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Climate Change and its Effect on Agriculture in Sub-Sahara Africa

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Abstract: Warming of the climate system is unequivocal as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. The Sub-Saharan African region has all the threat signs mentioned above, located in the tropical region and made up of least developed and developing countries with heavy dependence on agriculture. Agriculture is mainly rain-fed in this region and the majority of the people, most of which are poor, depend on it for their livelihoods. The agricultural sector also accounts for a large share of GDP and export earnings. As the study shows, the region is already experiencing higher temperatures which may adversely affect crop yield and consequently, food unavailability while changes in precipitation patterns may increase the likelihood of short-run crop failures and long-run production declines. It was concluded among other things that innovative farming practices such as conservation tillage, organic production, improved cropping systems, land restoration, land use change and irrigation and water management are ways that farmers can address climate change.

Key words: Climate change, food production, Sub-Sahara, ocean, temperatures, tropical region

INTRODUCTION

Since, the 20th century, the earth's temperature has been increasing quite notably and global climate change with the adverse consequences it could have on human survival has been debated widely in the literature in recent times. Different regions of the world and different aspects of human lives are already being affected by changes such as increasing temperatures, changes in precipitation patterns, shifts in seasons and generally, more adverse weather events. Natural shifts in global temperatures have occurred throughout human history. Scientists attribute the temp increase to a rise in carbon dioxide and other green house gases released from the burning of fossil fuels, deforestation, agriculture and other industrial processes.

Scientists refer to this phenomenon as the enhanced greenhouse effect. The Intergovernmental Panel on Climate Change (IPCC, 2007) reported that the average surface temperature of the earth increased by 1.3°F over the past century while an additional 3.2-7.2 degrees increase is projected over the 21st century. According to the Environmental Protection Agency, an increase in average temperature can: lengthen the growing season in regions with relatively cool spring and fall seasons; adversely affect crops in regions where summer heat already limits production; increase soil evaporation rates and increase the chances of severe droughts (IPPC, 2007). Climate change' refers to a change in the state of the climate that can be identified (using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to internal processes and/or external forcing. Some external influences such as changes in solar radiation and volcanism, occur naturally and contribute to the total natural variability of the climate system. Other external changes such as the change in composition of the atmosphere that began with the industrial revolution are the result of human activity. The naturally occurring greenhouse effect traps the heat of the sun before it can be released back into space. This allows the earth's surface to remain warm and habitable. Increased levels of green house gases enhance the naturally occurring greenhouse effect by trapping even more of the sun's heat, resulting in a global warming effect (Pew Center on Global Climate Change, 2008).

Some regions of the world may gain as a result of these changes however, the overall impacts of climate change are expected to be negative. Although, the pinch of climate change will be felt the world over, some parts of the world are more likely to suffer the effects of climate change more than others. The tropical regions of the world are likely to be more affected than the temperate

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regions while the developing nations are likely to be more affected than the developed nations. Again, agriculture, especially food production is more likely to be affected than other sectors thus threatening global food security. Global agriculture will be under significant pressure to meet the demands of rising populations using finite, often degraded, soil and water resources that are predicted to be further stressed by the impact of climate change. The ongoing buildup of green house gases in the atmosphere is prompting shifts in climate across the globe that will affect agro-ecological and growing conditions.

In addition, agriculture and land use change are prominent sources of global green house gas emissions. The application of fertilizers, rearing of livestock and related land clearing influences both levels of green house gases in the atmosphere and the potential for carbon storage and sequestration. Therefore, whilst ongoing climatic changes are affecting agricultural production, the sector itself also presents opportunities for emissions reductions.

The Sub-Saharan African region has all the threat signs mentioned above. It is located in the tropical region, it is made up of least developed and developing countries and is heavily dependent on agriculture. This region has been identified to likely be most affected by climate change. Agriculture is mainly rain-fed in this region and the majority of the people, most of which are poor, depend on it for their livelihoods.

The agricultural sector also accounts for a large share of GDP and export earnings in Sub-Saharan African countries. The region is already experiencing higher temperatures which may adversely affect crop yield and consequently, food unavailability while changes in precipitation patterns may increase the likelihood of short-run crop failures and long-run production declines. Indeed, the Intergovernmental Panel on Climate Change (IPCC) predicted that climate change could cause potential crop yields from rain-fed agriculture to decline by 50% in some African countries (FAO, 2009). Thus, food production, nutrition and poverty levels may continue to nose-dive.

WHAT ARE THE CAUSES OF CLIMATE CHANGE?

When looking for causes of climate change, one is interested in any process that can disturb the energy balance between incoming radiation from the sun and outgoing terrestrial radiation from the earth (the global energy balance). This is called climate forcing. Climate forcing forces the climate to change.

