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## CLIMATE CHANGE IN GHANA: IMPACTS ON AGRICULTURE AND THE POLICY IMPLICATIONS

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# GHANA POLICY JOURNAL

**An international journal on research dealing with policy-related issues concerning Ghana, and Ghana's links and relationships with the rest of the world.**

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# EDITORIAL

## Special Issue of the Ghana Policy Journal

## CLIMATE CHANGE IN GHANA: IMPACTS ON AGRICULTURE AND THE POLICY IMPLICATIONS

According to the Inter-Governmental Panel on Climate Change (IPCC), climate change will lead to increases in the frequency and intensity of natural disasters and extreme weather events such as droughts, floods and hurricanes; rising sea levels and the contamination/salinization of water supplies and agricultural lands; changes in rainfall patterns with an expected reduction in agricultural productivity in already fragile areas, especially in sub-Saharan Africa (SSA) and declining water quality and availability in arid and semi-arid regions. Climate change is also expected to affect food security in the sense that the reliance on rain-fed and low-input agriculture will mean that output will decline, resulting in lower incomes for farmers. This will in turn increase poverty levels and heighten the risk of malnutrition. The IPCC's Fourth Assessment Report (AR4), released in 2007, predicts that by 2050, yields from rain-fed agriculture in some SSA countries could be reduced by up to 50%.

In September 2013, the IPCC's Working Group I released its contribution to the Fifth Assessment Report (AR5). The report considers new evidence of climate change using improved climate models. The models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century. The report finds that each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. Greenhouse gases emitted from human activities contributed a global mean surface warming in the range of 0.5°C to 1.3°C over the period 1951-2010. It concludes that continued emissions of greenhouse gases (GHGs) will cause further warming and changes in all components of the climate system and that limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.

It is now widely accepted amongst scientists that Africa is amongst the most vulnerable regions in the world to climate change. This can be attributed to a number of factors. Africa is already amongst the hottest places on the Earth and therefore any further warming is bound to be catastrophic. Africa's vulnerability is heightened by the fact that most of the economies in this region rely mainly on natural resources and rain-fed agriculture, which are very sensitive to climate change and variability. For example, biomass provides about 80% of the primary domestic energy supply in Africa, while rain-fed agriculture contributes some 30% of GDP and employs about 70% of the population, and is the main safety net of the rural poor. Another reason is that many African countries are already under various forms of climate related stress (e.g., drought, floods, rainfall variability, HIV/AIDS), which, coupled with low adaptive capacity, make them highly vulnerable to climate change. In addition to climate change, other factors such as population growth will continue to put pressure on Africa's natural resources in the next 50 years. Expansion in both subsistence and small-scale commercial farming, as well as livestock grazing, will continue to put pressure on Africa's forest resources. For example, conversion to small-scale agriculture accounted for about 59% of forestland lost to farming within the period 1990 to 2000. Other contributors to deforestation include unsustainable wood harvesting practices and illegal logging.

In view of these dire predictions about climate change, the goal of this special edition of the *Ghana Policy Journal* is to provide a synopsis of the potential impacts of climate change on Ghana's agriculture and to draw out the implications for policy. The intention is to assist policy-makers and the general public in understanding the latest research on climate change conducted in Ghana that could inform the design of appropriate medium to long-term policy responses to the problem. Previous impact assessments from the IPCC and other research groups have been conducted using aggregate models. Although such models yield useful information on climate change, they tend to mask specific impacts for individual regions or countries. Thus, there is the need for country-specific assessments to inform policy.

The five papers in this volume represent a selection of ongoing research on climate change in Ghana. They focus exclusively on agriculture given its significance in Ghana's economy. The lead off paper is by Ferdinand Mawunya and Samuel Adiku and is entitled, 'Implications of Climate Change for Agricultural Productivity in Ghana: An Agrometeorological Perspective'. This paper sets the stage for the remaining papers by explaining the process of climate change for the benefit of non-technical readers. It begins with a definition of climate and climate change and proceeds to discuss the causes of climate change. This is followed by a discussion of the nature of climate change and the processes involved. The third section focuses on the links between climate and agricultural productivity. The penultimate section discusses actions that need to be taken in the face of climate change, while the final section concludes with a summary of the key highlights.

What will be the possible impacts of climate change on specific crops grown in Ghana? The second paper by MacCarthy, Adiku and Yangyuoru attempts to answer this question for maize production in the country. Maize is a major staple food crop for the majority of Ghanaians and accounts for about 20% of caloric intake. Previous studies conducted on maize in other parts of the world have shown that climate change has a variable impact depending on the location. Hence the need for site-specific assessments has become paramount. The authors attempt to answer the research question with the aid of a crop simulation model (CSM). The CSM takes into account rising temperatures and increasing carbon dioxide ($CO_2$) concentrations, as well as declining precipitation. Some adaptation options to mitigate climate change impacts are also assessed within the model. Two study sites were chosen – Tamale, representing the Guinea Savannah zone and Ejura, representing the transitional or semi-deciduous forest (Guinea Savannah) zone. Based on IPCC projections, the model assumes temperature increase by 2050 to be 2.4°C and $CO_2$ concentrations to be 530 parts per million. This information is combined with data on soil characteristics, historical weather data, crop characteristics and management practices and used as inputs into the CSM. The study finds that climate change results in the reduction of grain yield by 19-41% and biomass declines by 11-33% across both agro-ecological zones. The potential negative impact of climate change could be mitigated by adopting the use of heat- and drought-tolerant maize varieties.

The paper by Jørgen Olesen, Ngonidzashe Chirinda and Samuel Adiku reviews current trends in climate and agriculture in Ghana and assesses how the projected changes in climate will impact on agricultural production. The authors go on to discuss the adaptation options available to address the impacts of climate change. They observe that changes in Ghana's climate is already occurring with temperature increases of about 1°C, as well as delayed onset of rains and longer dry periods within the wet season. Ghana's climate is projected to lead to further increases in temperature and additional changes in rainfall patterns with possible regional differences. These changes are expected to adversely affect crop productivity in terms of reduction in crop yields and increased variability in yields. They recommend that effective adaptation to climate change should involve: i) Improved inputs of adapted crops and varieties, fertilisers and irrigation; ii) Appropriate management of soil fertility to improve water harvesting and nutrient supply and management of microclimate to avoid stresses; iii) Strengthening of research and advisory services to develop, demonstrate and implement new technologies and management systems; and iv) Development of a policy framework that facilitates effective implementation of agricultural climate change adaptations while also preserving the natural resource base.

In the fourth paper, Samuel Adiku follows up on the study by Olesen et al. by examining how climate variability affects agricultural production in Ghana. He provides empirical evidence of climate variability in terms of changing frequency of extreme events (i.e., droughts and excess rainfall). The evidence indicates that climate variability appears to be aggravated by climate change, which poses a serious threat to agricultural output. The author discusses three farmer-oriented coping strategies to minimise the adverse effects of dry spells and droughts. These include (i) weather forecast services to farmers to assist agricultural decision making; (ii) weather-index based agricultural insurance to support farmers in adverse weather conditions to help them remain and engage in agricultural practice and (iii) soil management practices that would minimise the vulnerability of crops to extreme climate variability. He argues that the successful operation of these coping strategies would depend critically on the overall climate change and variability policy of Ghana. The paper suggests, *inter alia*, that increased support for climate variability research, improvement of agriculturally tailored weather forecasting and farmer training in insurance and soil management are essential. He recommends that, for effective results, these coping strategies should be used in a combined package. Farmers who would rely on forecast-based advice should also adopt improved soil management practices and purchase insurance. Financial support for these aspects is absolutely necessary.

The projected negative impacts of climate change will not only affect farmers' crop yields and incomes, but also there will be flow-on effects to the rest of the sectors in the economy. This is because the other sectors use agricultural inputs in their production processes. The decline in agricultural output will have an immediate impact on the price of agricultural products and will also negatively affect exports of agricultural commodities, which will have a ripple effect on the economy. The final paper by Asafu-Adjaye captures these complex effects with the help of a computable general equilibrium model. The model is a global model which considers not only the impacts on Ghana, but also on regional groupings such as the EU, North America, Asia, other regions of Africa and the rest of the world. The study estimates that Ghana's real GDP will decline by about 12% per annum by 2050 as a result of the decline in agricultural productivity due to climate change. The results also indicate that Ghana could become a net importer of agricultural and food products and that the decline in agricultural productivity will cause the prices of both domestic and imported food to increase, putting upward pressure on inflation. The paper canvasses a number of policy options to enhance adaptation to climate change and variability. These include improving regional climate forecasting systems and their integration in model-based decision support systems, improving water storage and farming systems, investing in biotechnology research, improving infrastructure, improving farm support mechanisms, and constructing defensive structures.

**John Asafu-Adjaye**
Editor

# Implications of Climate Change for Agricultural Productivity in Ghana: An Agrometeorological Perspective

*Ferdinand D. Mawunya*[1]* *and Samuel G.K Adiku*[2]

## Abstract

Climate change is a phenomenon that is currently posing a lot of developmental challenges to many countries worldwide. These countries, majority of which are in sub-Saharan Africa, continue to struggle in their development because their economies are largely supported by agricultural commodities, mainly food and non-food crops. The crux of the matter is that, crop growth and development are intricately dependent on weather and climate. These latter factors are rarely stable and hence prone to high fluctuations at seasonal to annual time scales. The dependence of agricultural systems on an unstable weather and climate system accounts to a great extent, for the seemingly perennial instabilities experienced in agricultural and hence economic output of most developing countries. Thus, they become highly vulnerable to impacts of climate change thereby putting many areas of their lives at risk. Attempts were made in this paper to: (i) highlight the relationship between agriculture, particularly, crops and climate (ii) discuss the expected nature of the impact of climate change on agricultural crops grown in Ghana and (iii) share some views on necessary actions that Ghana needs to take in order to position itself in its attempt to confront the challenges posed to agriculture in Ghana by climate change impacts.

**Keywords**: Climate change, anthropogenic factors, photosynthesis, crop yield.

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## 1. Introduction

Agriculture is the most climate-dependent area of human life. In Ghana and most of sub-Saharan Africa as well as many developing countries worldwide, agriculture continues to play very significant roles in national economies. Climatic factors are rarely stable being characterised by high inter-seasonal to inter-annual variations everywhere in the world. For countries such as Ghana with 70% of its population deriving their livelihood from agricultural activities, changes in climate must be issues of great concern. The government of Ghana has taken a number of policy decisions towards mitigation of, and adaptation to climate change impacts. This paper discusses issues of climate change from an agrometerological point of view. It seeks to relate climate to agriculture and attempts to explain the relationship scientifically. The objective is to make it possible for any lay person to easily understand the climate-agriculture scientific relationship, in order to appreciate why climate change issues need to be tackled seriously particularly to safeguard the nation's agriculture.

The rest of the paper is organised according to the following main sections. Section 2 defines climate change and its causes. This is followed by a brief discussion of the nature of change of the principal climatic parameters, namely, temperature, precipitation and carbon dioxide ($CO_2$) levels in the third section. Section 4 discusses the link between climate and agricultural productivity through the process of plant photosynthesis. The penultimate section discusses what must be done to address climate change, while the final section contains the concluding remarks.

## 2. What is climate change and what are its causes?

The term 'Climate' refers to the average weather conditions, of any given geographic region, estimated over a long period of time, from a few weeks to infinite years, but generally for as long as 30 years or more (NASA, 2008; Wikipedia, 2013a). Weather on the other hand describes the state or condition of the atmosphere at a particular time (i.e., from a few minutes to few hours) and at a particular place (i.e., point location). Both climate and weather are described in terms of the same variable conditions such as solar radiation, precipitation, temperature, humidity, wind velocity and barometric pressure (American Heritage Science Dictionary, 2010).The difference between the two is that, in weather analysis the parameters are considered over short periods of time say a few seconds to a few hours, at or over a small location and on day-to-day basis. In climate analysis, the same parameters are considered but over a large spatial area such as a geographic region and over several years usually at least 30 years. Weather conditions may be regarded as transient as they may change within moments. For example, it may be rainy at a given location at a particular time but change to clear sunny conditions after a few minutes. In terms of values, climatic parameters are often much more stable and practically require multi-decadal time scales to show significant changes.

The Intergovernmental Panel on Climate Change (IPCC, 2011), defines “climate change” as “a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that which persists for an extended period, typically decades or longer. The change may be due to natural internal processes or external forcing or to persistent anthropogenic (human induced) changes in the composition of the atmosphere or in land use". As stated earlier, climate is described by parameters such as solar radiation, precipitation, temperature, humidity, wind velocity and barometric pressure. Canada's Action on Climate Change (CACC, 2012) therefore simplifies the definition as "a long-term shift in weather conditions identified by changes in temperature, precipitation, winds, and other indicators and can involve changes in average conditions and in variability, including extreme events. Simplifying the definition further, Wikipedia (2013a) defines climate change as "a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years and may be a change in average weather condition, or in the distribution of weather around the average conditions" (i.e., more or fewer extreme weather events).

Detailing of the causes of climate change is not intended in this discussion hence only a brief mention will be made. IPCC (2011) identifies natural internal processes, external forcings, persistent anthropogenic changes in the composition of the atmosphere or in land use as the general causes of climate change. Specifically, these causal factors include (i) oceanic processes such as oceanic circulation, that is, movement of ocean currents pushed by the wind, (ii) biotic processes, that is, interactions among living communities of plants and animals, (iii) variations in solar radiation (i.e., sunlight) received on earth which is also attributed to variations in the earth's orbit or the motion of the earth planet around the sun, (iv) plate tectonics which describes large-scale motions of the earth's lithosphere, that is, the crust and uppermost mantle which constitute the hard and rigid outer layer of the Earth, (v) volcanic eruptions, and (vi) human-induced or anthropogenic alterations of the natural world systems (Wikipedia, 2013a). Due to the overwhelming impact of human activities, climate change is easily perceived largely as human-induced. The anthropogenic activities include: industry, agriculture, mining, transportation, construction, deforestation and habitations (development of new human settlements).

## 3. The nature of climate change

In order to appreciate climate change, the next few sections present in brief, the nature of change of the principal climatic parameters – temperature, precipitation and $CO_2$ levels.

### 3.1 Temperature

Figure 1 shows the departure of mean annual global temperatures from the long term, 1880 to 2009, mean. Indications from the graph are that, in spite of the "rise-and-fall" nature of individual mean annual temperatures, the long term emerging trend is that of un-abating increase. It has been estimated that, global mean temperature could rise by 1.8°C by the end of the 21st century and that is about 66% over that at the end of the 20th century. The "likely" range of 1.1–2.9°C of temperature increase has been associated with this percentage increase based on expert judgement for the Special Report on Emissions

Scenarios (SRES B1) marker scenario. The highest estimate given so far has been a global mean temperature increase of 4.0°C, with a "likely" range of 2.4–6.4°C, (IPCC, 2007a). In Ghana, expected mean temperature increases are 0.6°C, 2.0°C and 3.9°C by the years 2020, 2050 and 2080 respectively over the 1961-2000 mean value (EPA, Ghana, 2011).

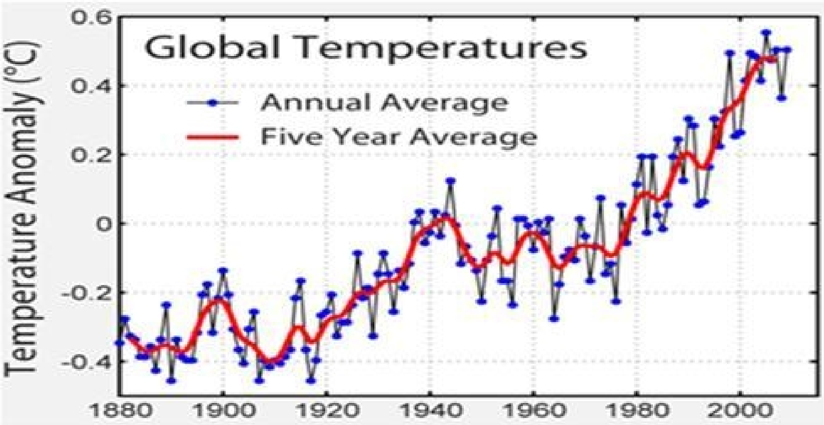


**Figure1:Global mean surface temperature difference from the average for 1880–2009**
Source: Herring (2012)

*3.2 Precipitation*

Figure 2 indicates that rainfall amounts over the African region between 1900 and 1965 generally exceeded mean annual values for most of the time. This was however followed by a downward trend which has since not shown any significant sign of reversal. Rainfall is the most variable climatic parameter and as such shows wide variability differences over ecological regions. In Ghana, based on 1961 to 2000 climate statistics, annual rainfall amounts are expected to decrease by 1.1 to 3.1% across all ecological regions by the year 2020 and by 13.0 to 21.0% by 2080 (EPA, 2011).

*3.3 Changes in global atmospheric carbon dioxide levels*

The global atmospheric concentration of carbon dioxide, perceived as the most important anthropogenic greenhouse gas has been found to increase from a pre-industrial value of about 280 ppm to 379 ppm [Figure 3, (IPCC, 2007b)]. The annual global carbon dioxide concentration growth rate between 1995–2005 averaged 1.9 ppm per year and was greater than for the 55-year period between 1960–2005 which averaged 1.4 ppm per year (IPCC, 2007b). In Ghana, the Environmental Protection Agency (EPA, 2011) indicates that Ghana's contribution to $CO_2$ emissions is 0.05% of global emissions. The EPA stated that though comparatively small, there is a potential for increase in the future if developmental pathways continue to be handled with “business as usual” attitudes.

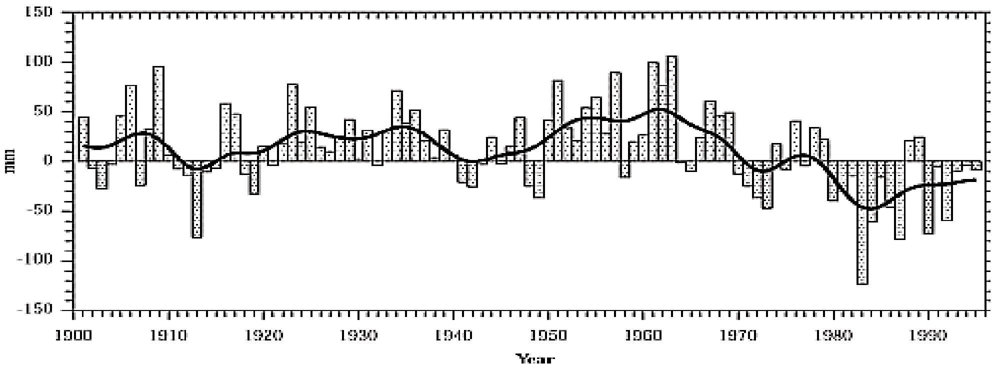


**Figure 2: Observed annual precipitation changes for the Africa region**

Source: IPCC(2001)

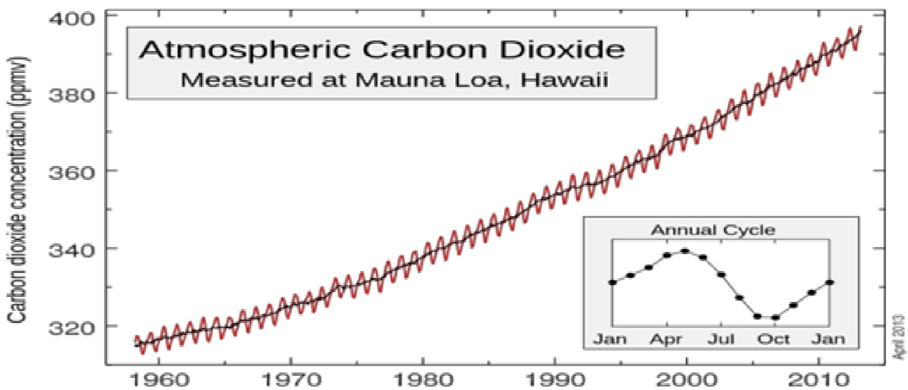


**Figure 3: The Keeling Curve showing observed atmospheric $CO_2$ concentrations as measured at Mauna Loa Observatory in Hawaii, USA**

Source: Wikipedia.org (2013b)

### *3.4 Climate change and changes in solar radiation*

Observations from different parts of the world indicate that solar radiation has gradually been increasing since 1985 (Figure 4). The phrase "global brightening" was suggested to describe the discovery that was believed to be a new trend as opposed to the term "global dimming" used since 2001 for the previously established decrease in solar radiation (Wild et al., 2005; Chiacchio et al., 2010). Observations from the Global Energy Balance Archive indicate regional decreases in all sky surface solar radiation from 1950s-1980s, followed by a gradual increase during the 1990s as depicted in Figure 4 (Allen et al., 2013).

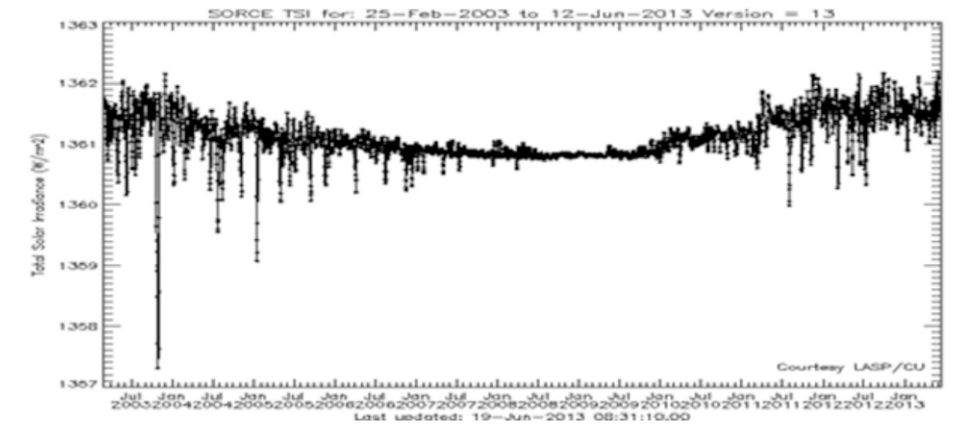


**Figure 4: Total Surface Irradiance (TSI) observed over Europe, China, Japan and India**

Source: Allen et al. (2013)

For Ghana, using the year 2000 as a baseline, mean daily solar radiation is expected to rise by 0.5 $MJm^{-2}d^{-1}$ by the year 2080 (EPA, 2011). While it is believed that solar radiation received on earth may be rising in magnitude, a review of available literature seems to suggest some degree of uncertainty among scientists with respect to its accurate measurement. *Hansen et al.*, (2005) noted that instrument inaccuracies are a significant source of uncertainty in determining the earth's energy balance from space-based measurements of incoming and reflected solar radiation and outgoing terrestrial thermal radiation.

