Economic Commission
for Africa

ACPC
African Climate Policy Centre

United Nations Economic Commission for Africa
African Climate Policy Centre

Working Paper 7

Climate Change and Agriculture: Analysis of Knowledge Gaps and Needs

nited Nations Economic Commission for Africa

African Climate Policy Centre

Working Paper 7

Climate change and agriculture in Africa – analysis of knowledge gaps and needs

November 2011

Acknowledgment

This paper is the product of African Climate Policy Center (ACPC) of United Nations Economic Commission for Africa (UNECA) under the Climate for Development in Africa (ClimDev Africa) Programme. The paper is produced with guidance, coordination and contribution of ACPC and contributing authors from various institutions. Contributions to this paper are made by Tom Owiyo, UNECA-ACPC; Seleshi Bekele Awulachew, UNECA-ACPC; Arthur Reidacker, consultant at UNECA-ACPC and Hailu Habtamu, Addis Abab University Department of Civil Engineering. The authors would also wish to thank Seydou Traore, UNECA-ACPC for the editorial work on the paper.

Please direct inquiries and comments to: *acpc@uneca.org*

A free copy of this publication can be downloaded at
http://www.uneca.org/acpc/publications

COMMON ACRONYMS

ACPC	African Center for Climate Policy
AfDB	African Development Bank
AUC	African Union Commission
AWM	Agricultural Water Management
CAADP:	Comprehensive Africa Agriculture Development Programme
CC	Climate change
CDM	Clean Development Mechanism
ClimDev-Africa	Climate for Development in Africa
CV	Climate Variability
ENSO	El Niño-Southern Oscillation
FAO:	Food and Agriculture Organization
FAR/ IPCC	Fourth Assessment Report /Intergovernmental Panel on Climate Change
GCMs	Global Climate Models
GDP	Gross Domestic Product
GHG	Green House Gas
ICRISAT	International Center for Research in
IWRM	Integrated Water Resources Management
MDGs	Millennium Development Goals
NAPAs	National Adaptation Programs of Action
NCCRS	National Climate Change Response Strategies
NEPAD:	The New Partnership for Africa's Development
SSA	Sub-Saharan Africa
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environment Programme
RECs	Regional Economic Communities
RCMs	Regional Climate Models
UNDP	United Nation’s Development Program
UNFCCC	United Nations Framework Convention on Climate Change
WTO	World Trade Organization

Table of Contents

COMMON ACRONYMS iii

LIST OF FIGURES vi

ABSTRACT 1

1. INTRODUCTION 2

2. AGRICULTURE IN AFRICA 3

2.1 Natural resources 3

2.1.1 Soil conditions 4

2.1.2 Water Availability 5

2.1.3 Soil erosion 5

2.1.4 Crop production and food security 5

2.2 Economic aspects of crop production 7

2.3 Livestock production 8

3. AGRICULTURE AND CLIMATE CHANGE IN AFRICA GAPS AND NEEDS 9

3.1 Agriculture policy and climate change 9

3.1.1 Climate change outlay 9

3.1.2 Climate change and policy cycles 9

3.1.3 The non-climate related challenges 10

3.2 Knowledge gaps and needs 11

3.2.1 The uncertainty around climate change predictions (the problem of GCM downscaling) 11

3.2.2 Uncertainty about the impact of CC and climate variability on agro-ecosystem(pests, diseases and water) 12

3.2.3 Uncertainty about impacts of CC on agricultural water supply 13

3.2.4 Lack of support and low investment in CC-proof agricultural research and technology generation 13

3.2.5 Weak systems for knowledge sharing on CC across agro-relevant sectors 14

4. AFRICAN AGRICULTURE IN INTERNATIONAL AGREEMENTS 15

4.1 The United Nations negotiations context 15

4.2 Importance of agriculture 16

4.3 The African context 17

4.4 Recommendations for African negotiators in agriculture ... 17
5. THE ROLE OF ACPC ... 18
6. CONCLUSIONS ... 19
REFERENCES ... 21

LIST OF FIGURES

Figure 1: (a): Evolution of maize yield and planted area in Kenya due to soil mineral depletion, insufficient mineral input and partly also to removal of fertilizer subsidies (Kenya nat. statistics); (b): yield gap for cereals between Sub- Saharan Africa and other regions has widened. *Source:* http://faostat.fao.org, accessed June 2007 4

Figure 2: Agricultural imports and exports of least developed countries, most of them being in sub-Saharan Africa (FAO, 2003) 6

Figure 3: Per capita food production in the 16 major regions of the world in 1990 and 2003 (from Rmankutty, Foley Olejniczack in Land use Change and Global food production in Land Use and Soil Resources edited by Braimh and Vleck Springer Science 2008) 7

ABSTRACT

This paper reviews the current status of agricultural production in Africa, the role of agriculture in the economies of African countries and in poverty reduction initiatives, the production trends and the public investments in the sector in recent years. It also assesses the vulnerability of the sector to the short term climate variability (CV) and long term effects of climate change (CC). The nexus between agricultural policy and research and development in CV and CC is also explored to identify existing knowledge gaps that prevent agricultural policy development from integrating CV and CC information. The study concludes by making some recommendations vis-à-vis the role of African agriculture in international CC negotiations.

Nearly 80 percent of the African population live in rural areas and subsist on agriculture, largely on smallholder production. On average, agriculture accounts for 15 percent of the gross domestic product of African countries. In spite of this, public investment in the sector by many countries in the continent declined rapidly in the past two decades. This has lead to emergence of unsustainable land use practices, depletion of the natural resource base (soil nutrients, water and forests) by agricultural producers. High cost of agricultural inputs, poor access to credit facilities and high cost of establishing efficient irrigation systems have all contributed to decrease in production per hectare and overall increase in poverty rates among rural populations in the continent.

Agriculture in the continent is therefore more vulnerable to the effects of short-term variability and long-term climate changes than are other regions. At the policy level, many countries in the continent have not integrated CC adaptation strategies in the agricultural and national economic development policies. Lack of appropriate policy framework for integration of adaptation and mitigation strategies in sector has also contributed to the decrease in investments on the sector over time. Most CC scenarios are generated from the Global Circulation Models (GCM) which are relatively coarse and regional circulation models (RCM), the downscaled versions of the former. Key knowledge gaps include the uncertainties that arise with the use of GCMs and the RCMs and uncertainty on the impact of CC and CV on agro-ecosystems, the impact of CC on agricultural water supply.

The synthesis concludes that even as scientists address the problems of uncertainty in the use of CC and CV information, there is urgent need to elevate the position of African agriculture in international CC negotiations. African countries need to start integrating the CC and CV into development policies and agricultural sector specific policies to stimulate investment in the sector. The interventions should be based on win-win technological options that improve land use efficiency and increase crop and livestock productivity. In addition, appropriate policies need to be developed along crop and livestock production value chains that enhance the viability of agriculture as an economic activity. The ACPC should play a coordination role of synthesizing data and information from CC and CV research into policy useable information for the countries and the Regional Economic Communities (RECs).

Key words: Climate and agriculture, Africa development, knowledge gaps, needs, actionable interventions

1. INTRODUCTION

Africa remains the only region in the developing world where agricultural yields are low and continue to decline. Despite the recent progress in agricultural and land management technologies, agricultural production in most parts of the continent are still at subsistence levels with the small holder producers who dominate the agricultural production landscape barely able to meet their own consumption needs. Agriculture plays a significant role in food security and poverty alleviation, especially in the rural African households. African agriculture is confronted by many challenges. The primary challenge is the low investment in the sector by many African governments. Indeed, in the recent decades, government investment in the sector has significantly decreased while the private sector has not been able to fill the financing void for a variety of reasons, ranging from the poor lack of business friendly policies, and perceived risks to investment in the sector. This has eventually leaded to poor and unsustainable agricultural practices in many parts of the continent. Other challenges include the poor access to capital, poor infrastructure, and poor market structures. As a result of these factors, small holder agricultural producers are often caught in perennial low productivity and a vicious cycle of poverty.

