can be grown. Maize having a relative maturity of 100 to 115 days is typically grown in the U.S. corn belt. Maize varieties with different relative maturities do not occur in parallel east-to-west zones because they are also dependent on prevailing weather patterns, topography, large bodies of water, and soil types (Hallauer, 2000).

In tropical regions, maize maturity increases due to altitude effects. Tropical land races of maize in the tropics characteristically show three to five ears and axillary tillering, as opposed to modern cultivars that suppress lower ears and tillers (Norman *et al.*, 1995). In the tropics Oxisols, Ultisols, Alfisols and Inceptisols are best suited for maize production; however, maize is adapted to a wide variety of soils in the tropics, from sands to heavy clay. It has the highest average yield per hectare and it is grown in most parts of the world over a wide range of environmental conditions ranging between 50o latitude north and south of the equator. It is also grown from sea level to over 3000 meters above sea level elevation (Singh, 1987). Maize is generally less suited to semi arid or equatorial climates, although drought-tolerant cultivars adapted to semi-arid conditions are now available. The crop requires an average daily temperature of at least 20 ºC for adequate growth and development; the optimum temperature for growth and development ranges between 25-30 ºC; temperature above 35 ºC reduces yields (Brink and Belay, 2006).

Climate change and maize production

Climatic change is a result of anthropogenic greenhouse gas emissions which have been on the rise since the pre-industrial era. This has been largely driven by economic and population growth and the greenhouse gas emissions are now higher than they were previously and the atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased (IPCC, 2014). According to (Besada and Sewan, 2009) argue that the

4th Assessment Report by the IPCC seemed to overlook Africa's concern about climate change. They claim the issue of climate change should not mainly be in terms of projections of carbon emissions and future environmental damages, but it is more about the links between climate change and contemporary disaster events which includes droughts, desertification, floods, and coastal storms.

They further argue that these climate change-related disaster events eventually threaten lives and livelihoods and are a hindrance to economic growth and social progress of the continent of Africa. Maize is currently grown all over the world (Shiferaw *et al.,* 2011). It can be grown between latitude 58°N and latitude 40°S and it grows best at moderate latitudes, but it can also be grown below sea level (Leff *et al.,* 2004). In Africa, 30% of the total area under cereal production is maize which accounts for over 30% of the total calories and protein consumed (Cairns *et al.,* 2013). Of the total maize production in the developing world, 67% comes from low and lower middle-income countries which shows that maize plays an imperative role in the livelihoods of a good number of poor farmers (Shiferaw *et al.,* 2011). Despite its importance, maize productivity in Africa with the exception of South Africa has remained quite low only increased from about 0.9 to 1.5 tons/ha while the yield remains highly variable (Cairns *et al.,* 2013).

The variation in yields is primarily due to the reliance on rainfall in unpredictable climatic conditions. With climate change, the yields of maize have been negatively affected in many regions (Besada and Sewankambo, 2009). Thus, even when compared to the top five maize producing countries in the world, maize yields in SSA have stagnated at less than two tons per hectare and less than 1.5 tons per hectare in Western and Southern Africa (Cairns *et al.,* 2013). In addition, in SSA, the highest growth in maize area, yields and production from the year 1961 to 2010 has been West Africa when South Africa is excluded, and the lowest has been in Southern Africa with yields at a little over 1 tons/ha (Smale *et al.,* 2011). The prime reason put forward for this discrepancy in maize yields between SSA and other regions is less adaptive capacity of smallholder farmers to climatic change-related effects. According to (Ngombe *et al.,* 2017) suggest the success of agriculture in SSA is hindered by the negative effects of climate change whereas (Hamududu and Ngoma, 2019) argue that the low adaptive capacity of smallholder farmers in SSA, combined with rain-fed farming systems (common in SSA), exposes them to climatic effects. This observation supports the findings of Smale *et al.,* (2011), who contend that the large yield disparity between SSA countries and countries with comparable production conditions is exacerbated when rain-fed areas are considered.

The lower maize yields in SSA are more attributed to drought stress than other reasons such as low soil fertility, weeds, pests, diseases, low input availability, low input use and inappropriate seeds (Cairns *et al.,* 2013). And poor irrigation schemes or lack of efficient irrigation systems (Ngoma *et al.,* 2017). While these climatic change-related effects on maize production may at first sight seem to be homogenous across SSA, maize production trends in some SSA countries like Zimbabwe and Zambia have changed perhaps as a result of shifts in agricultural policy. Zambia has in recent years recorded successive maize bumper harvests (Chapoto *et al.*, 2015) while accessibility to subsidized farm inputs in Zambia have had a positive effect on technical efficiency of maize production in most of Zambia's provinces (Ngombe, 2017).