## 4. Climate change and agriculture

The link between climate and agricultural productivity is established through the process of plant photosynthesis. This is a complex biochemical process by which green plants and some autotrophic (self-feeding) organisms synthesise organic compounds from carbon dioxide and water (with the release of oxygen) using light energy normally from the sun (i.e., solar radiation). For the sake of easy understanding, this complex process is often presented simply by the following chemical equation:

$$\text{Carbon dioxide} + \text{Water} \longrightarrow \text{Glucose} + \text{Oxygen}$$

This can be expressed in chemical notation as:

$$6CO_2 + 6H_2O \xrightarrow[\text{TEMPERATURE}]{\text{SOLAR RADIATION}} C_6H_{12}O_6 + 6O_2$$

Chemically, the glucose unit, $C_6H_{12}O_6$, produced is referred to as a 'simple sugar' and undergoes further chemical processes to become converted into complex sugars such as carbohydrates. Portions of the carbon products of photosynthesis are used by the plant itself for:

- aerobic respiration i.e chemically broken down to release energy for other biochemical processes of the plant
- (ii) conversion into the plant's own structural parts which is responsible for growth in size of the plant and,
- (iii) the remainder is finally stored as reserved photosynthetic product.

The latter may be food or non-food in nature. Reserves that are food in nature are the ones harvested by farmers as the various kinds of farm produce. The non-food reserves may take the form of various types of industrial materials such as fibres (e.g. cotton wool), wood (e.g. timber or even fuel wood) and many other plant products. Photosynthesis is fundamentally responsible for any produce or product obtained out of plants. Plant produce and products feature very prominently in the daily life of man, in national as well as international trade and politics. The importance of plant and plant products in the life of man can therefore never be overemphasised.

*4.1 Photosynthesis and climate change*

Crop yields are essentially end-products of photosynthesis. Any factor that affects the biochemical process of photosynthesis will therefore invariably impact on crop yields. From the chemical equation, it can be seen that the major atmospheric factors affecting photosynthesis and for that matter crop yields are carbon dioxide, water, solar radiation and temperature. Incidentally, it is the changing atmospheric status of these same factors that is bringing about the entire phenomenon of climate change. The horizontal arrow in the chemical equation is an indication that the photosynthetic process is an irreversible process. This means *once it is done, it cannot be undone.* In chemical reactions, it is the levels or quantities of reactants, in this case, carbon dioxide and water that determine the levels of the product, that is, the simple sugar glucose, which is the building block of carbohydrates. Solar radiation and temperature are not reactants but are environmental conditions that have a dominant influence on the photosynthetic process. A brief discussion explaining why and how changes in (i) levels of carbon dioxide and water and (ii) status of solar radiation and temperature and for that matter climate change will impact agriculture.

*4.1.1 Impacts of increasing atmospheric $CO_2$ levels*

Recall the photosynthetic equation:

$$6CO_2 + 6H_2O \xrightarrow[\text{TEMPERATURE}]{\text{SOLAR RADIATION}} C_6H_{12}O_6 + 6O_2$$

As noted already, $CO_2$ is a reactant in this equation. Keeping all other factors and conditions normal, it is expected that an increase in $CO_2$ should promote the reaction in the forward direction. That is the reaction will be enhanced leading to more photosynthetic products. This is observed to be the case for all plants. It is however observed that while plants classified as $C_4$ plants are generally more efficient in photosynthesis than their counterpart $C_3$ plants, $C_3$ plants show higher a response to $CO_2$ enrichment than $C_4$ plants (Allen and Prasad, 2004; Bury, 2009; SERC, 2013). $C_4$ plants are plants whose initial products of photosynthesis are four carbon-atom molecules (oxaloacetate), while $C_3$ plants are those whose products are a pair of three carbon-atom molecules (3-phosphogylycerate) [Biology-online, 2013]. $C_3$ photosynthesis is less efficient than $C_4$ partly because of an effect known as photo-respiration. This involves chemical combination of carbohydrates with oxygen in plants with the release of carbon dioxide. It requires the presence of light and takes place during photosynthesis. It occurs under stress conditions when the amount of carbon dioxide entering the plant is reduced due to the closure of stomata in order to reduce excessive water loss. Photorespiration then occurs to produce more carbon dioxide for photosynthesis. Unlike cellular or dark respiration, photorespiration does not produce any energy such as ATP and so consumes chemical energy (carbohydrate) rather than produces it (American Heritage Science Dictionary, 2005).

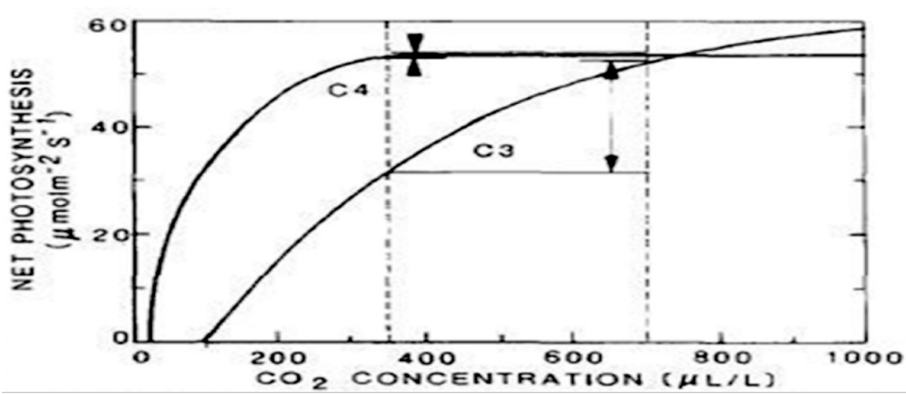


**Figure 5: The effect of $CO_2$ concentration on photosynthetic rate of $C_3$ and $C_4$ crops at constant temperature**

Source: T*aiz and Zeiger*(*1991*)

In Figure 5 above, as $CO_2$ levels increase, photo-respiration is suppressed and the photosynthetic efficiency gap between $C_4$ and $C_3$ plants rapidly closes. At a $CO_2$ concentration of 780 parts per million (ppm) which is double the current global levels of 390 ppm, the photosynthesis rates are the same. Beyond 780 ppm, $C_3$plants out-perform $C_4$ plants (T*aiz and Zeiger, 1991).*

Generally, $C_3$ plants are noted to have significantly higher $CO_2$ saturation capacity (50-150 scale level) than $C_4$ plants (0-10). This explains why $C_3$ plants will respond much more to $CO_2$ enrichment than $C_4$ plants. Nevertheless, out of the estimated 86 plant species that supply most of the world's food, only four (maize or corn, sorghum, millet and sugarcane) are $C_4$ plants and yet by estimation, these four contribute about 20% to global food production. This is due to the fact that $C_4$ plants have higher dry matter or carbohydrate production capacity than $C_3$ plants. The impact of increased levels of $CO_2$ on the output of $C_3$ and $C_4$ crops is illustrated in Figure 5.

For example, while $C_3$ crops such as soybean and wheat have average grain outputs of 1.8 and 2.0 ton/hectare respectively, $C_4$ crops such as maize (corn) and sorghum produce average yields of 5.5 and 3.2 tons/hectare respectively. Other $C_4$ plants include halophytes (i.e., salt-tolerant plants e.g. mangroves) and many tall tropical grasses, pasture, forage and weed species (Allen and Prasad, 2004; Bury, 2009; SERC, 2013).

Common $C_3$ food crops in Ghana and many tropical regions include: most small grain cereals (e.g. rice); all grain legumes or pulses (dry bean, soybean, groundnut or peanut, mung bean, faba bean, cowpea, common pea, chickpea, pigeon pea etc.); root and tuber crops (cassava, yams, potatoes, taro etc); vegetables, most oil crops (palm, sesame, sunflower, rapeseed, safflower etc.), nearly all fruits including banana, coconut, nuts and fibre (e.g. cotton, jute, sisal) crops. Trees and for that matter tree crops are also classified under $C_3$ plants as well as most horticultural crops. Some crops are known to exhibit a $C_3$ or $C_4$ pathway depending on prevailing conditions and include crops like some varieties of cassava, pineapple, opuntia, onions and castor. They are referred to as crassulacean acid metabolism (CAM) plants. Thus keeping other factors conducive to photosynthesis, increases in global $CO_2$ levels will be good news for agriculture generally. The negative implication is that, increased $CO_2$ levels will contribute to global temperature rises leading to global warming. Impacts of temperature increase or global warming on plants will be discussed in a subsequent section.

### *4.1.2 Impacts of changing $H_2O$ on photosynthesis*

In the photosynthetic equation, $H_2O$ or water is one of the two reactants. If $H_2O$ becomes a limiting factor, levels of photosynthetic product (carbohydrate) and hence crop yield will be limited. Effects of water on crop yields are usually demonstrated by crop water production functions. These are equations that express the relationship between the quantities of water used by crops and the amount of yield obtained. Figure 6 shows a graphical representation of a crop yield-water relationship. The graphical representation shows that while increasing water availability causes increased crop yields, the relationship is not a directly proportional relationship but curvilinear (note the thick black curve) up to a point and then deviates from curvilinearity where increased water no longer results in increase in yield (flat portions of curve starting from the locus of optimal yield-irrigation point).

Rainfall water, stored in the soil as soil water, is the main source of this water for photosynthesis, which takes place in plant leaves. Plant roots absorb soil water which gets to the leaves by a complex process known as transpirational pull through specialised tissues in the plant known as xylem vessels. Inadequate rainfall leads to insufficient soil moisture causing soil moisture stress. This in turn translates into leaf moisture stress which impacts negatively on the photosynthetic process. Apart from its role as a reactant in the photosynthetic process, water plays several other important roles in the growth and development of plants and is hence a very crucial factor for agricultural productivity.

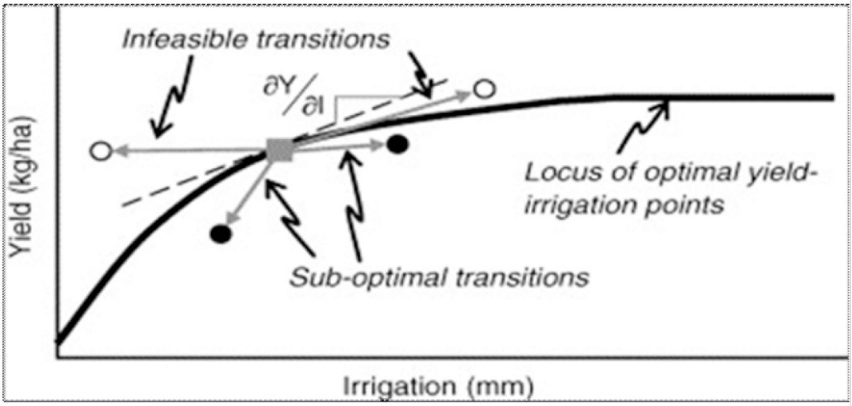


**Figure 6:General crop-water production function as determined from crop yield-irrigation gradients**

Source: Brumbelow and Georgakakos(2007)

Rainfall is a climatic factor, hence any change in climatic conditions will firstly affect the level of rainfall and hence rainwater supply to the soil. Secondly, it will affect soil moisture content and hence the amount of water absorbed by plant roots and distributed to all parts of the plant including the leaves where the photosynthetic process takes place. This will consequently affect the quantity of $H_2O$ in the photosynthetic equation and thus either promote or limit the process. The final outcome will either be increased or decreased crop yield depending on the nature of climate change. Since the 1960s some negative changes in seasonal rainfall characteristics have and continue to occur over the Africa region due to climate change (Figure 2). These changes have created problems for agricultural output when we recall that the photosynthetic process is an irreversible process. Once insufficient moisture causes disruptions at any growth stage of the crop, it becomes irreversible and hence reflects in the final yield.

Changes in rainfall characteristics that have negatively affected agricultural output in Ghana include:

(I) Late onset and early end of rains during the cropping season. This reduces the duration of field moisture availability to crops implying the rains may stop when the crops are still growing in the field and in need of water to complete their life cycle; and

(ii) Poor rainfall or drought leading to insufficient moisture or moisture stress during critical growth periods of crops.

Insufficient moisture during time of planting will lead to no or poor seed germination and seedling emergence or sprouting of cut-crops (e.g. cassava, yams and so on planted as cuttings) as well as poor establishment of crops in the field. Moisture stress during the reproductive growth stage (i.e., the periods of floral initiation), flowering and grain filling in cereals, flowering and fruit formation in fruit crops, tuber formation in root crops, flowering and nut formation in nut crops and others, will significantly reduce crop yields. On the opposite side, excessive rainfall leading to flooded or prolonged saturated field moisture conditions also creates un-aerobic (low or no oxygen) soil conditions. This negatively affects, particularly, upland crops that grow best in moist but unsaturated and well aerated soil environments.

Prediction outcomes of most global climate models indicate that climate change will result in more frequent rainfall extremes such as prolonged drought periods and floods (IPCC, 2007c). These are already being confirmed by real time meteorological records and media reports.

*4.1.3 Impacts of changing solar radiation*

Solar radiation or sunlight energy is not a reactant in the photosynthetic process but an environmental, weather and climatic factor exerting considerable influence on the process. Plant leaves have the capacity to absorb sunlight energy for use in the creation of chemical energy in a form known as adenosine triphosphate (ATP). The ATP molecules provide the chemical energy that propels the photosynthetic process to completion. As far as the equation is concerned, available solar radiation should promote the photosynthetic process as shown in Figure 7.

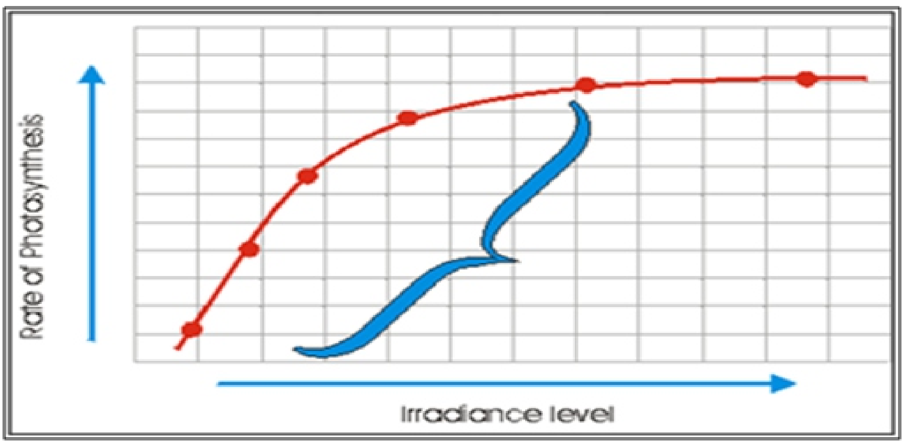


**Figure 7: Relationship between plant photosynthesis and solar radiation**

Source: Spilatro (1998)

The response curve can be divided into two phases. From low-light levels, the rate of photosynthesis increases as the irradiance level is increased (as highlighted by the blue parenthesis). Beyond the upper point of the parenthesis, referred to as the 'light saturation point', the rate of photosynthesis levels-off. Any further increase in the amount of light incident on the leaf does not cause an increase in the rate of photosynthesis. The extra amount of light is said to be 'saturating' for the photosynthetic process (Spilatro, 1998). It is noteworthy indicating that, $C_3$ and $C_4$ plants respond quite differently to solar radiation levels. While $C_3$ plants easily reach their light saturation levels, $C_4$ plants are noted to have no light saturation level. This is an indication that $C_4$ crops can withstand increasing solar radiation due to climate change much more than their counterpart $C_3$ plants.

With respect to impacts of elevated solar radiation on crops, Dumpert and Knacker (1985) noted that the results obtained with a given crop species are frequently contradictory when comparing the effects of UV-B exposures in growth chambers or greenhouses to those under field conditions. The reasons for this observation have included: differences in crop responses even for the same crop species by different investigators at different times and locations (Krupa and Kickert, 1989). Teramura *et al.,* (1991) later indicated that, in many cases these differences reflect cultivar and varietal differences in sensitivity within a given species. Another reason for the differences comes from the use of different UV-B light sources and some more reasons.

In spite of all these challenges, Krupa and Kickert (1989) and Runeckles and Krupa (1994) noted from artificial exposure studies that though there are exceptions, elevated surface-level UV-B radiation showed negative impacts on several aspects of plant growth including reduction in dry matter production and yield. Observations are that direct impacts of high UV-B radiation action on plants resulting in changes in form or function of plants appears to occur more often through altered gene activity rather than damage. The yield of some crop varieties may be decreased by elevated UV-B radiation but others may not be affected. While research continues to fine-tune solar radiation measurement and impacts assessment on crop yields, it may be safe to prepare for the unexpected.

### *4.1.4 Impacts of temperature changes*

Discussions so far have highlighted the fact that agricultural productivity largely depends on the process of photosynthesis. Crop yield is closely related to net photosynthesis defined simply as photosynthetic activity minus respiratory activity. Cellular respiration is the general process by which organisms oxidize organic molecules (e.g., sugars) and derive energy (ATP) from the molecular bonds that are broken and as such can be perceived as the opposite of photosynthesis. It is described by the equation:

$$\text{Glucose} + \text{Oxygen} \longrightarrow \text{Carbon Dioxide} + \text{Water} + \text{Energy}$$

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 36\ ATP$$

Photosynthesis leads to a build-up of organic materials or sugars in plants while respiration is the reverse or breakdown. Both processes occur simultaneously during day time but while photosynthesis occurs mainly during the day, respiration continues at all times. Both photosynthesis and respiration are biochemical reactions and each is affected by temperature. Increased temperatures provide heat that increases the kinetic energy and hence the rate of collision of the reactants subsequently speeding up the two chemical reactions. Figure 8 illustrates the impact of temperature on both processes. Both processes are acted upon by enzymes which are proteins. Holding all other factors constant, gradual increases in temperature cause increases in the rate of both processes. As temperature increases, a point is reached where the optimum temperature range of operation of the enzymes is exceeded.

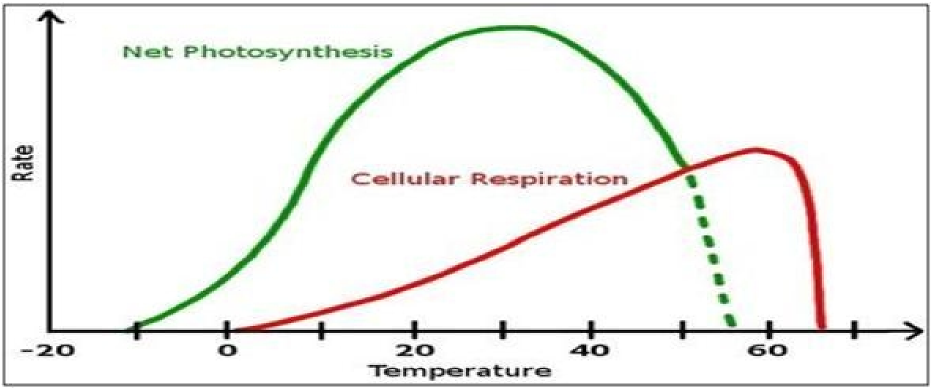


Figure 8:The effect of temperature on the rates of net photosynthesis and cellular respiration

Source: Barber (2013)

Excessive heat alters the shapes of enzymes and as such enzyme activity in both processes becomes disrupted. This is called "denaturing" of the enzymes leading to a fall in the rate of both processes. Net photosynthesis is determined by the difference in the degree of rise and fall of the two processes at any point in time. Photosynthesis takes place mainly during the day time while respiration occurs unceasingly both day and night. Thus high night temperatures can increase dark or cellular respiration of plants diminishing net biomass production. Dark respiration is the biochemical process taking place within plant cells at all times and which creates energy for growth, biosynthesis of structural compounds and maintenance of normal activities of living cells by oxidizing sugars which are photosynthetic products. The other type of respiration which also reduces photosynthetic output is photorespiration already discussed. Respiration therefore largely determines net photosynthesis which is a measurement of yield output. Any factor therefore that increases plant respiration will cause a limitation to crop output.

It is important to point out that the two main groups of plants, $C_3$ and $C_4$ respond slightly differently to temperature variations. While the optimum temperature range for photosynthesis in $C_3$ plants is 15-25°C, that for $C_4$ plants is 30-47°C. Temperature rise due to climate change should therefore be expected to affect $C_3$ crops more severely than $C_4$ crops (SERC, 2013).

#### *4.1.6 Combined effect of climatic factors*

For the sake of easy understanding, the discussion so far generally focused on impacts of the individual principal climatic factors. Holding other factors constant at optimum levels, their general change impacts on plants and therefore on agricultural crops have been shown through reported experimental results with many of them conducted in laboratories and green houses (controlled environments). In the natural world however; (i) crops are exposed to various levels of expected and unexpected variations of any of the climatic parameters. Crop yield output is an outcome of complex interactions of the soil, crop, management and climate factors. The first three can, and have always been modified quite appreciably by man for enhanced results. Research scientists are yet to muster the scientific abilities to manipulate climatic parameters to man's benefit.