Climate change (CC) and climate variability (CV) that has been experienced in many parts of the world add to the challenges that face the agricultural sector in the Africa. Considerable shifts in long-term averages and variability in rainfall and temperature, sea levels, frequency and intensity of droughts and floods have also been experienced (IPCC, 2007). Africa too has had its share of the increased climate variability and long-term changes. Incidences of extreme weather events like droughts and large fluctuations in precipitation patterns particularly the shortening of the length of growing periods have been occurring with increased frequency (Hassan, 2008). Given that agricultural production in Africa relies mainly on rainfall (with less than 4 percent of cultivated land under irrigation, World Bank, 2008), such fluctuations expose African agriculture to frequent production uncertainties.

In recent years, nearly all African governments have increased attention to and concerns about the consequences of short term changes in climate patterns, particularly the high variability in rainfall and high incidence of drought event to their economies and to the agricultural sector in particular (Hassan, 2008). Agriculture remains an important sector for many African economies, contributing an average of 15 percent of the gross domestic product (GDP) – increasing up to 50 percent in some countries (World Bank, 2008). However, the agricultural production system in the continent is highly diversified and impacted differently by both CC and CV.

To sustain agricultural production in the continent, African governments need to embrace appropriate policies that support the producers' capacities to adopt to the effects of CC and CV. The diversity of agricultural production systems in the continent imply an implicit need for tailored policies that are production system specific, take into account the local and regional conditions and maximizes the capacity of producers to adapt to the unfolding short term variability and long-term changes in climate. In other words, in spite existing uncertainties in the science of CC and CV, especially with regard to predictions, African governments need urgently embark on the implementation of policies that promote adaptation and mitigation for the agricultural sector.

Policy dialog needs to start by a synthesis of the agricultural production systems by agro-ecological and regional zones. A system vulnerability assessment should therefore be based on a composite assessment of climate variability and climate change, agricultural production systems and socio-economic circumstances of the agricultural producers. A key challenge to such a comprehensive synthesis is lack of appropriate up-to-date and up-to-scale information on climate change in the continent. There is a critical lack of sufficient knowledge at national and sub national scales that can effectively aid governments to develop appropriate policy interventions in the continent. The knowledge gap arises from the lack of high resolution weather and climate data and data collection centers in most parts of the continent, which makes it difficult to reliably upscale the results from global models.

This paper examines the current trends in African agriculture: the main production systems and state of African agriculture, discusses the link between African agriculture and climate change, the knowledge gaps and how the African Center for Climate Policy (ACPC) may contribute to bridging the gaps and promote the development and adoption of sustainable agricultural policies by African governments.

2. AGRICULTURE IN AFRICA

Agriculture provides a major contribution to the GPD of most African countries; averaging at 15 percent of total GDP. Although oil and mineral dependent economies rely less on the agricultural sector for their GDP (e.g., Congo, Nigeria, Algeria, Libya, DR Congo), a significant proportion of their population still depend on smallholder agricultural production for livelihood support. The African continent has a variety of pedo-climatic conditions, ranging from the semi-arid regions of the North East to the moist tropical conditions of the Congo Basin – a system almost comparable to Brazil. Africa’s population is projected to increase from the current estimate of one billion to about 2.3 billion by 2050. This high population will lead to increased demand for food and exert pressure on natural resource base. Today, about 200 million people do not get enough food every day!

2.1 Natural resources

Agriculture in the African continent is quite diverse and characterized by several climatic conditions. Some key natural characteristics include:

- It has 26% of arid land of the world; in Mediterranean and Subtropical zones, in Tropical zones and in Equatorial zones.
- It also has countries under moist tropical conditions, densely forested like Gabon, or at least with good rainfall which theoretically allow at least two cropping seasons per year.
- And the savannas that fall between these two ecosystems.

Such differences in natural conditions also lead to further variability in the availability of water and minerals which are key determinants of agricultural productivity.

2.1.1 Soil conditions

The diversity of soils in Africa is probably not possible to detail here. However, it is important to note that most Sub–Saharan African soils are phosphorous poor. Moreover, due to insufficient replenishment of soil minerals exported with harvests, many African soils are getting more and more mineral depleted making them unable to sustain agricultural productivity hence the decrease in crop yields witnessed in many parts of the continent in recent years, for example in Kenya (**Figure 1a**) and Sub-Saharan African (**Figure 1b**).

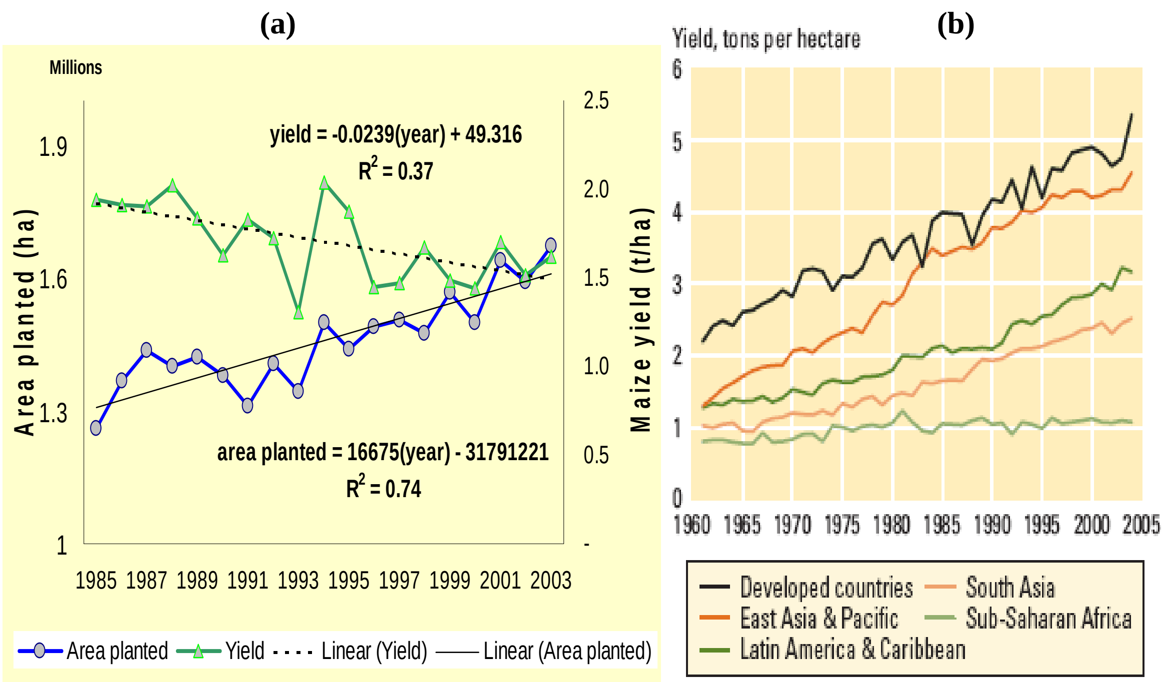

Figure 1: (a): Evolution of maize yield and planted area in Kenya due to soil mineral depletion, insufficient mineral input and partly also to removal of fertilizer subsidies (Kenya nat. statistics); (b): yield gap for cereals between Sub- Saharan Africa and other regions has widened. *Source:* http://faostat.fao.org, accessed June 2007.

Soil nutrient replenishment through the use of fertilizers in the continent has been quite low[1], averaging at about 10 kg per hectare, which is tenfold less than world average of about 110 kg per hectare. Egypt is a particular exception in the continent with respect to fertilizer use. Due to its limited arable land area, it drastically increased mineral input to about 500 kg per hectare in 2006 and more than 700 kg in 2008, levels that are now close to the maximum achievable. In addition to the severe shortage in mineral supply, most African crops can also not benefit from the increase of CO_2 concentration in the atmosphere those results from CO_2 fertilization effect.

