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African Climate Policy Centre**

Working Paper

**CLIMATE CHANGE IMPACTS ON AGRICULTURE IN
AFRICA AND THE UNFCCC NEGOTIATIONS: POLICY
IMPLICATIONS OF RECENT SCIENTIFIC FINDINGS**

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SUMMARY FOR POLICYMAKERS

Recent scientific studies provide more detail on the impacts of climate change on agriculture in Africa since the IPCC Fourth Assessment Report. The new scientific data provided by these studies can inform the African common position in the UNFCCC climate negotiations.

Key messages from the analysis:

- The overarching objective of the UNFCCC requires that greenhouse gas concentrations in the atmosphere be kept to a level and within a time frame *to ensure that food production is not threatened*.
- Recent science shows that from 1980-2008, due to rising global temperatures, global maize and wheat production has already decreased by 3.8% and 5.5% respectively.
- Currently, at 0.74°C of warming, African farmers and pastoralists are seeing changes in the timing of rains, in the severity of rains, in the temperatures they and their crops and animals are exposed to, and in the progressive drying of their soils. *Food production is already threatened by the temperature rise of the last century, and the committed warming due to greenhouse gas emissions of the last decades.*

With respect to the global goal for temperature rise:

- With 1°C of warming – the level expected approximately **one decade from now** – roughly 65% of current maize growing areas in Africa are predicted to experience yield losses under optimal rainfed conditions; under drought conditions, 75% of areas can expect yield declines of at least 20% for 1°C of warming.
- At the current rate of temperature increase, global average temperatures will have increased **1.5°C by 2050**. Average predicted production losses by 2050 for African crops are: maize 22%, sorghum 17%, millet 17%, groundnut 18%, and cassava 8%. Warming as low as 1.5°C therefore threatens food production in Africa significantly.

With respect to adaptation:

- Due to current and significant near-term predicted impacts on crop yields, adaptation in agricultural systems is an **urgent** imperative. Any chance at maintaining adequate production under the rising temperatures and changing precipitation patterns expected in coming decades requires that significant adaptation efforts must start now, with sufficient finance, technology transfer and capacity-building resources provided by Annex I countries.
- **Slow onset temperature rise** is already having and will continue to have serious consequences for African farmers, as well as pastoralists. A UNFCCC work programme on loss and damage must include consideration of significant and widespread impacts from increasing temperatures on agricultural yields, regional and global food production, and the livelihoods of those dependent on agricultural production. Means to compensate for losses and damage in the agriculture sector will be important.

With respect to mitigation efforts in agriculture:

- Africa's agriculture produces a fraction of the greenhouse gas emissions produced by developed country agriculture. Mitigation must remain a secondary concern of African governments, with emphasis given to adaptation and food security and other development concerns.

- Offsets for mitigation through carbon sequestration in soils will not contribute to permanent emission reductions, and thereby further threaten developing country agriculture.

Research relevant to a global goal for temperature rise

“All of Africa is very likely to warm during this century. The warming is very likely to be larger than the global, annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moister tropics.”

IPCC Fourth Assessment Report, Working Group I (Solomon 2007, section 11.2)

Global average temperature is expected to increase by 0.2°C per decade over the next two decades (IPCC Synthesis Report, 2007). If temperatures continue to increase at this rate, and based on the committed warming of current atmospheric GHG levels and current rates of GHG emissions this is expected, average temperature increase (from 1905) will reach **1.5°C by 2050**. Larger increases (0.3°C-0.4°C or greater per decade) are expected on cultivated land areas and large landmasses, including much of the African continent.

Projected impacts on crop yields

Researchers associated with the Stanford University Program on Food Security and the Environment have published a number of studies since the IPCC Fourth Assessment Report detailing impacts of climate change on agricultural production in the coming decades. They have concentrated their analysis on the next several decades, in order to provide policymakers with clear targets for adaptation research and development. They have also concentrated their analysis on agricultural systems within Africa.

Some of their main findings include:

- With 1°C of warming, roughly 65% of current maize growing areas in Africa will experience yield losses under optimal rainfed conditions; under drought conditions, 75% of areas can expect yield declines of at least 20% for 1°C of warming (Lobell et al., 2011).
- Average (median) predicted production losses by 2050 for African crops: maize 22%, sorghum 17%, millet 17%, groundnut 18%, cassava 8%. In Africa, impacts will be most severely felt in southern African maize and Sahel sorghum (Schlenker and Lobell, 2010).
- *“Food security [is] clearly threatened by climate change in the relatively near term”* (Lobell et al., 2008).

These data confirm and add specificity to work done in the early 2000s by CGIAR researchers Jones and Thornton (2003) who showed crop yields falling by 10-20% by 2050. Projected yield impacts are not all negative: yields are expected to increase in highland areas, such as the southern Ethiopian highlands, central and western highlands of Kenya and the Great Lakes region. (Thornton et al. 2009)

Research relevant to adaptation and the question of slow onset temperature rise

Water availability plays a crucial role in agricultural production in Africa, given the very high percentage of cropping systems that are rainfed, and the dependence of livestock on both pasture and water supplies. However, many researchers and analysts conclude that although rainfall variability will continue to be a concern for farmers and governments alike, such variability in the future may not look much different than rainfall variability in the past.

Temperature, on the other hand, will continue to rise, quickly taking agricultural systems outside the historical range of variability, creating novel climates and new threats. As temperatures slowly rise, historical extremes are exceeded. With a rise in temperature, soil moisture decreases, even with sufficient rainfall, thereby shortening the length of the growing season. In situations of reduced rainfall, increased temperatures can lead to what has been termed “global-change-type drought”, with soil moisture decline exacerbated by increased heat.

For the Stanford University research team, temperature is central to the impacts of climate change on agriculture in Africa:

- *“Temperature changes have a much stronger impact on yields than precipitation changes”* (Schlenker and Lobell, 2010).
- *“The majority of African countries will have novel climates over at least half of their current crop area by 2050”* (Burke et al., 2009).
- Climate extremes will become much more common as the climate warms, with *“relevant temperature thresholds for crops, such as 35°C or 40°C, to be exceeded on more days in most regions. ... Nearly all models agree that many major cropping regions will experience a rapid increase in days above 35°C, with most models projecting a more than doubling of the rate of exposure by mid-century”* (Stanford University, 2009).

Biological organisms have physiological limits to the amount of excessive heat they can endure. Important plant processes, such as pollination, grain filling and photosynthesis, shut down above threshold temperatures. High temperatures, whether lasting over a series of days or an extreme spike of several hours, can have serious negative effects on these processes, with downstream consequences for crop yields. Especially sensitive are the reproductive organs; extreme heat events of even short duration during flowering or pollination can severely reduce a harvest (Araus et al. 2008).

In livestock, heat stress *“will induce behavioural and metabolic changes, including reduced feed intake and thus a decline in productivity.”* However, *“whether the mean temperature increases of the coming decades are within the range that can be tolerated or not by existing distributions of different genotypes of cattle in the tropics is essentially unknown”* (Thornton et al. 2009).

Impacts on cropping and livestock systems

“Most worrisome for the Sahel is that average growing season temperatures by the end of this century, and even earlier for some parts of the region, are expected to exceed the hottest seasons recorded during the past century. ... New bounds of heat stress will make the region’s population far more vulnerable to poverty and hunger-related deaths and will likely drive many people out of agriculture altogether, thus expanding migrant and refugee populations” (Battisti and Naylor 2008).

The CGIAR (a consortium of international agricultural research institutes) estimates that the length of the growing period (LGP) will decline across southern and west Africa by 5% or more by 2050, while *“reliable crop growing days (a more discriminating indicator than LGP for rain-fed crops) decrease to critical levels, below which cropping might become too risky to pursue as a major livelihood strategy in west Africa and east Africa. ... High temperature stress (above 30C) will be widespread in east and southern Africa”* (Ericksen et al., 2011).

Thornton et al. (2009) predict significant shifts from cropping to livestock in some areas. *“Transitions are already occurring: in marginal areas of southern Africa, the reductions in length of growing period and the increased rainfall variability is driving systems to a conversion from a mixed crop-livestock system to a rangeland-based system, as farmers find growing crops too risky in those marginal environments.”*

Thornton et al. (2011) explore a range of adaptation strategies that should be considered by crop producers, pastoralists, and agropastoralists, noting that over time and with increasing temperatures, however, *“the options available for adaptation to climate change for SSA, whether domestic or foreign, are likely to decrease. What is unclear is at what point those options become too few for successful adaptation across a region.”* They conclude finally that: *“the prognosis for agriculture and food security in SSA in a 4°C+ world is bleak.”*

Research relevant to mitigation efforts in agriculture

Despite imminent and severe impacts of climate change on African agricultural production and the urgent need thus to prioritize adaptation in agriculture, within the long-term cooperative action negotiating track (AWG-LCA), agriculture has figured most prominently within discussions of cooperative sectoral approaches to mitigation.

Annex I countries' agricultural emissions dwarf emissions from Africa. Although population size is roughly equivalent between the two groups of countries, total Annex I emissions from agricultural sources are two times the amount emitted in African countries, and emissions from Annex I animal agriculture three times larger (Smith, 2007). Given the immense threat to agriculture in Africa from climate change, it makes little sense for African countries to take on mitigation burdens in the sector, rather than to focus on food security, rural livelihoods and other key issues of development concerns.