#### *4.1.7 Scientific research interventions*

Advances in science and technology have made it possible to make useful and timely predictions by means of climate forecasting using computer-based dynamic and statistical models known as Global or General Circulation Models (GCMs) [IRI, 2013]. There are also Regional Circulation Models (RCMs). These models are developed using long term climatic data collected by sensors mounted at meteorological stations, on ships, as buoys (anchored floats) and as satellites. Applications of these models have now made it possible to predict climate (particularly rainfall) fluctuations globally with lead times of about one year (Barnston et al., 1994; Chen et al., 1995; TOGA, 1996; Latif et al., 1998). Opoku-Ankomah and Cordery (1994), Adiku and Stone (1995), Adiku (2003), Adiku et al. (2007) and Mawunya et al. (2011) have all demonstrated the possibility of using GCM information to predict seasonal rainfall in Ghana. There are also climate-crop models which have almost become common-place. These also are models that can be used to simulate (or predict) site-specific crop growth and development and hence crop yields with requisite input soil, crop, management and climate information. These models have also been used for the prediction of yields of a number of crops in Ghana by Adiku et al. (2001, 2007), Mawunya (2008) and other researchers. Application of GCMs and climate-crop models for rainfall and crop yield predictions, respectively, as well as provision of information to aid decision making at both farm and national levels in Ghana are major aspects of research studies at the Department of Soil Science and the Soil and Irrigation Research Centre (SIREC, Kpong) of the College of Agriculture and Consumer Sciences, University of Ghana. With these technological developments, it has also become possible to (i) provide new estimates of how agricultural production will be impacted by climate change, and (ii) improve understanding of the impact of climate change on future agricultural production by utilizing site-calibrated crop models to coordinate projections of crop response under probabilistic climate change scenarios. Rosenzweig and Parry (1994) noted that, theoretically, system models are the only scientific tools which can help look into the future and assess the prospective effects of climate change.

## 5. What must Ghana do?

Discussions in this paper have been centred on agriculture and climate. Even though there is still more room for improvement, it could be said that fairly modest gains have been made by way of agricultural research in Ghana. Ghana's Council for Scientific and Industrial Research (CSIR), Colleges, Schools and Departments of Agriculture of the country's universities have been making laudable research efforts at improving agronomic, soil and management aspects of Ghana's agriculture. Irrigated lands account for 0.08% of Ghana's agricultural land (MOFA, 2003), with irrigated rice being the only beneficiary crop as far as irrigation in Ghana is concerned. Upland crops (crops not cultivated under waterlogged field conditions) are produced in Ghana under rain-fed conditions, that is; dependent entirely on rainfall. Yet these crops constitute the bulk of Ghana's food and non-foodstuffs. The rainfall dependence makes Ghana's crop production to be seasonal in nature meaning “no rainfall, no crop production”. The southern half of Ghana experiences two rainfall seasons namely: the major or first season spanning March to July; and the minor or second season spanning September to November. The northern half of Ghana experiences only one long rainfall season spanning May to October. Crop production is therefore limited to these rainfall seasons. Statistics show that Ghana's water resources can cover about 5% of the country's landmass (CIA, 2013). This quantity of water is enough to provide the necessary irrigation that could rid the country's agriculture of rainfall dependence. Irrigation is however expensive in terms of installation and management. It is even more expensive with respect to upland crop production given the very small areas of land, 0.4 to 1.2 ha (1 to 3 acres) cultivated by most Ghanaian farmers. It therefore appears that the only viable and comparatively less expensive option open to Ghana is high precision seasonal climate (particularly rainfall) forecasts that will lead to recommendation of best planting periods and hence best field management practices to Ghanaian farmers.

The implications of this antidote are as follows:

- It would be necessary to set up a permanent Climate Research Outfit that will operate in a multi-disciplinary manner. Such a unit would need to be staffed with Climate scientists, agronomists, soil scientists, meteorologists, agricultural economists, agricultural extension officers and specialists from all other relevant fields of study. Collaboration with some relevant government ministries or agencies e.g. Ministry of Food and Agriculture (MOFA), Environmental Protection Agency (EPA) may be needful. The unit could start “small” and grow “big” later.

- The task of these specialists would be to work in a coordinated manner and produce what are called relevant 'climate products and services' in a timely manner as and when needed by farmers.

- The outfit would provide advisory services such that farmers can plan and take advantage of a coming “good rainfall season” to maximise farm output and incomes. Farmers should similarly be alerted about a coming “poor rainfall season” in order to strategise to minimise crop yield losses and hence farm incomes.

- Provision of high precision climate forecast demands equipping the Ghana Meteorological Agency with state-of-the art equipment in order to capture relevant information on all climate scenarios.

- Several countries worldwide and even in Africa have already gone very far in this regard. Such an outfit will therefore need to link-up with these international climate research institutions for all forms of necessary collaboration.

- Manpower development cannot be ignored. Ghana has very few specialists in climate science and climate related fields of study who seem to be working most of the time independently in their individual 'enclaves'. A National Climate Research Institute (NCRI) can champion the needed manpower mobilisation and development. In the meantime, attention can be turned towards the country's universities to see which departments would be capable of developing suitable academic programmes to serve this need.

- A NCRI can start with full government financial and institutional support and gradually gain full or semi-autonomy. The essence would be to avoid bureaucracies that can lead to delays and interruptions in the research activities of the unit.

- Farmer-based organisations would need to be strengthened throughout the country in order to have active interactions with the NCRI.

- The Unit could work to address challenges posed by climate change in other areas such as health, flood events in settler communities, migration, construction and many others.

- Climate Research Institutes elsewhere have built tremendous credibility for themselves enough to win huge research contracts that keep them in good financial standing. A Ghana NCRI could do same.

- Many more views and perceptions could come-up for discussion on the establishment of a NCRI. A meeting of interested scientists, stakeholders, climate-oriented non-governmental organisations and so on can be organised for a brainstorming session on definite modalities prior to the 'birth' of such a unit.

While awaiting the establishment of a NCRI, support for the Ghana Meteorological Agency could be enhanced for improved climate information service delivery. On page 155 of the Ghana EPA Communication to UN 2 (2011), the EPA of Ghana states that “EPA has an energy resource and climate change unit which is well positioned to offer strategic technical support to the development and implementation of climate-smart projects which have a direct bearing on climate change issues in the country. In addition, the unit is supported by climate change focal points in the various departments in the Agency”. Thus it is trusted that EPA will continue to receive all forms of necessary support in order to continue delivery of these relevant programmes that should help agricultural planning as well.

## 6. Concluding remarks

The level of climate change in the future will be determined by human activities, in contemporary times and over the coming years that either reduce or increase impacts on the climate system. The close and intricate relationship between crops and the atmosphere by way of crops' need for climatic factors for growth and development underscores their vulnerability to climate variability and change. Adequate information on climate dynamics should make it possible to improve agricultural productivity through climate-informed strategic decision-making at all levels of agricultural planning.

This paper attempted to highlight the relationship between agriculture and climate and for that matter, the impacts of climate change on crop production in Ghana. Establishment of a Climate Research Unit that will operate in multidisciplinary dimensions, as pertains in some developed and developing countries, will be an effective way of taking the 'bull of climate change' by the horns in Ghana to confront the challenge holistically.

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# Assessing the Potential Impact of Climate Change on Maize Production in Two Farming Zones of Ghana Using the CERES-Maize Model

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## Abstract

Climate change resulting from increased atmospheric loading of $CO_2$ and its associated effects of increased global warming and declining rainfall in West Africa is a major threat to agricultural production in the region. This study assesses the impact of climate change and potential adaptation options on maize production in the Guinea Savannah and Forest-Savannah Transition agro ecologies in Ghana. A national aggregated climate change scenario, data on soil properties, 30 years historical weather data, crop characteristics and management practices are used as inputs to CERES-Maize, a crop simulation model, to assess the impact of climate change on the yield of the widely cultivated maize variety (*Obatanpa*). Afterward, some potential adaptation options to minimize adverse impacts of climate change on maize productivity were assessed. The simulation results show that climate change resulted in the reduction of maize grain yield by 19-41% across both agro-ecological zones. Though increased $CO_2$ under climate change may have resulted in carbon fertilization, under high fertilizer input systems the effect of increased temperature alone resulted in the largest yield reduction (22 to 46%) under climate change conditions compared with the historical condition. The simulation results also indicated that the introduction of a heat and drought tolerant virtual maize cultivar improved yields by 12 to 15% over the yield of the *Obatanpa* maize when grown under future climate change conditions. The findings suggest the need for a policy to support crop breeding research to develop climate-suitable varieties and also to support the use of crop simulation modeling as effective tools to assess agricultural technology under climate change conditions in Ghana.

**Keywords**: Adaptation, climate change, crop simulation modeling, maize yield.

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## 1. Introduction

Climate change has been accepted globally as a phenomenon that threatens agricultural productivity especially in the West African tropics due to the high dependence on weather for agricultural production. This change is attributed to increased atmospheric loading of CO2 and other greenhouse gases (Forster et al., 2007, Moriondo et al., 2011). The Intergovernmental Panel on Climate Change (IPCC) has since 2002 provided strong evidence of accelerated global warming as a result of increasing concentration of greenhouse gases ($CO_2$, methane, $N_2O$, etc.) in the atmosphere. This warming is associated with changes in the distribution and amounts of precipitation, and increased frequency of the occurrence of extreme weather events such as droughts and floods (Adiku and Stone, 1995; Singh et al., 2012).

The situational analysis of climate trends at two agro-ecological zones of Ghana shows a combined increase in historical temperature and decline in rainfall (Figure 1). Climate change is therefore an issue of concern for agricultural development in developing countries.

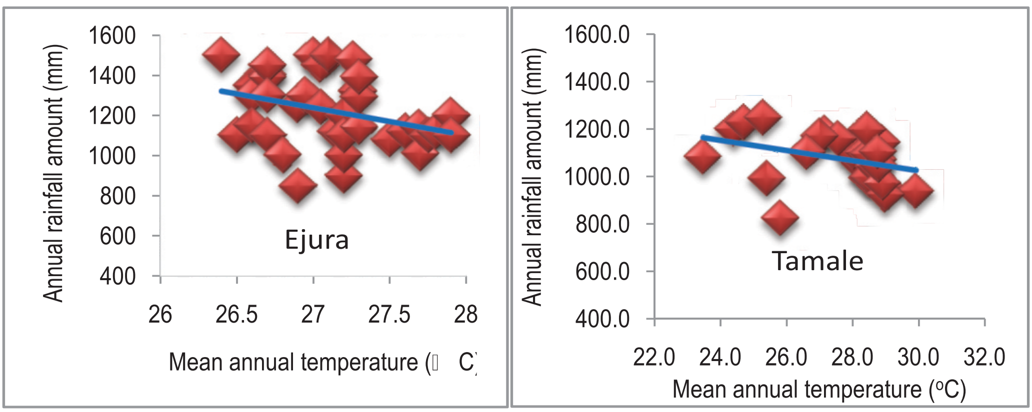



**Figure 1: Relationship between rainfall and annual mean temperature (1980 to 2010) for two agro-ecologies of Ghana**

The economy of Ghana is highly dependent on agriculture, employing about 60% of the workforce and contributing significantly to the country's Gross Domestic Product (GDP). Since almost all agricultural activities in Ghana are dependent on rainfall, its agricultural productivity is strongly influenced by changes in weather patterns. This makes agriculture (especially crop production) vulnerable to climate change. Yet, quantitative estimates of crop yield impacts continues to be lacking, resulting in difficulties in formulating of policy decisions for technology development that would offset the adverse effects.

Studies in other parts of the world have indicated variable results of the impact of climate change on crop depending on their location (Rosenzweig and Iglesias, 2001; FAO, 2001; Jones and Thornton, 2003; Hartkamp et al., 2001). Generally, whereas it is known that increased CO2 is beneficial to crop growth due to carbon fertilization, free air carbon enrichment (FACE) experiments showed that productivity could increase in the range of 5–10% for crops such as maize (*Zea mays*), with the increase in atmospheric carbon dioxide ($CO_2$) concentration (Tubiello et al. 2007). However, increasing temperatures and increased frequency of droughts could offset any such gains from carbon fertilization. Furthermore, given that rainfall is often very variable in space, site-specific studies are required to quantitatively assess how the local crop production is affected by climate change. Such studies are generally lacking in Ghana, apparently because of the need to use appropriate tools to assess the effect of complex interactions between $CO_2$, temperature, rainfall and management practices on crop growth and yields.

Crop simulation models (CSMs), provide us with the unique capability to carry out such assessments. The "Decision Support Systems for Agro-technological Transfer" (DSSAT) is a CSM that has been widely tested, used and recognized to be reliable in simulating crop yields under variable environmental and management conditions (Jones et al., 2003, Jones and Thornton, 2003). In Ghana, this tool was used by scientists such as Adiku et al. (2007), Dzotsi et al. (2010), Fosu et al. (2012) and MacCarthy et al. (2012) to assess the impact of weather, soil and management factors on maize yields in different ecosystems, with great reliability in yield predictions. The DSSAT model has well tested in-built algorithms that allow for the simulation of crop yield, growth and development as well as soil processes (water and nutrients). It integrates weather parameters (rainfall, temperature and solar radiation), soil properties, crop management practices and genetic traits of crops and hence is a suitable tool for climate change impact studies.

This study focuses on maize because of its importance as a major staple food crop for most communities and contributes about 20% of calories to Ghanaian diet (Braimoh and Vlek, 2006). The purpose of this study is twofold. First, the effects of increased temperature and $CO_2$ concentration, decreasing rainfall and nitrogen fertilizer application on maize productivity in the Guinea Savannah and transitional zones of Ghana under both historical climate and future climate scenario is assessed using the CERES-Maize model of DSSAT. Second, an adaptation technology that involves the development of a 'virtual' new heat and drought tolerant maize cultivar was assessed under the future climate change scenario in comparison with the currently cultivated *Obatanpa* variety.

## 2. Materials and methods

### *2.1 Study sites*

Two locations – Tamale, representing the Guinea Savannah zone and Ejura, representing the transitional (Semi deciduous forest-Guinea Savannah) zone (Ejura) – were selected for this study. Both areas contribute significantly to maize production in Ghana. Tamale is located at latitude 9°28" N and longitude 0°55" W, while Ejura is located at latitude 7°19" N and longitude 1°16" W. Both areas are underlined by voltaian sandstone, with clayey and sandy loam soils dominating. The mean annual rainfall and temperature are 1095 and 1264

[6] Carbon fertilization is increased plant growth due to increase $CO_2$ concentration in the atmosphere.

mm and 34 and 32 °C for the Tamale and Ejura, respectively. Tamale has a uni-modal rainfall pattern, that is, it has one rainy season from May to October with a peak in September while Ejura experiences a bimodal rainfall pattern from April to July with a peak in June as the major season and September to November with a peak in October as the minor season-. The major season at Ejura receives about 66% of the annual rainfall.

*2.2 The CERES maize model*

CERES-Maize is one of the suites of models in the DSSAT 4.5 crop simulation model (Hoogenboom et al., 2010). It simulates the growth, development and yield of maize on a daily time scale. The model utilizes daily weather (rainfall, solar radiation, minimum and maximum temperature), soil data (texture, bulk density, N, P, organic matter, etc.), farm management practices (planting date, planting density, fertilizer application rate and dates etc.) and crop genetic characteristics (crop development and growth coefficients) to simulate crop growth and yield. The phasic and morphological developments are calculated based on daily temperature, day length and genetic characteristics (Jones and Thornton, 2003). The model also has water and nutrient balance sub-modules that provide feedback that influences crop development and growth (Richie, 1998). The successful previous use of the model has been indicated above. The response of the model to elevated $CO_2$ has also been documented.

*2.3 Simulating the impact of climate change on maize yields*

The seasonal analysis program available in DSSAT v4.5 (CERES-Maize) was used to simulate the impact of climate change on maize productivity for the two sites. Several sets of simulation runs were carried out. First, thirty years baseline historic weather data (1980 to 2010) for each site was used to simulate maize yields under current climate conditions. For these simulation runs, the $CO_2$ concentration of the atmosphere was set to the current value of 380 ppm (Table 1). Second, climate conditions likely to obtain in the near future (2020 to 2050) were set up as shown in Table 1.

**Table 1: Climate scenarios for maize yield simulations**

| Factor | Baseline (1980 to 2010) | Future (2020 to 2050) | Reference |
|---|---|---|---|
| $CO_2$ (ppm) | 380 | 530 | IPCC (2001) |
| Temperature (°C) | historical | historical + 2.4 | WGB (2010) |
| Rainfall | historical | 0.90 x historical | WGB (2010) |

The effect of temperature was entered into the environmental modification option in the model as changes (delta method) in temperature, $CO_2$ was entered as an absolute value to replace the default value and rainfall was entered as a ratio of the baseline rainfall amounts. A planting window of 15$^{th}$ April to 30$^{th}$ May was given for planting to occur when soil water in the top 30 cm is above 40% of the extractable water. In the Guinea Savannah, a planting window of 15$^{th}$ May to 30$^{th}$ June was prescribed with the same moisture conditions as above as a pre-condition for planting to be carried out. A planting density of 4.4 plants/$m^2$ was used for both sites. Two levels of Nitrogen (N) fertilizer (30 and 120 kg N $ha^{-1}$) were applied in two splits at 14 and 45 days after planting. Application of 30 kg N $ha^{-1}$ is characteristic of farmer practices. Two soil types were selected for both sites (sandy loam and a clayey loam) with the soils in transitional zone being more fertile and with deeper rooting depths than in the Guinea Savannah.

*2.4 Developing adaptation technologies*

Maize adaptation to climate change was simulated by considering a 'new virtual' variety by modifying four attributes of the local *Obatanpa* variety[7]. This was done in four steps. Firstly, the density of roots was increased from beneath the 30 cm soil depth by 30%. This was to enable the plant roots to explore more of the soil profile for the uptake of water and nutrient resources as pertains under drought and/or nutrient stress conditions. Secondly, the root length to weight ratio of 0.98 was increased by 10%. Thirdly, the extractable water soil water in each layer was increased by 10% by redefining the lower limit of the soil by the following equation:

$$LL(Tol) = LL - 0.1*(DUL - LL) \quad (1)$$

Where LL is the lower limit (soil water content below which root water extraction ceases);
DUL is the upper limit (maximum soil water after drainage); and
LL (Tol) is the lower limit for the virtual cultivar.

This was based on the presumption that drought tolerant cultivars extract water more effectively from each soil layer (Singh et al., 2012). Finally, heat tolerance was improved by increasing the optimal and maximum temperature threshold for relative grain filling rate by 2°C in the genetic coefficient file of maize. The performance of the virtual cultivar was compared with that of the local variety (*Obatanpa*) under the future climate scenario.

The analysis of simulated maize yields under historical and future climate was based on statistical tests of differences between means.

## 4. Results

*4.1. Maize performance in the Transition zone*

The simulated yields of maize (*Obatanpa*) were varied with soil type, fertilizer application and climate scenario. The average yields of maize on the clayey and sandy loamy soils under baseline (historical) weather and low fertility in the transitional zone were 1669 ± 400 and 2146 ± 435 kg $ha^{-1}$, respectively (Table 2).

[7] A virtual varietyis a conceptual cultivar orideotype.

**Table 2: Effect of increased temperature, $CO_2$ concentration, and combined effect of temperature, $CO_2$ and rainfall on the yield of maize (Obatanpa) in the Guinea Savannah and Transitional zones of Ghana**

| | Historical | | Future | | | | | |
|---|---|---|---|---|---|---|---|---|
| Zone-soil type | Baseline yield (kg $ha^{-1}$) | | Temp effect % change | | $CO_2$ effect % change | | CC effect % change | |
| | L | H | L | H | L | H | L | H |
| GS Clayey loam | 1262 ±321 | 2416 ± 917 | -22 | -43 | +1 | +4 | -30 | -31 |
| GS Sandy loam | 1641 ±438 | 2221 ± 732 | -24 | -34 | +1 | +4 | -19 | -28 |
| T Clayey loam | 1669 ±400 | 2430 ± 704 | -35 | -45 | 0 | +4 | -28 | -40 |
| T Sandy loam | 2146 ±435 | 2970 ± 567 | -28 | -46 | 0 | +5 | -19 | -41 |

GS - Guinea Savannah zone, T- Transitional (Semi-deciduous-Guinea savannah) zone, L – low fertilizer level (30 kg N $ha^{-1}$),
H- high fertilizer level (120 kg N $ha^{-1}$)

Under high fertilization, average simulated yields were 2430 ± 704 and 2970 ± 567 kg $ha^{-1}$, on the clayey and sandy loams, respectively. Increased temperature impacted negatively on grain yield with yield reductions of 22 and 24% under low fertilizer input condition on the clayey and loamy soils respectively. The impact was higher under high N fertilization with yield reduction of 43 and 34% respectively on the clayey and Sandy loam. Increasing $CO_2$ concentration yielded no impact on grain production under low N fertilization, but an increase of 4 and 5% was simulated on the clayey and sandy soils respectively under high N fertilization. Combined effect of temperature and $CO_2$ under low fertilizer input system resulted in yield reduction of 29 and 19% for the clayey and loamy soils respectively. A similar trend was simulated for the high N fertilizer input condition but with a higher magnitude. The impact of climate change (combined effect of temperature, $CO_2$, and rainfall) resulted in yield reductions of 28 and 19% at low N fertilization on the clayey and sandy soils respectively. At high N fertilization, yield reductions were 41 and 40% on the clayey and sandy soils respectively. The impact of future climate was higher with higher N fertilization on both soils.