In contrast, the situation in Angola and Mozambique is different because prolonged civil strife and wars in the past have somehow depressed maize production and productivity trends (Smale *et al.*, 2011). However, being a highly susceptible crop to droughts, about 70–80% of maize losses in SSA are attributed to droughts and floods (Amondo and Simtowe, 2018). Depending on the weather conditions, farmers in some cases abandon who fields after planting (Mulungu and Tembo, 2018). According to Nelson *et al.*, (2017), the negative effects of climate change on crop production are more pronounced in SSA than in other parts of the world. Thus, severe and prolonged droughts, flooding and loss of arable land leading to reduced agricultural yields through such avenues as crop failure and loss of livestock (Besada and Sewankambo, 2009) which provide draught power and household income is still probable. Literature indicates that as a result of climate change, there is an observed 10% decline in maize yield, 15% decline in rice yield and 34% decline in wheat yield in SSA in previous years (IPCC, 2007). Yield projections indicate that by the year 2020, yields from rain-fed agriculture in some African countries could be reduced by up to 50% which would to a great extent affect food security and worsen the malnutrition situation (IPCC, 2007).

Mulungu *et al.,* (2017) demonstrated that in the worst-case scenario, maize yields in Zambia will decrease by

25%, primarily due to temperature increases, offsetting the gains from increased rainfall. According to Hamududu and Ngoma (2019) suggested decline in water availability in Zambia by 13% by the end of the century in 2100 at national level as a result of climate change which poses a much greater risk to field crops such as maize. Africa's inability to cope with the physical, human and socioeconomic consequences of the extremes of climate makes it the most susceptible to climate change (Besada and Sewankambo, 2009; Hamududu and Ngoma, 2019). What also adds weight to the incumbent problem is that majority of maize agricultural producers in SSA reside in rural areas.

For example, Mulenga *et al.,* (2017) point out that at least 83% of the 1.4 million smallholder households in Zambia grow maize which is a huge number. But the rural poor are more vulnerable to these changes in climate and consequently, hunger, poverty and malnutrition levels will more likely continue to rise which means that the severity of climate change will increase keeping other factors constant (Masipa, 2017). Because of this evidence, there is need to diversify from maize production as dependence on maize production in most SSA countries is a worry for food and nutritional security, especially when alternative supplements for dietary diversity are limited. (Shiferaw *et al.,* 2011).

Impacts of climate change on maize production attributes

Climate change is expected to overall decreasing the productivity of crop in all tropical and sub tropical countries through fluctuations existed growth length, increasing water stress, incidence of diseases, pests and weeds outbreaks (Niang *et al.,* 2014; Tetteh *et al.,* 2014). Several studies on the effects of climate change have been declared, but quantifying the impacts in each of the parameters is extremely difficult. Because the negative impacts of climate change is reduced by different agronomic practices, and may be some times the climate change make positive impacts. While climate change will also negative affect crops differently, that is, crops like maize, rice, wheat, beans and potatoes will be highly affected and crops like millet may be less affected since they are able to resist high temperatures and low water levels (Gemeda and Sima, 2015). Baker and Haggar (2007) reported that the main impacts of climate change impacts on the maize production. However, smallholder farmers in developing countries are the most vulnerable and disadvantaged people as they entirely depend on rain-fed agriculture (Tetteh *et al.,* 2014). Maize have been described as being highly sensitive to climate change, as largely deduced from modeling studies based on predictions of rising temperatures and changing rainfall patterns (Damatta *et al.,* 2018).

According to Cohn *et al.,* (2017) showed that in SSA and Latin America, a greater proportion of the variation in maize yields was associated with climate change. Hence, change in climate has potential to hinder sustainable development of nations by reducing production in yield which consequently leads to food insecurity (Gemeda and Sima, 2015). However, SSA has a huge potential for expanding maize production. About 88 million hectares (88 M ha), excluding protected and forested areas, which has not yet been planted, is suited to maize production (Smale *et al.,* 2011). For as long as farmers replace seed every season, advantages in yield can be significant (Smale *et al.,* 2011). The adoption of improved open-pollinated varieties and hybrids was at 44% of maize area in Eastern and Southern Africa in 2006–2007 minus South Africa, and it was at 60% in West and Central Africa. This statistic was a suggestion of a significant increase in adopting improved varieties more so in West and Central Africa (Smale *et al.,* 2011).