Climate forcing mechanisms: Climate forcing can be separated into internal and external types. External forcing operates from outside the earth's climate system and includes changes in the global energy balance due to variations in the earth's orbit around the sun and changes in the amount of energy coming from the sun. Internal forcing operates from within the climate system for example the change in the global energy balance due to changes in the composition of the atmosphere.

Orbital variations: On timescales of a millennium and longer, changes in the character of the earth's orbit around the sun can significantly affect the seasonal and latitudinal distribution of incoming solar energy. These are known as the Milankovitch cycles and are an example of external climate forcing. The change in energy receipt can amount to 10% or more in certain locations. The Milankovitch cycles force the changes between ice age and warmer conditions on earth, on time scales of 10,000-100,000 years. The last ice age occurred 18,000 years ago.

Solar variability: Solar variability is another example of external climate forcing. Physical changes within the sun may alter the intensity or character of the incoming solar energy. There is no doubt that variations do occur in various characteristics of the sun on a range of time scales. The 11 years cycle in the number of sunspots on the face of the sun is well known. But other parameters including the solar diameter, vary too and over different time scales. What is less clear is whether or not these changes produce significant variations in the total solar output.

The total solar energy received by the earth or solar constant has only been measured accurately since, the advent of the satellite era. In addition, changes which have been detected over the past 20 years are small in magnitude (<<1%), potentially too small to act as a mechanism of climate change. While the change in solar energy may be greater on longer time scales, this is only a speculative possibility.

Volcanic activity: Volcanic activity is an example of internal climate forcing. Explosive volcanic eruptions can inject large quantities of dust and sulphur dioxide, in gaseous form, into the upper atmosphere, the stratosphere where the sulphur dioxide is rapidly converted into sulphuric acid aerosols. Whereas volcanic pollution (from smaller eruptions) in the lower atmosphere is removed within days by rain, the volcanic dust and aerosols in the stratosphere may remain for several years, gradually spreading over much of the globe. Volcanic pollution results in a 5-10% reduction in the direct solar beam, largely through scattering as a result of the highly reflective sulphuric acid aerosols. Large eruptions such as the Mount Pinatubo (Philippines) eruption in 1991 can bring about a global cooling of up to 0.3°C lasting for up to 2 years.

Atmospheric composition: The changing composition of the atmosphere, particularly its green house gas content is a well-known example of internal climate forcing. Green house gases absorb terrestrial, long-wave radiation from the earth and re-emit this radiation up to space and down to the surface. The increase in the amount of downward energy warms the surface creating the greenhouse effect. A change in the green house gas content of the atmosphere will affect the energy balance of the climate system. For example if the amount of carbon dioxide is increased, more out-going radiation will be trapped in the atmosphere.

To restore the energy balance between energy coming from the sun and energy leaving the earth, the temperature of the atmosphere rises. This enhances the Earth's natural greenhouse effect. Changes in the concentrations of green house gases can occur in numerous ways. Natural changes in the carbon dioxide content of the atmosphere occurred at the end of the last Ice Age in response the Milankovitch cycles. Mankind, through energy generation, changing land use and other processes has produced a substantial change in the atmospheric composition over most recent centuries and it is feared that this continuing change will lead to a major shift in global climate (global warming).

Emissions trends: Climate change is the result of an increase in the concentration of Green House Gases (GHG) like carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Rising GHG emissions are associated with economic activity, particularly as related to energy, industry, transport and patterns of land use (the latter covers agricultural production and deforestation). As shown in Fig. 1, agriculture including land use change and forestry or LUCF, accounts for nearly one-third of global GHG emissions (WRI, 2008). Further analysis of Fig. 1 shows that agriculture alone contributed 13% of total global GHG emissions in 2000 or 5,729 Mt CO_2 equivalents. Emissions from this sector are primarily CH_4 and N_2O, making the agricultural sector the largest producer of non CO_2 emissions. Indeed, 60% of total global non CO_2 emissions came from this source in 2000 (WRI, 2008). Whilst agriculture also generates very large CO_2 fluxes (both to and from the atmosphere via photosynthesis and respiration), these are nearly balanced on existing agricultural lands.

Significant carbon release however, results from the conversion of forested land which is accounted for under the LUCF category. Finally, certain GHG emissions arising from agricultural activity are accounted for in other sectors such as those relating to (upstream) manufacture of equipment, fertilizers and pesticides, plus on farm use of fuels and the transportation of agricultural products.

Records of regional variations in emissions (non CO_2) from agricultural sources indicate that non-OECD countries emit nearly 75% of global emissions (WRI, 2008). As a result, the theoretical potential for agricultural sector mitigation is greater for developing countries than for industrialized nations. Asian countries account for 37% of total world emissions from agricultural production with Latin America and Europe a distant second and third place with 16 and 12%, respectively (WRI, 2008). In Asia, China accounts for over 18% of the total while Brazil alone is responsible for nearly 10% of agricultural emissions in Latin America (WRI, 2008).