[1]In 2006, for instance, the average annual mineral input per hectare from fertilizer was around 0.4 kg in Niger, 2.5 kg in Madagascar, 9 kg in Cameroun, 33 kg in Kenya and Ethiopia, 40 kg in Malawi, 54 kg in South Africa and 60 kg in Morocco (Source World Bank).

2.1.2 Water Availability

In areas that receive over 600 mm of average annual rainfall, the availability of minerals (especially N, P and K) is often the most important limiting factor to crop yield. Below this level of precipitation (600 mm), mineral nutrients also tend to limit dry matter production. Studies by The International Center for Research in (ICRISAT) in Niger, and other research carried out in Burkina Faso, Ethiopia[2] and a range of African countries[3] have shown benefits that can be obtained by adding fertilizer and organic matter in small water harvesting pits (also called Zai in the Sahel). Organic matter improves water retention, whereas mineral nutrient help seedling to colonize the soil more rapidly.

Under rainfed conditions, increased variability and irregularity in rainfall are major causes of crop failures. Addressing these challenges calls for investment in irrigation systems. Compared to other parts of the world, Africa has very low percentage of irrigated arable land estimated at about 4 percent in Sub-Saharan Africa (11 percent in Latin America and 36 percent in Asia in 1994/96[4]). However, North African countries (Egypt, Morocco and Libya) have higher amounts of irrigated land than Sub-Saharan countries. Nevertheless, the effects of climate change are already making water availability become scarcer hence the need for more efficient use.

2.1.3 Soil erosion

Another key challenge to agricultural production in Africa is the high risk and incidence of soil erosion. In the Sahel region, for example, the total rainfall may take place in just only three hours, leading to flush floods, as soils cannot absorb the water. Such precipitations are set to become even more violent in the future with climate change. Many measures have been adopted to prevent soil erosion (using pebbles, pits, banquettes, grass cover, or no-till practices). The latter have been experimented in many places. In Madagascar, the technique seemed only adequate for large farms that could afford fertilizer. Several years later, only a few hundred hectares have been treated/ reclaimed as majority of smallholders could hardly afford the required mineral inputs. Mineral fertilizer input is therefore integral to these practices.

2.1.4 Crop production and food security

Between 1997 and 1999, Sub-Saharan Africa cereals consumption was nearly 84.5 million tons, 84 percent being produced locally, and 16 percent imported. It has been demonstrated that with higher fertilizer inputs, these countries could become self-sufficient in cereal production and even be able to export (Riedacker, 2007).

[2] (Amedé et al 2011)
[3] (Techniques traditionnelles de conservation de l'eau et des sols en Afrique Editors r Reijs, Scoones and Toulmin, CTA, CDCS and Karthala Press)
[4] (data from the WB in Dontse 2011

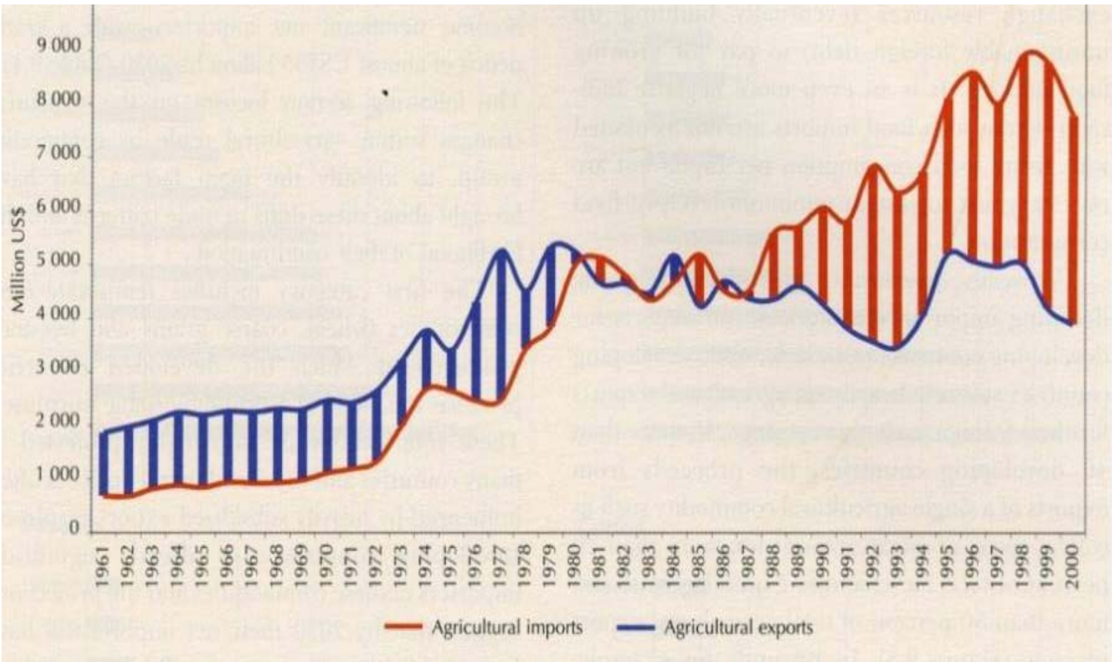

Figure 2: Agricultural imports and exports of least developed countries, most of them being in sub-Saharan Africa (FAO, 2003)

Food production trends in the continent have generally been changing over time. Many countries that were net exporter of agricultural products up to the 1980s have recently become major importers of agricultural products since the beginning of the 1990s (**Figure 2**). Africa (SSA and North Africa) still has a lower per capita food production compared to other parts of the world (**Figure 3**).

Other agricultural crops of significance to Africa include crops such as cotton in West Africa, palm oil in Cameroun[5], cocoa in Ivory Coast, sugar cane in many African countries, coffee, tea, fruits, and tobacco. These are major cash crops that support livelihoods, provide jobs to millions of households, and contribute to the national economies the countries. Production of these crops will be affected by the increasing drought periods which may be occasioned with climate change.

[5] According to JeuneAfrique (N° 2642 , 28 Aout au 4 Septembre) 200.000 ha are to planted in Cameroun by Biopalm energy from Singapour

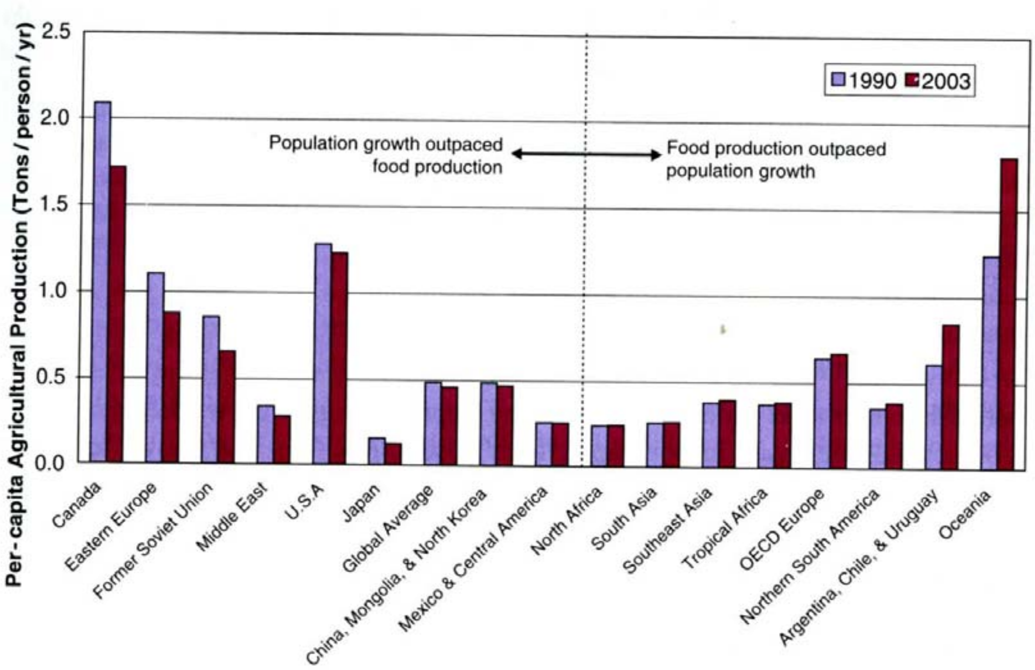

Figure 3: Per capita food production in the 16 major regions of the world in 1990 and 2003 (from Rmankutty, Foley Olejniczack in Land use Change and Global food production in Land Use and Soil Resources edited by Braimh and Vleck Springer Science 2008)