Carbon sequestration in soils has been proposed as a mitigation option that should be considered by African countries. However, soil carbon sequestration does not permanently remove carbon dioxide from the atmosphere and thus any change in practices leading to reversal of carbon storage would further threaten African agriculture. Moreover, to the extent that soil carbon sequestration is incentivized by the reduction (offsetting) of Annex I emission obligations, the enabling of continued A1 emissions will lead to further warming and further impacts on agricultural production on the continent.

1. INTRODUCTION

The impacts of climate change on the African continent are expected to be severe. Unfortunately negotiations under the UN Framework Convention on Climate Change have to date failed to adequately reflect the severity of impacts expected in Africa; the Annex I mitigation responses necessary to prevent those impacts; and the scale of financial, technological and capacity-building resources that will allow African countries to adapt with the speed and effectiveness required to protect agricultural production and food security for the hundreds of millions of people living on the continent.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4) summarizes the scientific evidence on impacts up until 2006. In the past five years since the publication of the report, scientific understanding of impacts of climate change has progressed considerably. Recent scientific literature is more detailed, specific, and takes advantage of developments in climate and scientific modeling to provide a more specific picture of current impacts and predicted changes over the next several decades.

The basic intent of this review is to provide a summary of new scientific information post-AR4 that may be relevant to African Group of Negotiators. The report reviews selected recent scientific literature, aiming to augment information both on the current impacts of anthropogenic warming on agricultural systems in Africa, as well as, to the extent possible, prediction of future impacts. With regard to future impacts, we place an emphasis on the near term – 2020-2050, rather than the end of the century. We concur with the reasoning of Mueller et al. (2011) that, given the short time left to respond to impacts that will manifest in 2020, these should warrant the greatest concern.

It is important to bring a more detailed, up-to-date understanding of climate impacts on agriculture in Africa – both current and anticipated – into the UNFCCC discussions. In this context, we must emphasize that there will be significant impacts on agriculture in Africa between now and 2050 – *before* global average temperature increases by 1.5°C. This fact cannot be emphasized enough in terms of its bearing on the African position in the negotiations – *to accept a global goal of 1.5°C already means to accept significant hardship, reduction and elimination of livelihoods, and serious disruption of food security across the entire African continent.*

1.1. The UNFCCC Context for Agriculture

The centrality of agriculture to the UNFCCC and global action to prevent dangerous anthropogenic interference with the climate system is evidenced by the reference in the Convention’s objective – that stabilization of greenhouse gas concentrations in the atmosphere should be at a level “*achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.*”

Agriculture appears in the UNFCCC negotiations principally as a crosscutting issue – relevant to almost all of the main negotiating topics, yet for the most part appearing only incidentally. Only one small portion of the AWG-LCA negotiating text deals exclusively with agriculture, within the mitigation section on cooperative sectoral approaches.

However, the potential and imminent impacts on agriculture from climate change should have an enormous bearing on African negotiating positions, particularly in the context of the following topics:

- A global goal to limit average global temperature increase;
- Enhanced action on adaptation, including a work programme on loss and damage;
- Enhanced action on mitigation, in particular mitigation commitments by developed country Parties; and
- Means of implementation: finance, technology, and capacity building.

In particular, the severity of climate change impacts on agriculture has significant bearing on the global goal and the ambition of Annex I emission reductions. A 2°C world is likely to have unacceptable consequences for agricultural production on the African continent. Currently, at 0.74°C of warming, African farmers and pastoralists are seeing changes in the timing of rains, in the severity of rains, in the temperatures they and their crops and animals are exposed to, and in the progressive drying of their soils. ***Food production is already threatened by the temperature rise of the last century, and the committed warming due to greenhouse gas emissions of the last decades.*** A doubling of the warming seen to date – to 1.5°C – will mean crops in some regions will fail too often for crop producers to maintain that livelihood strategy. Pastoralists in many areas will be forced to migrate distances too far and too frequently for water and pasture to remain pastoralists. Two degrees will be too much for agriculture in Africa – adaptation in many areas will simply not be an option.

1.2. The IPCC Fourth Assessment Report (AR4)

“All of Africa is very likely to warm during this century. The warming is very likely to be larger than the global, annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moister tropics.”

IPCC Fourth Assessment Report, Working Group I (Solomon, 2007, section 11.2)

To establish a starting point for the analysis in this report, we first review some of the relevant evidence presented in the IPCC AR4.

On the rate of global and regional temperature rise

Global average temperature is expected to increase by 0.2°C per decade over the next two decades (IPCC Synthesis Report, 2007). If temperatures continue to increase at this rate, and based on the committed warming of current atmospheric GHG levels and current rates of GHG emissions this, global average temperature increase (from 1905) will reach ***1.5°C by 2050***. Larger increases (0.3°C-0.4°C or greater per decade) are expected on cultivated land areas and large landmasses (Figure 1 on the next page shows temperature increases expected on continents until 2050).

On recent observed changes in temperature and precipitation

“In the Sahelian region of Africa, warmer and drier conditions have led to a reduced length of growing season with detrimental effects on crops. In southern Africa, longer dry seasons and more uncertain rainfall are prompting adaptation measures.” (Parry et al. 2007, 9)

With respect to observed changes in drought duration and intensity

“Changes in SSTs [sea surface temperatures] and associated changes in the atmospheric circulation and precipitation have contributed to changes in drought, particularly at low latitudes. The result is that drought has become more common, especially in the tropics and subtropics, since the 1970s.” (Solomon et al. 2007, 54)

Continental Surface Temperature Anomalies: Observations and Projections

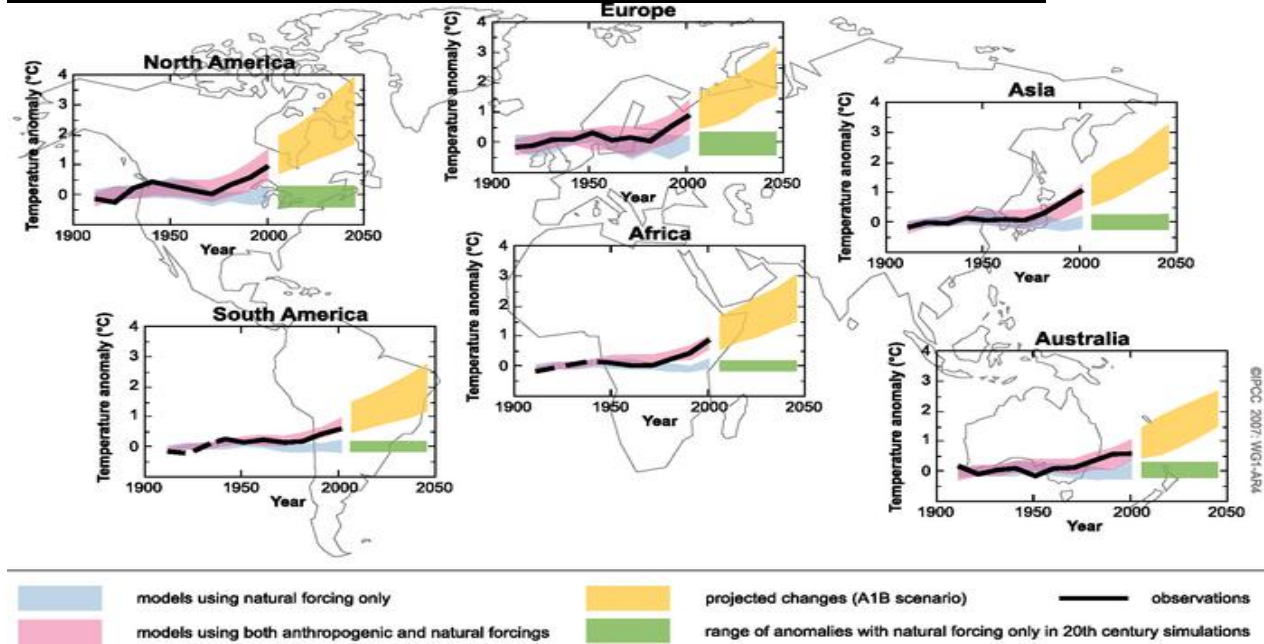


Figure 1: Decadal mean continental surface temperature anomalies (°C) in observations and simulations for the period 1906 to 2005 and in projections for 2001 to 2050

Source: Solomon et al 2007, Figure TS.29

In Figure 1, anomalies are calculated from the 1901 to 1950 average. The black lines represent the observations and the pink and blue bands show simulated average temperature anomalies (i.e., pink includes anthropogenic and natural forcings and blue includes only natural forcings). The yellow shading represents the 5th to 95th percentile range of projected changes according to the SRES A1B emissions scenario. The green bar denotes the 5th to 95th percentile range of decadal mean anomalies from the 20th-century simulations with only natural forcings (i.e., a measure of the natural decadal variability).

General predictions about agricultural production in Africa

“Agricultural production, including access to food, in many African countries and regions are likely to be severely compromised by climate change and climate variability. The area suitable for agriculture, the length of growing seasons and yield potential, particularly along the margins of semi-arid and arid areas, are expected to decrease. ... In some countries, yields from rain-fed agriculture could be reduced by up to 50% by 2020” (Parry et al., 2007, 13).