*4.2 Maize yields in the Guinea Savannah zone*

In the Guinea Savannah zone, grain yield under historical weather data and low fertilization produced average simulated yields of 1262 ± 321 and 1641 ± 438 kg $ha^{-1}$ on the clayey and sandy loam respectively (Table 2). Under high fertilization, simulated yield averaged 2416 ± 917 and 2221 ± 732 kg $ha^{-1}$ clayey and sandy loam soils respectively. Increasing temperature resulted in grain yield decline of 22% on the clayey loam and 24%

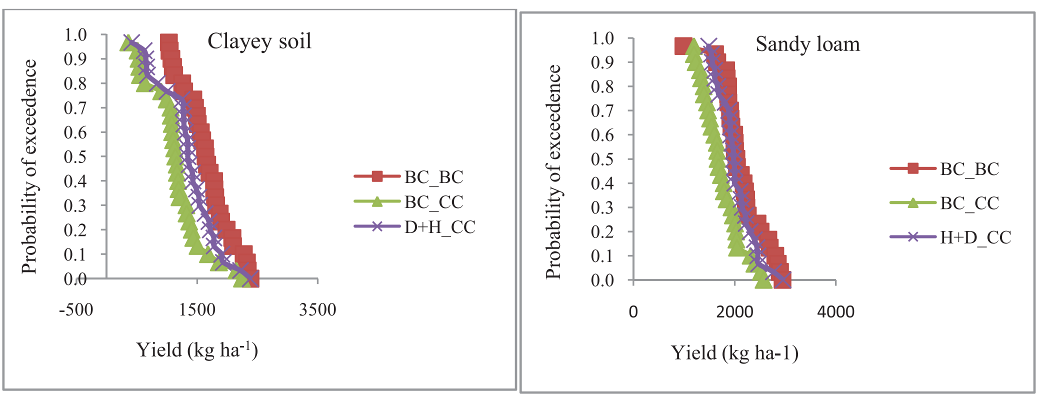
on sandy loam under low N fertilization. Under high N fertilization, percentage yield reduction was higher on the clayey loam (43%) than on the sandy loam (34%). The effects of temperature on grain yield were generally lower at lower N fertilization (Table 2). Increasing $CO_2$ concentration did not impact on grain yield under low N fertilization while yield increases of 4% were simulated under high N fertilization on both clayey loam and sandy loam soils. Combining the effect of temperature increase with $CO_2$ fertilization resulted in a reduction in grain yield loss relative to that of the temperature effect scenario at both levels of N fertilization. Under the climate change effect, grain yield declined by 30 and 19% on the clayey loam and sandy loam respectively under low fertilizer input levels. Under higher fertilization, yield decline of 31 and 28% were simulated for the clayey loam and sandy loam respectively. As in the Transitional zone, yield reduction was higher with higher N fertilization.

*4.3 Response of the virtual cultivar to climate change*

*4.3.1 The Transitional zone*

The simulated yield distributions of the local and virtual maize cultivar under future climate for the Transitional Zone are shown in Figure 2. In interpreting the Figure, curves that lie to the right indicate superior performance. Thus, it is observed that the yield of the *Obatanpa* variety under historical (shown for easy reference) was far superior to the others under both low and high fertilizer application rates (Figures 2a and 2b). It was shown in Table 2 that the mean yields were 1669 and 2146 kg ha$^{-1}$ for clayey and sandy loam respectively for low N application. For the high N application rate, the mean yields were and 2430 and 2970 kg ha$^{-1}$ for clayey and sandy loam respectively.

(a) Low N



(b) High N

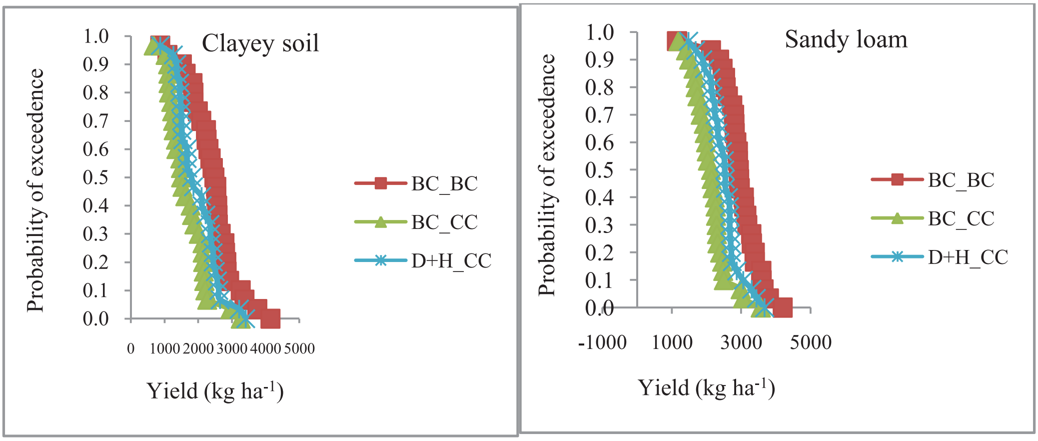


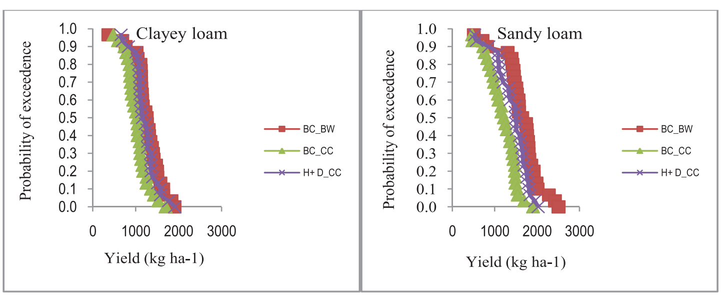

**Figure 2: Simulated grain yield distribution of local and virtual maize for baseline and future climate conditions for (a) low N and (b) high N conditions in the Transition Zone.**
(BC_BC is *Obatanpa* under historic climate; BC_CC is *Obatanpa* under future climate, and H+D_CC is virtual heat and drought tolerant variety under future climate change).

However, the performance of the *Obatanpa* variety under future climate was very poor, yielding as low as 1032 to 1339 kg ha$^{-1}$ for both low and high N application, respectively. The reduction in mean yield was between 27 and 41%. On the contrary, the virtual variety performed better with a mean yield in the range of 1431 to 1773 kg ha$^{-1}$, outyielding *Obatanpa* by about 14%. Thus, though the yields of the virtual variety still fell short of the historical yield of *Obatanpa*, it could be deduced that the virtual variety would be more adapted to future climate.

### *4.3. Guinea Savannah Zone*

The deductions for the Transition Zone also hold generally for the Guinea Savannah Zone (Figure 3). Under historical climate, mean grain yield of 2146 ±435 kg ha$^{-1}$ and 1669 ± 400 kg ha$^{-1}$ on the sandy and clayey soils respectively under low N fertilization.

(a) Low N



(b) High N

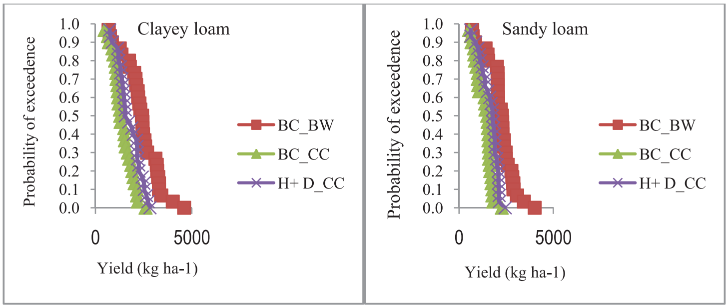



**Figure 3: Simulated grain yield distribution of local and virtual maize for baseline and future climate conditions for (a) low N and (b) high N conditions in the Guinea Savannah Zone**

(BC_BC is *Obatanpa* under historic climate; BC_CC is *Obatanpa* under future climate, and H+D_CC is virtual heat and drought tolerant variety under future climate change).

Simulated yield distributions of new variety were consistently higher than (to the right) those of the *Obatanpa* variety under future climate. On the sandy soil with low fertilization, simulated yields were reduced by 27% under future climate for the *Obatanpa* variety while loss using the new variety was 13%. On the clayey soil, yield reduction of 3 % was obtained under future climate using new cultivar compared with 18% yield reduction using *Obatanpa* with low fertilization.

The probabilities of obtaining lower yields were higher under future climate with the *Obatanpa* variety compared with the new variety (Figure 3). The coefficient of variation is a measure of the variability in yield and used as a proxy to uncertainty. The effects of future climate were generally higher at a higher level of fertilization, resulting in lower nutrient use efficiencies. Similarly, the probability of obtaining higher yields with new cultivar was higher than that of *Obatanpa* under future climate. Coefficient of variation was also consistently higher with simulated yields of *Obatanpa* than those of the new variety under future climate across sites and soil type. Thus, yields will be more stable with new variety than the *Obatanpa* under future climate.

## 5. Discussion and policy implications

The analysis of the long-term historical weather at Ejura (Transition Zone) and Tamale (Guinea Savannah Zone) of Ghana provides evidence of increasing temperatures with associated decrease in rainfall. Literature courses show that these trends in weather will continue in future. The issue of interest to policy formulation is how these changes will impact on future agricultural productivity in Ghana, especially with respect to maize which is a major staple crop.

CERES-Maize module of DSSAT was used to quantify the effect projected climate change on the yield of maize in the Guinea Savannah and Transitional zones in Ghana.

The simulated declines in yield from this study were reported in another study on maize in the Upper East region of Ghana (Tachie-Obeng et al., 2010). Generally, lower responses to fertilizer were observed across soils and sites under climate change. This can be partially attributed to shortening of growth duration by 8 to 10% of the normal crop duration. This implies less time available for the uptake of resources (water, nutrients, solar radiation, etc.) for adequate yield production. The impact of climate change was more severe with high N fertilization. This will be a disincentive to the promotion of fertilizer use by smallholder farmers as the unit returns from each kg of fertilizer declines under future climate.

Positive yield response of maize to elevated carbon dioxide was due to increased photosynthetic activity resulting in increased specific leaf area, leaf weight, improved nutrient uptake and use efficiency, biomass production and grain weight (Jones and Thornton, 2003). The positive effects of $CO_2$ fertilization were reduced by temperature rise. Increase in temperature alone resulted in large reductions in grain yield (15 to 48%).
It is also evident that future climate will reduce the efficiency of fertilizer use. However, given that the unit price of the produce might increase in response to market forces, farmers may still be motivated to use inorganic fertilizers. Government policy on fertilizer subsidy may need to be maintained and strengthened to ensure farmers have access to fertilizers at affordable prices, required quantities and at the right time.

Policy formulation will require quantitative estimates of future yields. This study has demonstrated that crop simulation approaches offer the appropriate tools for the required projections. The simulation results clearly show that the yield of maize (*Obatanpa*) which is currently widely cultivated would decline by as much as 41% under future climate in both the Transitional and Guinea Savannah Zones of Ghana. As a result, this reduction will have serious economic and food security implications if appropriate adaptation strategies are not put in place to mitigate the effect. .

Several adaptation options could be explored. In this study, we focused on the development of an “ideotype” or a “new” heat and drought tolerant variety which has been shown to out-perform *Obatanpa* under future climate. It also produced more stable yields than the *Obatanpa* variety under future climate. These results underscore the need for policies to support crop breeding research to develop agro-technologies whose performance could be tested under future climate. There is also the need for government policy to urgently focus on supporting research into other climate change adaptation measures by the relevant institutions.

Furthermore, it has been shown that simulation modeling offers an effective tool for probing a wide range of climate, soil, and management effects on crop yields. Ghana and indeed the rest of West Africa has very limited capacity in simulation and modeling literacy. A major policy implication would be to support training in the use of modeling tools for agro-decision making and planning among the many actors in the agricultural sector (e.g. Ministry of Agriculture, research staff, NGOs, etc.).

## 6. Conclusion

The effect of climate change on maize grain yield was found to be negative with yield losses ranging from 19 to 41%. This will have some economic and food security implications which have to be assessed. The impact of climate change was more severe at higher level of N fertilization. Government fertilizer subsidy policy needs to be maintained to encourage small holders to access. Breeding for heat and drought tolerance traits to be infused in the *Obatanpa* maize variety will reduce the impact of climate change on grain yield significantly. Given the significant positive impact of heat and drought tolerance, there is the need for investments to be made for the breeding for these tolerance traits for maize. This will call for Government policy for the agricultural sector to be directed to funding research, particularly for the breeding of heat tolerance in maize to improve the resilience of maize production to the effect of climate change. Additionally, government policy for agricultural research should also target the training of more scientists on the use of crop simulation models as a tool to assess future climate impact and explore possible adaptation measures to mitigate the impact of climate change.

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# Climate Change Impacts on Crop Productivity and Possible Adaptations in Ghana

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## Abstract

Change projected increases in temperature and changes in rainfall associated with human-induced climate change are expected to be particularly harmful in tropical and subtropical regions where yields are predicted to decline due to excessively high temperatures and increased drought risks and higher frequency of extreme climatic events causing yield losses. In Sub-Saharan Africa, climate change is generally projected to cause considerable yield losses in most agricultural crops. Therefore, adaptations to climate change in agriculture are particularly challenging in developing countries, but also extremely important. The paper reviews current trends in climate and agriculture in Ghana and how projections of climate change will impact on agricultural production and which options exist for adapting to the projected climate change. Changes in the climate of Ghana have already been observed with temperature increases of about 1°C and with delayed onset of rains and with longer dry periods within the wet season. Climate is projected to further increase temperature and lead to additional changes in rainfall patterns with possible regional differences. These changes in climatic conditions will mostly affect crop productivity negatively by reducing crop yields and leading to greater variability in yields. Effective adaptation to climate change in Ghana is expected to involve: 1) Technologies applied in agriculture, including improved inputs of adapted crops and varieties, fertilisers and irrigation, 2) Management of soil fertility to improve water harvesting and nutrient supply and management of microclimate to avoid stresses, 3) Strengthen research and advisory services to develop, demonstrate and implement new technologies and management systems suited for changed climate, and 4) Policy frameworks that facilitate effective implementation of agricultural climate change adaptations while also preserving the natural resource base.

**Keywords**: Climate change, crop productivity, adaptation.

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## 1. Introduction

At the global level, continuing growth in human population and consumption mean that global demand for food will continue to increase at current rates for at least four decades to come (Godfray et al., 2010). This increase in demands challenges the current lack of productivity increases in many crops, and the fact that there has, for about two decades, been no net increase in the global agricultural arena. The recent patterns of increases and volatility of food prices is also an indicator of stresses in global food supply. Changing climate and other environmental stresses as well as the quality of the agricultural resource base (including soil fertility) are among the factors that will be challenging the future possibilities of meeting demands for food, fibre and bioenergy.

The growing population in Sub-Saharan Africa along with environmental degradation, impending climate change, lack of energy, and dwindling water and land related resources are already now affecting land use and its productivity (Le et al., 2012). This may deprive many poor people of sustainable livelihood and health opportunities and consequently the possibility for improving their living conditions, quality of life and welfare.

The agricultural sector in Ghana and its future growth is central to sustainable land use development since agriculture is the mainstay of more than half of the population, and it accounted for around 32% of the GDP in 2008 but with a larger proportion of the population directly depending on agriculture for their livelihoods (Diao, 2010). Agriculture in Ghana therefore continues to be vital for ensuring food supply and food security as well as alleviating rural poverty. Agriculture is also important for exports in Ghana, and these export crops, in particular cocoa, contributed to 36% of exports in 2007.

Climate change resulting from greenhouse gas emissions and land use changes is generally projected to exacerbate the current and emerging problems with food security for many developing countries (Ingram et al., 2008). This is due to the expected negative effects of warming on agricultural production in tropical and subtropical regions, where yields are predicted to decrease due to excessively high temperatures and increased drought risks and higher frequency of extreme climatic events causing yield losses. In Sub-Saharan Africa, climate change is generally projected to cause considerable yield losses in most agricultural crops (Schlenker and Lobell, 2010). Therefore, adaptations to climate change in agriculture is particularly challenging in developing countries, but also extremely important (Mertz et al., 2009).

In this paper we aim to review current trends in climate and agriculture in Ghana, how projections of climate change will impact on agricultural production and which options exist for adapting to the projected climate change. We also consider the roles of different actors in supporting climate change adaptation.

## 2. Climatic zones and agricultural regions in Ghana

Ghana's land surface can be categorised into six agro-ecological zones of fairly homogeneous climate, terrain, soil, vegetation and land use: Sudan savannah, Guinea savannah, coastal savannah, forest-savannah transition, deciduous forest and rain forest (Figure 1). Ghana has a tropical climate with distinct wet and dry seasons (Table 1). The annual mean temperature is generally above 24°C, but annual rainfall varies considerably across the country with the lowest rainfall in the coastal savannah and the highest in the rainforests of the south-eastern parts of the country.


**Figure 1: Agro-ecological zones of Ghana**

Source: FAO (2013)

The vegetation in the coastal savannah zone is mainly grass and scrub with rather poor soils Staples crops such as maize, cassava and vegetables are widely produced in this zone, which also supports livestock, including cattle. The forest zone has the largest rainfall, but the soils are generally not very fertile, and agriculture in this zone is dominated by cocoa and staple crops such as cassava, plantain and taro.

**Table 1: Agro-ecological zones of Ghana**

| Agro-ecological zone | Area ($km^2$) | Mean temperature ($^oC$) | Annual rainfall (mm) | Major rainy season | Minor rainy season |
|---|---|---|---|---|---|
| Sudan savannah | 9,500 | 28.6 | 958 | May-Sep | |
| Guinea savannah | 147,900 | 28.1 | 1100 | May-Sep | |
| Coastal savannah | 4,500 | 27.1 | 800 | May-Sep | Sep-Oct |
| Forest-savannah transition | 8,400 | 26.0 | 1252 | Mar-Jul | Sep-Oct |
| Deciduous forest | 66,000 | 26.1 | 1402 | Mar-Jul | Sep-Nov |
| Rain forest | 9,500 | 26.2 | 1985 | Mar-Jul | Sep-Nov |

Source: Armah et al. (2010)

The forest-savannah transitional zone covers regions north of the forest zone, where forest vegetation has given way to savannah. The soils are fairly fertile and support a wide variety of crops such as maize, yams, cassava and to some extent plantain. Large-scale commercial farming is widespread in the zone.

The Guinea savannah zone covers about 57% of the land area in Ghana. This zone has only one rainy season, which starts in late April or early May, reaches a peak in late August or early September and tails off in October. This followed by a long dry period in which crops can only be grown under irrigation. The soils are generally poor with better soils in the floodplains and along river banks. Rice is the most important cash crop in the zone and is produced in the valley bottoms. Cotton, another important cash crop, is more important to small-scale farmers. Millet, sorghum and yams are principal food crops in the zone, but maize, groundnuts and vegetables are widely produced. Livestock production is an important activity in the zone with over 70% of the country's population of cattle, sheep and goats.

## 1. Current agricultural production in Ghana

There are large regional differences across Ghana in agricultural structure and activities (Diao, 2010). The forest zone is from an economic point of view the most important agricultural producer, accounting for 43 % of agricultural GDP. This is to a large extent due to the large area of cocoa that contributes not only to agricultural income, but also Ghana's exports. The area of cocoa in Ghana constitutes about 1.6 mill. ha, which is equivalent to the total cereal area (Table 2). The coastal savannah zone contributes 10% of agricultural GDP and the remaining 47% is distributed across the other savannah zones. The staple crops that include cassava, yams, taro, sweet potato and plantain constitute about 1,9 mill. ha, which is about equal to the area of cereals and pulses combined.

**Table 2: Cropping area in 2011, yields as average of 1990-2006 and yield gaps of major crops in Ghana**

| Crop | Area (1000 ha) | Average yield (Mg/ha) | Achievable yield (Mg/ha) | Yield gap (%) |
|---|---|---|---|---|
| Maize | 1023 | 1.5 | 2.5 | 40 |
| Rice | 197 | 2.1 | 3.5 | 40 |
| Millet | 179 | 1.5 | 0.7 | 47 |

| | | | | |
|---|---|---|---|---|
| Sorghum | 243 | 1.0 | 1.5 | 33 |
| Cassava | 889 | 11.9 | 28.0 | 58 |
| Taro (cocoyam) | 204 | 6.7 | 8.0 | 16 |
| Yams | 404 | 12.4 | 20.0 | 38 |
| Plantain | 336 | 8.1 | 10.0 | 19 |
| Sweet potato | 74 | 8.5 | 18.0 | 53 |
| Cowpea | * | 1.0 | 1.3 | 23 |
| Groundnut | * | 0.8 | 1.0 | 20 |
| Soybean | * | 0.8 | 1.0 | 20 |
| Cocoa | 1600 | 0.4 | 1.0 | 60 |

Note:
The total area of pulses in 2011 was 250,000 ha.

Source: Diao (2010)

The growth in agricultural production in Ghana has been mainly driven by land expansion and the growth in productivity remains a challenge as can be seen from the estimated yield gaps of individual crops in Table 2. The cultivated land expanded by 60% over the period from 1994 to 2006, but has been slowing lately (Diao, 2010). Cocoa has been the main driver of land expansion.

The low yields in agriculture are mainly caused by low soil fertility and insufficient use of modern technologies such as fertilisers and improved seeds. The variable climatic conditions, in particular in terms of rainfall probably also plays a role for the lacking yield progress.

## 4. Climate trends and projected climate change in Ghana

Temperatures in Ghana have increased by about 1°C over the past 40 years (Hansen et al., 2012). This has also been associated with more frequent warm extremes. In contrast there were no significant changes in annual rainfall over the period 1960-2005 for 16 meteorological stations in Ghana (Lacombe et al., 2012). However, there was a reduction in the number of wet season days totalling less than 20 mm of rainfall between 6° and 9.5°N. There was also a delay of about 0.5 day/year in onset of the wet season at several locations. Finally there was a lengthening of dry periods by about 0.1 day/year in the wet season in the south and centre of Ghana.