2.2 Economic aspects of crop production

Economic factors have also played a major role in contributing to the low productivity in the agricultural sector in the continent. Key among them include:

- high cost of inputs (especially fertilizer)[6];
- low use of agricultural equipment: in Africa, there are 2 tractors per thousand workers compared to 812 in Europe in 1994/96 (CEDRES, 2011, from WB development indicator in 1999). This however, could be attributed not only to lack of capital, but also to the small land acreages, which makes use of machinery economically unviable;
- high cost of establishing efficient irrigation and drainage schemes;
- lack of access to credit (from Banks) by small scale investors.

[6] When fertilizer is available their cost is, according to IFDC (2006), 2 to 6 times higher than on the world market. Moreover due to the poor African railway network and to the bad state of roads, transportation costs of fertilizer from harbors to the fields are higher than for instance in India. It is therefore (1) important to distinguish the cost of fertilizer in the balance of trade (fertilizer, gasoline and lorries for transportation) and at the users level, and (2) to compare that national cost with that of importing cereals and other agricultural commodities

The preponderance of smallholder production systems with low average acreage per family implies that decreasing the cost of inputs may be a most effective mechanism to increase crop production. Previously, agricultural companies, especially those involved in the production of cash crops like cotton and sugarcane provided fertilizer and other inputs to farmers to boost production. However, such systems were sustainable only as long as the companies remained viable. With many such companies collapsing in recent times, farmers have been exposed to yield decreases due of lack of inputs. Without a sufficient increase of yields, most producers who mainly produce for domestic consumption will not be able to even feed themselves, let alone the rapidly growing population of African cities.

2.3 Livestock production

Livestock production is an important component of the economy in many African countries especially those with semi-arid grasslands. With climate change this economic and livelihood support activity may suffer from increasing drought periods. Pastoral and agro-pastoral systems in marginal areas of the Maghreb are today already confronted with huge challenges due to social transformations, new economy and innovative techniques. Some recent development in this sector includes use of cereals and purchased feeds as risk management strategies to address dwindling pasture resources. Other adaptation strategies include strategies include minimizing the walking distances of animals to watering points and on site feeding mainly on barley from extensive production on the rangelands. Forage trees and *Cactus Opuntia* have also been planted on the rangelands.

Improving animal diets reduces their vulnerability and decreases the production of methane (the second most important GHG, besides CO_2) per unit of meat or milk[7]. Similar improvements are underway in the Sahel as well as in Ethiopia to improve the milk or meat production per cow. In Ethiopia for instance, it has been shown that, milk productivity (liters per ha) of livestock as well as livestock water productivity (liters of milk per m^3 of water) can be increased with interventions in crop management (fertilizer, water harvesting, introduction of fodder trees, urea treatment of residues) and animal management (crossbreeding, reduction of the number of ox, concentrates, improved food-feed crops[8]). Herniaux and Lehouerou[9] have also shown that in the Sahel primary production of grassland is constrained by the poor content of these soils in phosphorous and nitrogen and their low organic matter content.

It is also worth noting that under certain conditions; cropping can feed more people than extensive grazing. Other limitations to livestock production, for example, in central Africa, include pests and diseases like the Tsetse fly infestation. Climate change therefore introduces many uncertainties in the livestock sector, including the distribution of the tsetse fly that are not yet fully understood. It is therefore imperative that African governments adopt appropriate policies that will support sustainable production in the sector.

[7]Riedacker 2007 Communication at the EU–Africa on Agriculture Forum in Berlin June 2007)
[8]Desheemaeker et al 2011 Analysis of Gaps and possible interventions in crop-livestock systems of Ethiopia.Expl. Agric. (2011) volume 47 (S1), pp 21-38 Cambridge UniverstityPress 2011.
[9] Les parcours du Sahel in « Parcours et production animale en zone de parcours. Etats des connaissances, 2006, Sécheresse vol. 17. N° 1-2 Janvier 2006, 51-71

3. AGRICULTURE AND CLIMATE CHANGE IN AFRICA GAPS AND NEEDS

3.1 Agriculture policy and climate change

3.1.1 Climate change outlay

According to the Fourth Assessment Report (FAR), Africa has experienced a trend of greater warming since the 1960s across many parts of the continent with significant regional variations (IPCC, 2007). Most of the existing knowledge about the future scenarios of climate comes from modeling of the response of few selected crops to climate change and on the results of controlled agronomic experiments and crop growth simulation modeling (Hassan, 2008). However, agricultural production in Africa has remained low for decades and in some cases shown disturbingly diminishing trends.

With such low yields and productivity levels to begin with, Africa has a high level of exposure to production risks associated with climate variability and climate change. Africa's vulnerability is further aggravated by other factors including overreliance on rainfed production, high levels of poverty, low levels of human and physical capital and poor infrastructure that leads to poor access to input and product markets. Improving agricultural production in Africa would therefore require a comprehensive policy environment that would stimulate appropriate investments from public and private sources.

3.1.2 Climate change and policy cycles

One of the existing challenges to the development of appropriate policies that would enhance the capacity of Africa's agricultural producers adapt to climate change and mitigate its effects is the mismatch in time horizons between policy formulation and data on climate change and variability. While at the continental level, the state of knowledge on climate change is considerable, information at higher resolutions – regional, national and sub national levels at which most policy dialog occurs is hardly sufficient. The FAR for example, asserts a relatively faster warming in tropical rainforest and southern regions compared to the rest of Africa. It notes that regional variations are complex to capture and identifies general trends that for example, indicate that between 1960 and 1988, there has been a decline in mean annual precipitation of between 20 to 40 percent in the Sahel region compared with a 2 to 4 percent decline in tropical rainforest regions.

The challenge to most policy making is the ability to downscale such broad regional scenarios to national and sub national levels. Indeed, it is necessary too to align both climate change analysis and policy formulation along key agro-ecological zones and the major crop and livestock value chains that they define. This would enable appropriate adaption and mitigation policies to be developed at relevant levels and scales for sustainable agricultural production under different climate change outlay scenarios.

Developing effective policies along agricultural product value chains require concerted and concordant efforts by experts on climate change and policy professionals. And this does not necessarily require convergence of climate change predictions. Indeed many are instances where the directions of change from climate modeling introduce more uncertainty into policy dialog. However, policy formulation, especially in the agricultural sector needs to focus on the win-win options that promote sustainability of agricultural production and land use management. Significant progress has been made in the continent towards addressing the low investment in agriculture and the poor policy environment in the continent in recent years. Under the Comprehensive African Agricultural Development Program (CAADP) initiative, African heads of state highlighted four strategic agricultural commodities (cassava, maize, rice and wheat) for which appropriate policies and investments are needed to make African countries sufficient in food production and to improve the livelihoods of the rural households.