“By 2020, between 75 and 250 million of people [in Africa] are projected to be exposed to increased water stress due to climate change” (Parry et al., 2007, 13).

“Agricultural losses are shown to be possibly severe for several areas (e.g., the Sahel, East Africa and southern Africa) accompanied by changes in the length of growing periods impacting mixed rain-fed, arid and semi-arid systems under certain climate projections” (Parry et al., 2007, 48).

“New studies confirm that Africa is one of the most vulnerable continents to climate variability and change because of multiple stresses and low adaptive capacity. Some adaptation to current climate variability is taking place; however, this may be insufficient for future changes in climate” (Parry et al., 2007, 13).

Climate impacts that will have direct and/or indirect effects on agricultural production in Africa

[There is a] *“very likely increase in frequency of hot extremes, heat waves and heavy precipitation, ... [and] likely [precipitation] decreases in most subtropical land regions, continuing observed recent trends” (AR4 Synthesis Report, 2007, 8).*

“Agriculture in low latitudes [is likely to be especially affected] due to reduced water availability” (AR4 Synthesis Report, 2007, 9).

“Drought-affected areas will likely increase in extent. Heavy precipitation events, which are very likely to increase in frequency, will augment flood risk” (Parry et al., 2007, 11).

“At lower latitudes, especially seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1-2°C), which would increase the risk of hunger” (Parry et al., 2007, 11).

“Increases in the frequency of droughts and floods are projected to affect local crop production negatively, especially in subsistence sectors at low latitudes” (Parry et al., 2007, 12).

“Projected changes in the frequency and severity of extreme climate events have significant consequences on food and forestry production, and food insecurity, in addition to impacts of projected mean climate (high confidence). Recent studies indicate that increased frequency of heat stress, droughts and floods negatively affects crop yields beyond the impacts of mean climate change, creating the possibility for surprises, with impacts that are larger, and occur earlier, than predicted using changes in mean variables alone. This is especially the case for subsistence sectors at low latitudes” (Parry et al., 2007, 38)

“Smallholder and subsistence farmers, pastoralists and artisanal fisherfolk are likely to suffer complex, localized impacts of climate change (high confidence)” (Parry et al., 2007, 39).

1.3. An Analytical Baseline for Temperature and Yields

Two recent reports, from the World Meteorological Organization (WMO, 2011) and the Program on Food and the Environment at Stanford University (Lobell et al., 2011) provide something of a baseline from which to begin an analysis.

Recent African temperature data from the World Meteorological Organization. The World Meteorological Organization releases yearly statements on the status of the world’s climate. In its most recent report (WMO 2011), the WMO concludes that:

“For ... Africa, 2010 was the warmest year on record. It was also the warmest year on record for ... West Africa [and] the Saharan/Arabian region” (3).

“Temperatures averaged over Africa were 1.29°C above the long-term average, breaking the previous record by 0.35°C. ... All twelve months of 2010 were at least 0.7°C above normal” (5).

“[t]he Saharan/Arabian region was 2.22°C above normal, 0.89°C above the previous record and the largest annual anomaly ever recorded for any subregion outside the Arctic” (5-6).

“East Africa, which had never had a year as much as 1°C above normal prior to 2003, has now reached this threshold in eight successive years” (6).

Global yield impacts of current climate changes. Stanford researchers recently published analysis in *Science* magazine documenting that from 1980-2008, due to rising global temperatures, global maize and wheat production has already decreased by 3.8% and 5.5% respectively (Lobell et al., 2011).

1.4 Scientific Uncertainty and Policymaking: On Why Policymakers Must Work with Worst-Case Scenarios

Political attacks on the IPCC have made scientists incredibly cautious with respect to how they convey the information generated by their models and empirical studies. The IPCC as a practice assigns likelihoods to the information they present in their periodic reports. Such a characterization of scientific uncertainty is certainly helpful for policymakers. But decision-makers must also have information about worst-case scenarios that might arise, in order to prepare adequately to respond to extreme events.

For example, one-hundred year floods don't occur every hundred years – the probability of a flood of a particular magnitude might be that it occurs once in one-hundred years, but it is still possible to have two floods of this magnitude take place within several years of each other. And the changing climate is, in fact, causing such extreme events to occur with increasing frequency.

“Guidance for policy can best be drawn from a risk management perspective, studying specifically the probability of high-impact scenarios.” (Mueller et al. 2011) In any sort of crisis situation, a government must prepare for the worst. Whether a disruption of power supply might result from inclement weather, a gas explosion, or deliberate sabotage, governments must have emergency plans in place to provide essential energy to hospitals and other services. In the case of the future of crop production in a country, a similar type of precautionary approach is necessary to maintain food security for the population.

Scientists must be given the political space to explain to decision-makers what the worst-case situations might be. Decision-makers must take into consideration the uncertainties with which climate modelers and agriculture experts are working, and request information that reflects the range of uncertainties. Scientists should not be frightened into downplaying the more serious impacts that are foreseen – this only serves to worsen threats to food security if indeed policymakers are not prepared for the breadth and severity of possible impacts on food production.

2. BACKGROUND: CLIMATE BASICS RELEVANT TO AGRICULTURE

Climate change poses monumental challenges for agriculture with respect to the climate variables most important to plants and animals, temperature and rainfall.

Biological organisms have physiological limits to the amount of excessive heat they can endure. Important physiological processes shut down above threshold temperatures. Both plants and animals depend fundamentally on water as a basic component of their bodies and their existence. And, of course, animals depend on plants for their sustenance, hence a significant focus here on impacts of climate change on both crops and grassland. As climate change increases both average and, more importantly, extreme temperatures, we expect impacts on yields of crops and milk, and limits on the areas where crop and livestock production can occur. As climate change increases the variability in the amount of rainfall, water supplies essential to life will be affected, with consequences for agricultural production.

2.1. Temperature Extremes and Crop Yields

While much concern has been raised about the impacts of climate change on rainfall variability and distribution, changes in temperature may cause the most disruption to crop yields in the coming decades.

Temperature is significant for a range of crop physiological processes, the most important being pollination and grain filling, as well as basic photosynthesis. High temperatures, whether lasting over a series of days or an extreme spike of several hours, can have serious negative effect on these processes, with downstream consequences for crop yields. Especially sensitive are the reproductive organs; extreme heat events of even short duration during flowering or pollination can severely reduce a harvest (Araus et al., 2008; Semenov and Halford, 2009).

More generally and less acutely, high temperatures cause plants to develop more quickly, with grain filling happening more quickly, shortening the growing season and reproductive phase and thus reducing yields (Barnabás, 2008; Semenov and Halford, 2009). The phenomenon is not crop specific: “[a]nalysis of crop responses suggests that even moderate increases in temperature will decrease yields of corn (maize), wheat, sorghum, bean, rice, cotton, and peanut crops” (Hatfield, 2008).

Higher nighttime temperatures can also negatively influence yield. U.S. maize yields were predicted to drop significantly in 2010 precisely because of this – high temperatures at night during last year’s cropping season “didn’t give the crop a chance to “rest” and limited kernel growth” (Berry, 2010).

Unfortunately the major models that have been developed to evaluate the impacts of climate on agriculture do not model well the temperature dependency of these key variables (Stanford University, 2009), likely leading to serious underestimation of the potential impacts of rising temperatures on agricultural production and yields. Moreover, most recent scholarship also calls into question an over-optimistic reliance on the potential for increased CO₂ concentrations to counter the yield-reducing effects of increasing temperatures (for example, see Long et al., 2005 and Long et al., 2006).

Higher temperatures will affect crop yields more or less in a linear fashion up to certain thresholds. Once those thresholds are passed, crop yields drop off dramatically as essential reproductive and physiological processes are crippled or shut down entirely.

Pollen. Pollen viability declines with rising temperatures until a threshold is reached, above which pollen dies (Stone, 2001). Temperatures above 35-38°C have been shown to cause pollen to lose viability in maize (Rosenzweig et al., 2001; Maestri, 2002; Barnabás, 2008; Hatfield, 2008).

Seed development. The development of young plants – from the earliest embryo stages – can cease if temperatures exceed temperature thresholds (Klueva et al., 2001; Maestri, 2002).

Photosynthesis. Photosynthesis rates are reduced at higher temperatures, as the activity of an important enzyme in the photosynthetic process (Rubisco, or ribulose 1,5 biphosphate carboxylase/oxygenase) is decreased above 35°C; as temperatures rise the reduction in the rate of photosynthesis will become an important limit to crop yields (Barnabás, 2008).

Researchers associated with Stanford University’s Program on Food Security and the Environment have been looking closely at the possible impacts of rising temperatures on crop yields globally, and paying particular attention to the extreme highs and crop thresholds that will be breached, even in the near future. As average temperatures (and/or variance in temperatures) shift even slightly, the number of extreme days increases (see figure 2). The Stanford researchers summarize that:

“the shift in average temperatures alone will cause relevant temperature thresholds for crops, such as 35°C or 40°C, to be exceeded on more days in most regions. ... Nearly all models agree that many major cropping regions will experience a rapid increase in days above 35°C, with most models projecting a more than doubling of the rate of exposure by mid-century” (Stanford University, 2009).