Projections of future climate are made to explore likely future climates arising from human activities, including greenhouse gas emissions (Houghton, 2009). Nonetheless, projections of climate change are inherently uncertain (James and Washington, 2013), which is due to the natural variability in climate systems; imperfect ability to model the atmosphere's response to any given emissions scenario; difficulties in evaluating appropriate methods to increase the temporal and spatial resolution of outputs from relatively coarse spatial resolution of climate models; and the range of possible future emissions. Several general circulation models (GCM) have made use of the widely used IPCC emission scenarios (IPCC, 2000; Hulme et al., 2001) to project future climatic conditions for Ghana. These emission scenarios portray collective choices that societies make with respect to economic growth, population growth, and options for energy-generated technologies, and global and local solutions to economic, social and environmental sustainability (McCarthy, 2009).

Hulme et al. (2001) proposed four climate change scenarios for Africa, which were based on those in the IPCC (2000). Specifically, they combined the SRES A2 emission scenario with high climate sensitivity (4.5°C), SRES A1 and SRES B2 with medium climate sensitivities (2.5°C) and SRES B1 with low climate sensitivity (1.5°C) to obtain A2-high, A1-mid, B2-mid and B1-low, respectively. Tan et al. (2009) used data provided by the EPA (2000) to develop three climate change scenarios: No climate change (NCC), where average precipitation as well as minimum and maximum temperature recorded from 1971 to 2000 were assumed to remain unchanged until 2100, low climate change (LCC) and high climate change (HCC) (Table 3).

For Ghana, all recent projections made using GCMs agree that there will be an increase in air temperature for all agro-ecological zones which will decrease from the semi-arid Northern region to the coastal Southern regions but changes in precipitation will vary considerably both spatially and temporally (EPA, 2000; World Bank, 2010; Stanturf et al., 2011; McSweeney et al., 2012). Increased air temperature will lead to increased evaporative demand thus altering atmospheric circulation patterns and contributing towards increased frequency of extreme events and drying. The frequency of days and nights that are considered 'hot' in the current climate is projected to increase, and the frequency of those considered 'cold' is expected to decrease (McSweeney et al., 2012). Additionally, in most parts of Ghana, the onset of the rainy season is expected to shift to later periods of the year, but the end of the rainy season and the total amounts of rainfall will remain largely unchanged (van de Giesen et al., 2010). Overall, even though there are huge uncertainties in future climatic conditions due to the limited number of studies on climate change projections and difficulties in representing convective systems (Cook and Vizy, 2006), all projections show warming with associated changes in rainfall patterns.

**Table 3: Changes in air temperature and precipitation projected using GCM models relative to the late 20th century**

| Study region | Emission scenario | No. of GCMs | Period | Change in min. temp. (°C) | Change in max. temp. (°C) | Change in mean temp. (°C) | Change in annual rainfall (mm) | Reference |
|---|---|---|---|---|---|---|---|---|
| Wa district | A2 | 9 | Medium | 2.2 | 2.1 | 2.0 | +86 | Tachie-Obeng et al., 2010 |
| Wa district | A2 | 9 | Long | 4.2 | 4.0 | 3.9 | +97 | Tachie-Obeng et al., |
| Assin district | LCC† | 7 | Long | 2.5 | 2.4 | | -140 | Tan et al., 2009 |
| Assin district | HCC† | 7 | Long | 3.3 | 3.3 | | -296 | Tan et al., 2009 |
| Bawkusavanna | LCC† | 7 | Long | 3.1* | 2.6* | | -105* | Tan et al., 2010 |
| Bawkusavanna | HCC† | 7 | Long | 4.7 | 3.8 | | -240 | Tan et al., 2010 |
| Southern Ghana | B1-low | 7 | Short | | | 0.8 | nc[a]/nc[b] | Hulme et al., 2001 |
| Northern Ghana | B1-low | 7 | Short | | | 0.9 | nc[a]/nc[b] | Hulme et al., 2001 |
| Southern Ghana | B1-low | 7 | Medium | | | 1.2 | nc[a]/+3[b] | Hulme et al., 2001 |
| Northern Ghana | B1-low | 7 | Medium | | | 1.4 | +19[a]/-3[b] | Hulme et al., 2001 |
| Southern Ghana | B1-low | 7 | Long | | | 1.5 | nc[a]/+4[b] | Hulme et al., 2001 |
| Northern Ghana | B1-low | 7 | Long | | | 1.7 | +23[a]/-4[b] | Hulme et al., 2001 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Southern Ghana | A2-high | 7 | Short | | | 1.8 | +6[a]/+5[b] | Hulme et al., 2001 |
| Northern Ghana | A2-high | 7 | Short | | | 2.0 | +27[a]/-5[b] | Hulme et al., 2001 |
| Southern Ghana | A2-high | 7 | Medium | | | 3.4 | +11[a]/+9[b] | Hulme et al., 2001 |
| Northern Ghana | A2-high | 7 | Medium | | | 3.8 | +52[a]/-9[b] | Hulme et al., 2001 |
| Southern Ghana | A2-high | 7 | Long | | | 5.2 | +18[a]/+14[b] | Hulme et al., 2001 |
| Northern Ghana | A2-high | 7 | Long | | | 5.8 | +79[a]/-13[b] | Hulme et al., 2001 |
| Ghana | A2 | 15 | Short | 0.9 | 1.6 | 1.2** | Nc | McSweeney et al., 2012 |
| Ghana | A1B | 15 | Short | 0.9 | 1.7 | 1.3** | Nc | McSweeney et al., 2012 |
| Ghana | B1 | 15 | Short | 0.7 | 1.4 | 1.0** | Nc | McSweeney et al., 2012 |
| Ghana | A2 | 15 | Medium | 1.7 | 3.0 | 2.5** | Nc | McSweeney et al., 2012 |
| Ghana | A1B | 15 | Medium | 1.8 | 3.0 | 2.5** | Nc | McSweeney et al., 2012 |
| Ghana | B1 | 15 | Medium | 1.0 | 2.2 | 1.8** | Nc | McSweeney et al., 2012 |
| Ghana | A2 | 15 | Long | 3.0 | 5.2 | 4.0** | Nc | McSweeney et al., 2012 |
| Ghana | A1B | 15 | Long | 2.5 | 4.6 | 3.1** | Nc | McSweeney et al., 2012 |
| Ghana | B1 | 15 | Long | 1.5 | 3.0 | 2.1** | Nc | McSweeney et al., 2012 |

Notes:
†see Tan et al. (2009) for description of scenarios.
* during growing season (from April to October).
** median; nc=no change
[a]December to February; [b] June-August; near-term future−2020-2030; medium-term future−2060-2050; long-term future−2080-2100.

## 5. Climate change impacts on crop yields in Ghana

Since agriculture is a climate-sensitive sector, climatic factors such as temperature and precipitation remain the predominate sources of inter-annual variability of crop production (Howden et al., 2007). In dry land areas, crop productivity may be depressed by high evaporative demand, runoff and drainage losses following intense rainfall which may be as high as 50% of received rainfall (Biazin et al., 2012). Moreover, there are other potential stressors including pest and disease pressure, increased frequency of extreme events such as droughts and floods that may contribute towards or exacerbate the projected negative yield change ($\approx$ -13%) in the West Africa region (Knox et al., 2012). The aggregation of production impacts over West Africa may hide considerable heterogeneity of climate change impacts on agricultural production in Ghana (Jones and Thornton, 2003).

For Ghana, using 2000 as the base year, yields of maize were projected to decrease by about 15% by 2050 (Jones and Thornton, 2003). Schlenker and Lobell (2010) showed that compared to average yields over the period 1961-2006, mean yields of maize, sorghum, millet and groundnuts will decrease by about 20% towards the middle of the century (2046-2065). Using crop yields for 2000 as the base year, Nutsukpo et al. (2012) found that by 2050, climate change would cause an overall yield decrease of less than 25% for rain-fed maize and rice and above 25% for groundnuts. However, regional variations in yield were observed with yield increases being projected in some areas (De Pinto et al., 2012). With the 1990/1991 cropping season as the base year, cassava yields are expected to correspondingly decrease by 3%, 13.5% and 53% in 2020, 2050, and 2080, and cocoyam yields are projected to decrease by 11.8%, 29.6% and 68% in 2020, 2050 and 2080, respectively (Armah et al., 2011).

Several studies have shown that in cases where yields are expected to decrease, yield gains are possible if adaptations options are pursued (Tubiello et al., 2000; Fischer et al., 2005). For instance, Biazin et al. (2012) proposed combining an array of indigenous and recently developed rainwater harvesting techniques with other agronomic practices and modifying them to improve both water management and crop yields. They ground their argument on the fact that, in semi-arid regions, rainfall variability and non-productive losses of water limit crop productivity more than the total amount of rainfall. Particularly in Northern Ghana, where crop production is more vulnerable to drier conditions and farmers have low adaptive capacity (Antwi-Agyei et al., 2012), there is definitely a need to adopt new or modify existing rainwater harvesting technologies and techniques to improve water and crop productivity.

## 6. Climate change adaptation in agricultural systems and policy

Though there are a multitude of uncertainties, it is clear that the magnitude and rate of projected climate changes will require adaptation (Vermeulen et al., 2010). Adaptation to climate change involves reducing the consequences or impacts of climate change by adjusting processes, policies, strategies and priorities. Basically, climate change adaptation can broadly be classified as either autonomous or planned (policy-driven). Whereas autonomous adaptation refers to actions taken by the farmer (micro-level), planned adaptation efforts are based on decisions made by government, the private sector and development partners (macro-level) to effectively manage actualities or threats of climate change (Howden et al., 2007; Stage, 2010). Adaptation to the projected climate change in Ghana should focus on how vulnerable, resource-poor smallholder communities can survive under hot weather conditions, late commencement of the rain seasons, shorter and more variable rain seasons, and low soil moisture conditions (Boko et al., 2007; Bryan et al., 2013).

In this study, we classify crop-related adaptation activities into the following four categories:

- Access to and affordability of critical inputs;
- Adoption of appropriate management practices;
- Access to research and extension services;
- Enactment of enabling policies by government and development partners.

Whereas the first two categories relate to activities that are conducted at the micro-level, the third and fourth categories are related to activities conducted at the macro-level. These are briefly discussed below.

### *a. Access to and affordability of critical inputs*

To adapt to climate change, farmers in Ghana should have access to critical inputs such as improved seeds, fertilizers, agrochemical and where possible, irrigation water. In particular, improved and appropriate seeds are important for obtaining maximum benefits from other critical inputs (e.g. water, fertilizers and agrochemicals) and general management (Table 4). For example, access to improved and affordable early-maturing and drought/heat tolerant crops (i.e., cowpea) and varieties would allow for both in-field (e.g. intercropping) and on-farm (e.g. rotation systems) crop diversification which secure farmers against complete failure and in some cases contribute towards fertility building (Tambo and Abdoulaye, 2013). Access to low interest credit allows smallholder farmers in Ghana to invest in critical inputs and technologies that reduce their vulnerability to climate change such as improved seeds, fertilizers and agrochemicals (Fosu-Mensah et al., 2012). Besides tangible inputs, farmers receive information and knowledge inputs from external sources (e.g. research and extension) and also use local or indigenous knowledge in designing or implementing farm activities.

*b. Adoption of appropriate management practices*

For crop production systems in Ghana, management practices for adaptation should focus on key drivers of change in this sector namely, the climate, crops, soil, land and water. There are several management practices given in the literature that enable African smallholder farmers to adapt to climate change and variability (Table 4). These practices include crop selection, changing planting dates exploiting spatial diversity of landscape - situating fields in fertile areas and/or close to water sources (e.g. wetlands), rainwater harvesting, conservation agriculture practices (e.g. cover crops, residue management, agroforestry, terracing, intercropping, mulching, manure application) and irrigation (Thomas et al., 2007; Bryan et al., 2009; Kristjanson et al., 2012). To enhance adoption of management practices that are appropriate for climate change adaptation among smallholder farmers, it is important to identify those which would be acceptable, reduce crop production risks and have multiple on-farm and landscape benefits. An example of such a practice would be agroforestry which increases amounts of fodder, results in shading of crops and livestock from extreme high temperatures, stabilizes soils and reduces erosion risk and also increases crop productivity (Nguyen et al., 2013). However, in some cases it may be more profitable to diversify to high value crops (i.e., horticultural crops) using water from shallow wells for irrigation (Laube et al., 2012) or completely abandon field crop production and switch to livestock or find other livelihood options (Thomas et al., 2007; Bryan et al., 2009).

*c. Access to research and extension services*

Where farmers have access to critical inputs, it is vital that they manage them effectively and efficiently. Basically, knowledge on appropriate management practices is either indigenous or transferred to farmers through various information channels, including research and extension services. The major roles of research and extension services include modifying, testing, demonstrating and promote adoption of smarter technologies and techniques that improve farmer resilience to climate variability.

A recent study conducted by Fosu-Mensah et al. (2012), in the Sekyedumase district of Ghana, showed that access to extension services has a positive and significant impact on climate change adaptation. However, in Ghana, the productivity of frontline extension services is low and needs to be enhanced by providing adequate support to their core activities (Baah et al., 2009).

Adequately resourced extension officers should continuously conduct 'mandatory' on-farm demonstrations that allow farmers to contribute, observe and evaluate technologies and techniques aimed at enhancing progressive adaptation by increasing crop productivity. This interactive dissemination method will lead to repeated farmer exposure to appropriate technologies and techniques, stimulate farmer innovation, and increase adoption rates of technologies and techniques that reduce vulnerability to climate change (Doppler, 2000; Ziervogel, 2004; Kristjanson et al., 2012).

**Table 4: Activities reported as having the potential to enhance climate change adaptation in smallholder crop production**

| Inputs | Management | Research and extension | Policy |
|---|---|---|---|
| Selecting appropriate crops and varieties suited for the changing climate (drought/heat tolerant, shorter growth period, mixed-cropping)<br><br>Creation of local seed banks or seed distribution centres improving accessibility of seed. | Making informed decisions on appropriate field sites; timing of farm operations (tillage, sowing, fertilization, weeding, pest control, irrigation or drainage, harvesting); appropriate rates (sowing, fertilization, irrigation, agrochemicals) and crop densities. | Information sharing on<br><br>weather forecasts, improved varieties, appropriate technologies and techniques and also on viable crop markets with farmers | Subsidies and/or tax incentives to make agricultural inputs more affordable for vulnerable farmers<br><br>Output price support schemes<br><br>Crop insurance (index-based insurance) |
| Collecting soil samples for testing to determine soil pH and the level of residual nutrients and adjust input levels appropriately. | Selection of appropriate soil and water conservation techniques (residue retention, mulching, rainwater harvesting) | Development and adoption of improved techniques and technologies for monitoring and forecasting crop yields | Infrastructure development to improve accessibility of inputs and provide alternative off-farm income |
| Supply crops with adequate amounts of all major nutrients from either mineral fertilizers, animal manure or crop residues | Selecting appropriate technologies for farm operations (tillage, weeding, pest control and post-harvest processing and storage of crops) | Research aimed at reducing uncertainties in climate change projections and improving climate information systems and weather forecasts | Food relief in disaster situations (floods, droughts) |
| Obtaining other important farm inputs (agrochemicals, farm machinery, capital, labour) | Maintaining farm machinery in good working condition | Conducting participatory on-farm research with farmers | Improving security of tenure |
| External and indigenous knowledge | Keeping records of farm activities and taking time to reflect on what is and is not working | Simplifying messages from scientific literature for easier understanding by famers and policy makers | Making education accessible and affordable for vulnerable communities |

| | | | |
|---|---|---|---|
| Seeking knowledge on the most profitable livelihood option and planning agricultural activities according to realisable capacities- reduce work overload | Consulting research and extension staff on better management options | Designing research that is aligned with farmer needs | Building institutional capacity through training |
| Improving access to water (irrigation wells) | Sharing knowledge with other farmers | Extending timely soil testing facilities to farmers | Climate monitoring and communication |
| Improved access to low interest credit | Seeking information on weather forecasts including extreme events (droughts and floods) as well as pest and disease attacks | Anticipating negative effects of the market environment on smallholder farmers and disseminating information on potential risks | Insurance mechanisms that reduce farmers' risk exposure |
| Improved access to farm machinery and availability of draught power for farm operations | Diversification of cropping systems (intercropping, crop rotation, proper use of legumes, agroforestry) | Promoting farmer networks, farmer-field-schools, | Improving farmer access to credits, farm machinery |
| | Afforestation to provide natural shades for livestock | Training farmers on good financial management | Market creation for new and existing crops |

Whereas focus should be placed on technologies and techniques that minimize production risks (Kato et al., 2009), it is important to note that low acceptability and limited financial resources to invest in new technologies may hinder their uptake (Below, 2009). However, while issues related to acceptability of new technologies and techniques could be addressed by blending them with indigenous techniques (Grothmann and Patt, 2005), government intervention and promotion of farmer networks may be beneficial for reducing the burden of high investment costs related to new technologies. Furthermore, farmer networks can be used for collective procurement of farm inputs, collective marketing of farm products and farmer-to-farmer training (Below et al., 2010).

*a. Enactment of enabling policies by government and development partners*

Smallholder farmers in Africa generally have insufficient assets, resources, and ability to choose among adaptation options thus they require both technical and institutional support in order to adapt (Boko et al., 2007; Lemos et al., 2002). For instance, if prices of critical inputs such as fertilizers are beyond the reach of smallholder farmers – as occurred in Ghana since the progressive removal of fertilizer subsidies from 1987 (FAO, 2005), to encourage fertilizer use, government could enact policies targeted at subsidizing certified seeds and fertilizer, as has been done by the government of Ghana in recent years (Government of Ghana, 2012). Nonetheless, it is critical that inefficiencies associated with the implementation of these subsidies are addressed as they threaten their effectiveness (Branoah, 2011; Fosu-Mensah et al., 2012). Moreover, considering the inter-regional differences in climate change projects and vulnerability there may be need for region-specific policies to reduce vulnerability and enhance climate change adaptation, particular attention should be on Northern regions where both impacts and vulnerability are high (Antwi-Agyei et al., 2012).

Reducing logistical costs associated with distribution of critical inputs and marketing of produce decreases input prices and increases returns from farm produce. For example, development partners (government, private sector and the donor community) may reduce logistical costs by improving and maintaining infrastructure (i.e., road networks). Furthermore, promoting the establishment of local input procurement and distribution facilities through strategic public-private partnerships will improve accessibility of critical inputs in remote areas (IFDC, 2012). Ultimately, increasing access to affordable critical inputs, information (weather, management, etc.), low interest credits and lucrative markets, will reduce major barriers for smallholder farmers to adapt to climate variability. However, in most Sub-Saharan countries including Ghana, a lack of institutional capacity and insufficient funding often makes these costly interventions impossible (Boko et al., 2007).

*b. Harmonizing adaptation efforts*

As adaptation occurs at multiple levels and involves multiple actors, it is clear that creative synergy of stakeholder efforts is of utmost importance to obtain maximum benefits from the limited available financial resources (Below et al., 2010). A good investment of limited resources would be to focus on strategic activities such as improving accessibility and affordability of critical inputs, enhancing the productivity of frontline extension services to support and advise farmers on smarter management options and enacting policies that support a spectrum of adaptation opportunities (Figure 2). Additionally, it is prudent for development partners to invest resources towards creating opportunities for stakeholders to meet and explore opportunities for innovative synergy in transforming scientific and indigenous knowledge on climate change adaptation into actions. As stated by Below et al. (2010), examples of such synergistic efforts in developing countries can be found in Bangladesh (Ayers, 2009) and Mozambique (Osbahr et al., 2008). In Bangladesh, money obtained from different several climate change funds is managed by a board of trustees that includes representatives from national government and international donors, thus reducing transaction costs (Ayers, 2009). In Mozambique, community representatives, agricultural extension officers, NGOs and local authorities meet regularly to explore adaption options, these interactions have led to the wide-spread adoption of drought-resistant or faster-maturing crop varieties (Osbahr et al., 2008).

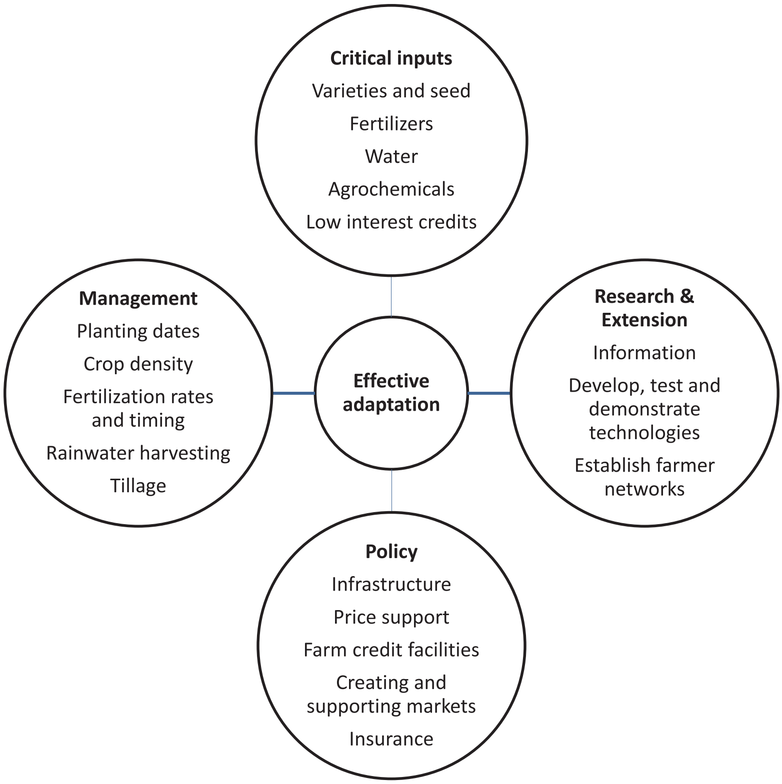


**Figure 2: Activities in different areas for effective climate change adaptation in smallholder crop production systems of Ghana**
Source: Authors analysis

Table 4 outlines the different activities that can be pursued by stakeholders to enhance climate change adaptation and increase crop productivity in Ghana. Success in overcoming the challenges and key barriers limiting current and projected crop productivity hinges on leadership and creative engagement of all critical stakeholders (farmers, policy makers, researchers, extension, private sector and development partners), to ensure beneficial harmonization of individual efforts

## 7. Conclusions

Changes in the climate of Ghana have already been observed with temperature increases of about 1°C over the past 40 years and with changes in the timing of rainfall, with delayed onset of rains and with longer dry periods within the wet season. The continued global emissions of greenhouse gases are projected to further increase temperature and lead to additional changes in rainfall patterns with possible regional differences. These changes in climatic conditions will mostly affect crop productivity negatively by reducing crop yields and leading to greater variability in yields. To minimise the negative effects of climate change and take advantage of any new opportunities there is a strong need to strengthen; 1)

Technologies applied in agriculture, including improved inputs of adapted crops and varieties, fertilisers and irrigation, 2) Management of soil fertility to improve water harvesting and nutrient supply and management of microclimate to avoid stresses, 3) Strengthen research and extension to develop, demonstrate and implement new adapted technologies and management systems suited for changed climate, and 4) Policy frameworks that facilitate effective implementation of climate change adaptation in the agricultural sector while also preserving the natural resource base.