Jones and Thornton (2003) reported that the global circulation model (GCM) postulated three major types of response of maize crop to climate change and these include (1) the productivity of the crop will decrease but to an extent that can be readily handled by breeding and agronomy. (2) the maize crop benefits from climate change. For example in the Ethiopian highlands that surround Addis Ababa, the yields are predicted to increase even up to 100% at times although many of the pixels showing yield increases are adjacent to pixels where yields are predicted to decrease, sometimes drastically, (3) "maize yields decline drastically, all other things being equal, that major changes may have to be made to the agricultural system, or even human population may be displaced" (Ching, 2010).

According to Abate *et al.,* (2015), most of the results from Africa showed a projected yield reduction of up to 40% across all types of projections as well as sub regions even if there was a large difference in the impacts that were reported. However, only about 12% of the total sample from this study reported an increase in yield for maize grown in East, West and Northern Africa. Results for South Asia showed a similar negative projected impact but with the variation being wider (Abate *et al.,* 2015). Following (Ching, 2010) maize production is likely to reduce by 4.6 million tons per year to 2025 and this decrease will more than double to 11.6 million tons per year by 2055. In Africa, the total production impacts of the likely future climate change to 2055 on smallholder rain-fed maize production are comparatively modest. Aggregated results, however, conceal variability, that is, in other areas yields will increase and areas where subsistence agriculture is the norm, yields will reduce (Jones and Thornton, 2003).

According to Tesfaye *et al.,* (2015) reported that biophysical impacts of climate change and the impact of climate change on maize production, consumption and food security. It will changes in potential maize cultivation area, changes in maize yields and yield response to fertilizer. Under maize cultivation area, aggregating the change in land area suitable for maize production in SSA by the year 2050 shows a small change of 0.6–0.8% which conceals regional differences. By 2080, due to increasing areas suitable for maize cultivation in Eastern and Southern Africa, the cultivation area for SSA may increase by 1.3–2.5% whereas suitable maize cultivation areas in Central and Western Africa may reduce by 1.2–1.4%. And because of climate change, Sub-Saharan Africa countries that surround the Sahara Desert and the coastal areas of Angola are likely to lose areas that are suitable for maize production. Hence, some countries are likely to experience greater reduction in maize cultivation area by 2050 and 2080 and other countries are likely to experience an increase in maize production areas (Tesfaye *et al.,* 2015).

Under changes in maize yields, the outputs of CERES-maize (crop estimation through resource and environment synthesis) indicated a large spatial difference in maize yields under the projected climate in 2050 and 2080 across Sub-Saharan Africa. By 2050, in some parts the change in yield may be within ±5%, some may experience a reduction in yield of between 5 and 25%, other parts may experience a reduction of more than 25% and some parts of SSA may experience an increase in yields by up to 25%. By 2080, yields are likely to reduce even further in many areas and only a few will maintain the current maize yields.

Under maize yield response to fertilizer levels, even if application of fertilizer increases maize yield for both the baseline and future climate conditions, the yield response of maize to fertilizer application was less under climate conditions than the baseline conditions. However, the impact was less with high level of fertilizer application than with low level of zero application.

Outputs from IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) shows that global maize production may decrease by 40–140 million tons by 2050 depending on the GCM projections. Therefore, this reduction in the global maize production may result in a decrease in global maize consumption across SSA which may lead to a decrease in daily caloric intake that is derived from maize. Consequently, the reduction in the daily caloric intake is likely to worsen food insecurity across SSA and this may result in the number of people at risk of hunger to increase by 17–37 million people. According to (Tetteh *et al.,* 2014) the impacts of climate change in Ghana in the near future are expected to worsen especially if nothing is done about the trend. With global climatic changes, the combination of abiotic and biotic stresses are likely to increase and these are damaging to crops (Shiferaw *et al.,* 2011). What have been more common are the negative impacts of climate change on crops than positive impacts (IPCC, 2014) and "climate change will act as a multiplier of existing threats to food security" (Kotir, 2011). With high confidence, the IPCC projected increases in annual mean temperatures to be larger in the tropics and subtropics of SSA than in the mid-latitudes (IPCC, 2014). Furthermore, by the end of this century rainfall will become more intense and more frequent over most of the mid-latitude land masses and wet tropical regions.