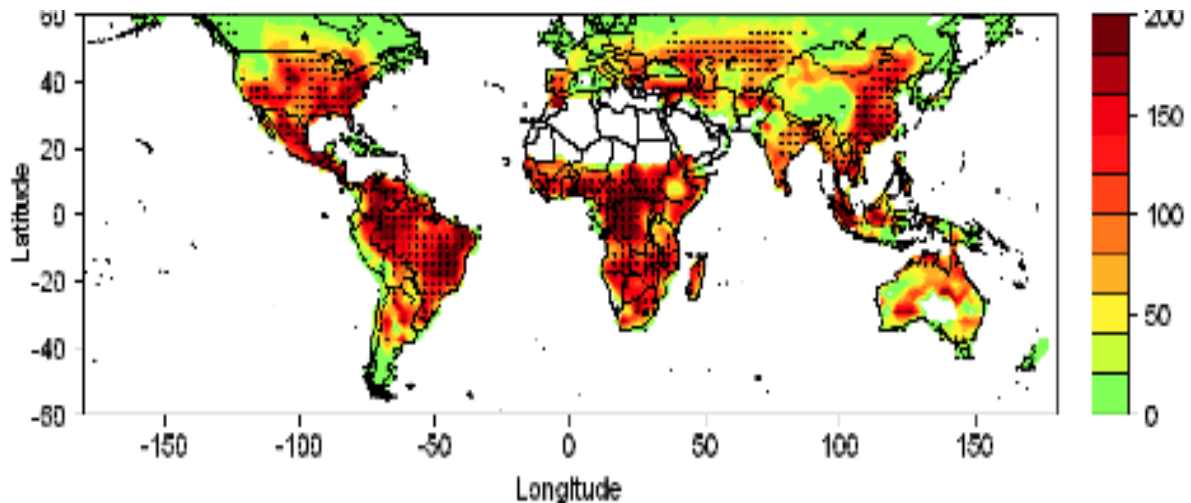


Figure 2: Simulated change in days above 35°C during the growing season in 2050 (% increase above 1990 levels), averaged across 12 climate models

Dots indicate where at least 10 of 12 models agree on the direction of change.

Source: Stanford University, 2007

Schlenker and Roberts (2009) (also associated with the Stanford program) use crop models and a large dataset of yields from the U.S. Midwest to estimate the effect of temperature extremes on maize yields, with troubling results. Their results “suggest a marked dropoff of yields when canopies are exposed to temperatures above 30°C” (see Figure 3).

In summary, “the clear message from the crop community is that [temperature] thresholds are well defined, they can be effective over short time-periods and can extensively damage yield productivity” (Porter and Semenov, 2005).

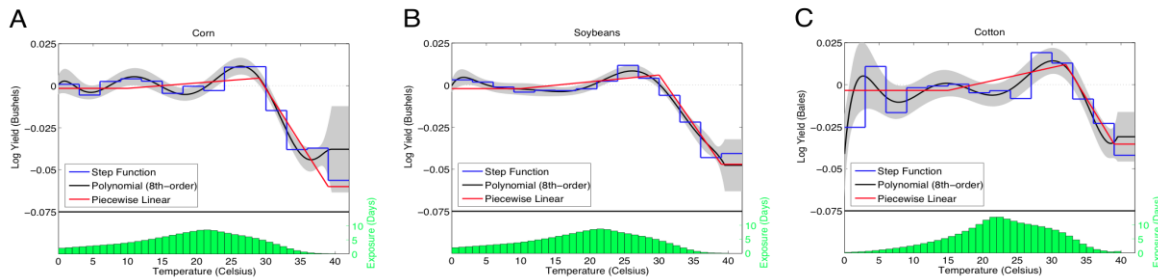


Figure 3: Nonlinear relation between temperature and yields
Source: Schlenker and Roberts, 2009.

2.2. Temperature Increases and Livestock

Climate change can affect the quality and quantity of feeds, drastically reduce water availability, and change the abundance and distribution of diseases, disease vectors, and natural predators and parasites of vectors themselves. As mentioned above, animals depend on plants as food, so any change in crop or forage production can have impacts on animal feed supply in a variety of ways:

- “Sustained increase in mean temperatures results in significant changes in rangeland [plant] species distribution, composition, patterns and biome distribution.
- Small changes in temperature can alter C3/C4 balance significantly and often result in changes in livestock productivity.
- Increased temperatures increase lignification of plant tissues and therefore reduce the digestibility and rates of degradation of plant species.
- In situations where maize stover is a key dry-season resource for cattle, for example, there are likely to be important implications in the reduction in maize biomass for livestock, in addition to the implications of reductions in maize grain for food security” (Thornton et al., 2009).

With regard to direct impacts of temperature increases on animals, Thornton et al. (2009) conclude that heat stress “will induce behavioural and metabolic changes, including reduced feed intake and thus a decline in productivity.” However, “whether the mean temperature of the coming decades are within the range that can be tolerated or not by existing distributions of different genotypes of cattle in the tropics is essentially unknown” (Thornton et al., 2009).

2.3. Precipitation Changes: Amount, Frequency, Distribution, Variability, Predictability

While temperature changes under changing climatic conditions will for most locations on the planet move in a single direction, the same is not true for the other climate variable of concern:

precipitation. Nevertheless, there are some basic predictions that can be made about future precipitation changes relevant to understanding possible impacts on agricultural production in Africa:

- With warming temperatures, the atmosphere will hold more water.
- Rainfall events may change in frequency and in the amount of rain that falls at one time. A more saturated atmosphere means that heavier rainfall events will become more common.
- The variability in amount of yearly rainfall is likely to remain within historical ranges in many regions. *“Climate change will manifest itself in part, and possibly largely, as a change in the frequency of events that are currently experienced within current climate variability.”* (Washington et al. 2006) In Africa, rainfall variability may not change significantly, although given the historic magnitude of variability, this is not necessarily good news.
- Yearly rainfall amounts may remain more or less constant, yet if rain falls in fewer, heavier events, with less infiltration and more runoff of rainwater, the amount of soil moisture available for plant growth, and hence the length of the growing season, may be reduced. *“Both thermodynamic arguments and climate model simulations suggest that precipitation may become more intense but less frequent under GHG-induced global warming. This may increase flash floods and runoff, but diminish soil moisture and increase the risk of agricultural drought.”* (Dai 2010)
- *“Rain falling in heavier bursts does not necessarily equate to more rain over a year—although this may occur in some regions. In fact, greater evaporation as the weather gets hotter may exacerbate droughts and [desertification](#) in dry regions.* (Parliament of Australia 2008)
- Climate models are not capable now of predicting changes in rainfall patterns. *“Climate models fail to reach a robust agreement regarding the twenty-first century outlook for African rainfall.”* (Giannini et al. 2008) Often suites of models will completely disagree on the direction of the change (for example, see later discussion on Horn of Africa and IPCC model predictions).
- Models are not yet adequately sophisticated with respect to sea surface temperatures and land change processes to be able to give accurate indications as to future patterns of rainfall on the African continent. *“Future efforts to predict drought will depend on ability to predict tropical sea surface temperatures.”* (Dai 2010)
- Seasonal forecasts can provide information in the months leading into a planting season about the onset of rains and the total amount of rain to expect over the course of the season. However those predictions will not be able to include information about the frequency of rain events and the amount of rain to fall during the events, thus also providing likely less information than desirable for agricultural production.
- A conclusion that can be derived from these bullet points is that rainfall variability will continue as the problem that it has been across Africa. While variability may not increase, coupled with a likely increase in heavier rainfall events and increase in temperatures, soil moisture levels across the continent are likely to continue to decrease and cropping in many areas will progressively become difficult.

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2.4. The Relation of Rainfall and Temperature to Soil Moisture Status and Length of the Growing Season

Temperature and soil moisture are, of course, related. Higher temperatures lead to increased plant evapotranspiration as well as evaporation of soil moisture. Decreased soil moisture leads to a shortening of the growing period, threatening plants more frequently with low moisture stress towards the end of the season. (Rosenzweig 2001; Stanford University 2009)

Rainfall is an important component of soil moisture status. However, the amount of rain falling at a time, infiltration potential, and temperature will all combine to influence the amount of water in the soil over the growing season and hence the amount of agricultural production possible. With increasing temperatures, even remaining within the normal bounds of rainfall variability can lead to exacerbated impacts of dry spells.

“Soil moisture changes do not always match precipitation changes. Increased heavy precipitation and reduced light to moderate rain can increase the runoff to precipitation ratio, and increases in surface air temperature and radiative heating can lead to higher atmospheric demand for moisture. These processes can result in drier soils even if the precipitation amount increases.” (Dai 2010)

2.5. Rainfall, Temperature and Livestock

Although it may seem like a statement of the obvious, to bring animals into the analysis we should note that there is *“a strong relationship between drought and animal death. Projected increased temperature and reduced precipitation in such regions as southern Africa will lead to increased loss of domestic herbivores during extreme events in drought-prone areas”* (Thornton et al., 2009)

2.6. Extreme Events: Heat Waves, Floods Droughts

The *IPCC Fourth Assessment Report* addressed whether there has been a change in extreme events like heat waves, droughts, floods and hurricanes. *“Since 1950, the number of heat waves has increased and widespread increases have occurred in the numbers of warm nights. The extent of regions affected by droughts has also increased as precipitation over land has marginally decreased while evaporation has increased due to warmer conditions. Generally, numbers of heavy daily precipitation events that lead to flooding have increased, but not everywhere.”* As evidence of the significant interest in extreme events – from their links to increase in global average temperatures to the desire to understand how their frequencies are changing – the IPCC is presently completing work on a Special Report on Extreme Events (IPCC SREX) to be published in November 2011.