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# Farmer-Oriented Coping Strategies for Minimizing Climate Variability Impact on Agricultural Production in Ghana

*Samuel G.K. Adiku*[1]

## Abstract

This paper focuses on the impact of climate variability as one of the major challenges to sustained agricultural production in Ghana. The evidence shows that climate variability continues to increase and is apparently aggravated by climate change. Not only has the season become more erratic but the shifts in the within-season distribution of rainfall are additional issues farmers must contend with. Three farmer-oriented coping strategies that could be used to minimize the adverse effects of climate variability are discussed. These include forecast climate services, crop insurance and improved soil management. To be effectively implemented, it would be necessary to train farmers in the rudiments of rainfall measurement, insurance concepts and soil management. These are among the major challenges which handicap the adoption of improved technologies and therefore must be urgently addressed. It is proposed that these coping strategies should be used in combination. Farmers who would rely on forecast climate-based advice should also adopt improved soil management practices and purchase insurance.

**Keywords**: Agricultural production, climate variability, coping strategies, small-scale farmers.

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## 1. Introduction

For many years, farmers the world over have transacted their operations under one major "uncontrollable" factor, namely the climate. A typical economic production function would consider factors such as capital, labour, know-how and so on but climate remains outside–that is, lies outside their control. The variability of climate, defined here as the short term season to season or year-to-year changes in weather characteristics such as onset of the season, duration of the season, total rainfall amount and its distribution within the season, has a major effect on production. Irrespective of the level and intensity of the controllable factors, the success or otherwise of an agricultural venture largely depends on the nature of the season's weather conditions.

Over time, two main approaches have been evolved to deal with the climate variability problem. The first involves the development of technology, especially irrigation, either to supplement or even completely substitute, rainfall, thus minimizing the dependence of agricultural production on the nature of the season. Many developed countries have taken this path and have sustained production for many years. The investment and maintenance costs of this technology can be prohibitively high but the output can justify its use.

Most developing countries have not been able to take this path. Rather, there has been the dependence on accumulated knowledge (also called Indigenous Knowledge, IK) to adjust farming operations to minimize the impact of adverse weather on production (Roncoli et al., 2003). This provides an outlook for the coming season upon which investment decisions could be based. The major drawback is a declining reliability of IK over time, because oral traditions are hardly documented and hence the chain of information flow between generations becomes vague. Furthermore, as people migrate out of the agrarian sector, substantial content of the IK is also lost. The overall effect is that rain-fed agriculture has become more risky with time.

Scientific evidence globally has shown that climate variability has increased significantly over the last 40 years, and that this increase can be linked to climate change, (defined as the persistent change in climate variables in the long term). Though not the focus of this paper, albeit brief, a background on climate change is provided here. Climate change is attributed to increased carbon dioxide ($CO_2$) loading of the atmosphere due to increases in $CO_2$ emissions. Historically, the increased loadings are attributed largely to fossil fuel burning in industries, automobiles, etc. and this is largely associated with industrialized countries. However, it is also known that land use change, deforestation, poor soil management, indiscriminate bush and forest burning and agriculture in general contribute about 55% of the current total $CO_2$ emissions to the atmosphere (Nelson, 2009).

Over the past 200 years, since the industrial revolution, the atmospheric $CO_2$ concentration has almost doubled. The interaction of the increased atmospheric $CO_2$ with radiation emitted by the earth, alters the energy balance and results in the warming of the earth, because the emitted $CO_2$ somewhat acts as a "blanket" that prevents the escape of long-wave heat emitted by the earth. This effect is often termed "global warming". Worldwide, global temperatures have increased by 1°C over the last 30 years and projections show further increases by mid-century.

Global warming has consequences for the hydrological cycle and hence climate variability. Given these associated shifts in weather patterns, it is obvious that the reliance on IK alone for agricultural planning would be ineffective. The aim of this paper is to review work done in Ghana on the impact of climate variability on agricultural production within the short term. The paper also explores some coping strategies that could augment farmers' IK to minimize the impact of climate variability on agricultural production.

## 2. Evidence of climate variability in Ghana

Though climatology and meteorology are subjects taught in many educational institutions in Ghana, scientific interest in climate variability has seen a dramatic rise over the last three decades. Detailed statistical analysis on long-term data shows that below-normal rainfall conditions persisted in some locations such as the Upper East Region of Ghana, for over 18 years (1972-1990) before recovery (Dietz et al., 2004). It is also evident that the frequency of drought years (defined as a year with total annual rainfall below the 25 percentile of the cumulative frequency distribution) has increased in many parts of Ghana (Table 1). Previous works showed that drought year frequency reached 3 to 4 out of every 10 years in the late 1980s compared with 1 or 2 in 10 years during the earlier years. As more data has now become available, this analysis needs to be updated.

**Table 1: Number of drought events in 10-year groups (decades) at different sites in Ghana**

| | Location | | | |
|---|---|---|---|---|
| Year group | Axim | Accra | Kumasi | Bawku |
| 1935-1939 | 0 | 1 | 1 | 0 |
| 1940-1949 | 1 | 2 | 1 | 2 |
| 1950-1959 | 0 | 1 | 1 | 0 |
| 1960-1969 | 2 | 1 | 0 | 1 |
| 1970-1979 | 3 | 2 | 2 | 4 |
| 1980-1989 | 5 | 3 | 3 | 3 |

Source: Adapted from Adiku and Stone (1995)

Rainfall anomaly analysis also shows that the swings from drought to flood years have increased in areas such as the Afram Plains from the late 1970s (Figure 1). In general, normal years have become less common, posing tremendous challenges to the Ghanaian farmer.

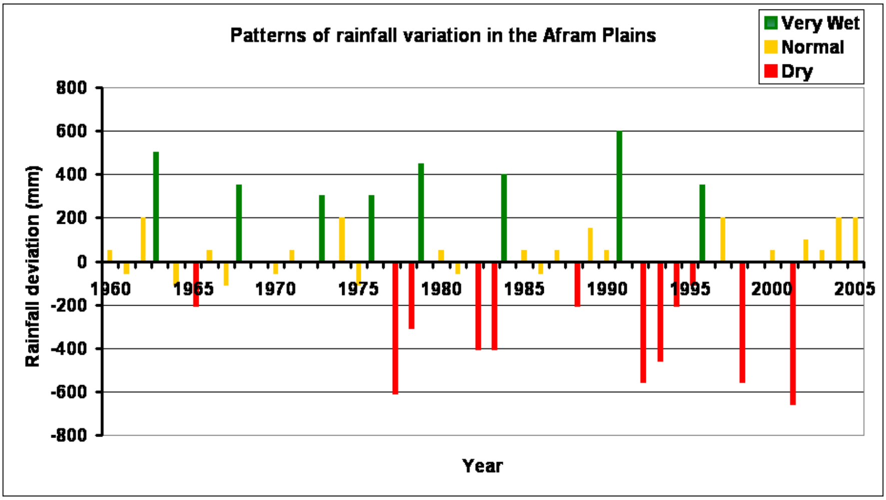


**Figure 1: Rainfall anomalies for the Afram Plains of Ghana**

Source Adiku et al. (unpublished)

Opoku-Ankomah and Cordery (1994) were probably among the first to link the variability of the Ghana's rainfall to global circulation phenomena such as the Sea Surface Temperatures (SSTs). They showed that rainfall anomalies in several places in Ghana could be linked to the variations of the SSTs of the southern Atlantic and hence there could be a predictability of the rainfalls. This work was followed by that of Adiku and Stone (1995) and Adiku et al. (2007a) who showed significant correlation between rainfall in several locations of Ghana and the Southern Oscillation Index (SOI) of the Pacific.

Analysis of long-term climate data also shows a general increase in temperature in Ghana with a steady annual rise of 0.06°C per year (EPA, 2001). The effect of rising temperatures on rainfall in not clear cut but there is a tendency that at several locations (e.g., Wa, Tamale, Accra and Sunyani) the two weather variables are negatively correlated (Figure 2). In effect, if global warming persists, lower rainfall should be expected.

## 3. Impact of climate variability on Ghanaian agriculture

The bulk of the evidence indicates that for many years, Ghana's economy has relied largely on agricultural production. Agriculture accounted for 34% of the GDP and employs about 36% of the population (Ministry of Agriculture, 2010). The evidence also shows that agricultural production is largely rain-fed with irrigated land constituting only 0.2% of the total land area of Ghana (Ministry of Agriculture, 2010). In the wake of increasing climate variability, the reliance on rainfall for agricultural production increases the risks in the sector, which undermines sustained production and food security. Despite Government's efforts to modernize agriculture by investing in mechanization, among others, there continues to be an out-migration, especially of the youth, from the sector.

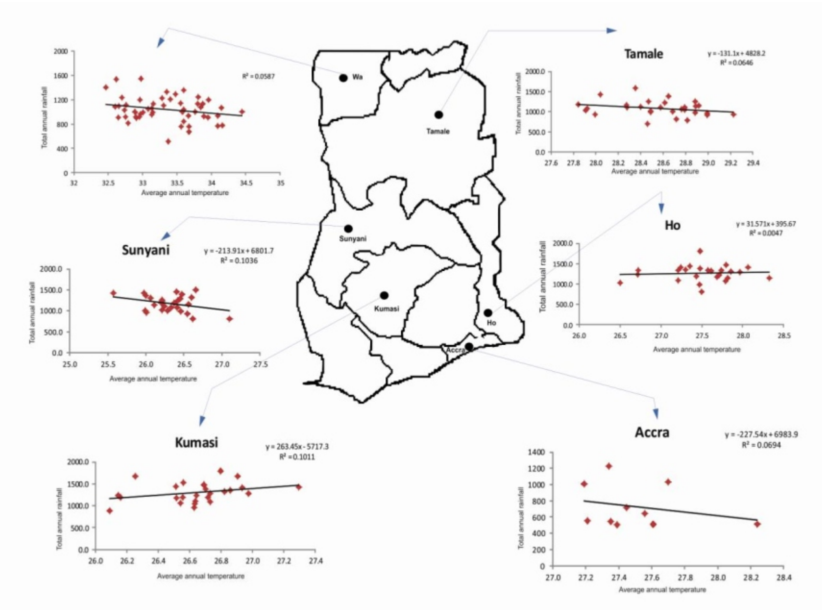


**Figure 2: Relationship between rainfall and temperature at several locations in Ghana**
Source: Author's analysis

Previous unpublished surveys by the author show that the average age of farmers is well over 45 years. Productivity has declined with many farms recording maize yields below 1000 kg/ha while there is a potential of attaining more than 4000 kg/ha under well managed and good rainfall conditions. Not only is agricultural productivity affected by uncertain rainfall, but also the quality of the produce is also low and unable to compete effectively with food imports. This deteriorating condition in agricultural production as a consequence of increased climate variability requires interventions. Three farmer-oriented coping strategies are proposed below.

## 4. Coping Strategies to minimize climate variability impact on agricultural production

This section discusses three coping strategies  climate forecast services, crop insurance and soil managementthat could assist farmers to minimize the negative impacts on agricultural production caused by climate variability.

### *4.1 Weather forecast services for farmers.*

If increased climate variability, defined in terms of erratic and shifts in season onset, increased dry spells and uncertain within-season distribution, are major issues of concern, then it is plausible that improved fore-knowledge on the coming season would provide the opportunity to farmers and other agricultural workers to make informed decisions in agricultural planning.  Indeed the worth of climate services to agriculture has been well demonstrated in several Asian countries, and increasingly in the Sahel Regions of West

Africa and East Africa, enabling farmers to make improved decisions regarding crop and variety choices, sowing dates and the use of appropriate husbandry practices during farming in the next season.

Not much progress has been made with regard to short-term weather forecasting in Ghana. Some effort by Adiku et al. (2007a) shows that the fairly good correlation established between Ghana's rainfall and the ENSO (El Nino-Southern Oscillation) could provide a basis for a reliable seasonal rainfall prediction. Using the DSSAT crop model, it has been shown that simulated yields of peanut using ENSO-based selected variety and sowing dates out-yielded those based on IK-selection at Akatsi in the Volta Region of Ghana (Adiku et al. 1995, 2004, 2007a). Following these simulated results, a field test was carried out on a sample of 26 peanut farmers at Akatsi. ENSO-based weather forecast information was communicated to the farmers in February prior to the season that normally begins in April. The forecast information was accompanied with advice on sowing dates and variety choice to maximize the outcome of the coming season whose outlook was good. The results showed that although only 15% of the farmers heeded the forecast advice, they obtained significantly higher peanut yields than those who rejected the advice (Adiku et al., 2007b). Whereas the proportion of gainers was low, it is conceivable that with consistent education, farmers could learn to appreciate the value of weather forecasts and use them in their decision making.

The major handicap to this knowledge-based technology is the non-availability of the weather services infrastructure. Except for the general seasonal outlook provided annually by the Ghana Meteorological Agency, properly tailored forecast information is required for the agricultural sector. The specific details on the selection of crop and varieties well suited for the season, sowing dates, etc., have already been mentioned. There is a need for a platform for interaction between producers and users of climate forecast information; and support for research is required to improve the prediction skills. These remain major challenges to the use of the forecast technology.

*4.2 Weather-index based crop insurance for reducing agricultural risk under climate variability*

The second coping strategy to minimize climate variability impact on agriculture is crop insurance. Insurance is commonly required by law for automobiles because of the high risk of accidents. Increasingly property insurance is becoming common in Ghana. Recently, the Government of Ghana introduced health insurance schemes to the general population. However, agricultural insurance is a fairly new introduction in Ghana. Whereas crop insurance would not prevent crop loss in the event of a poor season, it would ensure that farmers would remain credit worthy and could re-invest in agriculture in the next season. This would ensure the sustenance of agriculture.

Non-Governmental Organizations such as the IPA (Innovation for Poverty Action) are among the first to explore the possibility of introducing weather-index based crop insurance to farmers in Ghana. The data generated provided information on aspects such as plausible premiums, payout rates, willingness to participate in insurance, etc. A major drive to roll out nation-wide weather-index based crop insurance was, however, initiated by the German International Cooperation (GIZ) in collaboration with the National Insurance Commission. Details on the project can be obtained from GIZ publications. They developed a meso-scale insurance product that targets groups such as agricultural banks and input dealers, among others. These groups were encouraged to insure their credits and loans extended to farmers.

In a related study within a CCAFS (Climate Change and Food Security) project, Adiku et al. (2012) were able to demonstrate the feasibility of extending a micro-scale crop insurance product directly to farmers. The farmer-tailored product is for maize and sells at a premium of $5.00 per acre (approximately 0.5 ha) and in the event of total drought related crop failure, the farmer would receive a payout of $50.00. The determination of the level of payout depends on the output of an adapted crop insurance model introduced from South Africa. Important input data for the model are obtained from previous works on soil-plant-water relations, as well as from relevant FAO literature. Weather data input is obtained from the Ghana Meteorological Agency. While it may seem too early to assess the success of this coping strategy, positive response and acceptability by farmers is observed. In a pilot project at Lawra (Upper West Region) where only an initial number of 15 farmers and extension workers were trained on crop insurance, as many as 80 farmers have recently purchased the crop insurance product for the current season.

The major challenge is the requirement for training of farmers to understand and interpret rainfall data and to learn simple ways of documenting these data. Further, there is the need to fully explain the weather-index based insurance concept. Considerable effort was made to achieve the successful training of farmers in the Lawra pilot project in order to establish the foundations of crop insurance. Ideally, farm schools must be established locally to play these roles more effectively.

*4.3 Soil management as a tool for minimizing climate variability impact on crop growth*

It is often not obvious that there is a link between soil management and climate variability impact on crop growth. The scientific evidence however shows that the effect of water stress on crop growth can be dampened considerably with good soil management. The soil is the buffer between rainfall and water losses in agricultural fields and hence a reservoir for water for plant growth. The water storage ability depends a great deal on how the soil is managed. It is commonly known in the soil science literature (Hillel, 1980) that the retention of crop residues on the field as mulch reduces runoff, increases infiltration and also reduces evaporation. Hence crop growing on a mulched soil could still continue growth and development processes under longer dry spells than those growing on “clean and bare” fields. In other words, the severity and duration of water stress effect on crops from a well-managed field is far reduced. Furthermore, improved soil fertility supports plant vigour and enhances its ability to withstand stresses compared to stunted crops growing on poor soils.

Within the framework of an IITA (International Institute for Tropical Agriculture, Nigeria) and CIMMYT (International Maize and Wheat Improvement Center, Mexico) soil management project, Adiku et al. (2013) surveyed maize fields in the Lawra District of the Upper West Region of Ghana. A striking observation was made between two maize fields growing on the same soil type lying 50m apart. Though planted at about the same time, the maize on these fields reached very different growth stages at the time of visit. Discussions with the farmers showed there was no irrigation and hence it could be inferred that both fields received the same amount of rainfall from sowing to the time of visit. Whereas the maize of one field was stunted (0.3m or knee high) with yellow leaves that were rolled (a sign of wilting) and the field was weedy, the maize on the other field was almost 1.0m, green and well established. Excavation of the soil beneath (Figure 3) showed a major difference in soil management with the vigorous plant having received considerable amounts of manure and fertilizer. The soil receiving manure had a distinct dark top soil that improved not only the fertility but also the water retention ability. In effect, soil management can be an effective method of reducing the climate variability risks and ensure sustained crop growth.

As with the other interventions, soil management requires not only good expertise in the subject but often creates new challenges as it demands residue retention on the field, a practice that competes with other uses (fuel and fencing material, etc.). Alternative energy sources must be found to “free” residues for agricultural purposes. In this regard, the injection of carbon credit funds would be useful. Farmers who adopt improved soil management to maintain soil carbon should be supported by the fund to offset any incurred by retaining residues. Manure application to large fields poses a challenge to labour, requiring engineering innovations for haulage and spreading.

## 5. Conclusion and policy implications

This paper has examined the issue of climate variability as it affects agricultural production in Ghana. The paper provided evidence of climate variability in terms of changing frequency of extreme events (droughts, excess rainfall). The evidence also showed that climate variability is apparently aggravated by climate change and this poses a threat to agricultural production. Not only has seasonal rainfall become more erratic but also the shifts in the within-season distribution of rainfall are additional issues farmers must contend with.

**Figure 3: Impact of soil management on the ability of maize to withstand climate variability**
Notes: Left panel: poor soil management and poor growth with high vulnerability to climate variabilityRight panel: and well-managed soil and vigorous growth and low risk to climate variability.

Source: Adiku et al. (2012b)

Three farmer-oriented coping strategies that could be used to minimize the adverse effect of dry spells and droughts were discussed. These include, (i) weather forecast services to farmers to guide agricultural decision making, (ii) weather-index based agricultural insurance to support farmers in adverse weather conditions to still remain and engage in agricultural practice and (iii) soil management practices that would minimize the vulnerability of crops to extreme climate variability in their fields. The successful operation of these coping strategies would depend on the overall climate change and variability policy of Ghana. The paper suggests, among others that increased support for climate variability research, improvement of agriculturally tailored weather forecasting and farmer training in insurance and soil management are necessary. For effective results, these coping strategies should be used as a combined package. Farmers who would rely on forecast-based advice should also adopt improved soil management practices and purchase insurance. Financial support for these aspects is necessary.

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# The Economic Impacts of Agricultural Productivity Losses from Climate Change: Estimates for Ghana and the World and the Policy Implications

*John Asafu-Adjaye*[1]

## Abstract

Ghana, like most African countries, will surfer adverse impacts from climate change because her economy is dependent on climate sensitive sectors such as agriculture and forestry which provide the bulk of domestic energy supply, food and employment. About a third of Ghana's Gross Domestic Product is contributed by the renewable natural resource sector. Agriculture in particular will be seriously affected because it is mainly rain-fed. Knowledge of the scale and magnitude of the impacts is necessary in order for policymakers to design appropriate policies to address the challenges posed by climate change. In this regard the objectives of this paper are twofold. First, it will estimate the impacts of the projected decline in agricultural productivity in Ghana as a result of future climate change. Second, it will address the implications of managing the impacts with a specific focus on agriculture. This is done using a macroeconomic model of the world economy that features many regions and countries of the world including Ghana. The results indicate that Ghana and other African countries will experience the most adverse impacts from climate change, while European and North American economies will experience the least impacts. Given that the study only considers the impacts of climate change in agriculture, the total cost to the economy would be much higher if other impacts were to be taken into consideration. A number of policy recommendations are made including improving regional climate forecasting systems and their integration in model-based decision support systems, improving water storage and farming systems, investing in biotechnology research, improving infrastructure, improving farm support mechanisms and constructing defensive structures.