The CAADP approach aims to marshal efforts in formulating appropriate policies, investing in research and development and developing adaptation and mitigation measures for short, medium and long term challenges to agricultural production. These objectives directly contribute to the achievement of the millennium development goals (MDGs) 1 (eradicate extreme poverty and hunger) and 7 (ensure environmental sustainability).

Developing appropriate policy framework for the agricultural value chains (including the CAADP) requires effective national and regional instruments/institutions. The last decade has seen African countries converge efforts towards the establishment of Regional Economic Communities (RECs) with considerable success. The RECs have become increasingly influential in coordinating regional efforts on many fronts. They have contributed the development of regional common market for goods and services, harmonization of policies and standards and promotion of direct investment in regional projects and free movement of labor and people. In a similar vein, the RECs can play a pivotal role as a convergence point where country policies may be synthesized and developed into regional policy frameworks for promoting investment and research and development in Africa's agricultural sector. In this context, the RECs could ensure that effective feedback loops exist to promote integration of regional strategies and policies into national plans.

3.1.3 The non-climate related challenges

As has been noted already, public financing to the agricultural sector has greatly diminished in recent decades partly as a result of the structural adjustment programs embraced by many countries in the 1908s and partly due to the low economic performance in the 1990s. Two critical sub-sectors have particularly been affected – agricultural research and agricultural extension, both of which play a critical role in the development and dissemination of appropriate agricultural production technologies. Evidence of on-going changes in climate patterns implies a need for African agriculture to adapt to these changes and institute medium and long-term measures that would ensure sustained agricultural production over time. Such investments would go hand in glove with appropriate investments in weather and climate data collection systems.

It must also be noted too that agricultural production relies on other key sectors in any economy. Good and reliable road infrastructure and access to credit and other financial services are some of the necessary ingredients for sustainable agricultural growth and development. A major factor contributing to the low use of improved agricultural technology is the poor access to credit facilities by the smallholder agricultural producers. Even where producers have access to improved technologies like use of organic fertilizers to improve soil mineral nutrients, the high cost of such input hinders their adoption ability to adopt to such technology. In addition, poor road infrastructure intractably contributes to high transport costs of inputs and produce and sometimes also leads to high post harvest lose of agricultural produce.

3.2 Knowledge gaps and needs

3.2.1 The uncertainty around climate change predictions (the problem of GCM downscaling)

It is globally agreed that the projections of CC are inherently uncertain. This results from the natural variability in the climate system, 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 climate models. These uncertainties are compounded by the lack of and unreliability of basic information on the effect of climate change on specific sectors like agricultural. The uncertainty in such basic information makes the quantification and evaluation of impacts and adaptation options more difficult (Vermeulen *et al.*, 2010).

A key knowledge gap in CC projection is lack of tools and models at spatial and temporal scales appropriate for decision-making. The global climate models (GCMs) are more commonly used for this purpose but with a relatively coarse spatial resolution (i.e., with scales of a few hundred kilometers and larger) (Padgham, 2009). Regional climate models (RCMs) which are downscaled from GCMs have a much higher resolution (simulating features with scales as small as few kilometers) and are alternatively used for climate adaptation planning. However, RCMs are prone to error propagation from the GCMs and require significant computational resources, and their results are sensitive to the selection of domain and resolution.

In fact RCMs are useful for identifying where general sensitivity to climate change exists, which can help to inform adaptation planning at broad scales but with the assumption that the information from the RCM is reasonably robust. RCMs may also be used in situations where information about future conditions is needed, where impacts will be predominately long term or where multiple, economically important sectors intersect. However, practical future planning for sectors like agriculture are complicated by two factors: the uncertainly in the predictions and the mismatch in planning horizons (planning for this sector is normally one to three decades; a period over which the signal from anthropogenic forcing upon which climate models linked to emissions scenarios are based is weak (Padgham, 2009)). Impacts of climate change on agricultural production in the continent are often aggregated over large areas such as the country or region, and this can hide considerable heterogeneity in climatic conditions and agricultural production (Vermeulen *et al.*, 2010).

Further in other studies (Paeth and Thamm, 2007; Smith *et al.*, 2007), significant disagreement regarding the long-term direction of precipitation still remains among climate models for large areas of Africa reflecting knowledge gaps about convective precipitation in the tropics. The magnitude of regional scale temperature rise over the 2020–2030 periods is also not well estimated due to the predominance of natural internal variability in the climate system and land degradation processes relative to the comparatively weak signal originating from anthropogenic climate forcing factors. Besides, lack of data for modeling, lack of technical capacity for meteorological and long-term agro-ecosystem monitoring, and an over-reliance on secondary information sources remain major bottlenecks for adaptation planning in the continent (Michael *et al.*, 2009). Thus, information at finer spatial and temporal scales is needed for regional and local impact studies. There is also a need for ground truthing of predictions models using available daily climatic data.

To close the gap towards uncertainties as to the direction and magnitude of climate change, it is also quite important that clear definitions, perceptions and indicators of climate change according to different stakeholders are identified and used in developing models for use in the region. Communities have different indicators which they rely on in determining whether climate has changed or not. While some consider increasing frequency of drought or disappearance of certain plants to be an indication of changing climate others feel that these are normal events which occur after certain periods. Because of the many and often different indicators people use, it is important that more work is done in defining the indicators which can be reliably used in developing the models.

3.2.2 Uncertainty about the impact of CC and climate variability on agro-ecosystem(pests, diseases and water)

On average, 30 to 50% of the yield losses in agricultural crops are caused by pests despite the application of pesticide to control them (Oerke *et al.*, 1994). Insects are the most diverse class of organisms on Earth; they have either direct or indirect detrimental and beneficial effects on humans and natural ecosystems. Agricultural Losses from pests are most severe in the subtropics and tropics because of warmer temperatures, and longer growing seasons. However, it is difficult to accurately quantify the potential impacts of climate change on pest damage because of the complex and highly variable response of pests and their hosts to what could potentially be multiple and interactive shifts in environmental conditions.

These conditions include elevated CO_2, ozone, and temperature; changes in relative humidity and cloudiness; shifts in rainfall distribution and wind patterns; and land-cover and land-use change in response to climatic and non-climatic signals. Nevertheless, there are broad trends in how agricultural pests respond to extreme weather events, such as during El Niño episodes and changes in pest behavior under elevated CO_2 and temperature from controlled studies, which provide at least an initial indication of the potential threat from climate change. In spite of this fact it is yet unknown how climate change will aggravate the pest situation in Africa (Oerke *et al.*, 1994).

Fortunately, depending on the complexity and species richness, agro-ecosystems can have a good potential to provide a high level of natural biological control, and hence ecosystem complexity can increase ecosystem resilience to pest outbreaks. However, little is known on how climate change may affect multitrophic levels or competitive interactions. Recent studies indicate that climate change can dissociate predator-prey relationships, because of a higher sensitivity of higher trophic levels to climatic variability or of different temperature optima compared with pests (Voigt *et al.*, 2003). In this respect, divergences in the thermal preferences of the pest and its natural enemy will lead to a disruption of the temporal or geographical synchronization, increasing the risk of host outbreaks (Hance *et al.*, 2007).

Therefore, if adequate pest management strategies are not developed and made available to farmers it could, ultimately, lead to greater losses in both crop quantity and quality. In this regard, African scientists need to collaborate to assess the consequences of climate change for a wide range of pests of important agricultural crops in Africa. In addition, the impact of increased temperature should also be studied on selected pests' natural enemies so as to provide clues for the future resilience of agricultural systems to cope with pest problems.

3.2.3 Uncertainty about impacts of CC on agricultural water supply

Water is the defining link between the climate and agriculture. But even without climate change, water stress is already being seen in many parts of the world. The increasing demands of this critical resource among various sectors has made water availability an urgent issue that farmers the world over are confronted with. And typically, the most extreme shortages are experienced by those least able to cope with them – the most impoverished inhabitants of developing countries. Climate change will exacerbate an already critical situation (Moorhead, 2009).