Box 1: Selected extreme events in Africa since 2000.

2000: Successive tropical cyclones that struck Madagascar, Mozambique and southern Africa early in the year caused severe flooding which led to hundreds of casualties. The third consecutive year of below-normal rainfall in the greater Horn of Africa aggravated existing drought conditions over much of the area, resulting in severe food shortages. Tens of millions of people were affected; especially hard hit were Ethiopia, and parts of Djibouti, Eritrea, Kenya, Somalia and the United Republic of Tanzania.

2005: Long-term drought continued in parts of the Greater Horn of Africa, including southern Somalia, eastern Kenya, south-eastern Ethiopia, north-eastern United Republic of Tanzania and Djibouti, with 11 million people at risk of starvation.

2006: Heavy rains ended prolonged drought in Greater Horn of Africa, leading to worst flooding in October/November in 50 years.

2010: The Sahel region and West Africa were hit by extreme precipitation events. Niger, which had been gripped by prolonged drought, suffered devastation from flash floods in July. Hundreds of thousands were made homeless in Benin by flooding.

Source: World Meteorological Organization. (WMO 2010)

One question consistently posed to scientists, and a topic likely to be addressed in the SREX report, is whether we can attribute extreme events to climate change. The answer given in the vast majority of circumstances is two-fold:

- No single event can be attributed to changing climatic patterns, but
- We can make several predictions about future extreme events:
 - The magnitude, frequency, and duration of extreme events will likely be altered due to atmospheric warming, and
 - We can expect more powerful storms, and hotter, longer dry periods.

“It needs to be understood, however, that an individual cyclone or hot spell cannot be attributed to climate change. There have always been extremes in weather. Climate change deals with long-term trends, not individual events. In addition, we should bear in mind that monitoring, measurement and reporting arrangements have improved over time, which complicates identification of trends in these events, and so a longer period of data collection is required to improve our understanding of change. However, a directional long-term climatic trend (e.g., an increase in temperature) increases the probability that an extreme event (e.g., a heat wave) could occur. For example, the central European heat wave of 2003 that caused over 30,000 excess deaths was made about three times more likely by the underlying trend of increasing temperature” (Parliament of Australia, 2008)

As in this previous quote, many scientists talk in terms of probability – that while it is impossible to link a particular event with increased global average temperatures and climate change, we can talk specifically about the increasing probability of extreme events such as droughts, floods, or heat waves. One visual way to understand why the probability of temperature extremes increases is found below in figure 4.

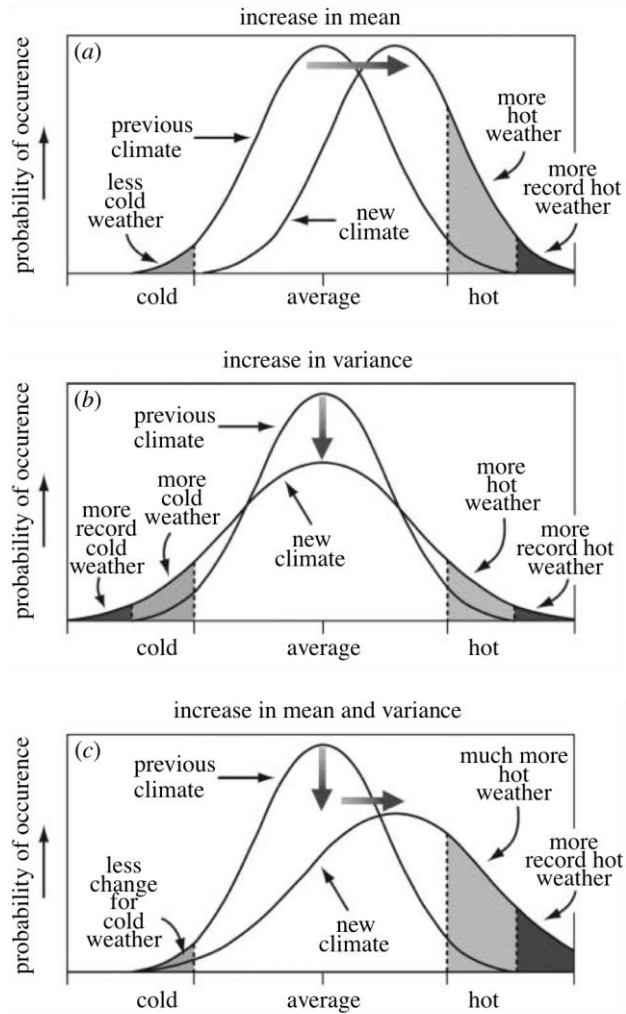


Figure 4: Postulated changes in the distribution of temperatures involving changes in their (a) mean, (b) variance and (c) both on the frequency of occurrence of extreme conditions
Source: Porter and Semenov (2005), adapted from Houghton et al. (2001)

3. CONSIDERING A GLOBAL GOAL

One of the central issues in UNFCCC negotiations surrounds the global goal for temperature increase. If indeed we are to limit increases in greenhouse gas emissions to a level that ensures food production is not threatened, what is that level? Negotiations have focused debate principally on the resulting temperature, rather than a particular atmospheric concentration. The Cancún Agreements identify a target of 2°C, with the possibility after review to strengthening the goal to 1.5°C. We present evidence in the following sections that a goal of 2°C will have serious impacts on agricultural production in Africa, as will 1.5°C, the average temperature rise expected by 2050.

3.1. Impacts at 0.74°C (now)

While keeping in mind that no single extreme event is easily linked to climate change, there are strong indications that two recent droughts in Africa – the Sahel drought in the 70s and 80s and the current Horn of Africa drought – are linked to a rise in sea surface temperatures. Sea surface temperatures are increasing as the overall temperature rises on the planet.

In his thorough review of drought under global warming, Dai (2010) concludes:

*“Recent surface warming has enhanced evaporative demand over land and contributed to the drying since the 1980s. Because a large part of the recent surface warming is attributed to human-induced GHG increases, we can conclude that anthropogenic GHG increases have contributed to the recent drying over land. Furthermore, **the increased GHGs likely have contributed to the warming in the Indian Ocean. ... which in turn have contributed to the drying in Africa.**”*

Drought in the Horn of Africa: a global-change-type drought. Perhaps because of the historical variability in rainfall and regular occurrence of droughts on the African continent, it is difficult to consider droughts of recent years as anything different than historical climatic patterns. However changing sea surface temperatures are altering precipitation patterns on continents. According to Giannini et al. (2008), *“African rainfall variability is primarily driven by changes in remote sea surface temperatures, rather than in local properties of the land surface itself.”*

Higher sea surface temperatures have led to changes in precipitation patterns so that rain now falls over the Indian Ocean rather than the Horn of Africa. Williams and Funk (2011) demonstrate that this altered regional precipitation pattern is linked with a steady decrease in the Horn’s long rains during the last three decades (35-45% below normal).

In Funk’s position with the USAID Famine Early Warning System he has been working to call attention to the problem for the last several years. In 2008, he and a co-author pointed out that *“oceanic warming seems to reduce onshore moisture transports while increasing continental atmospheric stability.”* They concluded that:

“warming in the central Indian Ocean disrupts onshore moisture transports, reducing continental rainfall. Thus, late 20th-century anthropogenic Indian Ocean warming has probably already produced societally dangerous climate change by creating drought and social disruption in some of the world’s most fragile food economies.”

Moreover, these researchers predict that the phenomenon will continue:

“Drier, rather than wetter conditions in the century ahead appear likely. The anthropogenic Indian Ocean warming response appears to be one of the most consistent and well-

understood responses to greenhouse gas emissions. This anthropogenic warming appears to have already significantly altered the earth's largest circulation feature and impacted its most food insecure inhabitants.” (Williams and Funk 2011)

While these conclusions run counter to the bulk of the IPCC models, scientists who study these sea surface temperature and land interactions increasingly agree that the models have not done a good job at this interface. Conway (2011), for example, notes that “*studies are appearing that suggest that even where there is climate model convergence, such as for wetter conditions during December-February in East Africa, that current trends and physical interpretation may be counter to IPCC multimodel projections.*”

Sea surface temperature changes and the Sahel drought. While many are reluctant to link the Horn of Africa drought with climate change, more than one group of researchers who specifically study sea surface temperature/land interactions in global climate models has made rather confident statements about the links that can be made between sea surface temperature rise and drying of continents, in particular Africa – both with respect to the Sahel drought of the 70s and 80s as well as the current drought in the Horn of Africa. For example Giannini et al. (2008) conclude:

“that anthropogenic forcings played a non-negligible role in the late twentieth century drying of the Sahel, although there is little doubt that a large fraction of the observed variations in Sahel rainfall was generated by natural SST [sea surface temperature] variability. A rough estimate suggests that the anthropogenic contribution is about 30% of the recent long-term drying trend.”