**Keywords**: Agricultural productivity, climate change, economic impacts, Ghana.

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## 1. Introduction

Climate change is a serious environmental problem confronting the world. There is consensus amongst a majority of scientists that the Earth is warming at an alarming rate. Global surface temperatures (including over land and sea) have increased by 0.5°C over the period 1901–2010 and about 0.5°C over the period 1979–2010. Climate records indicate that all of the ten warmest years in the global temperature records up to 2011 have occurred since 1997, with 2005 and 2010 being the warmest two years in more than a century of global records (AMS, 2012). Globally, the sea level has risen by an average of about 17 cm in the 20$^{th}$ century, with the rate of increase accelerating since the early 1990s. It is widely believed that human activities, particularly burning of fossil fuels and deforestation, are amongst the prime causes of the changes observed in the 20$^{th}$ century and are likely to contribute to further changes in the 21$^{st}$ century.

Although the African continent accounts for less than 7% of total global $CO_2$ emissions and its emissions per capita are less than half the global average, she will bear the brunt of further global warming (AfDB, 2011). Africa is particularly vulnerable because it is already one of the hottest places on the Earth; as such any further warming is likely to have dire consequences. Africa's vulnerability is heightened by the fact that most of the economies in this region rely mainly on natural resources and rain-fed agriculture, which are highly sensitive to climate change and variability. For example, biomass provides about 80% of the primary domestic energy supply in Africa, while rain-fed agriculture contributes some 30% of Gross Domestic Product (GDP), employs about 70% of the population and is the main safety net of the rural poor (World Bank, 2012).

Like most African countries, Ghana is particularly vulnerable because its economy relies heavily on climate-sensitive sectors such as agriculture, forestry and hydro-energy. Agriculture in particular is the backbone of Ghana's economy, providing employment and sustenance to the vast majority of the population. With irrigation almost nonexistent, Ghana's agriculture is highly vulnerable to climate variability. About 35% of Ghana's land mass is desert and desertification is already currently proceeding at an estimated 20,000 ha per year (EPA, 2009). Ghana's coastline has a length of 565km and the coastal regions of Ghana may be vulnerable to sea level rise. Sea level in this region is projected by climate models to rise by 18 to 56cm in the 2090s, relative to 19801999 under the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenario (SRES) A2.

Even without climate change, agriculture in Ghana faces serious challenges such as low productivity due to low input usage (including fertilisers), water supply variability and high transactions costs. There are also market imperfections in the input markets and services including land, labour, credit and extension. The market failure in the agricultural sector therefore increases the vulnerability of resource-poor farmers and complicates the effects of climate-induced shocks, which in turn makes it more difficult for them to cope with climate change.

In order for decision makers to develop an appropriate response to climate change, it is important for them to have knowledge about the scale or magnitude of the impacts. With this in mind, this paper has two key objectives. Firstly, it will investigate the economy-wide effects of the projected decline in agricultural productivity in Ghana as a result of future climate change. Secondly, it will discuss the implications of managing the impacts with a focus on the agricultural sector given its importance in the Ghanaian economy. The balance of the paper is organised in the following fashion. Section 2 provides the context for the study by discussing the background to Ghana's economy. This section also provides the latest available research on Ghana's current and future climate based on global circulation models (GCMs). Section 2 also presents estimates of the impact of climate change on agriculture by the 2080s for selected African countries including Ghana. Section 3 describes the modeling approach used to estimate the economic impacts of climate change. In Section 4 we present and discuss the simulation results. Section 5 discusses the policy implications of the findings, while Section 6 contains the concluding remarks.

## 2. Background to the economy

This section provides a brief overview of Ghana's economy and the projected impacts of climate change. It begins by describing the main drivers of economic growth. Following that it discusses the current climate and presents some projections on the future climate. It then examines the estimated impacts of climate change on agricultural productivity. In Section 3 these estimated impacts are then used as inputs into a global macroeconomic model to assess the impacts of climate change on Ghana and other regions of the world.

### *2.1 Economic growth*

Ghana's economy has grown from strength to strength since the return to multiparty democracy in 1994. The economy has grown at an average rate of about 7% per annum during the last decade and 9% during the last five years (Figure 1). Growth dipped to about 4% in 2009 due to the effects of the 2008 Global Financial Crisis (GFC) but has recovered strongly since then. Ghana and many other African countries appear to have weathered the effects of the GFC mainly on account of the fact that most of them are not fully integrated into the global financial economic system. Ghana joined the ranks of oil exporters in December 2010 and was the best performing economy in the world in 2011 with a growth rate of nearly 15% (Figure 1). Economic growth in 2013 is projected to be 8%.

Despite the emergence of oil and gas as a driver of growth, Ghana's economy continues to depend heavily on its renewable natural resources. Although the share of agriculture (which includes forestry and fisheries) in GDP has declined from 40% in 2003 to 23% in 2012 (see Figure 2), the sector accounts for close to 70% of total employment. Consequently, the country's economic base remains narrow and vulnerable to the vagaries of commodity prices, agricultural supply shocks, and the changing climate. Most of the population—especially the poor—rely on natural resources for their livelihoods (World Bank, 2007). Although the service sector (particularly communications) dominates the economy, its effect on employment has not been exceptional given that it is capital rather than labour intensive.

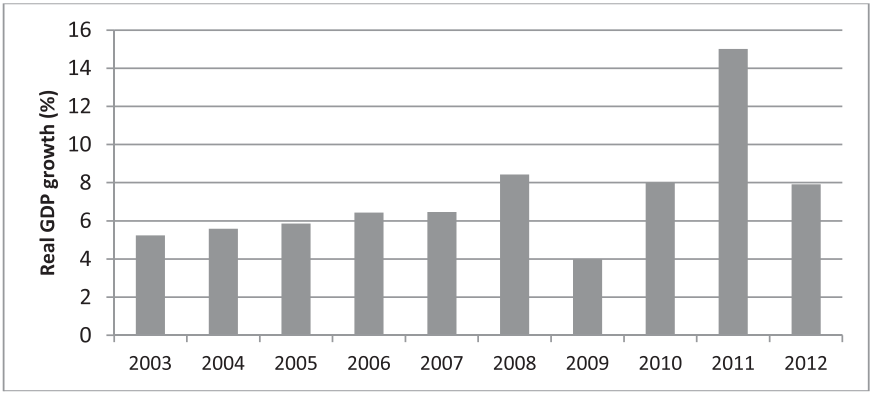


**Figure 1: Ghana: real GDP growth, 2003–12**
Source: World Bank (2013)

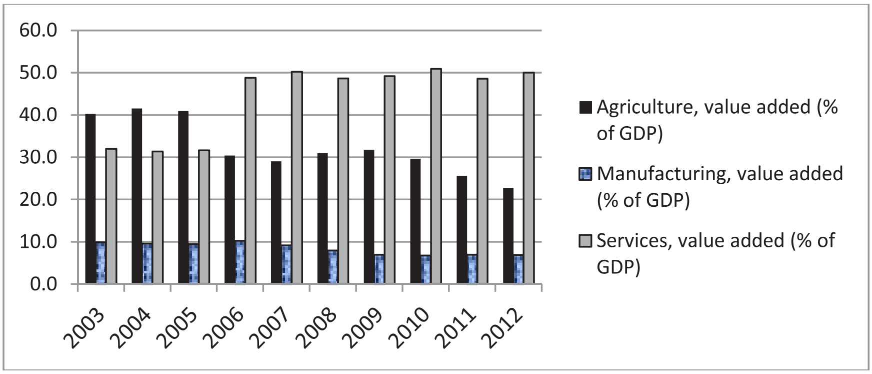


**Figure 2: Ghana: major components of GDP, 200312**
Source: World Bank (2013)

## *2.2 Ghana's current climate and future projections*

Ghana's tropical climate is strongly under the influence of the West African Monsoon. The rainfall patterns are mainly determined by the movement of the tropical rain belt (the Inter-Tropical Conversion Zone, ITCZ). The southern regions of the country tend to experience two rainy seasons. The main rainy season occurs from March to July and the minor season from about September to November. The northern part of the country experiences a single rainy season that occurs between May and November, followed by a dry season between December and March. The northern and central regions receive about 150250mm per month in the peak months of the wet season (July to September). The seasonal rainfall in Ghana varies considerably on inter-annual and inter-decadal timescales, due in part to variations in the movements and intensity of the ITCZ, as well as variations in timing and intensity of the West African Monsoon. These variations have been attributed to the El Niño Southern Oscillation (ENSO) and partly to the North Atlantic oscillation (Nicholson and Selato, 2000). El Niño events are generally associated with drier than average conditions in West Africa. The northern regions of Ghana experience the greatest seasonal variations in temperature. These regions experience the highest temperatures during the dry season with a temperature range of 2730°C, with the lowest temperatures occurring in the rainy season with a temperature range of 2527°C. In the southern part of the country, temperatures reach a high of 2527°C in the warmest season (January, February, March), and are lowest during the major rainy season with a range of 2225°C. Annual rainfall in Ghana tends to be highly variable on inter-annual and inter-decadal timescales. Rainfall over Ghana was particularly high in the 1960s, and decreased to particularly low levels in the late 1970s and early 1980s, which has led to an overall decreasing trend during the period 19602006, with an average decline of 2.3mm.

Ghana's mean annual temperature is projected to increase by 1.03.0°C by the 2060s, and 1.55.2°C by the 2090s (McSweeney et al., 2008). Warming is projected to be most rapid in the northern inland regions compared to the coastal regions. All the projections indicate substantial increases in the frequency of days and nights that are considered 'hot' compared to the current climate, but the range of projections between different models is large. Projections of mean annual rainfall averaged over the country from different models indicate a wide range of changes in precipitation for Ghana, with around half the models projecting increases and half projecting decreases.

In a recent study, the World Bank (2010) developed climate projections for Ghana using both historic and monthly precipitation and temperature data. Climate projections from two GCMs, the National Center for Atmospheric Research (NCAR) CCSM3 and Commonwealth Scientific and Industrial Research Organization (CSIRO) Mk3.0 models with SRES A2 emission forcings, were used to generate “Global Wet” and “Global Dry” scenarios for Ghana. In addition, the climate projections from the two GCM/SRES combinations with the lowest and highest climate moisture index for Ghana are used to generate a “Ghana Dry” and a “Ghana Wet” scenario (Table 1). It is interesting to note that the globally “wettest” GCM actually projects a drier future climate for Ghana than the globally “driest” GCM under emission scenario A2 based on projected deviations for the crop moisture index.

**Table 1: GCM scenarios for Ghana**

| Scenario | GCM | SRES | Crop Moisture Index Deviation |
|---:|---:|---:|---:|
| Global Wet | ncar_ccsm3_0 | A2 | -17% |
| Global Dry | csiro_mk3_0 | A2 | 9% |
| Ghana Wet | ncar_pcm1 | A1b | 49% |
| Ghana Dry | ipsl_cm4 | B1 | -66% |

Source: World Bank (2010)

The projections indicate fairly wide fluctuations in annual temperatures in all four Ghana agro-ecological regions (northern savannah, southern savannah, forest, and coastal) for all four scenarios. However, the trend over the period 2010–50 indicates warming in all regions, with temperatures increasing the most in the northern savannah region—with increases of up to 2.2–2.4°C, leading to average temperatures as high as 41°C—while also presenting the widest range of temperature variability (5.7°Crange). All agroecological regions show significant precipitation variability compared to the baseline scenario. The coefficient of variation of annual precipitation in Ghana varies between -9% (global wet scenario) to -14% (Ghana dry scenario). Using a crop model (CliCrop-Ghana), the study used the changes in precipitation and temperature from the four GCMs to estimate annual changes in yield for major food crops over the period 20062050. Although there is wide variation in the projections, most of the models predict a decline in yields for all the crops. For example, yam output declines by as much as 2.7% per annum over the period.

### *2.3 Impact of climate change on agricultural productivity*

One of the most comprehensive analyses of the impacts of climate change on global agriculture through the 2080s was undertaken by Cline (2007). First, he examined a series of agricultural impact models, namely crop models and Ricardian models. Next, he applied detailed climate projections to the various agricultural impact models to develop a set of alternative impact estimates. He then arrived at a set of preferred estimates, applying judgmental weighting of estimates by likely reliability, of the likely impacts of climate change with and without carbon fertilization. Table 2 reports Cline's estimates of the impact of global warming on agriculture for selected African countries including Ghana. The first three columns present Ricardian estimates for dryland and irrigated agriculture without carbon fertilization, and a weighted average of the two, respectively. The fourth column presents crop model forecasts without carbon fertilization, while the last two columns provide a synthesis of results for the two approaches with and without carbon fertilization. Carbon fertilization is the process by which rising levels of atmospheric $CO_2$ increase crop and forest growth rates by stimulating photosynthesis (e.g., see Reilly, 1992, 1994).

The Ricardian estimates show declines in output for all the countries in the sample. Consistent with the rainfall forecasts, the severest losses are in the northern Sahara region, followed by southern Africa, while the smallest losses are in tropical and eastern Africa. These losses are reduced to some extent in countries with a significant share of cropland under irrigation. In the case of Ghana, the weighted average crop loss for a *Business As Usual* (BAU) scenario without carbon fertilization using the Ricardian model is 8.2% per annum, while the crop model projects a loss of 19.8% per annum. Cline's preferred estimate for Ghana is a loss of 14.3% per annum. An issue of major concern is the high number of severe effects for dryland agriculture. Four countries in the sample have declines of 100%, while another three experience declines of about 50% or more.

## 3. The modelling approach

### *3.1 Model description*

To analyse the potential impacts of productivity losses in agriculture from climate change on Ghana's economy, we perform a counterfactual simulation using a computable general equilibrium (CGE) model. General equilibrium models are noted for their ability to measure the impacts of one or more policy variables on several sectors simultaneously. An alternative analytical approach is to use partial equilibrium (e.g., econometrics) models. However, these are inadequate because they do not capture the economic feedbacks involved and also do not account for the direct and indirect effects. Recent studies have used computable general equilibrium (CGE) models to assess the sectoral impacts of climate change policies (e.g., see Asafu-Adjaye and Mahadevan, 2013; McKibbin et al., 2011).

**Table 2: Estimates of the impact of global warming on agriculture by the 2080s for selected African countries** (percent)

| | Ricardian estimates | | | | Preferred estimates | |
|---|---|---|---|---|---|---|
| Country | Dry Land (without carbon fertilization) | Irrigated (without carbon fertilization) | Weighted average (without carbon fertilization) | Crop model estimates (without carbon fertilization) | without carbon fertilization | with carbon fertilization |
| Angola | -26.6 | -26.2 | -26.3 | -25.3 | -25.8 | -14.7 |
| BurkinaFaso | -16.5 | 20.9 | -16.5 | -32.1 | -24.3 | -13.0 |
| Cameroon | -19.1 | -31.9 | -20.3 | -19.8 | -20.0 | -8.0 |
| Congo,Dem.Rep. | -5.5 | 23.2 | -4.1 | -25.2 | -14.7 | -1.9 |
| Ethiopia | -31.4 | -53.9 | -31.4 | -31.1 | -31.3 | -20.9 |
| Ghana | -3.0 | -41.6 | -8.2 | -19.8 | -14.0 | -1.1 |
| IvoryCoast | -3.6 | -74.2 | -7.0 | -19.8 | -14.3 | -1.5 |
| Kenya | 8.3 | 20.8 | 15.0 | -25.7 | -5.4 | 8.8 |
| Madagascar | -20.5 | -16.4 | -20.3 | -32.1 | -26.2 | -15.1 |
| Malawi | -33.6 | -10.2 | -31.5 | -31.1 | -31.3 | -21.0 |
| Mali | -100.0 | -11.9 | -39.0 | -32.1 | -35.6 | -25.9 |
| Mozambique | -30.6 | 2.8 | -23.6 | -19.8 | -19.8 | -21.7 |
| Niger | -100.0 | 36.3 | -36.1 | -32.1 | -34.1 | -24.2 |
| Nigeria | -13.7 | -1.8 | -12.1 | -24.9 | -24.9 | -18.5 |
| Senegal | -100.0 | -55.2 | -84.0 | -19.8 | -51.9 | -44.7 |
| SouthAfrica | -51.5 | -39.6 | -47.0 | -19.8 | -33.4 | -23.4 |
| Sudan | -100.0 | 9.5 | -81.1 | -31.1 | -56.1 | -49.5 |
| Tanzania | -16.3 | -1.1 | -16.3 | -32.1 | -24.2 | -12.8 |
| Uganda | -1.7 | -4.8 | -2.5 | -31.1 | -16.8 | -4.3 |
| Zambia | -48.5 | -37.7 | -47.1 | -32.1 | -39.6 | -31.0 |
| Mean | -36.5 | -14.7 | -27.8 | -27.0 | -27.7 | -17.8 |
| Median | -26.6 | -11.9 | -23.6 | -31.1 | -25.8 | -18.5 |

*Source*:AdaptedfromTables5.4and5.8ofCline(2007)

The agricultural productivity effects of climate change and variability on Ghana are likely to arise from the interaction of two forces; First, from the potential reduction in agricultural output and second, from a slowdown in economic activity brought on by the indirect effects on other sectors of the economy. The CGE model used here is the Global Trade Analysis Project (GTAP), a multiregional static CGE model which captures world economic activity in 57 different industries of 87 regions of the world (Hertel, 1997). In this study, we use the latest database in the series, the GTAP 8 database, which includes updated data to 2007 for the various countries. In this simulation, we have aggregated the database into nine regions – North America, EU, Asia, Ghana, West Africa, North Africa, East and Central Africa, Southern Africa and the Rest of the World (ROW). The African regions are North Africa, East Africa, Southern Africa, and the rest of Sub-Saharan Africa. The countries in these regional aggregates are shown in Table 3. We have also aggregated the industrial sectors into 11 sectors: Grains and Crops; Meat and Livestock; Forestry; Fishing; Mining; Food Processing; Textiles and Apparel; Manufacturing; Utilities and Construction; Transport and Communications; and Other Services.

**Table 3: Countries in the regional aggregates**

| **North America** | **East Africa** | **European Union** | **Asia** |
|---|---|---|---|
| Canada | Tanzania | Austria | China |
| UnitedStates | Uganda | Belgium | HongKong |
| Mexico | Malawi | Denmark | Japan |
| | Mozambique | Finland | Korea |
| **North Africa** | Zambia | France | Taiwan |
| Algeria | Zimbabwe | Germany | Indonesia |
| Morocco | Madagascar | UK | Malaysia |
| Tunisia | | Greece | Philippines |
| RestofNorth Africa | **Ghana** | Italy | Singapore |
| | | Luxemburg | Thailand |
| | **West Africa** | Netherlands | Vietnam |
| **Southern Africa** | Senegal | Portugal | India |
| Botswana | Cameroon | Spain | Bangladesh |
| SouthAfrica | Nigeria | Sweden | SriLanka |
| RestofSACU | Benin | | RestofAsia |
| RestofSADC | Burkina Faso | | |
| | Cote d'Ivoire | | **Rest of the World** |
| | Togo | | Allother countries |

The GTAP model is referred to as a *comparative-static* model because it provides projections at only one point in time, the solution. The comparative static approach may be illustrated with the aid of Figure 3. In the absence of climate change, the Ghanaian economy could be on growth trajectory A at, say, a 9% per annum growth rate. With climate change, there is a decline in the economy's growth rate, reaching a lower trajectory of B of, say, 4% per annum at some future date T*. Comparative statics is only concerned with the gap AB and it does not say anything about how the economy got to point B. The gap AB is 5 percent at T*, which is the decrease in the economy's growth rate due to climate change.

The model uses an algebraic framework resulting from imposing the conditions of producer and consumer maximization on the accounting framework of the SAMs. The algebraic framework is used to analyse the behaviour of numerous economic agents including producers, households, and governments. The standard GTAP assumption is perfect competition and constant returns to scale where bilateral trade is handled via the Armington framework (products are differentiated by country of origin). The model assumes that there is a regional household that collects all income and allocates across private consumption, government, and saving. Household demand for commodities and services are in constant different elasticity form, which assumes non-homothetic preferences and is more flexible than the constant elasticity of substitution form. Producers are assumed to have a constant elasticity of substitution production function (Hertel and Tsigas 1997; McDonald and Walmsley, 2003).

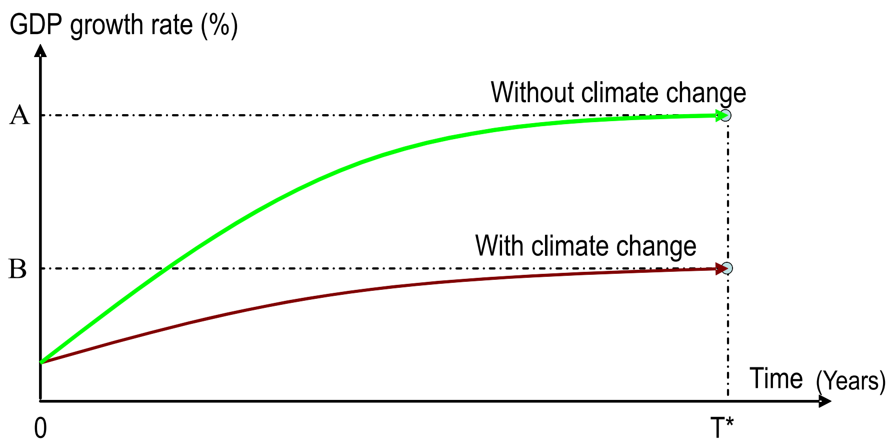


**Figure 3: Illustration of the Comparative Static Approach**

In the model closure we set taxes, tariffs and technical change parameters exogenously. Since population is determined by demographic factors, it is also set exogenously. Our closure rules also reflect the situation in developing countries where there is no full employment of unskilled workers. In most of these countries there is commonly an excess supply of unskilled labour that can be used by industries in case there is an increase in production. To account for this fact, wage rates are assumed to be exogenous and labour supply is assumed to be endogenous. Lastly, we account for fixed prices in the market for commodity exports. In this application, we have aggregated the 57-sector GTAP database to 11 sectors to facilitate the solution.