The fifth assessment report of the IPCC reports that hazards that are related to climate worsen other stressors which have often resulted in negative outcomes for livelihoods of the poor people. Climate-related hazards affect the lives of poor people directly and indirectly through reduced crop yields or destruction of homes and increased prices for food and a reduction in food security, respectively (IPCC, 2014).

Depending on the level of input supply and GCM projections in SSA, yields will reduce by 6–12% and 9–20% in 2050 and 2080, respectively (Tesfaye *et al.,* 2015). Moreover, these figures vary according to region and the most reduction in maize yields will be in Western and Southern Africa (Tesfaye *et al.,* 2015). Even if maize yields will be negatively affected by climate change by 2050 across maize mega environments, dry and wet lowland MMEs will experience the greatest reductions (Tesfaye *et al.,* 2015). Literature shows that by the end of the twenty-first century, East Africa will be likely to lose about 40% of its maize production and a general consensus is that climate change will affect maize productivity (Adhikari *et al.,* 2015). Therefore, "the impact of climate change on global maize production may cause supply shocks in maize markets across the globe which could affect food prices and, in turn, lead to some adjustments in food production, consumption and trade patterns worldwide" (Tesfaye *et al.*, 2015).

Temperatures

Climate change will negatively affect the agricultural sector and the impact will vary by adaptation as well as rate of temperature (IPCC, 2007). In line with temperature variation, the projection is that crop productivity will slightly increase at mid to high latitudes and will decrease at lower latitudes, more so in seasonally dry and tropical regions. The increase in crop productivity will occur at local mean temperature increases of up to 1–3°C and in some regions but will decrease at temperature beyond this magnitude. On the other hand, at lower latitudes, reduction in crop productivity is projected to decrease even at minor local temperature increments of 1–2°C. In particular, cereal productivity is highly likely to decrease more at lower latitudes and less at mid to high latitudes, though this would vary in some regions with temperature increase (IPCC, 2007). Although maize is usually considered as a warm season crop, it is actually more sensitive to high temperature stress as compared to other crops (Tesfaye *et al.*, 2015). At higher temperatures, maize yields will reduce but at the same time production or multiplication of some weeds and pests will be encouraged (Shiferaw *et al.*, 2011). At a high temperature of 35°C, maize yield reduces by 9% with a one-inch reduction in rainfall (Adhikari *et al.*, 2015). Temperatures above a threshold level that results in irreversible damage to crop growth and development and is a function of intensity, duration, and the rate of increase in temperature. Further, different plant tissues and organs, and different developmental stages are affected by heat stress in different ways, depending on the susceptibility of the dominant metabolic processes that are active at the time of stress (Larkindale *et al.*, 2005).

Accumulated or acute high temperatures can cause an array of morphological, anatomical, physiological, and biochemical changes within maize. The threshold temperature for maize varies across environments (Stone, 2001). Thus, even if plant breeders have developed maize varieties that grow well under different biophysical environments (Banziger and Diallo, 2004) sound maize productivity is still under threat by climate change effects. To stabilize maize yields under elevated temperatures it is necessary to understand the mechanisms responsible for yield loss. The temperature threshold for damage by heat stress is significantly lower in reproductive organs than in other organs (Stone, 2001). Successful grain set in maize requires the production of viable pollen, interception of the pollen by receptive silks, transmission of the male gamete to the egg cell, initiation and maintenance of the embryo and endosperm development (Schoper *et al.*, 1987).

High temperature during the reproductive phase is associated with a decrease in yield due to a decrease in the number of grains and kernel weight. Under high temperatures, the number of ovules that are fertilized and develop into grain decreases (Schoper *et al.*, 1987). Seedlings growing in high soil temperatures are likely to suffer further damage as the associated slower growth rate delays canopy closure, consequently reducing soil shading. Above 35 C, maize leaf elongation rate, leaf area, shoot biomass, and photosynthetic CO2 assimilation rate decrease (Watt, 1972). Elongation of the first internode and overall shoot growth of maize has been suggested as the most sensitive processes of the vegetative stage to high temperatures (Weaich *et al.*, 1996). C4 plants have a higher optimum temperature for photosynthesis compared to C3 plants due to the operation of a CO2- concentrating system that inhibits rubisco oxygenase activity (Berry and Bjo¨rkman, 1980). However, a comparison of the photosynthetic responses and sensitivity of the light reactions in both C3 and C4 crop plants subjected to brief heat stress suggested that the C4 pathway alone did not necessarily confer tolerance to high temperature. Differences in photosynthetic response were more closely associated with light reactions, particularly the sensitivity of photosystem II activity under elevated temperatures.