Other current observations documented in the scientific literature. There is a troubling dearth of data and expertise in Africa that can contribute to both increasing the accuracy of global circulation models and increasing seasonal and interannual predictive capacity for the benefit of farmers. The dearth of climate expertise means that few scientific papers have been published to date with data on recent climate trends in Africa. Two of these papers indicate the value that such research could have for understanding climate impacts and responses at the sub-regional level:

- West (2008), studying trends in Burkina Faso, documented a decrease in the number of big rains over the last thirty years as well as the accuracy of farmer perceptions compared to available climate data. Farmers now view drought as normal.
- New et al. (2006), working in southern Africa, documented a decrease in extreme cold days and an increase in extreme hot days. The data show that the average duration of hot days, as well as the diurnal temperature range, is increasing in Namibia, Botswana, Zambia, and Mozambique. Most precipitation indices did not exhibit significant trends, but there was an increase in daily rainfall intensity and the length of dry spells, as well as the annual 1-day maximum rainfall.

3.2. Near-term Impacts from 2020-2050 (1°C – 1.5°C)

“Food security [is] clearly threatened by climate change in the relatively near term.” (Lobell et al. 2008)

Several research groups have done significant work since AR4 looking at crop and livestock production in Africa, using new analytical approaches that couple historical crop production data with weather data, as well as regional climate modeling. The crop research highlighted below has been carried out principally by the Stanford University Program on Food Security and the

Environment, while the livestock research is led by a group at the International Livestock Research Institute in Kenya. Most important to keep in mind is the relation of predicted impacts in this temperature range and timeframe with the current international policy debates around a global goal of 2°C.

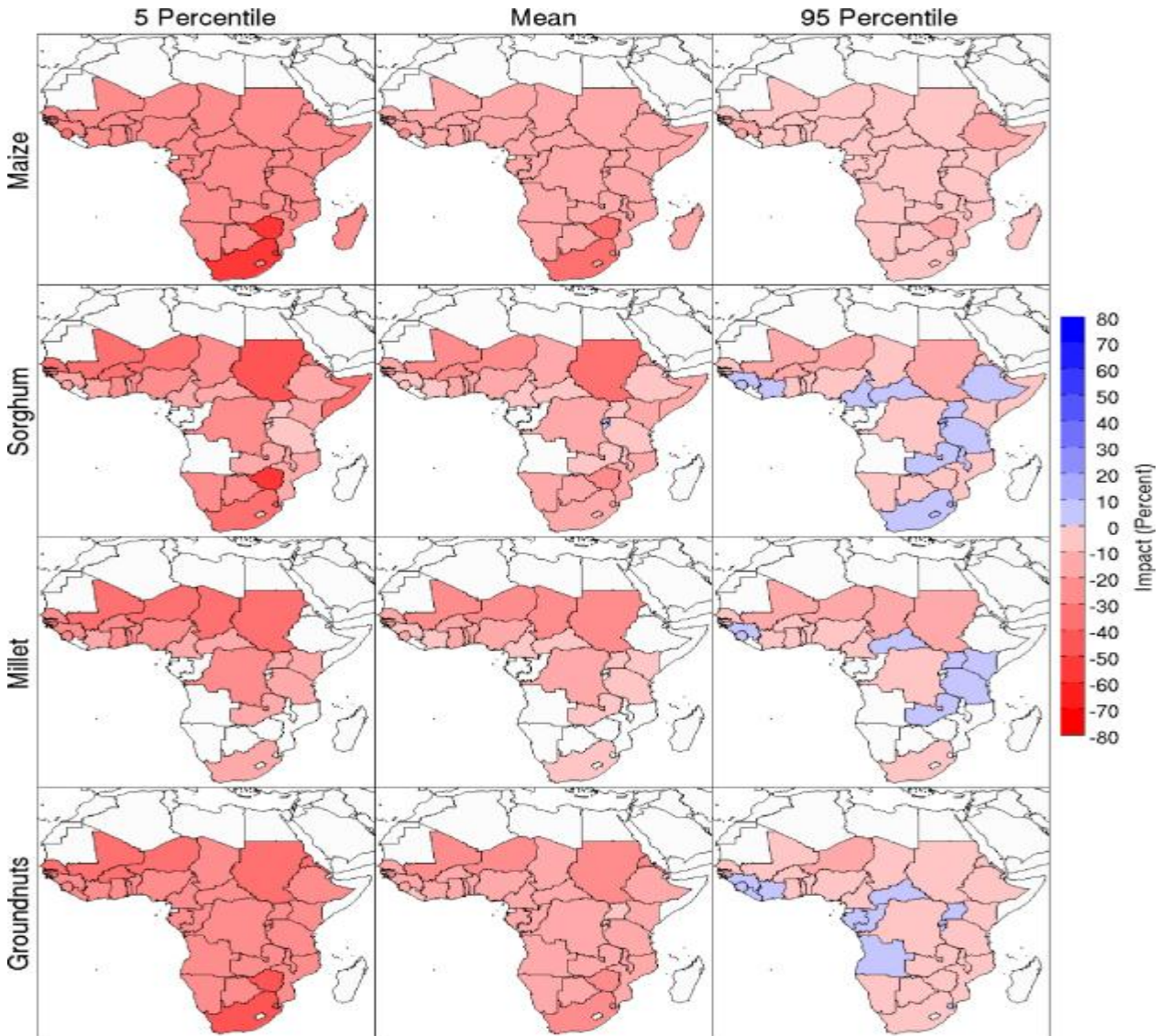


Figure 5: Distribution of impacts from climate change by country (per cent yield change) Mean impacts (middle column) as well as the 5 and 95 percentile (left and right column, respectively) are shown. Each row represents one crop.

Source: Schlemker and Lobell, 2010

Impacts by 2020 (1°C).

- With 1°C of warming, roughly 65% of current maize growing areas in Africa will experience yield losses under optimal rainfed conditions (assuming current management methods are maintained); under drought conditions, 75% of areas can expect yield declines of at least 20%. (Lobell et al. 2011)

Impacts by 2050 (1.5°C).

- Average (median) predicted production losses by 2050 for African crops: maize 22%, sorghum 17%, millet 17%, groundnut 18%, cassava 8%. In Africa, impacts will be most severely felt in southern African maize and Sahel sorghum. (Schlenker and Lobell 2010) These data confirm and add specificity to work done in the early 2000s by Jones and Thornton (2003) that showed crop yields falling by 10-20% by 2050.

-

High temperature stress (above 30°C) will be widespread in east and southern Africa. (Ericksen 2011) Hot spots by 2050 are “*mixed arid-semi-arid systems in the Sahel, arid-semi-arid rangeland systems in parts of eastern Africa, the coastal regions of eastern Africa, and many of the drier zones of southern Africa.*” Yields are expected to increase in highland areas, such as the southern Ethiopian highlands, central and western highlands of Kenya and the Great Lakes region. (Thornton et al. 2008)

4. KEY QUESTIONS FOR ADAPTATION

Changes to African agriculture under climate change will be significant. An increase in the variability of rains, coupled with increased temperatures, will mean agriculture becomes more risky than it is currently. Some agriculturalists will be able to adapt their production systems to continue to produce food, while many will be forced to seek other economic options and livelihood strategies.

Thornton et al. (2011) explore a range of adaptation strategies that should be considered by crop producers, pastoralists, and agropastoralists, noting that over time and with increasing temperatures, however, *“the options available for adaptation to climate change for SSA, whether domestic or foreign, are likely to decrease. What is unclear is at what point those options become too few for successful adaptation across a region.”*

Development of novel climates over much of the continent means a much-increased need for crop breeding – by both researchers and farmers – to adapt varieties to those climates.

Slow onset temperature rise is already having and will continue to have serious consequences for African farmers, as well as pastoralists. Considerations of loss and damage must include the significant and widespread impacts from slowly increasing temperatures on agricultural yields, regional and global food production, and the livelihoods of those dependent on agricultural production.

4.1. Changes in Agricultural Production Systems

Impacts on agricultural production will be diverse and widespread. One clear consequence of warming will be a change in regions where particular crops can be grown. This change will have impacts on all agricultural producers – smallholder and commercial farmers alike. Countries with significant export production will likely see dramatic changes in the size of their commercial sectors. In some regions shifts will be seen from crop production to livestock production. Pastoralists will see ranges reduced as precipitation patterns change.

Tea production is predicted to decline significantly in Uganda. Researchers at the International Center for Tropical Agriculture (CIAT 2011a) investigated the suitability of areas for tea production relative to predictions for future climates in the main tea growing areas of Uganda. According to their research, many districts will become unsuitable for tea production by 2050, including the districts of Kyejojo, Bundibugyo, Bushenyi, Kanungu, and Masaka. There will be limited areas where suitability for tea production increases, usually in areas currently protected as forests, at higher elevations.