Emissions from agriculture come from four principal subsectors: agricultural soils, livestock and manure management, rice cultivation and the burning of agricultural residues and savanna for land clearing (Table 1).

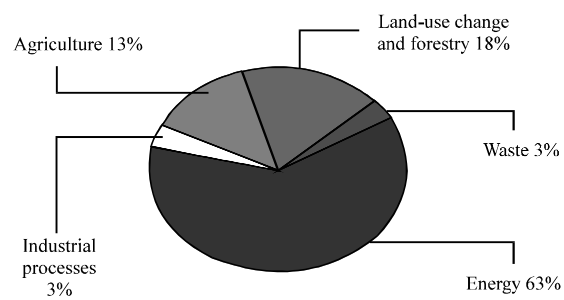

Fig. 1: Share of global GHG emission by sector, year 2000; drawn from data from WRI (2008)

Table 1: Agriculture emissions by region, 1990-2020 (Mt CO_2-eq)

Country	1990	2000	2010	2020
Africa	664	934	1098	1294
China/CPA	1006	1159	1330	1511
Latin America	890	1097	1284	1505
Middle East	62	74	99	125
Non-EU Eastern Europe	21	19	21	24
Non-EU FSU	410	217	246	279
OECD90 and EU	1346	1283	1306	1358
SE Asia	823	946	1084	1214
World total	5223	5729	6468	7311

Drawn from data used in USEPA

Figure 2 shows the share of pollutants derived from each of these sectors. Agricultural soils (N_2O) and the enteric fermentation and manure management (CH_4) associated with livestock production account for the largest of these shares. Emissions from agriculture are expected to rise due to increased demand for agricultural production, improved nutrition and the changing dietary preferences of growing populations that favor larger shares of meat and dairy products (Delgado *et al.*, 1999). This will also lead to increased pressure on forest resources due to agricultural expansion. Global agricultural emissions were found to increase by 14% from 1990-2005 and a 38% rise is expected for the entire period 1990-2020. Agricultural emissions in developing countries are expected to increase by 58% in 2020. Meanwhile, emissions from the burning of agricultural residues and savanna and N_2O from soils are projected to grow by over 40% from 1990 levels.

From a mitigation perspective, one of the largest challenges lies in aligning increasing demands for food, shifts in dietary tastes and demand for agricultural commodities for non-food uses with sustainable, low-emitting development paths.

Recent climate change and variability in Africa: Annual mean surface temperature in Africa has increased 0.53°C since, 1895 with the greatest warming occurring during the Northern Hemisphere Spring (March to May) and Summer (June to August).

Two distinct warming trends occurred during the 20th century, the first in the 1920 and 1930s and the second since about 1980. Whilst computer models have suggested that the cause of this warming may be due to the rise in green house gas concentrations in the atmosphere, other possible mechanisms may include natural variations in solar irradiance or surface ocean temperatures.

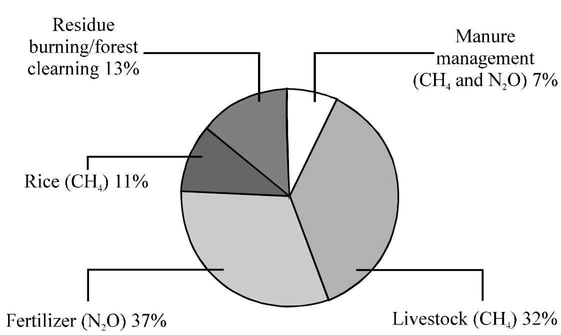

Fig. 2: Sources od emission from agricultural sector (2000); drawn from data presented in USEPA

The Sahel: Large natural fluctuations in rainfall from one year to the next place stresses on African societies based primarily on agriculture. The 30 years desiccation of the Sahel in Northern Africa however, provides one of the most striking examples of long term climate change in recent times and one that may represent the first signs of manmade global warming. Again, this is not to say that increases in green house gas concentrations have single-handedly brought about the long term drought. Models have revealed that human-induced changes to the land-surface characteristics can through feedback processes, generate self-sustaining drought. Nevertheless, it is likely that these effects remain secondary to the variability of the wider global climate system.

Simulations performed by the UK Meteorological Office have demonstrated a link between Atlantic sea surface temperatures and Sahelian rainfall. Lower North Atlantic ocean temperatures are associated with reduced precipitation. The physical basis of this relationship may lie in a disturbance to the atmospheric circulation induced by the underlying sea surface temperature pattern. The question can then be raised: has the enhanced greenhouse effect caused a change in the Atlantic surface ocean temperature? Some evidence suggests that the cause may be found within the natural climate system for example a change to the energy transport of the ocean due to a reduction of northward ocean circulation. Other evidence points to a link with rising green house gas concentrations.