Rain fall

In SSA, there has been some countries which had too much rainfall which led to severe flooding and unfavorable livelihood consequences. These countries included Burkina Faso in 2007 and 2009, Mozambique in 2000 and 2001, Ethiopia in 2006 and Ghana in 2007 and 2010 (Kotir, 2011). And in the year 2017 Niger, Nigeria, Burkina Faso, Guinea, Mali, Sierra Leone, Ghana, and Central African Republic experienced floods that destroyed lives and the agricultural sector (UNOCHA, 2017). These rainfall-related disasters are more common in some countries. For example, Malawi has had 40 weather related disasters between 1976 and 2009 (Pauw *et al.*, 2011). Floods are very destructive and their impacts, which includes deaths and injuries of people and exposing people to toxic substances, are instant. Flooding is world over but the difference is the degree of the impacts which is dependent on the adaptive capacity of a country. Poor countries suffer more from the impacts of flooding as compared to developed countries which have high capacity to adapt (Gemeda and Sima, 2015).

Crop production can also be impacted by too much water. Heavy rainfall events leading to flooding can wipe out entire crops over wide areas, and excess water can also lead to other impacts including soil water logging, anaerobicity and reduced plant growth. Indirect impacts include delayed farming operations (Kettlewell *et al.*, 1999). However, the extreme opposite of too little rainfall, drought, is also a reality. Due to increased frequency of droughts, yields of grains and other crops could decrease substantially across the continent. The drought conditions could lead to maize being no longer grown in some areas (Ching, 2010). In southern Africa, the 2002–2003 drought experience resulted in a food deficit with an estimation of 14 million people who were at a risk of starvation and in eastern Africa in 2005–2006 and 2009, maize fields were struck by severe droughts (Shiferaw *et al.,* 2011). In the coming decades, so much droughts will be experienced in most of SSA (Kotir, 2011). More than 100 million people were affected by drought in Africa, for example over the period 1991–2008, Kenya was affected by drought about seven times which affected about 35 million people and Ethiopia was affected by drought about six times in 25 years (1983–2008) (Gemeda and Sima, 2015). Therefore, variation in rainfall make it less conducive for maize production in almost three quarters of countries in the world and results in yields declining (Jones and Thornton, 2003). Changes in temperature and rainfall increase the frequency and severity of extreme events. Warming has exacerbated droughts, and desertification in the lowlands of the country is expanding. The increase in severity of short, heavy rains in the highlands leads to increased flooding in the lowlands, causing further soil degradation in already exposed areas (although it can also increase fertility).

Climate change scenarios in maize growing regions of Africa

Climate projections were developed using the outputs of few global climate models at low resolution. Large variation exists within the outputs of global climate models and for regional application the use of multiple models reduces the error in both the mean and variability. It also focus on low resolution modeling at the country level masks large variation in key factors, such as climate and topography, and reduces the potential application of projections as decision making tools for identifying priority areas for research. Thornton *et al.,* (2009) reported that large spatial variation in simulated yield production changes of maize and beans within the highlands of Ethiopia and Kenya. There is a pressing need to identify future breeding targets and hot---spots of vulnerability to climate change in maize growing areas. The CIMMYT maize breeding program is organized around the concept of mega---environments, or areas with broadly similar environmental characteristics with respect to maize production, to target its breeding programs. Mega---environments were delineated using environmental factors (maximum temperature, rainfall and sub---soil pH), as explanatory factors for genotype by environment interaction of advanced hybrids from multi---environmental trials (Setimela *et al.,* 2005; Banziger *et al.,* 2006).

Similar combinations of climatic and edaphic conditions exist within and across continents, allowing maize mega-environments to be approximately identified on the basis of GIS data. Hodson *et al., (*2002) indicated that some maize mega- environments were identified across Africa (dry low land, dry mid altitude, highland, wet low land, wet lower mid altitude and wet upper mid altitude). Varieties developed at key sites within mega-environments should have broad adaptation across the mega-environment. As climatic conditions change at particular experimental sites and maize producing regions, mega-environment assignments will need to be re-assessed to guide breeders to appropriate new varieties and target environments.