“In 2020 suitable areas start decreasing quite seriously in most of Uganda’s current tea growing areas. ... In 2050 tea production according to its climate-suitability is predicted to disappear almost completely.” The mean annual temperature is expected to increase 2.1-2.3°C by 2050. (CIAT 2011a)

Suitability of land area for cocoa production in Ghana and the Côte d’Ivoire to fall dramatically. CIAT scientists have carried out similar research on cocoa-producing areas – investigating the suitability for cocoa production in future climates. Their results suggest that by 2030 declines in production will already be noticeable. By 2050, *“a rise of 2.3 degrees Celsius will drastically affect*

production in lowland regions, including the major cocoa-producing areas of Moyen-Comoe, Sud-Comoe and Agneby in Côte d'Ivoire, and Western and Brong Ahafo in Ghana. Farmers in these areas are particularly vulnerable since cocoa production is often their primary source of income.” (CIAT 2011b)

In contrast to the case of tea, where production could possibly be moved to higher altitudes, the cocoa industry in flat Ghana and Côte d'Ivoire does not have this option. Not only will small producers lose an important livelihood strategy, but the national governments dependent on foreign exchange earnings from cocoa will lose a significant source of revenue. Cocoa is responsible for 7.5% of GDP in Côte d'Ivoire and 3.4% in Ghana. (Lacey 2011)

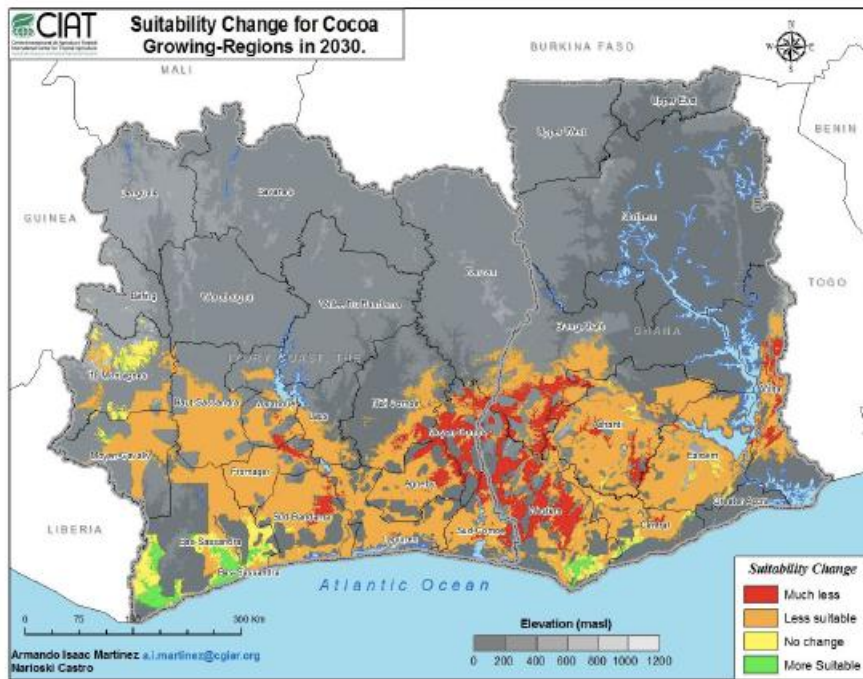


Figure 6: Suitability Changes for Cocoa Growing-Regions in 2030
 Source: CIAT, 2011b

In some areas there will be a transition from cropping to mixed and pastoral systems. Thornton et al. (2009) predict significant shifts from cropping to livestock in some areas.

“Parts of east and southern Africa are likely to see considerable shifts in cropping and livestock activities. Transitions are already occurring: in marginal areas of southern Africa, the reductions in length of growing period and the increased rainfall variability is driving systems to a conversion from a mixed crop-livestock system to a rangeland-based system.”

Writing about changes expected in Kenya, Herrero et al. (2010) reach similar conclusions about transitions in crop-livestock systems: *“Even under moderate greenhouse gas emission scenarios, the patterns of African cropping and livestock keeping will likely see substantial shifts by the middle of this century.”*

“Changes in the productivity of rainfed crops and forage, reduced water availability and more widespread water shortages, changing severity and distribution of important human, livestock and crop diseases” could lead to *“major changes in livestock systems, related to livestock species mixes, crop grown and feed resources and feeding strategies.”* (Thornton et al. 2009)

Pastoralists will be threatened by changing precipitation.

“Although pastoralists have developed resilient livelihood systems to deal with their harsh and unpredictable environment, the new dynamics introduced by global change will amplify potential impacts. The main factor in pastoral strategies, for example, is livestock mobility, i.e., moving herds to areas with better grazing conditions and securing access to critical resources during the dry season and in times of crisis. With climate change, the number, distribution and productivity of permanent pastures and water points, which are so critical for livestock survival during the dry season, are bound to decline.” (FAO 2010)

4.2. Breeding Challenges

Breeding challenges cannot be underestimated. The rapid development of novel climates and steady reduction in the length of growing seasons due to both an increase in temperature and a decrease in soil moisture will keep both professional breeders and farmer breeders in a Red Queen race, running as fast as they can just to stay in the same place. These efforts will require an enormous amount of international cooperation and financial support if we are to succeed at maintaining crop and livestock production in many areas of the continent.

Novel climates. As temperatures rise, they slowly move out of the range of historical variability. Researchers propose to collect genetic resources from areas where climates currently are analogues for future climates. These materials can then be used in breeding programs necessary to continue adapting crops to changes that will happen.

A key challenge for breeders will be to continue breeding towards unknown climates, keeping pace with climatic changes. Given the unknowability of the targets, and the pace of change – potentially quicker than is possible with breeding – it is not clear how successful these efforts can be over the long term.

Burke *et al.* (2009) look specifically at Africa’s three primary cereal crops – maize, millet and sorghum – across the continent to better understand future growing environments in order to direct breeding and crop variety conservation efforts. They find that the warmest recent temperatures are “*on average cooler than almost 9 out of 10 expected observations for 2050.*” The authors further note that “*the majority of African countries will have **novel** climates over at least half of their current crop area by 2050.*” (Burke *et al.* 2009, emphasis added)

“For temperature, nearly all crop regions move rapidly outside of historical experience. ... within two decades, growing season average temperature will be hotter than any year in historical experience for 4 years out of 10 for the majority of African maize area, growing to nearly 9 out of 10 by 2050. ... Similar results were obtained for millet [and] sorghum.” (Burke et al. 2009)

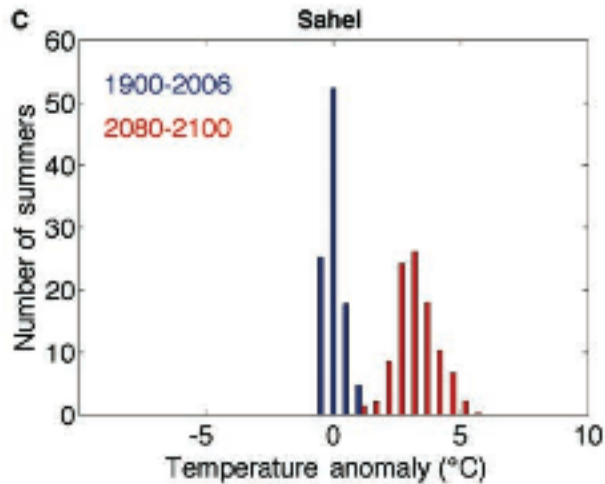


Figure 7: of summer (June, July, and August) averaged temperatures (blue) observed from 1900 to 2006 and (red) projected for 2090 for the Sahel

Source: Battisti and Naylor, 2009

Changes in the length of the growing period. The CGIAR (a consortium of agricultural research institutes) estimates that the length of the growing period (LGP) declines by 5% or more across southern and west Africa by 2050, while “*reliable crop growing days (a more discriminating indicator than LGP for rain-fed crops) decrease to critical levels, below which cropping might become too risky to pursue as a major livelihood strategy in west Africa and east Africa. ... High temperature stress (above 30°C) will be widespread in east and southern Africa.*” (Ericksen et al. 2011)

With increased evapotranspiration at higher temperatures soils will dry out more quickly, and because of reduced soil moisture “*the length of the growing period ... is anticipated to shorten in many regions, particularly Southern Africa, and the frequency of plants experiencing low moisture stress is expected to increase.*” (Stanford University 2009)

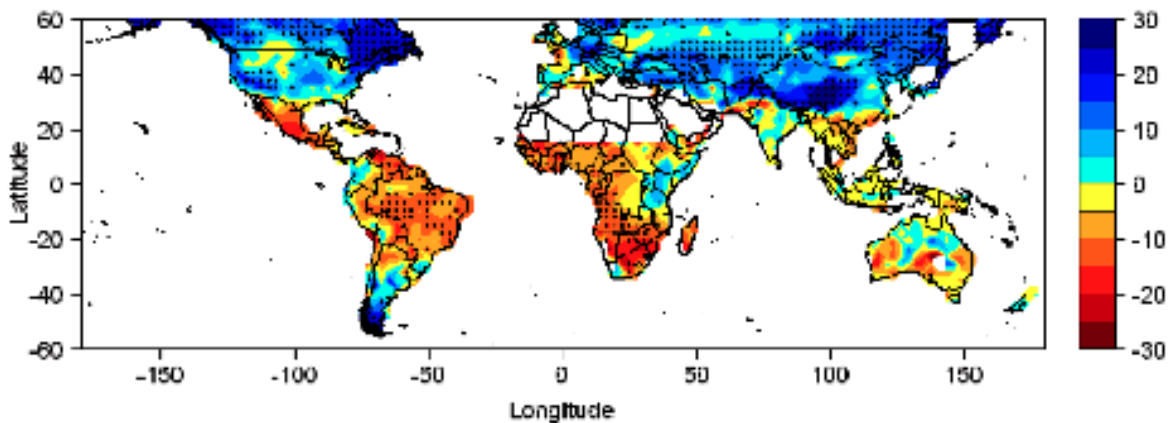


Figure 8: Simulated change in growing season length in 2050 relative to 1990, averaged across 12 climate models. Dots indicate where at least 10 of 12 models agree on the direction of change.