Southern Hemisphere Africa: During the early 1990s, severe drought was experienced in much of the Southern Hemisphere Africa. Over parts of Southern Zimbabwe and South-Eastern Botswana, rainfall levels were only 10% of the long term average during the rainy season of 1991/92. It is widely accepted that the cause of this drought was largely the result of El Nino phenomenon, the periodic warming of the South-Eastern Pacific surface ocean and related shifts in atmospheric circulation. The 20th century rainfall trend in the Sahel is shown in Fig. 3.

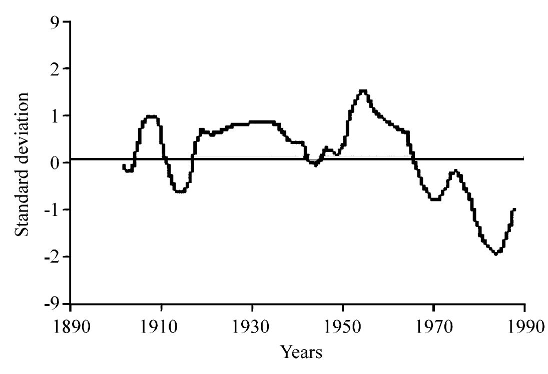

Fig. 3: Rainfall trend

Future climate change in Africa: Using computer models to simulate climatic responses in Africa to changing green house gas concentrations has been shown to be subject to a large degree of uncertainty. That is to say, the range of scenarios generated by models is large. That said, most models predict marked changes in land surface temperature (0.5-2°C increase by 2050) whilst increases in the temperature of the surface ocean are somewhat lower. Warming is most pronounced over existing desert regions of the Sahara and Kalahari. Modelling the changes in African rainfall by 2050 is subject to an even higher degree of uncertainty than for temperature changes. In the most optimistic case, rainfall is seen to increase by between 20 and 70% by 2050 whilst in the worst case, extensive drought and desiccation would be experienced in all areas.

Impacts of future climate change in Africa: How Africa responds to future climate change will depend upon the sensitivities of her ecosystems, natural resources and national economies. When addressing the impacts of climate change, it is necessary to place this in the global context of agricultural systems, economic development and population growth. Much of Africa is dependent upon agriculture for both the sustenance of individual livelihoods and national economies. For this reason, any increase in temperature coupled with a fall in rainfall could have potentially drastic consequences on the growing of crops. Higher temperatures will increase the rate of evapo-transpiration thereby reducing the soil moisture availability. Increases in rainfall may or may not be enough to compensate for increases in surface temperature.

Changes in rainfall will also affect reservoir storage, water table level and groundwater recharge. Warmer temperatures would facilitate the increased breeding season of agricultural pests and in some areas, the over-wintering of pests may be allowed for the first time. It is conceivable however that reduced rainfall may decrease pest damage in some areas. A reduction in rainfall and/or an increase in temperature will be detrimental to the quality of drinking water and to irrigation systems used for agriculture.

The migration of natural species of flora provide a useful yardstick to measure to rate and severity of climatic change. Most climate models used to simulate vegetation movements have revealed an expansion and desertification of existing semi-arid regions such as the Sahel, presumably as a consequence of reduced rainfall and higher temperatures. The existing climate in much of Africa supports the spread of vector-borne disease such as malaria and hygiene related illnesses such as cholera.

It is fair to say that adequate water supplies would remove much of this threat, nevertheless, climate remains a substantial influence on human health in Africa. Climate impacts models have demonstrated that increases in temperature could enlarge the number of areas equitable for malaria transmission via the mosquito. The most sensitive areas would include those presently experiencing low endemicity where changes in climate would have the most dramatic influence on prevalence.

INTER RELATIONSHIP BETWEEN AGRICULTURE AND CLIMATE CHANGE: HOW DOES CLIMATE CHANGE INFLUENCE AGRICULTURE? AND HOW DOES AGRICULTURE INFLUENCE CLIMATE CHANGE?

How does climate change influence agriculture?: Climate change may have beneficial as well as detrimental consequences for agriculture. Some research indicates that warmer temperatures lengthen growing seasons and increased carbon dioxide in the air results in higher yields from some crops. A warming climate and decreasing soil moisture can also result in production patterns shifting northward and an increasing need for irrigation. Changes, however will likely vary significantly by region. Geography will play a large role in how agriculture might benefit from climate change. While projections look favorable for some areas, the potential of increased climate variability and extremes are not necessarily considered. Benefits to agriculture might be offset by an increased likelihood of heat waves, drought, severe thunderstorms and tornadoes. An increase in climate variability makes adaptation difficult for farmers.