Most of the world's countries classified as water stressed are in Africa. A reduction in run-off of up to 40 percent has been recorded in some major river basins in Africa, with a consequent reduction in reservoir storage. Although uncertain, it has been predicted that projected changes in climate will significantly affect surface water supplies over 25 percent or more of the continent by the end of this century. Temperature rise, changes in runoff volumes, and an increased frequency and severity of extreme events with climate change are likely to exert severe pressure on agriculture's water supply. Future water resource availability for agriculture could further be constrained by the increasing urbanization and industrialization of society (Michael *et al.*, 2009).

Although currently Africa has very little irrigation (less than 5% compared with more than 30% of the land in Asia), predicted declines in water availability put serious limits on the irrigation potential. The other challenge is the high cost of developing new water supply and irrigation schemes given current and expected worsening scarcity in the future. Development of successful new irrigation projects (water storage and conveyance infrastructure) in Africa has been estimated to cost between US$3,600 and US$ 5,700 per hectare (ha) at 2000 prices (Inocencio *et al.*, 2006). At present this amount is expected to increase given the high economic instability in the world.

3.2.4 Lack of support and low investment in CC-proof agricultural research and technology generation

Many broad-scale analyses identify regions and crops that will be sensitive to progressive climate change (Jones and Thornton, 2003; Parry *et al.*, 2007) but there is sparse scientific knowledge as to how current farming systems can adapt, and which current farming systems and agricultural practices will enable adaptation. As climates effectively migrate, the transfer of best practices and technology from one site to the next will be crucial. Many of these are grounded in local knowledge.

Knowledge must be linked with action – changes in policies, institutions, technologies and management strategies – if it is to help enhance food security and resilience to climate change. For example, national adaptation programs of action (NAPAs) are being developed in many countries by national ministries of environment with the support of the United Nation's Development Program (UNDP), but most are not based upon scientific evidence as to the range of relevant adaptation options and impacts in different environments. Reasons for the disconnect between science and policy may be that the knowledge most needed by policymakers and other action-oriented stakeholders is not given priority in research and development efforts, and when available, is rarely communicated in ways that best support decision making, management and policy (Vermeulen *et al.*, 2010).

It is very clear that more effort in research is needed to understand and quantify climate damages on vulnerable natural and managed African systems, especially agriculture where the biggest impacts are expected. In response to climate change impact on African agriculture a good potential exists for promoting water productivity (e.g., drip irrigation and mulching practice) on high-value crops (Karlberg *et al.*, 2009). This will require provision of the right incentive structure and technology research investments.

However, most countries in Africa lack a coherent policy framework for climate change research and adaptation. This is particularly the case in countries which have not embarked on a comprehensive planning process for adapting to climate change, often articulated in National Adaptation Plans of Action (NAPA) and/or National Climate Change Response Strategies (NCCRS). Moreover, government institutions are faced with major challenges that undermine adaptive capacity, for example, weak coordination mechanisms as a result of conflicting and overlapping mandates and inadequate financing for adaptation. There is also limited space for civic engagement (particularly for Non-Governmental Organization and Community-Based Organization participation) due to financial, human resources and political constraints. A multi-tier approach is therefore required to build the capacities of governments and communities in Africa to effectively respond to and adapt to climate change.

3.2.5 Weak systems for knowledge sharing on CC across agro-relevant sectors

There is no comprehensive framework that pulls together and integrates what is known about the climate system, the way it may change in the future, and the associated impacts on agro-ecosystems, the livelihoods of those who depend on them, and food security. Access to data and information is a critical bottleneck for adaptation planning in many African countries because data sets are scarce, not centralized, or not readily shared among government ministries. Given the potentially immense information gaps in undertaking adaptation, greater support and investments are needed in computational and spatial analysis capacity, as well as in education and skill development for effective data generation, organization, and interpretation.

Further, governments' policies aimed at promoting farm-level adaptation need to emphasize the critical role of farmers' education; provision of improved climate, production and market information and the means to implement adaptations through affordable credit facilities. Other needed public interventions to help promote adaptation measures and reduce vulnerability include insurance against climate risks to farmers and provision of safety nets.

4. AFRICAN AGRICULTURE IN INTERNATIONAL AGREEMENTS

We start this section by a brief review of the present context of climate change negotiations even if changes are expected in the near future given that the first commitment period of the Kyoto Protocol is ending in 2012. The discussion has a two-pronged approach; the global is first presented followed by the African specific context. The section concludes with some suggestions to the African negotiators in agriculture in order to better defend African interests.

4.1 **The United Nations negotiations context**

Scientific knowledge of decisions makers is generally based IPCC (Intergovernmental Panel on Climate Change) synthesis reports. On the basis of the conclusions of the first IPCC report in 1990, the UN launched (February 1991) negotiations for a climate convention. This led to the United Nations Framework Convention on Climate Change (UNFCCC), commonly known as the "Climate Convention", approved in May 1992. The Kyoto Protocol approved in 1997, which entered into force in 2004 and other agreements that may be elaborated in the future are only instruments under this Framework Convention.

Since 1993 IPCC reports serve as a scientific and technical basis for negotiations under the UNFCCC. However, although the IPCC conclusions and recommendations are*" policy oriented" ,*they are by and large not "*policy prescriptive".* IPCC does not tell how information contained in these reports can be mainstreamed in national policies by taking into account the local constraints and policies. Nor does it indicate how they can be used in international negotiations (especially agricultural policies that do have unique requirements with regard to developing countries) either under the climate change negotiations or under agricultural negotiations, for instance, in the WTO. It also does not express views not yet accepted by dominant institutions like Washington consensus[10].

Governments and negotiators, collectively or individually have to make the best use of its findings. Each country therefore needs to carefully mobilize its specialists from different sectors and ministries, particularly the ministries responsible for agriculture and that in charge of the national economy and budget in order to steer the development and implementation of appropriate policies to promote adaption to climate change in the agricultural sector.

In its article 2, the Climate Convention states that its ultimate objective is to stabilize GHG concentration in the atmosphere at a level that prevents any dangerous interference with the climatic system. It asserts that this will be achieved in a manner which (i) *allows ecosystems to adapt naturally to climate change*, (ii) *does not threaten food production* and (iii) *allows sustainable economic development.* For all these three objectives, interests and priorities of countries and continents; instance that of old industrialized countries, those under rapid

[10] The final part of that sentence may be removed, after discussions if this is considered as necessary by ACPC.

industrialization and the developing ones are often at variance. African countries whose GPDs depend to a large extent on agricultural production are often more concerned by the impact of climate change on the agricultural production than are the more developed countries. Indeed, the agricultural sector of some industrialized countries may even benefit, in the short term, from climate change, for example, due to the higher price of agricultural commodities.

4.2 Importance of agriculture

Negotiators dealing with the agricultural sector need to clearly understand the role of agriculture in the economies of developing countries – from the perspectives of the impact of climate change and climate variability in agriculture, the need to feed ever growing populations and current production constrains in the sector. African agriculture is faced with the challenges of adapting to the future climate conditions and the imminent challenge of increase food production today to cope with climate variability and increasing population. Increasing current average food production does provide a safety for both producers and countries – in terms of reserves that they can rely on in times when production is low. Such food reserves are important especially at national and regional levels as strategies for coping with famine risks.

However, at the negotiations, countries have different priorities. Industrialized countries and some rapidly developing countries are more concerned by the rate of industrial development and by their fossil energy consumption than most Sub-Saharan African countries who are more concerned with agriculture. Moreover, in some of the industrialized countries (including some states in China, India and Brazil) agricultural yields can hardly be practically increased when local environmental conditions are taken into consideration.