CIMMYT's global maize breeding programs played great role in mega-environments in the developing world. Although it should be noted that end-use characteristics, color preferences, and other factors may often prevent the direct substitution of, say, lowland-adapted varieties for varieties in mid-elevation maize mega-environments that are experiencing warming. Thus, in addition to being able to source germplasm from mega---environments with conditions similar to those arising from climate change in their own areas, breeders will need the capacity to rapidly move stress tolerance traits into germplasm preferred by people in the target environment they serve. Previous research strongly suggests maize growing regions of Africa will encounter increased growing season temperatures and frequency of droughts (IPCC, 2007).

To establish changes in maximum temperatures and annual rainfall difference at the maize mega-environment level within countries, downscaled outputs from Special Report on Emissions Scenarios models with data provided by CIAT (Ramirez and Jarvis, 2008) were used with the climate change models. Values within mega environments within the respective countries were averaged. The results of temperature simulations for 2050 across maize mega environments within Africa show a general trend of warming, in agreement with previous projections conducted at the country level (IPCC, 2007; Burke *et al.,* 2009). In sub---Saharan Africa warming is the greatest over central southern Africa and western semi---arid margins of the Sahara and least in the coastal regions of West Africa. Maximum temperatures are predicted to increase by 2.6 °C, with the increase in minimum temperatures slightly lower, with an average of 2.1 °C. In agreement with Burke *et al.,* (2009), the range of temperatures within a country is likely to be larger than the range of temperatures across years (2010---2050). In maize, increasing maximum (day) temperatures have a greater, negative impact on yields than minimum (night) temperatures (Lobell *et al.,* 2011). Average optimum temperatures in temperate, highland tropical and lowland tropical maize lie between 20---30 °C, 17---20 °C, and 30-34 °C, respectively (Badu---Apraku *et al.,* 1983; Chowdhury and Wardlaw, 1978). Maximum temperatures currently exceed optimal temperature conditions for lowland tropical maize (34 °C) within several countries (Burkina Faso, Chad, Eritrea, Gambia, Mali, Mauritania, Niger, Nigeria, Senegal and Sudan) although the area of maize grown within several of these regions is small. Maize is an important crop in the highlands of Kenya, Ethiopia and Tanzania. Average temperatures within these regions are currently at the threshold for highland maize and will likely exceed this threshold by 2050. Lobell *et al.,* (2011) showed that maize yields in Southern Africa declined linearly by 1 % under optimal conditions and 1.7 % under drought stress for every accumulated degree day above 30°C. In the dry low lands of Burkina Faso, Cameroon, Chad, Gambia, Mali, Mauritania, Niger and Senegal mean temperatures are predicted to increase above 30°C and could reduce maize yields.

Precipitation projections suggest monthly rainfall patterns will change in all locations, however the direction and magnitude of change varies with location. In the highlands of Ethiopia rainfall will decrease during the maize growing season (May–October), particularly during the critical reproductive stage. Another report found that for some southern, south-western and south-eastern regions, Belg (Feb-May) and Kiremt (June-Sept) rainfall have decreased by 15-20% between 1975 and 2010. In West Africa rainfall will decrease during the maize growing season in the wet upper mid-altitude of Nigeria and the wet lowland of Benin; however in the wet lowland mid-altitude of Nigeria and the wet lowland of Ghana, total rainfall during the maize growing season will increase. In East Africa there is a consistent increase in rainfall between December and February across mega-environments. In the wet lowland mid-altitude of Kenya there is little change in total rainfall during the maize growing season, however in the dry lowlands rainfall is projected to decrease during the maize reproductive stage, with the onset of the short rainy season also delayed. In Southern Africa the maize growing season is November– April. Monthly rainfall projections suggest a general increase in rainfall during the maize growing season, ranging from 3 % in the dry lowlands of Zimbabwe to 18 % in the dry lowlands of Mozambique. However, in agreement with Shongwe *et al.,* (2009), the onset of the rainy season is delayed. Low rainfall in May in all locations in Southern Africa is likely to result in a delay in planting. While rainfall during the maize growing season in the drought-prone lowlands Southern Africa may increase slightly, it is unlikely to translate into higher yields as evapotranspiration will increase under higher temperatures (Cook and Vizy, 2012). Under climate change, increased extreme rainfall events are expected to increase (IPCC, 2007) however, data available for modelling did not allow the prediction of rainfall distribution within each month thereby masking extreme events.