### *3.2 Assumptions*

The reference case for the simulation is a scenario in which it is assumed that there are no climate change impacts on future economic growth. This situation is then compared to a *Business as Usual* (BAU) climate change scenario. Based on Cline (2007), it is assumed that agricultural productivity in the major producing regions of the world will decline over the medium to long term because of projected changes in climate. Based on Stern (2006), it is also assumed that there will be an overall slowdown in global economic activity as a result of climate change. Because we are using a static model to analyse impacts that are well into the future, we also assume that the structure of the world economy will remain unchanged. Alternatively, we can interpret the results as the likely economic outcome if the predicted effects of global warming were to occur sooner. The assumed changes in agricultural productivity applied as shocks in the model are provided in Table 4 and are based on Cline's preferred estimates. Agricultural productivity in North America and the EU is projected to decline by 14.5% and 9.4%, respectively, while reductions for Asia and the Rest of the Word are projected to be 19.3% and 19.7%, respectively. Agricultural productivity for Ghana is projected to decline by 14.3% over the period. Estimates for the rest of SSA range from 21.2% (North Africa) to 33.4% (Southern Africa) and are based on averages for the respective countries in the model.

**Table 4: Impact of global warming on agricultural productivity**

| Country/Region | % Change |
|---|---|
| North America[a] | -14.5 |
| EU[b] | -9.4 |
| Asia[b] | -19.3 |
| Ghana | -14.3 |
| West Africa | -24.8 |
| North Africa[c] | -21.2 |
| East and Central Africa[c] | -14.1 |
| Southern Africa[c] | -33.4 |
| Rest of the World (ROW)[b] | -19.7 |

Notes:
a. Average for Canada, US and Mexico taken from Cline (2007) Table 5.10.
b. Taken from Cline (2007) Table 5.10.
c. Average for the countries in respective regions in Table 5.8 of Cline (2007).

## 4. Simulation results and discussion

Figure 3 presents simulation results for the impacts of the estimated decline in agricultural productivity due to climate change on the key sectors of Ghana's economy. As would be expected, production of Grains/Crops and Meat/Livestock declines by 18.3% and 5.34% per annum, respectively. Other sectors that decline in output significantly include Fishing, Food Processing and Utilities/Construction. Not surprisingly, these sectors are sensitive to temperature and/or precipitation. It is very likely that the large reduction in the output of the Utilities/Construction sector is due to the decline in energy production which is currently heavily dependent on hydroelectric power generation. Sectors that thrive even under climate change include mining, manufacturing and forestry. The growth in forestry is a little counter intuitive because it is supposed to be a climate-sensitive sector. However, there could also be a carbon fertilization effect in this sector**.** On the other hand, the growth in manufacturing is not surprising. The decline in agricultural productivity as a result of climate change reduces the net returns in this sector and therefore resources such as capital and labour are re-directed into sectors with higher rates of return such as forestry and manufacturing.

The simulation results shown in Table 5 indicate that net exports of agricultural commodities increase for North America and the EU, US, while they decline for Asia, Ghana and the rest of SSA. The fall in agricultural production in Asia and Africa implies that countries in these regions become net importers of food (results not shown here).

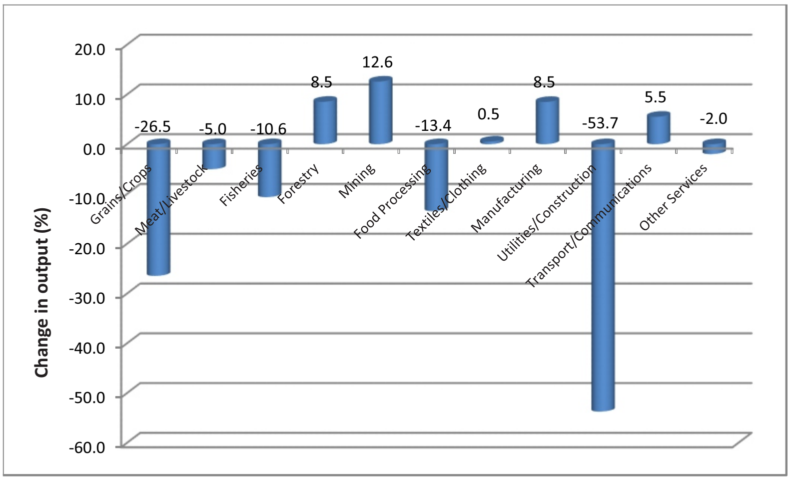


**Figure 3: Impact of climate change on Ghana's economy (% change in output)**

Source: GTAP model simulations

**Table 5: Impacts of climate change on merchandise exports by sector (% changes)**

| | North America | EU | Asia | Ghana | West Africa | East & Central Africa | Southern Africa | ROW |
|---|---|---|---|---|---|---|---|---|
| GrainsCrops | 63.4 | 67.8 | -18.7 | -64.2 | -42.3 | -29.5 | -45.2 | 9.7 |
| MeatLstk | 14.9 | 12.4 | 10.6 | -70.2 | -16.5 | 16.2 | -16.2 | 33.9 |
| Fisheries | -4.5 | -2.5 | -5.9 | -21.6 | 8.0 | 2.7 | -0.7 | -3.7 |
| Forestry | -3.7 | -2.1 | -0.1 | 7.6 | 7.2 | 1.3 | -2.0 | -3.0 |
| Mining | -3.3 | -2.9 | -2.0 | 11.2 | 0.1 | -1.2 | -1.6 | -2.1 |
| FoodProc | 10.8 | 9.2 | -8.2 | -3.8 | -20.1 | -0.6 | 2.9 | 0.0 |
| TxtApparel | 12.1 | 8.1 | -7.9 | -9.6 | -34.1 | 0.1 | 18.5 | 5.9 |
| Manufacturing | -3.0 | -2.3 | 1.6 | 4.0 | -6.5 | -1.8 | 1.3 | -0.6 |
| Util_Cons | -3.4 | -2.4 | 1.5 | -1.7 | 2.8 | -0.9 | 0.3 | -0.5 |
| TransComm | -1.9 | -1.4 | -0.1 | 5.9 | -2.5 | 0.6 | 1.4 | -1.0 |
| OthServices | -3.2 | -1.8 | 2.6 | -4.7 | 3.2 | 0.5 | 1.6 | -0.6 |

Source: GTAP model simulations

As expected, the decline in net agricultural exports in SSA is higher relative to all other countries on the basis of the climate predictions. For example, in the case of Grains/Crops sector the declines range from 29.5% (East and Central Africa) to 64.2% (Ghana). Net exports of non-renewable natural resources (minerals and forestry products) increase for Ghana and some SSA countries but decline in the advanced countries. Figure 4 shows that the terms of trade (the ratio of export to import prices) increase slightly in the North American region, remain unchanged in the EU but decline in Ghana and other regions of the world (with the exception of East and Central Africa).

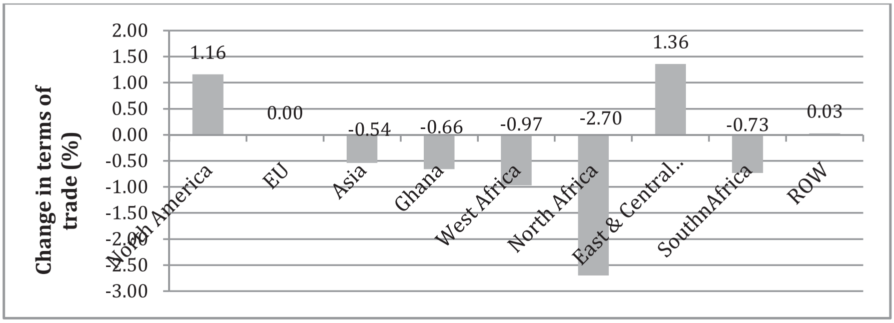


**Figure 4: Impacts of climate change on the terms of trade (%)**

Source: GTAP model simulations

Given that Ghana (as well as other SSA countries) is heavily dependent on agriculture for national income and sustenance, the fall in the terms of trade implies that farmers receive less for their produce. As a result Figure 5 shows that household disposable incomes in the SSA region decline quite significantly, with the estimates ranging from 6% (North Africa) to 16% (Ghana). The net effect of climate change is a decline in welfare in all regions across the world, reflecting a decline in agriculture, food processing and other climate sensitive economic activities.

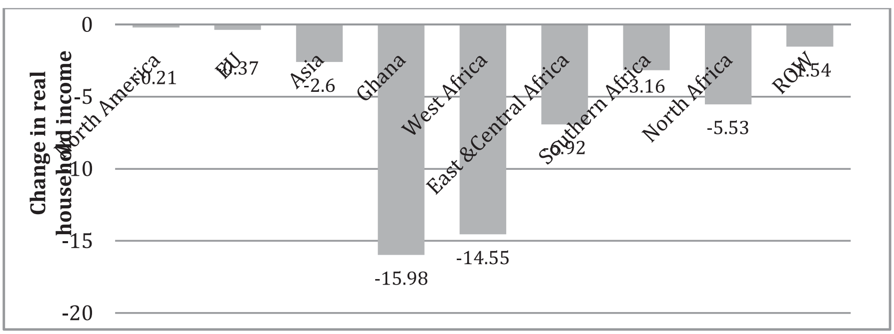


**Figure 5: Impact of climate change on real household income (%)**

Source: GTAP model simulations

As expected, the decline in agricultural output as a result of global warming has greater adverse impacts on SSA countries given that their economies are agricultural-based. GDP declines by as much as 12% for Ghana, 13% for West Africa, 10% for Southern Africa, 6% for North Africa 7% for East and Central Africa, 2% for Asia and 1.5% for the rest of the world (Figure 6). By contrast, GDP increases by less than 0.5% for North America and the EU. For Ghana (as is also the case for most SSA countries), the results indicate that global warming would lead to an increase in the prices of both domestic and imported goods and services (see Figure 7). The largest price increases would be for imported agricultural products and processed food. This would put upward pressure on inflation, as confirmed by the increases in the GDP deflator. Although our model does not specifically have a variable to directly measure poverty, it can be surmised that with the decline in household income and the increase in price inflation, there will be an increase in poverty especially amongst those in the lower income classes.

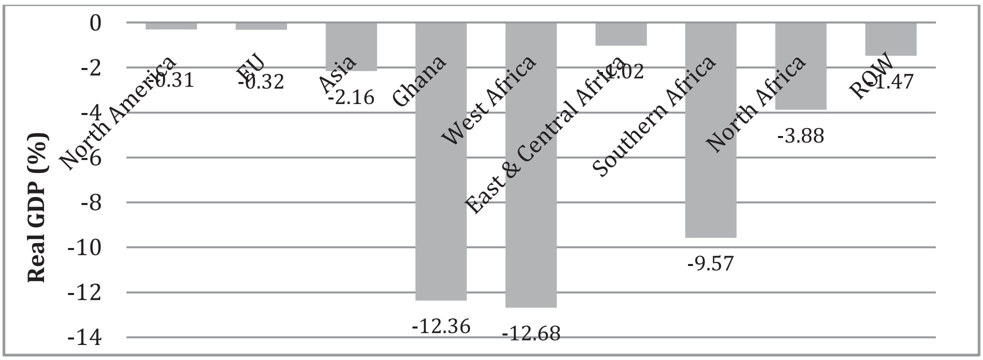


**Figure 6: Impact of climate change on real GDP (%)**

Source: GTAP model simulations

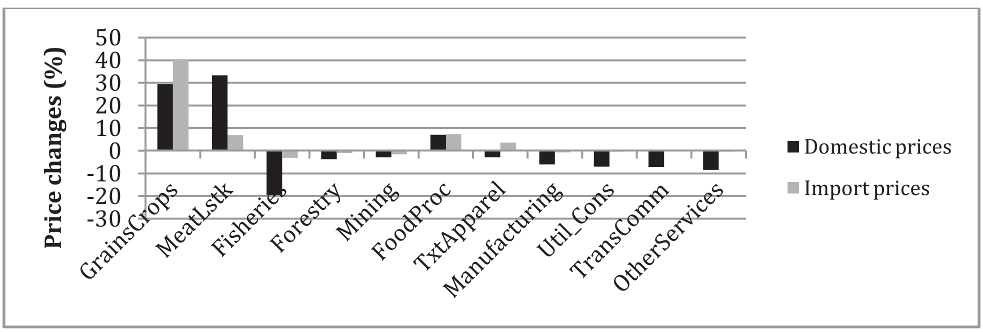


**Figure 7: Impact of climate change on domestic and import prices (%)**

Source: GTAP model simulations

## 5. Policy implications

In this section, we first consider measures that can be taken to build adaptive capacity in Ghana at the national level, farm level and household level. Following that, we discuss possible barriers and limitations to effective adaptation.

### *5.1 Building adaptive capacity*

Adaptive capacity refers to the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate (IPCC, 1995). Adaptive capacity can be enhanced at the national/regional level through the development of institutional measures and appropriate infrastructure. At the farm level, there are a number of actions that could be taken to build adaptive capacity. Each of these issues is briefly discussed below.

#### *5.1.1 National/regional level measures*

Institutional and governance factors have been identified as playing a critical role in local communities' abilities to adapt to and cope with climate variability and change. Yet, in many SSA countries, the institutional and legal frameworks have been found to be insufficient to deal with environmental degradation and disaster risks (Sokona and Denton, 2001; Beg *et al*., 2002). In a case study of responses to multiple stressors in a rural community in KwaZulu-Natal, South Africa, O'Brien and Vogel (2003) identified institutional organization and governance as being among the factors which reduce the ability of farmers to secure sustainable livelihoods and cope with multiple stresses, including climate. They highlight the need for a better understanding of both formal and informal institutions at the local level in efforts to enhance adaptation to climate change and variability. Brooks *et al.* (2005) have also shown that adaptation can be successful and sustainable when linked to effective governance systems, civil and political rights and literacy. Other institutional measures that can enhance adaptation include developing appropriate land use and water management plans to regulate land and water for future use. In some cases, new policies and institutions would need to be developed to support the new land use and water management arrangements.

There are a number of options to enhance adaptation that are technology related. These include improving regional climate forecasting systems and their integration in model-based decision support systems. However, as O'Brien and Vogel (2003) have observed, there is limited support for climate risk management in agriculture and therefore a limited demand for such seasonal forecast products. It is important to emphasise the need for Ghana to set up early warning systems that could reduce vulnerability to the risks associated with climate change and variability. Improved water storage systems, shallow ground irrigation systems and improved farming systems could enhance resilience to drought stress. Investment in biotechnology research is one means to promote development of drought-resistant, pest-resistant, and drought-tolerant grain. There is a need for government to invest in rural infrastructure and marketing institutions to improve access to materials such as fertilizer, seeds and credit that could enhance agricultural productivity. Extreme climatic events may have a major impact on the availability of, and access to, seed. There is therefore a need to strengthen formal and informal seed systems as part of the adaptive strategy to address climate change.

Improvements in physical infrastructure may also improve adaptive capacity (Sokona and Denton, 2001). For example, a general deterioration in infrastructure could threaten water supply in periods of droughts and floods. The construction of defensive structures such as mangrove belts, tree shelterbelts, and levees are also useful proactive strategies to enhance adaptation.

### *5.1.2 Farm/household level measures*

In the medium term, farmers can adapt to climate change and variability by means of appropriate crop selection and changing the timing of planting. This is already happening to some extent in Africa (Kurukulasuriya and Mendelsohn, 2006). However, such measures may only be effective for adapting to temperature changes in the region of 12°C. Their effectiveness will decline with higher temperatures for which new adaptation measures will be required. These include the introduction of new varieties to withstand the higher temperatures, diversification of production systems and livelihoods, and a shift to intensive agriculture. Although agriculture is a major source of livelihood in Africa, there is evidence that off-farm incomes are increasing in some areas - up to 6080% of total incomes in some cases (Bryceson, 2002). It is expected that this trend will continue as a form of income diversity in the face of climate change and variability. There is a need for supporting policies and programs to assist farmers in the process of adaptation. The issue of access to inputs has already been mentioned above. In addition, provision of capital and extension services could increase household welfare and enhance resilience.

## *5.2 Roles of key stakeholders*

Various interest groups and stakeholders are required to work together to improve the response to climate change at the international, regional, national and local levels. We consider below the roles of governments, the private sector, NGOs, and the development agencies.

### *5.2.1 Government*

Given that climate change policies will become increasingly important in the years to come, there is a strong case for the government to set up entire ministries or divisions within ministries to oversee and coordinate the implementation of policies and initiatives. The role of government, in this regard, is to remove existing structural and institutional deficiencies that constrain the peoples' ability to adapt to and mitigate climate change, and to assist in the promotion of climate change strategies. There is a need to speed up the on going economic reforms to reduce inflation, reduce fiscal deficits, reform the financial sector, and improve economic freedom by minimizing government interference and reducing the costs of doing business. Non-climate change policies have the potential to affect GHG emissions as much as climate change policies. Therefore there is a need to examine all government policies (both macroeconomic and sectoral) to ascertain the extent to which they can be modified to achieve GHG reductions.

The UNFCCC is supposed to assist developing countries in planning for adaptation through the development of National Adaptation Programmes of Action (NAPAs). As of mid-2013, 49 NAPAs have been submitted to the UNFCCC to date, of which 29 are African countries (UNFCCC, 2013). The initial indications are that the NAPAs face the same constraints on effectiveness and legitimacy as other national planning processes. Thomas and Twyman (2005) have noted the need for wider and more representation processes in the preparation of the NAPAs.

One means to offset the effects of global warming is through increased international trade. However, Africa's share of global exports is currently under 3%, although the developing countries' share of global exports increased from 32% in 2000 to 37% in 2006 (UNCTAD, 2007). Pending the negotiation of and effective world trade agreement, there is a need for the government to press for better deals in current North-South initiatives such as the Economic Partnership Agreement with the EU. In order to take advantage of any favourable trading arrangements, the government needs to ratchet up efforts to enhance the competitiveness of the agricultural sector. This includes removing the perennial bottlenecks of poor transportation and marketing networks, and lack of extension support. In particular, there is a need for an increase in public expenditure on agricultural research to deal with the challenges of climate change and variability.

#### *5.2.2 Private sector and NGOs*

The private sector has a role to play mainstreaming climate mitigation strategies into its planning and operational processes. For example, climate mitigation considerations could be considered foremost in the purchase of plant and machinery and in the construction of offices and factories. While government could ensure compliance with climate change requirements through legislation, the best way forward at this stage appears to be through voluntary agreements between governments and the private sector. There may be incentives for firms to reduce their costs through adopting environmentally friendly (or eco-efficient) practices, while there might be opportunities to profit from promoting and marketing eco-efficient products. At this point in time, the insurance sector has played a limited role in SSA in terms of climate change mitigation. There is an opportunity for it to promote risk prevention through working with the building industry and government to implement and strengthen building standards and to develop best practices. In SSA, climate risk insurance and crop insurance are virtually non-existent. This is one area where the government and industry could collaborate to assist farmers to address climatic contingencies and price volatility. NGOs have been active in efforts to promote awareness about climate change and have a continuing role to play in educating local communities about climate change adaptation and mitigation.

### *5.2.3 Development Partners (Multilateral, Bilateral and Regional Institutions)*

The multilateral and bilateral aid agencies also have a crucial role to play in mitigation and adaptation by incorporating climate risk into their lending policies. There is also a need for them to work more closely with climate-change researchers in the design and implementation of projects in order to achieve positive outcomes in the areas of mitigation and adaptation. Agrawala and van Aalst (2005) have identified the following as the major constraints to the successful mainstreaming of climate change issues into development policies: relevance of climate information for development-related decisions; uncertainty of climate information; compartmentalisation within governments; segmentation and other barriers within development-cooperation agencies; and trade-offs between climate and development objectives.

## 6. Conclusions

The macroeconomic implications of the decline in agricultural productivity were simulated using the GTAP model of the world economy. The world economy was aggregated into nine regions, comprising North America, the EU, Asia, Ghana, West Africa, North Africa, East and Central Africa, Southern Africa and the rest of the world. The policy simulations undertaken in this study indicate that Ghana and other African countries will experience the largest impacts from climate change in terms of decline in economic growth and income losses, whereas European and North American economies will experience the least impacts. The decline in agricultural production will have a flow on effect on most sectors of the economy with the exception of mining and manufacturing. Real GDP for Ghana is estimated to decline by about 12% per annum. It is important to note that this estimate only considers the impacts of climate change in agriculture. Therefore the total cost to the economy would be much higher if other impacts are taken into consideration. Climate change would cause the country to be a net importer of agricultural and food products. The decline in agricultural productivity will cause the prices of both domestic and imported food to increase. This will put upward pressure on the inflation rate. The terms of trade declines in Ghana and other SSA countries will lead to a reduction of disposable incomes. The decline in household incomes, coupled with the price rises, imply that there would be an increase in poverty.

A number of options to enhance adaptation to climate change and variability were canvassed. These include improving regional climate forecasting systems and their integration in model-based decision support systems, improved water storage and farming systems, investment in biotechnology research, improvement in infrastructure, improvement in farm support mechanisms, and construction of defensive structures. Lack of information, institutional and governance shortcomings, biophysical and socio-cultural factors and inadequate financial resources were noted as constraints to adaptation. Mitigation was noted as a necessary option to rein in climate change since unabated climate change could make adaptation very costly. Action would be required at the international, regional, national and local levels to limit GHG emissions. There is a need for Ghana and developing countries, particularly those in Africa, to investigate the cost implications of any future climate agreement so as to strengthen their bargaining positions in these negotiations.

Finally, the government, private sector organizations, NGOs, and the development partners would need to work together to enhance adaptation to and mitigation of climate change. In particular, there is a need for governments to mainstream climate related issues into national and regional development plans and processes. Likewise, the development agencies should mainstream climate risk into their lending policies and processes. It was suggested that the development agencies should cooperate closely with climate scientists in the design and implementation of projects in order to enhance adaptation and reduce emissions.

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