To effectively defend African agriculture, negotiators need to be familiar with economic priorities and constraints of their countries (e.g., policies in different sectors, constraints of national budgets, balance of trade). Equally, they need to understand the mechanisms the have been used by other countries to boost and sustain production – for example subsidies in the developed and rapidly developing economies (Europe, USA, China and India). Finally, it is important for African negotiators to understand and be able to clearly articulate the need to increase land use efficiency (e.g., increasing yields, reducing the fallow periods, multiple cropping) both for adaptation to climate change and for GHG mitigation.

While each country may continue to pursue national interests and priorities, least developed and developing countries need to defend common positions, especially in relation to agriculture and food production. In this regard, the New Partnership for Africa's Development (NEPAD) has in the past elaborated interesting recommendations. For example, in the 2006 Abuja declaration at the international conference on fertilizer, it put at the top of priorities the objective of increasing annual fertilizer input per hectare from 9 kg to 50 kg by 2015[11].

Finally African negotiators and policy makers need too to analyze other existing challenges in African agriculture, for example, the lack of access to credit, poor road and market

[11] Abuja Declaration on Fertilizer for the African Green Revolution

infrastructure in relation to almost all the other major agricultural regions in the world. Questions need to be raised as to why African smallholders have not benefited from initiatives like CDM[12].

4.3 The African context

During the negotiations on the international agreements, industrialized countries, China India and Brazil delegations include specialists from virtually all economic sectors (e.g., Energy, Industry, Transport, Agriculture, Forestry, Waste Management Economy), from different ministries and also from different scientific sectors (e.g., climatology, bioclimatology, agronomy, industrial research). On the contrary, the African delegations are usually small and hardly have any specialist of agriculture (from ministries of agriculture and from research scientists) dealing with climate change. This is an untenable situation and requires urgent attention in order for African agriculture to secure the strong position that it deserves at the international negotiations. Negotiators must constantly be cognizant of the need to balance priorities from different sectors even within the African teams. This paper makes some suggestions how these challenges may be overcome in the later sections.

Monitoring changes in GHG emissions in agriculture, and in forestry is also more costly than for instance in the energy or waste management sector. For example, it is still too expensive to measure changes in organic matter contents in soils in comparisons to the benefits, which could be obtained under the CDM. Due to climate variability it is also difficult to rely on annual yields. At least averages for 5 year periods could be more sensible. These challenges imply that different rules than those applied in other sectors like energy, transport needs to be introduced to fully capture the agricultural sector. This call for additional work, which the countries concerned, must be ready to undertake.

The differences in focus, interests and priorities between the developing countries heavily reliant on agriculture and the industrialized countries which depend on fossil fuel needs to be critically and continuously examined by the negotiators. Industrialized countries would like, for example, to present "Capture of CO_2 and Storage (CCS)" as a promising option, when in actual fact, improving land use efficiency would be more viable option for African Agriculture. African negotiators in agriculture need to emphasize in all forums, including in the media, that investing in GHG mitigation through increasing land use efficiency in African agriculture is not only a much cheaper 'win-win' option for the world than CCS for GHG mitigation, but also useful for CC adaption and food security.

4.4 Recommendations for African negotiators in agriculture

A befitting observation by one African scientist, Tilahun Amédé on the role of inputs, especially fertilizers on increasing agricultural productivity and improving land use efficiency:

"Deforestation and land degradation in Africa is happening because of low productivity of farm lands to satisfy household food demand. Increasing land productivity by 30 percent will increase landscape cover by about 18 percent. But for this to happen, we need to replenish the soils by

[12] Prior to the Kyoto Protocol in 1997 it was suggested by Brazil to establish a Clean Development Fund (CdF) which was converted into the CDM. It is known that the CDM was beneficial for China India Brazil etc. and a failure for Africa!

chemical fertilizer, including micronutrients. In Europe, excess use of fertilizer is the major concern of the environment. In Africa fertilizer is the solution to rehabilitate the environment".[13]

General recommendations

- Countries need to engage their national scientist and technical experts, agricultural economists and policy makers to determine mechanisms and the cost of improving yields and land use efficiency as a win-win strategy. In addition, costs and benefits, in CO_2 equivalent also to be calculated.
- There is need to underscore the fact that increasing inputs can help to reduce GHG emissions – but the assessment needs to be undertaken at the global landscape level. This is contrary to conventional wisdom.
- Increasing productivity in the livestock sector, i.e., milk production per animal, is not only good for improving livelihoods; it is also appropriate for climate mitigation. This is because the amount of GHG emissions par liter of milk or meat decreases with improved animal diets. These established facts need to be brought to the fore as win-win opportunities during for African agriculture during negotiations.

Recommendation for policy maker, negotiators and agricultural specialists

Negotiators can rarely be experts in all the required knowledge domains. They may however, set national platforms for convergence of research and policy and by enabling research and policy work through grants to assess cost and benefits of various win-win options for African agriculture. These assessments need to be done in the context of sustainable development, which includes agriculture and other sectors. As funding is, and will likely remain scarce, economical costs and benefits are to be assessed as properly as possible in the interest of each country and of global sustainable development.

5. THE ROLE OF ACPC

It is clear that Africa is the continent still facing food insecurity, having insufficient production and productivity. The agricultural system is highly vulnerable to the effects of climate change. With the establishment of the ACPC and adoption of the Climate for development in Africa (ClimDev-Africa) programme, the continent expects to see much development in addressing some of the above problems and issues of climate and development. African countries will be able to take climate issues at the highest level of their national agendas including national policies.

The ACPC has three broad activity areas around which its work programme is defined. These are the (i) knowledge generation, sharing and networking that consist of research, knowledge management, peer learning, and outreach activities (ii) advocacy and consensus building and (iii) advisory services and technical cooperation, which comprise capacity mobilization, capacity building and technical assistance. The Centre is an integral part of the ClimDev-Africa programme, which is a joint initiative of the African Union Commission

[13] The journal of Experimental Agriculture, Vol 47 Supplement 1 January 2011 Improving Water Productivity of Crop-Livestock Systems in Drought –prone Regions Cambridge University Press 181 pages

(AUC), the United Nations Economic Commission for Africa (UNECA) and the African Development Bank (AfDB).

The ACPC will work in the climate adaptation with a view to addressing gaps identified in the high level African bodies and interventions that contribute to policy, technological and institutional innovations; capacity mobilization, development and building; understanding the economics of adaptation; defining scoping document on tools, instruments and methods in the agriculture and other key sectors. Therefore ACPC as a continental body that is responsible for overseeing climate policy related issues must make sure that the climate information and products that are provided to policy makers are based on good data and good science leading to overcoming the challenges of climate change adaptations. Based on its mandate and convening power, ACPC will need to facilitate the following issues:

- coordinate with countries and carry out advocacy, at the highest level, for investing in sustainable agricultural development that could help to cope with climate variability and climate change as well as reduce the production and productivity gaps;
- assist regional bodies such as NEPAD to mainstream climate change in the investment programs;
- assist countries to develop appropriate policies and strategies based on emerging science, tools and methods in understanding climate change and its nexus to agriculture.

To undertake these roles effectively, the ACPC will also engage in the generation of climate information and data and appropriately synthesize and disseminate the information, to support policy decisions in the agriculture and other relevant sectors. ACPC will also carry out any relevant coordination roles as may be desirable by the African countries and across institutions. It will closely work with AUC in several categories such as in training African negotiators, enhancing common policies and strategies in agricultural sector and overall transformation of agriculture in Africa

6. CONCLUSIONS

Even without the effects of climate change, the agricultural sector in Africa is facing numerous challenges that have perennially low productivity and exposed larges swathes of African households to cyclical food shortages and famine. African countries have not sufficiently invested in the sector; producers who are largely small holders have to contend with poor road infrastructure making access to inputs and markets for produce difficult, and lack of credit facilities among other challenges.