The US Department of Agriculture released a report in May 2008 that focused on the effects of climate on agriculture, specifically on cropping systems, pasture and grazing lands and animal management (Backlund *et al*., 2008). The following findings are excerpted from the report:

- With increased carbon dioxide and higher temperatures, the life cycle of grain and oilseed crops will likely progress more rapidly
- The marketable yield of many horticultural crops such as tomatoes, onions and fruits is very likely to be more sensitive to climate change than grain and oilseed crops
- Climate change is likely to lead to a northern migration of weeds. Many weeds respond more positively to increasing carbon dioxide than most cash crops

- Disease pressure on crops and domestic animals will likely increase with earlier springs and warmer winters
- Projected increases in temperature and a lengthening of the growing season will likely extend forage production into late fall and early Spring
- Climate change-induced shifts in plant species are already under way in rangelands. The establishment of perennial herbaceous species is reducing soil water availability early in the growing season
- Higher temperatures will very likely reduce livestock production during the Summer season but these losses will be partially offset by warmer temperatures during the Winter season (Backlund *et al*., 2008)

How does agriculture influence climate change?

Agriculture's contribution to green house gas emissions: Agriculture activities serve as both sources and sinks for green house gases. Agriculture sinks of green house gases are reservoirs of carbon that have been removed from the atmosphere through the process of biological carbon sequestration.

The primary sources of green house gases in agriculture are the production of nitrogen-based fertilizers; the combustion of fossil fuels such as coal, gasoline, diesel fuel and natural gas and waste management. Livestock enteric fermentation or the fermentation that takes place in the digestive systems of ruminant animals, results in methane emissions.

Carbon dioxide is removed from the atmosphere and converted to organic carbon through the process of photosynthesis. As organic carbon decomposes, it is converted back to carbon dioxide through the process of respiration. Conservation tillage, organic production, covers cropping and crop rotations can drastically increase the amount of carbon stored in soils.

GLOBAL IMPACTS OF CLIMATE CHANGE

Global impacts of climate change have been predicted to be overall, negative. Melting mountain glaciers and snow-pack, disruption in the timing of river flows and more frequency in the incidence of wildfires are climate change impacts that are already visible globally. The initial measurable economic consequences include increased costs of wildfire response and some restrictions on recreational use of public lands, shifts in the timing of hydropower generation and increasing competition for irrigation water in some basins in addition to other difficult to measure consequences (Torn and Harte, 2006). Average temperatures have been estimated to increase from 1.8 and 4.0°C by 2100 thus melting snow in the Polar regions. This may result in rising sea levels which will in turn displace populations and destroy the infrastructure in low lying coastal areas. The impacts of climate change on agriculture are likely to be both positive and negative, depending on the region and the type of agriculture. The regional impacts are predicted to be negative in the poorest, most vulnerable parts of the tropics where increase in population density and agricultural intensity on soils that are fragile and vulnerable to degradation exist. On the other hand, more developed temperate regions such as the USA will have impacts at the farm level which could include shifts in crop and livestock mix that could become more profitable.

The rate of climate change will also affect impacts on all biological processes including agriculture. Thus, the higher the rate of climate change, the higher will be rates of obsolescence of all types of capital, both produced and natural and thus the greater will be the costs of adaptation be for farmers, the private sector providing technology and inputs to farmers and for government institutions responsible for infrastructure and policy. Also, elevated levels of atmospheric CO_2 on crop yields could increase crop productivity substantially by 50% or more although, these effects are likely to be constrained by other factors such as water and soil nutrients, particularly in the developing countries. Changes in rainfall amounts and distribution will lead to an increased frequency and intensity of extreme climatic events such as floods and drought. Dry areas are expected to even get drier thus increasing the pressures on water resources in arid regions, the risk of famine, hunger and poverty (Ebi *et al*., 2008).

Changes in consumer incomes and in market infrastructure will be critical but highly uncertain factors of climate change impacts. The rate of economic growth is likely to be a key determinant of people's vulnerability to climate change. High rates of economic growth as in many developing regions will reduce vulnerability to the impacts of climate change and be only modest while it will be vice versa in regions with little or no economic growth. Indeed, the most vulnerable regions of the world are undoubtedly in the tropics, particularly the semi-arid regions where higher temperatures and reduction in rainfall and increases in rainfall variability could have substantially negative impacts and in coastal areas that are likely to be flooded due to sea level rise. These impacts are likely to be most severe in isolated regions where transportation costs are high, incomes are extremely low and most rural households are highly dependent on agriculture for their livelihoods and for their food. These adverse impacts are predicted to be most severe in parts of Sub-Saharan Africa and other isolated areas in Southwestern and South Asia. Low-lying areas in

South Asia, Indonesia and other poor coastal regions are also likely to be severely impacted due to their vulnerability to sea level rise and a limited ability to adapt by moving to higher ground or making investments to protect vulnerable areas. As a result, the risk of malnutrition and hunger in the developing world, particularly in the highly vulnerable regions, is predicted to increase during this century (IFPRI, 2009).