Adaptation and mitigating technologies and practices for addressing progressive climate change

Research on maize has a very important role to play when it comes to adaptation to climate change in vulnerable areas (Shiferaw *et al.,* 2011). Africa has been projected to be affected the most by climate change due to limited institutional, financial and technological capacity, adaptation to climate change will be difficult and complex (Shiferaw *et al.,* 2011). It is expected that research and plant breeding will mitigate many of the detrimental effects but the negative effects of climate change are what is expected if farmers continued to plant the same varieties in the same way in the same areas.

Some autonomous adaptations that will help offset some negative impacts of climate change include shifting of planting dates, modifying crop rotations or an uptake of pre-existing crop varieties (Knox *et al.,* 2012). To ensure food security for a growing population of SSA, it is very critical to adapt agricultural systems to climate change (Tesfaye *et al.*, 2015). Important steps towards designing and implementing measures that are appropriate are to identify hotspots of climate change and understand associated socioeconomic impacts at different spatial scales (Tesfaye *et al.*, 2015). Continued investment in maize productivity remains crucial to the growth of agriculture and food security even if there has been success in the past, which includes policies that favor maize production and productivity as well as development and adoption of new and improved maize seed and fertilizer (Smale *et al.*, 2011). For instance, the maize area covered by improved varieties in Ethiopia grew from 14% in 2004 to 40% in 2013 (Abate *et al.*, 2015). There is need to invest in research to produce a new generation of improved varieties that are tolerant to drought, resistant to pests, and nutrition-efficient (Smale *et al.*, 2011). Therefore, if appropriate actions are not put in place to reduce the negative effects of climate change, the danger of food insecurity is expected to increase (Khanal *et al.*, 2018).To manage the current climate change and for future adaptation to these variations, there is need for maize varieties that are tolerant to drought, heat and water logging and are resistant to diseases and pests and insects, and to effectively contribute to mitigating climate change, practicing conservation agriculture and precision agriculture would be helpful (Shiferaw *et al.*, 2011).

Breeding for disease and insect resistance requires an understanding of parasite biology and ecology, disease cycles, and drivers influencing the evolution of plant-pathogen interactions because unlike abiotic stresses, biotic stress resistance is influenced by genetic variability in the pest/pathogen population. As a result of the evolving pest/pathogen populations and the changes in fitness favoring new pathotypes /biotypes, improving resistance to biotic stresses has been a long-term focus of agricultural researchers. The long-term success of breeding for disease or insect pest resistance will depend on a more in-depth and clear understanding of the nature of the pathogen, diversity of virulence in pupation, type of genetic resistance, availability of suitable sites (hot spots), selection environments and methodologies for rapidly generating multiple stress resistant inbred lines, and their use in hybrid or variety development. Significant progress has been made over the decades in the identification of stable genetic resistance for major maize diseases (Pratt and Gordon, 2006; Welz and Geiger, 2000). However, the population structure of most maize pathogens remains inadequately characterized. CIMMYT has also developed several insect pest-resistant populations, inbred lines, and varieties, especially for the stem borers and post-harvest insect pests (weevils and grain borers) through projects such as Insect Resistant Maize for Africa (IRMA). In addition, several inbred lines have been developed combining resistance to stem borers and storage pests and these are currently being tested in eastern Africa. Wide testing of these materials in Kenya, Tanzania, and Uganda is being done under IRMA.

The dynamics of insect pests are also strongly coupled with environmental conditions. Insects do not use their metabolism to maintain their body temperature and are dependent on ambient temperature to control their body temperature. Temperature is therefore the single most important environmental factor influencing insect behavior, distribution, development and survival, and reproduction. Insect life stage predictions are calculated on accumulated degree days, which is a function of both time and temperature. Increased temperature can speed up the life cycle of insects leading to a faster increase in pest populations. It has been estimated that a 2 °C increase in temperature has the potential to increase the number of insect life cycles during the crop season by one to five times (Petzoldt and Seaman, 2005; Bale *et al.*, 2002; Porter *et al.*, 1991).

The increased global warming and drought incidences will favor insect proliferation and herbivory, which will likely increase the incidence and severity of insect-related damages as well as aflatoxin and fumonisin mycotoxins in maize. Higher average temperatures have the potential to change the geographical distribution of crops. This may, in turn, result in an expansion of the geographical distribution of insect pests and their associated pathogens (e.g. maize streak virus, and corn stunt complex that are vectored by different species of leaf hoppers), resulting, in a change in the geographical distribution of diseases. Agriculture is estimated to account for 20 % of anthropogenic greenhouse gases (IPCC, 2007).