Climate change and climate variability threaten to diminish the ability of the African agricultural producers to produce enough food for own consumption as well as for feeding the ever-expanding human population even further. The role of Agriculture is central to most African economies and the livelihoods of most of its people. As such, African governments must step up investments in the sector, adopt effective policies that will promote production and encourage adaptation to existing climate variability and long-term changes in climate. Appropriate policies that can support the producers' capacities in Africa to adopt to the effects of CC and CV are needed.

Although climate change scenarios are still wrought with uncertainties, African position at the international negotiations need to focus on win-win options, for example those that promote land use efficiency and increase land productivity and increase food production. Meanwhile, African countries need also to invest in climate data generation, embrace mechanisms of information sharing and coordinate regional actions through identified agricultural value chains. The African Climate Policy Center will play a key role in linking science with policy at regional, national and sub national levels.

REFERENCES

Agoumi, A. (2003). Vulnerability of North African countries to climatic changes. Adaptation and implementation strategies for climate change. International Institute for Sustainable Development.

APF (2007). Climate Change and Africa. 8th Meeting of the Africa Partnership Forum 22-23 May 2007. Berlin, Germany.

Christensen, J. H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, et al. 2007. Regional climate projections, Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller. Cambridge: Cambridge University Press.

Cilliers, J. (2009). Climate change, population pressure and conflict in Africa. Institute for Security Studies. Paper 178.

CEDRES. 2011. ACTES DU COLLOQUE.Tome 3. Thème: « Quelle agriculture pour un développement durable de l’Afrique ? ». Ouagadougou, Burkina Faso - du 6 au 8 décembre 2010.

FAO. 1999. The State of Food Insecurity in the World. Food and Agriculture Organization of the United Nations.

FAO. 2003. World agriculture: towards 2030/2050. Prospects for food, nutrition, agriculture and major commodity groupsInterim report Global Perspective Studies Unit Food and Agriculture Organization of the United Nations Rome, June 2006, Edited by Jelle Bruinsma http://www.fao.org/es/ESD/gstudies.htm; 78p.

FAO (Food and Agricultural Organization). 2007. “FAOSTAT”. Rome, Food and Agricultural Organization (FAO).

Funk, C., M. D. Dettinger, J. C. Michaelsen, J. P. Verdin, M. E. Brown, M. Barlow, and A. Hoell. (2008). Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. Proceedings of the National Academy of Sciences 105(32): 11081–86.

Hance T, J. van Baaren, P. Vernon, and G. Boivin (2007).Impact of extreme temperatures on parasitoids in aclimate change perspective. Ann. Rev. Entomol. 52, 107-126.

Hassan, R. M. (2009). Implications of Climate Change for Agricultural Sector Performance in Africa: Policy Challenges and Research Agenda. Journal of African Economies.Volume19, Issue 2. Pp. ii77-ii105.

Hewitson, B. (2007). High resolution regional climate change scenarios for Sub-Saharan Africa. Project summary information. In Assessment of Impacts and Adaptation to Climate Change, Final Report of the AIACC Project, 57–60. Submitted by The International START Secretariat, Washington, DC, and The Academy of Sciences for the Developing World, Trieste, Italy. Prepared by N. Leary, J. Kulkarni, and C. Seipt.

Inocencio, A., D. Merrey, M. Tonosaki, A. Maruyama, I. de Jong, and M. Kikuchi (2006).Costs and Performance of Irrigation Projects: a Comparison of sub-Saharan Africa and Other Developing Regions.International Water Management Institute (IWMI), Colombo, Sri Lanka.

IPCC (Intergovernmental Panel on Climate Change), 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Summary for policy makers. Online at http://www.ipcc.cg/SPM13apr07.pdf

Jones, P. G. and P. K. Thornton (2003). The potential impacts ofclimate change in tropical agriculture: the case of maize in Africaand Latin America in 2055. Global Environmental Change, 13: 51-59.

Karlberg, L., J. Rockström and M. Falkenmark (2009). Water Resource Implications ofUpgrading Rainfed Agriculture – Focuson Green and Blue Water Trade-offs. In eds. Rainfedagriculture : unlocking the potential / edited by S. P. Wani, J. Rockström, and T. Oweis. Rainfedagriculture : unlocking the potential. Cabi International, UK.

Michael K., A. Buck and C. Eastaugh (2009). Policy Brief - Making African forests fit for climate change. A REGIONAL VIEW OF CLIMATE-CHANGE IMPACTS ON FORESTS AND PEOPLE, AND OPTIONS FOR ADAPTATION. International Union of Forest Research organizations.

Moorhead, A. (2009). Climate, agriculture and food security: A strategy for change. Climate Change, Agriculture and Food Security (CCAFS), December 2009.

Nkem J., M. Idinoba, M. Brockhaus, F. Kalame, and A. Tas (2008). Adaptation to Climate Change in Africa: Synergies with biodiversity and forests African Ministerial Conference on Environment (AMCEN).

Oerke E.C., H.W. Dehne, F. Schönbeck, and A. Weber(1994). Crop production and crop protection. Estimatedlosses in major food and cash crops. Amsterdam: Elsevier Science. 808 pp.

Padgham, J. (2009). Agricultural Development Under a Changing Climate: Opportunities and Challenges for Adaptation. Joint Departmental Discussion Paper- Issue 1.The International Bank for Reconstruction and Development / The World Bank, Washington.

Paeth, H., and H. P. Thamm. 2007. Regional modeling of future African climatenorth of 15° S including greenhouse warmingand land degradation. Climatic Change83:401–27.

Parry, M.L., O.F.Canziani, J.P. Palutikof, P.J. van der Linden, C.E. Hanson, eds.Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Reportof the Intergovernmental Panel on Climate Change.CambridgeUniversity Press, Cambridge.

Riedacker, A. 2007. Quelle Place dans les Négociations sur le Climat, pour la période post 2012, de l'Agriculture, de la Sécurité Alimentaire et de la Réduction de la Déforestation dans les pays peu Développés? Contribution au Débat pour la Réunion Organisée pour les Négociateurs des pays Francophone par l'OIF Paris 2-4 Avril 2007.

Satterthwaite, D. (2009). The implications of population growth and urbanization for climate change. Human Settlements Group, International Institute for Environment and Development (IIED) Paper presented at Expert-Group Meeting on Population Dynamics and Climate Change, UNFPA and IIED In Collaboration with UN-HABITAT and the Population Division, UN/DESA, 24 to 25 June 2009.

Smith, D. M., S. Cusack, A. W. Colman,C. K. Folland, G. R. Harris, and J. M.Murphy. 2007a. Improved surface temperatureprediction for the coming decade froma global climate model. Science 317:796–99.

UN-HABITAT Report (2008). Projects steep growth of African urbanpopulation, http://www.unhabitat.org/content.asp?cid=6041&catid=5&typeid=6&subMenuId=0.

Vermeulen, S.J., P.K. Aggarwal, A. Ainslie, C. Angelone, B.M. Campbell, A.J. Challinor, J.W. Hansen, J.S.I. Ingram, A. Jarvis, P. Kristjanson, C. Lau, G.C. Nelson, P.K. Thornton, and E. Wollenberg (2010). Agriculture, Food Security and Climate Change: Outlook for Knowledge, Tools and Action. Climate Change, Agriculture and Food Security (CCAFS), report No. 3.

Voigt W, J. Perner, A. J. Davis, T. Eggers, J. Schumacher, R. Bährmann, B. Fabian, W. Heinrich, G. Köhler, D. Lichter, R. Marstaller and F.W. Sander (2003). Trophic levels are differentially sensitive to climate. Ecology84, 2444-2453.

World Bank. 2008. Agriculture for Development. world development report, DOI: 10.1596/978-0-8213-7233-3, 386p.