Impacts in SSA: The impacts of climate change are predicted to affect the livelihoods of Africans in many ways. IFPRI (2009) reported that by 2020, between 75 and 250 million people are predicted to be exposed to increased water stress due to climate change. By 2020, yields from rain-fed agriculture in some countries could be reduced by up to 50%, increasing food insecurity and hunger. By 2080, an increase of 5-8% of arid and semi-arid land in Africa is projected. Climate change is likely to affect the distribution patterns of infectious diseases for example, there is likely to be an increase in mosquitos which spread dengue and yellow fever. Sea levels are projected to rise by around 25 cm by 2050; Africa's coastal areas are already experiencing environmental problems including coastal erosion, flooding and subsidence. IFPRI (2009) outlined the following as occurring and/or expected impacts of global warming in SSA.

Increased weather variability and extremities: The climate in Africa is predicted to become more variable and extreme weather events (like drought, heat waves and flooding) are expected to be more frequent and severe with increasing risk to health and life. This will result in increased crop losses due to insect pests, considerable reductions in yield of crops and additional costs of healthcare both to individuals and government.

Changes in temperature and precipitation: In many regions even small changes in temperature, precipitation and water availability can have devastating effects on agricultural output and therefore on food security. Warmer temperatures and changes in amount and seasonality of precipitation will likely destabilize agricultural production that still depends largely on rainfall for irrigation. This expected drop in output is at a cost to the farmers and also to the peoples of the region since price increases as a result of scarcity may lead to reductions in their real incomes.

Famine and disruption of socio-economic well-being: Famine and widespread disruption of socio-economic well-being are possible consequences. This may lead to migration which will result on increased population pressure in some areas and loss of human capital in other areas. The attendant problems of migration such as health issues and pressure on infrastructural facilities are at a cost to government. The farmers that remain in the rural areas will also incur costs from shifting production systems to adapt to changing weather and climate conditions and also the crop losses that are likely to occur.

Revenue losses: Africa may lose close to 50% of its revenue from agricultural production due to climate change (IFPRI, 2009). Since, the majority of the people of SSA are largely dependent on agriculture for their livelihoods then poverty and depravation will increase. This implies that the already poor region will get poorer as a result of climate change.

Decreasing water supply: Decreasing precipitation and water supply coupled with an increasing population will lead to severe water scarcity and stress. Further food and water shortages and increasing desertification are expected to follow from shorter growing seasons and lower yields and the overall loss of large areas suitable for agriculture or pastures. It is unlikely that areas that possibly will receive more precipitation can provide sufficient compensation. Water shortages are expected to reduce crop yield, depress food production and agricultural output generally. Perennial crops are likely to be more affected than annual crops (Torn and Harte, 2006).

Increased occurrence of natural disasters: Flooding, landslides and drought already occur in Africa and their frequency of occurrence is expected to increase as the rate of climate change increases. This is expected to cause more loss of agricultural land and output. The loss of physical capital and social infrastructure is also likely to occur resulting in economic losses both to individual farmers, communities and governments.

Increase in poverty and migration: Poverty and human migration will continue to increase due to increased intensity of already existing natural or human induced detrimental conditions such as: land degradation, fires and deforestation, loss of wetlands, declining biodiversity, increasing dust storms, spread of climate sensitive diseases (malaria, tuberculosis, diarrhoea, etc.). This will lead to rapid urbanization and continual alteration of the environment.

Adaptation and mitigation strategies: From the foregoing, it is clear that action must be taken to address the problem of climate change in SSA. Indeed, the growing evidence of the occurring climate changes and their substantial impacts on agriculture compels the sector to adapt. IPCC (2007) has estimated that adaptation to climate change could cost Africa some 5-10% of its gross domestic product however, both mitigation and adaptation will require the attention of governments and policy makers in order to coordinate and lead initiatives. Adaptation to Climate change can be tackled from the following perspectives:

Farmers' adaptation mechanisms: Farmers and institutions supporting the agricultural sector in SSA will be less able to adapt to climate change than farmers and the food industry in the industrialized world, particularly in the poorest and most vulnerable areas. However, farmers' in this more threatened region can employ several strategies to adapt to climate change. IFPRI (2009) reported that farmers' main adaptation strategies include switching to more drought tolerant crops such as millet and switching to different varieties of the same crop such as more drought tolerant maize. Farmers are also changing planting dates, increasing irrigation, building water-harvesting schemes, changing the amount of land under cultivation and buying livestock feed supplements.

Farmers can also shift production practices to help mitigate the current carbon footprint of the food production system which produces about 14% of global Green House Gas (GHG) emission. Ecoagriculture is one approach that has been developed in order to manage agricultural landscape to enhance rural livelihood and agricultural production while conserving or restoring ecosystem services and biodiversity. This includes employment of soil conservation and biodiversity enhancement practices, protection of water supplies and the use of improved agricultural practices such as natural control of pest and diseases. Ecoagriculture practices are expected to add commercial value through, enhance yield and improved quality. This approach is currently being encouraged in Africa by a non-governmental organization Ecoagriculture Patners.