The use of fertilizers, agricultural machinery for tillage practices and irrigation are associated with increased CO2 emissions through fuel consumption (Cairns *et al.*, 2012). Improved agronomic practices such as conservation agriculture have the potential to mitigate global warming through reduced greenhouse gas emissions and increasing C sequestration. However maize production systems in African are predominately rainfed, relying on animal traction or manual land preparation, with very limited fertilizer use (smallholder farmers in African use less than 10 kg/ha (Morris, 2007). Furthermore SSA accounts for just 3.6 % of the world emissions of CO_2 (Collier *et al.*, 2008).

Thus adaptation to climate change may be more important than mitigation within this region. New maize varieties with improved drought and heat tolerance will play an important role in adapting maize systems to climate change in SSA, however maize yields in this region are currently amongst the lowest in the world. Maize breeding alone will be unable to adequately contribute on the scale required to both increase current yield levels and offset potential yield losses associated with climate change and increased climate variability. As previously discussed, while growing season temperatures may not increase above the threshold temperatures for sub-tropical and tropical maize by 2050, the higher growing season temperatures will increase plant transpiration thereby increasing planting water use and reducing plant-available soil water. Improved soil water status has the potential to both buffer plants against the potential effects of drought stress under intermittent rainfall and reduce the severity of a drought event (Thierfelder and Wall, 2010). Conservation agriculture is a system of agronomy based on minimum soil disturbance through ploughing, residue retention and crop rotations (Hobbs, 2007).

Conservation agriculture practices increase stored soil water by improved water infiltration, reduce evapotranspiration and reduce water runoff (Verhulst *et al.*, 2010; Thierfelder and Wall, 2012). Several studies have shown that conservation agriculture techniques are associated with increased soil moisture content (Dendooven *et al.*, 2012; Verhulst *et al.*, 2011) showed that, under mild drought, yields of maize grain under conservation agriculture were 1.8 to 2.7 times higher than under conventional management practices. Higher soil water content under conservation agriculture may be an important mechanism by which maize production is buffered against short drought periods during the growing season (Fischer *et al.*, 2002; Thierfelder and Wall, 2010).

The new concept was developed by FAO in 2010 which integrates the three dimensions of sustainable development (economic, social and environmental) by jointly addressing food security, ecosystems management and climate change challenges. CSA is an approach to guide and transform agricultural systems to support development, food security effectively and sustainably under a changing climate. CSA is not a new production system: it is a means of identifying which production systems are best suited to respond for the challenges of CC in specific locations. CSA interventions can addresses climate change related issues by systematically integrating climate information into the planning of sustainable agricultural systems (FAO, 2013).

Summary

The impacts of climate variability has been adapting by Farmers for a long period of time. But, based on current scientific knowledge, the probably impacts of climate change are out of the range of farmers' previous experiences and represent a greater challenge. Climate change will, hence, severely test the farmers' resourcefulness. Climate change potentially threatens productivity and production of maize, a field crop that depends on water availability. Literature has shown that climate change effects on maize production and productivity are serious and if proper adaptation strategies to negative effects of climate change are not followed, these impacts would deepen in the near future. Maize is predominantly grown by smallholder farmers in the African countries, who mostly cultivate small parcels of land, which are often degraded and might be lost cultivate land of maize some sub-Saharan African country. It adds further challenges to the existing problems and undermines efforts that are being made to enhance food security in the African. Governments and international agencies need to boost efforts to minimize effects of droughts, floods or in fact ensure that climate change effects are minimized. While I believe these efforts are in place, taking a longer step at improving adaption may mitigate these negative effects.

For example, conservation agriculture, climate smart agriculture, effective policies, increased research and development of resilience abiotic and biotic stresses maize varieties to adapt climate change, increased adoption of climate-smart adaption strategies, and call for world leaders to reconsider the negative effects of human activities on the ecosystems are highly encouraged in reviewed. Therefore, international levels will all be required to ensure the technologies reach the intended beneficiaries and make the desired impacts.. Thereby, our results suggest that adjusting the sowing date to minimize the impact of heat stress, as well as using early-maturing cultivars and new varieties are more effective and primarily required under future climate conditions for the continent.

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