Chapter

Climate Change Impacts on Sustainable Maize Production in Sub-Saharan Africa: A Review

Kelvin Mulungu and John N. Ng'ombe

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 sub-Saharan Africa (SSA). But climate change threatens agricultural potential in SSA thereby risking food security especially that most maize production is rain-fed in these countries. Thus, numerous studies have examined impacts of climate change on maize production and productivity resulting in several adaption strategies being promoted to mitigate the negative effects of climate change. But to the best of our knowledge, there has not been any studies in literature that provide a review of impacts of climate change on maize production and productivity in SSA. This chapter therefore provides a review of empirical climate change impacts on maize production and its productivity in SSA. We chose SSA because most countries in SSA are underdeveloped and therefore more vulnerable to climate change effects. This is important because this review will provide an easier access of such results for both scholars and policy makers in search of empirical impacts of climate change on maize production and productivity in SSA.

Keywords: climate change, maize, smallholder farmers, sub-Saharan Africa

1. Introduction

Climate change is a real phenomenon worldwide [1] as observed in the increase in atmospheric and oceanic temperature, decreased amounts of snow and ice as well as a rise in sea level [2]. The earth's surface has been warmer in past three successive decades [2] resulting higher average temperature compared to the past centuries. The term "climate change" is defined differently among different stakeholders even though the contents are similar in context. IPCC [3] defines climate change as a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Based on the United Nations Framework Convention on Climate Change (UNFCCC), climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods [3].

Impacts of climate change vary depending on the state of development of a region. For example, IPCC [4] suggest that rising temperatures and changing precipitation rates will most likely hamper success of rain-fed agriculture in most developing countries. Africa is one of the continents that is projected to experience rising temperatures of at least 1 to 2°C and higher likelihood of extreme weather [5, 6]. Thus, the effects of climate change will more directly affect agriculture because about three-quarters of Africa's population depends on agriculture for a livelihood and Africa's agriculture is mainly rain-fed [7–11].

For sub-Saharan Africa (SSA), agriculture largely contributes to employment of the majority of the people in rural areas and significantly to the Gross Domestic Product (GDP) of most countries. Thus, a large number of people in SSA is employed in agriculture and increasing agricultural productivity is necessary to reducing poverty and food insecurity (AGRA [12]). However, the rise in temperatures and increased stochastic rainfall variations have both direct and indirect grave consequences on crop yields and agricultural productivity. While agriculture is so important to most developing economies in SSA, most agricultural sectors in SSA have performed poorly relative to other developing world regions [8]. Kotir [7] contends that over the past 50 years, agricultural productivity has been steadily declining in SSA and recorded the slowest increase across the world over and that this would only get worse with climate change. Taken together, this evidence suggests production of maize, a vital crop for many millions in SSA [13] may have its production in danger in the face of climate change.

Maize, a field crop that is one of the most cultivated crops in the world, is a staple crop for most countries in SSA [13]. While maize remains an important crop for many millions in SSA, its yields in developing countries (including SSA) are lower than in developed countries [14–16]. More importantly, maize production depends on water availability, and most of SSA's agriculture is rain-fed, which makes maize production an obvious candidate to be affected by weather shocks such as droughts—one of the negative consequences of climate change. Lobell et al. [17] suggest maize is sensitive to daytime high temperatures above 30°C and with climate change, the projected 2°C in temperatures for most parts of Africa would affect maize production, which would further lower maize productivity levels in SSA despite the increasing demand for maize.

Because climate change impacts are seemingly being felt, numerous studies have examined impacts of climate change on maize production and productivity resulting in several adaption strategies being promoted to negate the negative effects of climate change (e.g., [5, 14, 18–21]). To the best of our knowledge, there has not been any studies in literature that provide a comprehensive review of impacts of climate change on maize production and productivity in SSA. This chapter therefore provides a detailed review of climate change impacts on maize production and its productivity in SSA. We chose SSA because as mentioned earlier, most countries in SSA are underdeveloped and their agriculture is rain-fed—making them more vulnerable to climate change effects. This is important because this review will provide an easier access of such results for both scholars and policy makers that are in search of empirical impacts of climate change on maize production and productivity for relevant policy.

This rest of the chapter is organized as follows. The next section provides the main literature review of studies that have examined climate change impacts on maize production and productivity specifically in SSA. Adaptation to climate change as well as relative importance of temperature and rainfall are also discussed.

2. Literature review

2.1 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 before and the atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased [2, 7]. Besada and Sewankambo [1] 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 originated from Mesoamerica and is currently grown all over the world [13]. Maize 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 [22]. In Africa, 30% of the total area under cereal production is maize which accounts for over 30% of the total calories and protein consumed [14]. 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 [13].

Despite its importance, maize productivity in SSA with the exception of South Arica has remained quite low—only increased from about 0.9 to 1.5 tons/ha while the yield remains highly variable [14, 23]. The variation in yields is mainly due to dependence on rainfall under uncertain climatic conditions. With climate change, the yields of maize have been negatively affected in many regions [2]. 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 [14]. 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 [24].