Trade: The adverse effects in some regions are likely to be reduced through, international trade with other regions that have been positively impacted. Collectively the regional and global impacts are not likely to be large and may even prove to be positive. This is because some regions will gain comparative advantage in crops which they hitherto did not have while new economic opportunities will present themselves which could enhance livelihoods (Ebi *et al*., 2008).

Non governmental agencies: These could also bring professionals together such as meteorologists, agronomists, government officials to work with farmers, village elders, local leaders in order to identifying areas and sectors most vulnerable to climate change and adaptation strategies suited to local conditions. This will reduce farmers' vulnerability to climate change.

Agriculture's role in mitigating climate change: Several farming practices and technologies can reduce green house gas emissions and prevent climate change by enhancing carbon storage in soils; preserving existing soil carbon and reducing carbon dioxide, methane and nitrous oxide emissions. These include:

Conservation tillage and cover crops: Conservation tillage refers to a number of strategies and techniques for establishing crops in the residue of previous crops which are purposely left on the soil surface. Reducing tillage reduces soil disturbance and helps mitigate the release of soil carbon into the atmosphere. Conservation tillage also improves the carbon sequestration capacity of the soil. Additional benefits of conservation tillage include improved water conservation, reduced soil erosion, reduced fuel consumption, reduced compaction, increased planting and harvesting flexibility, reduced labor requirements and improved soil tilth.

Improved cropping and organic systems: Recent reports have investigated the potential of organic agriculture to reduce green house gas emissions (RI, 2008). Organic systems of production increase soil organic matter levels through the use of composted animal manures and cover crops. Organic cropping systems also eliminate the emissions from the production and transportation of synthetic fertilizers.

Components of organic agriculture could be implemented with other sustainable farming systems such as conservation tillage, to further increase climate change mitigation potential. Farming practices that conserve moisture improve yield potential and reduce erosion and fuel costs also increase soil carbon. Examples of practices that reduce carbon dioxide emissions and increase soil carbon include direct seeding, field windbreaks, rotational grazing, perennial forage crops, reduced summer fallow and proper straw management (Alberta Agriculture and Rural Development, 2011). Using higher-yielding crops or varieties and maximizing yield potential can also increase soil carbon.

Land restoration and land use changes: Land restoration and land use changes that encourage the conservation and improvement of soil, water and air quality typically reduce green house gas emissions. Modifications to grazing practices such as implementing sustainable stocking rates, rotational grazing and seasonal use of rangeland can lead to green house gas reductions. Converting marginal cropland to trees or grass maximizes carbon storage on land that is less suitable for crops.

Irrigation and water management: Improvements in water use efficiency through, measures such as irrigation system mechanical improvements coupled with a reduction in operating hours; drip irrigation technologies and center-pivot irrigation systems can significantly reduce the amount of water and nitrogen applied to the cropping system. This reduces greenhouse emissions of nitrous oxide and water withdrawals.

Nitrogen use efficiency: Improving fertilizer efficiency through practices like precision farming using GPS tracking can reduce nitrous oxide emissions. Other strategies include the use of cover crops and manures (both green and animal), nitrogen-fixing crop rotations; composting and compost teas and integrated pest management. The ATTRA Farm Energy Web site contains information about reducing nitrogen fertilizer on the farm at the following link: www.attra.ncat.org/farm _ energy/nitrogen.html.

Methane capture: Large emissions of methane and nitrous oxide are attributable to livestock waste treatment, especially in dairies. Agriculture methane collection and combustion systems include covered lagoons and complete mix and plug flow digesters. Anaerobic digestion converts animal waste to energy by capturing methane and preventing it from being released into the atmosphere. The captured methane can be used to fuel a variety of on-farm applications as well as to generate electricity. Additional benefits include reducing odors from livestock manure and reducing labor costs associated with manure removal.

Biofuels: There is significant scientific controversy regarding whether biofuels-particularly those derived from oilseeds (biodiesel), feed corn (ethanol) or even from cellulosic sources are carbon neutral. To ascertain the true climate neutrality of biofuels requires a careful life-cycle analysis of the specific biofuel under consideration. Also, an analysis is needed to understand what the global land use change implications will be if farmers grow more of a specific biofuel feedstock.

Other renewable energy options: Renewable energy opportunities such as wind and solar also present significant opportunities for the agriculture sector to reduce green house gas emissions.

Mitigation potential and options in agriculture: The technical potential for GHG mitigation in developing country agriculture by 2030 indicates significant opportunities for emissions reductions, together with an enhanced income earning potential for farmers and associated benefits from lower natural resource degradation (Table 2).