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. Ng'ombe et al. [25] suggest the success of agriculture in SSA is hindered by the negative effects of climate change while [6] contend that less adaptive capacity of smallholder farmers in SSA coupled with their rain-fed farming systems (common in SSA) expose their vulnerability to climatic effects while. This observation corroborates [24] who suggest that the large gap in yield between countries in SSA and countries with comparable production conditions is larger 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 [14] and poor irrigation schemes or lack of efficient irrigation systems [26, 27].

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 [28] 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 [29]. 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 [24]. However, being a highly susceptible crop to droughts, about 70–80% of maize losses in SSA are attributed to droughts and floods [11]. Depending on the weather conditions, farmers in some cases abandon who fields after planting [19].

According to Nelson et al. [30] 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 [1] 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 [3]. 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 [3]. Mulungu et al. [31] show that for maize in Zambia under the worst-case scenario, maize yields will decrease by 25% driven mainly temperature increases offsetting the gains from increased rainfall. Hamududu and Ngoma [6] suggest 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 [1, 6, 7, 10, 23]. What also adds weight to the incumbent problem is that majority of maize agricultural producers in SSA reside in rural areas. For example, [5] 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 [32]. 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 [13].

According to the report by the [3] climate change will negatively affect the agricultural sector and the impact will vary by adaptation as well as rate of temperature. 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 [3].

Although maize is usually considered as a warm season crop, it is actually more sensitive to high temperature stress as compared to other crops [20]. At higher temperatures, maize yields will reduce but at the same time production or multiplication of some weeds and pests will be encouraged [13]. At a high temperature of 35°C, maize yield reduces by 9% with a one-inch reduction in rainfall [23]. Thus, even if plant breeders have developed maize varieties that grow well under different biophysical environments [33], sound maize productivity is still under threat by climate change effects.

2.2 Adaptation to climate change

Research on maize has a very important role to play when it comes to adaptation to climate change in vulnerable areas [13]. 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 [13]. 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 [34].

To ensure food security for a growing population of SSA, it is very critical to adapt agricultural systems to climate change [20]. 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 [20]. 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 [24]. For instance, the maize area covered by improved varieties in Ethiopia grew from 14% in 2004 to 40% in 2013 [35]. 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 [24]. 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 [36]. 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 [13].

2.3 Relative importance of temperature and rainfall

Even if temperature is an important factor in the year-to-year production, it is not as important as rainfall in determining agricultural production. 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 [7] 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 [37]. These rainfall-related disasters are more common in some countries. For example, Malawi has had 40 weather-related disasters between 1976 and 2009 [38]. 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 [9]. Increases in temperature and variation in rainfall therefore make it less conducive for maize production in almost three quarters of countries in the world and results in yields declining [39].

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 [40]. 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 [13]. In the coming decades, so much droughts will be experienced in most of SSA [7]. 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) [9].

Climatic change impact on crop productivity greatly varies from region to region [8] and climate change will also 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 [9]. However, smallholder farmers in developing countries are the most vulnerable and disadvantaged people as they entirely depend on rain-fed agriculture [8]. Cohn et al. [10] 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 [9]. 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 [24]. For as long as farmers replace seed every season, advantages in yield can be significant [24]. 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 [24].

In the study done by Jones and Thornton, 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. For example, in eastern Brazil, the changes in maize yield are predicted to be moderate with some pixels (plots of land) showing a slight yield advantage, (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" [40].

According to [35], 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 [35]. Following [40] 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 Latin America and 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 [39].

Tesfaye et al. [20] outlined the biophysical impacts of climate change and the impact of climate change on maize production, consumption and food security. The biophysical impacts of climate change include changes in potential maize cultivation area, changes in maize yields and yield response to nitrogen levels. 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.

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 nitrogen levels, even if application of nitrogen increases maize yield for both the baseline and future climate conditions, the yield response of maize to nitrogen fertilizer application was less under climate conditions than the baseline conditions. However, the impact was less with high level of nitrogen application than with low level of nitrogen 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 [8] 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 [13]. What have been more common are the negative impacts of climate change on crops than positive impacts ([2]) and "climate change will act as a multiplier of existing threats to food security" [7]. 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 [2]. 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 [2]. 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 [20]. Moreover, these figures vary according to region and the most reduction in maize yields will be in Western and Southern Africa [20]. Even if maize yields will be negatively affected by climate change by 2050 across maize mega environments (MMEs), dry and wet lowland MMEs will experience the greatest reductions [20].

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 [23]. 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" [20].

3. Conclusion

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. 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 we believe these efforts are in place, taking a longer step at improving adaption may mitigate these negative effects. For example, more competent irrigation technologies, increased research and development of drought-tolerant maize varieties, 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 literature.

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Conflict of interest

The authors declare no conflict of interest.

Author details

Kelvin Mulungu[1†] and John N. Ng'ombe[2,3*]

1 Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, CO, USA

2 Department of Agricultural Economics and Extension, University of Zambia, Lusaka, Zambia

3 Department of Agricultural Economics, Oklahoma State University, Stillwater, OK, USA

*Address all correspondence to: ngombe@okstate.edu

† Senior authorship is not implied.

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