However, the economic potential for mitigation in agriculture depends on the price of carbon and on policy, institutional and transaction cost constraints. It is estimated that the economic potential is about 36% of technical potential at carbon prices of up to $25 per t CO_2-

Table 2: Agricultural practices and benefits

Conservation practice	GHG objectives	Additional benefits
CROPS		
Conservation tillage and reduced field pass intensity	Sequestration, emission reduction	Improves soil, water and air quality. Reduces soil erosion and fuel use
Efficient nutrient management	Sequestration, emission reduction	Improves water quality. Saves expenses, time and labor
Crop diversity through rotations and cover crops	Sequestration	Reduces erosion and water requirements. Improves soil and water quality
Animals		
Manure management	Emission reduction	On-farm sources of biogas fuel and possibly electricity for large operations, provides nutrients for crops
Rotational grazing and improved forage	Sequestration, emission reduction	Reduces water requirements. Helps withstand drought. Increases long term grassland productivity
Feed management	Emission reduction	Reduces quantity of nutrients. Improves water quality. More efficient use of need

http://soils.usda.gov/survey/global_climate_change.html eq, 44% at prices of up to \$50/t CO_2-eq and 58% at prices of up to \$100/t CO_2-eq (Smith *et al*., 2007). Smith *et al.* (2007) and USEPA have found that soil carbon sequestration and rice cultivation mitigation strategies, respectively offer the highest economic potential and with best prospects in developing countries which account for three fourths of global technical potential with Asia accounting for 40%, Africa 18% and Latin America and the Caribbean 15%.

Role of public sector in mitigating climate change impacts

Investment in Green House Gas (GHG) reduction technology: Existing technology for reducing green house gas emissions across all sectors of the economy must be deployed in order to improve energy efficiency and also to manage emissions from the energy researchers use. For instance, buildings are responsible for 38% of CO_2 emissions per year the government could invest in green buildings.

These are buildings which have systems for efficient resource use of water and energy with reduced human impact on the natural environment, natural landscaping, efficient material use and recycling. It is apparent that a system of regulation to ensure the economic value of carbon sequestration will be an important policy development in the agricultural sector. In addition, government could invest in more irrigation facilities to enable farmers gain control over water and thus ensure unhindered food production.

Investment in afforestation and reforestation programmes: This is a natural method of reducing GHG emission.

Investment in physical infrastructure and human capital: Investment in physical infrastructure and human capital to reduce poverty and human migration in addition to raising the standard of living of the people of the region.

Credit institutions: Credit institutions should be available and adequate for farmers to have access to affordable credit to increase their ability to change production strategies.

Increasing access to extension services: Increasing access to extension services for farmers is of great need in order to increase their knowledge and skill in adapting to climate change. Thus, government should invest massively in this.

Agro-meteorological interpretation committees: Agro-meteorological interpretation committees can be set up across countries of the SSA, comprising experts and beneficiaries, to analyse, project and transform meteorological data into useable forecasts for farmers. This advisory information could helps farmers and other households prepare for the coming season thus minimizing crop losses.

Strengthening of agriculture-support institutions: Strengthening of agriculture-support institutions both private and public institutions that support agriculture and rural development.

General economic development: General economic development will also play an important role by providing farmers and rural households with sources of income that are less dependent on climate than agricultural sources of income.

Investment in agricultural research: Investment in agricultural research and outreach must be increasing and consistent to ensure development of crop varieties that are resistant to extreme weather conditions.

Role of the private sector: Firms must invest in low-carbon energy projects and low and zero-carbon technologies. Indeed, only technology which reduce the impacts of climate change and facilitate adaptation should be used.

Role of research: The development of improved seeds and cultivars to make crop production system less sensitive to climate variability and climate change is pertinent. However, in the past, it has taken about 15 years to develop a new crop variety. Increased efforts must therefore be made to develop new varieties of crops that can adapt to new conditions. Biotechnology may also speed up adaptation and reduce vulnerability to drought, extreme temperatures and pests. This must also be carefully investigated.

CONCLUSION

Whilst natural climatic variability, particularly for rainfall is large in Africa an Africa-wide warming is noticeable during the 20th century. At the regional scale, significant climatic changes have been witnessed, particularly the recent desiccation of the Sahel. These changes may have natural causes or they may be a manifestation of the man-made enhancement of the greenhouse effect. Projecting future climate change in Africa is subject to a high degree of uncertainty. Large difference exists between model scenarios, particularly for estimations of future rainfall. Despite the relative scarcity of impact models for Africa, it seems likely that global warming will have many detrimental effects within the continent, particularly regarding agricultural systems.

Traditional systems in Africa have developed strategies to cope with the extremities of existing climatic variability. In many cases However, these systems are and will continue to strain under the pressures of economic development and population growth as well as from the threats of global warming. In addition, innovative farming practices such as conservation tillage, organic production, improved cropping systems, land restoration, land use change and irrigation and water management are ways that farmers can address climate change. Good management practices have multiple benefits that may also enhance profitability, improve farm energy efficiency and boost air and soil quality.

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