Source: Stanford University, 2009.

4.3. Loss and Damage – Slow Onset Temperature Rise

Discussions on loss and damage have often centered on rehabilitation efforts after extreme events – reacting and responding to the visually compelling images of destruction after floods and crop-searing drought. A more insidious, and ultimately more costly impact on African agriculture will occur through slow temperature rise, eventually displacing millions of pastoralists and farmers and severely reducing agricultural production on the continent.

Battisti and Naylor (2009) single out the Sahel to elaborate on the consequences of slow temperature rise (Figure 6 above). Year-to-year temperature variability in the Sahel is low, but growing temperatures are high; millet and sorghum yields are currently stagnant.

“Most worrisome for the Sahel is that average growing season temperatures by the end of this century, and even earlier for some parts of the region, are expected to exceed the hottest seasons recorded during the past century. ... New bounds of heat stress will make the region’s population far more vulnerable to poverty and hunger-related deaths and will likely drive many people out of agriculture altogether, thus expanding migrant and refugee populations.”

In the words of the authors: ***“Ignoring climate projections at this stage will only result in the worst form of triage.”*** (Battisti and Naylor 2009, emphasis added)

5. MITIGATION ACTION: THE AGRICULTURAL MITIGATION BURDEN LAYS WITH ANNEX I COUNTRIES

Any discussions of agricultural mitigation should start from an understanding of where emissions in the sector, and hence mitigation obligations, are located.

Annex I agricultural emissions dwarf emissions from Africa. Although human (and cattle) population size is roughly equivalent between the two groups of countries,¹ total Annex I emissions from main agricultural sources (fertilizer use and animal agriculture) are roughly two times the amount emitted in African countries, and emissions from Annex I animal agriculture three times larger (Smith, 2007; Steinfeld, 2006). We focus most of our analysis here on livestock emissions to illustrate the dramatic differences in emissions between African and Annex I countries.

Table 1: GHG emissions by main sources in the agriculture sector in sub-Saharan Africa and developed countries

Region		N ₂ O soils	CH ₄ enteric	CH ₄ , N ₂ O manure
Sub-Saharan Africa	Mt CO ₂ -eq/year	350	244	16
	% of source's world total	13	13	4
Middle East and North Africa	Mt CO ₂ -eq/year	101	41	3
	% of source's world total	4	2	1
Developed regions ²	Mt CO ₂ -eq/year	700	554	225
	% of source's world total	26	30	52

Source: Derived from Smith et al., 2007.

5.1. Nitrous Oxide and Methane Emissions from Agriculture

Nitrous oxide and methane emissions from fertilizer production and use and animal production make up the bulk of the emissions from the sector. Both gases have significantly more global warming potential than carbon dioxide, with one tonne of methane equivalent to approximately 26 tonnes of CO₂ and nitrous oxide equivalent to approximately 310 tonnes (Mitloehner et al., 2009).

Nitrous oxide. The most important sources of nitrous oxide emissions come from both the production and use of synthetic nitrogen fertilizers. Reduction in the use of synthetic fertilizers by

¹ The population of North and sub-Saharan Africa is approximately 1 billion; of the Annex I countries, 1.2 billion.

² Former Soviet Union, Central and Eastern Europe, Western Europe, OECD Pacific, OECD North America.

reliance on organic fertilizers through the use of compost and manure is a means of permanent emission reduction. Nitrous oxide is also emitted by manure as its nitrogen volatilizes (IPCC, 2006).

Methane. Livestock are a significant contributor to global methane emissions, particularly those reared in industrial confinement systems. The two principal sources of agricultural methane emissions are enteric fermentation and emissions from manure management. Manure emissions of methane from concentrated livestock operations that store animal waste in large lagoons are much greater than emissions from composted manure incorporated into soils, due to the anaerobic processes involved in decomposition in lagoons. *“These conditions often occur when large numbers of animals are managed in a confined area (e.g., dairy farms, beef feedlots, and swine and poultry farms) where manure is typically stored in large piles or disposed of in lagoons”* (IPCC, 2006).

Despite roughly similar number of cattle per capita and many more small ruminants in Africa than in the Annex I countries (see table 2 below), Smith et al. (2007) conclude that Annex I methane and nitrous oxide emissions from livestock are much greater than the emissions from African livestock (table 1 above). The differences are likely due to a combination of factors, including differences in manure handling (industrial lagoons vs. distributed decomposition) and differences in diet leading to increase in enteric fermentation of industrial livestock.

Table 2: Comparing animal populations in sub-Saharan Africa and Annex I countries

Animal		SSA	Annex I
Cattle	Population (in millions)	213	227
	Animals per capita	.35	.36 (U.S.)
Small ruminant	Population (in millions)	370	9
	Animals per capita	0.6	.03 (U.S.)

Source: Steinfeld 2006.

5.2. Mitigation Action: Emission Reduction vs. Sequestration

Mitigation in agriculture can be accomplished either through reducing emissions from the sector or by sequestration of gases already emitted somewhere else. Reducing or eliminating emissions is the preferred option, as those emission reductions are then permanent. Sequestration is necessarily impermanent, as gases are temporarily stored in agroforestry systems or soils and can be released easily with a change in practices.

Carbon sequestration in soils has been proposed as a mitigation option that should be considered by African countries. However, soil carbon sequestration does not permanently remove carbon dioxide from the atmosphere and thus any change in practices leading to reversal of carbon storage would continue to threaten African agriculture. Moreover, to the extent that soil carbon sequestration is incentivized by the reduction (offsetting) of Annex I emission obligations, the enabling of continued Annex 1 emissions will lead to further warming and further impacts on agricultural production on the continent.

6. WHAT ARE THE IMPLICATIONS OF THE NEW SCIENTIFIC DATA FOR UNFCCC NEGOTIATIONS?

The above information about the immediacy and severity of climate change impacts on African agriculture has bearing on a number of issues being negotiated within the UNFCCC framework:

- Shared vision and the global goal
- Enhanced action on adaptation
- Enhanced action on mitigation
- Means of implementation: finance, technology transfer and capacity building

6.1. Shared Vision: A Global Goal to Limit Average Global Temperature Increase

A global goal of anything beyond 1.5°C is untenable. In fact, given the substantial impacts on agricultural production in Africa expected for 1.5°C, this goal is difficult to justify either scientifically or from a policy perspective. *The African common negotiating position, of reaching and stabilizing at a temperature well below 1.5°C, is appropriate.*

6.2. Enhanced Action on Adaptation

Given the enormity of impacts on agriculture, action on adaptation in Africa is urgent. The scientific assessment of impacts detailed here provides an indication of the short-, medium- and long-term adaptation needs on the continent, needs that must be addressed immediately through the institutions of the UNFCCC and other relevant UN bodies.

Adaptation Committee. The Adaptation Committee, established in the Cancún Agreements, should immediately take up the issue of agriculture. The COP should decide to establish a work programme on agriculture, under the guidance of the Adaptation Committee, similar to the ongoing work programme on loss and damage under the SBI.

Adaptation finance. Substantial funding for agricultural adaptation must be forthcoming, through the Adaptation Fund, the Green Climate Fund and other mechanisms. As the majority of countries on the African continent are LDCs, the responsibility of Annex I countries to provide funding is clear.

African governments must carefully assess the costs of adaptation. The investments needed are significant (as noted also in later sections on technology transfer and capacity building) – in meteorological capacity, early warning systems, breeding and extension, farmer-to-farmer information transfer. World Bank and others have provided estimates of global need, but governments need to ground-truth these global figures based on possible worst-case scenarios and the more detailed information presented here, and what effort is needed at national and regional levels to deal with those impacts. The costs are clearly substantial, but working with real numbers from a national assessment is preferable to using externally generated estimates.

Work programme on loss and damage. A work programme on loss and damage was established under the Cancún Adaptation Framework. Included in the mandate for the work programme are loss and damage due to *extreme events* and to *slow onset temperature rise*, both key threats posed to agricultural production and food security by climate change. Several components could be included

in the work programme as means to provide more data about impacts on agriculture to inform negotiations:

- A technical paper on projected impacts of slow onset temperature rise on agricultural yields, food production regionally and globally, and livelihoods of those dependent on agricultural production.
- Establishment by the UNFCCC regime of more formal relationships with the FAO, CGIAR CCAFS, and the WMO to monitor and inform negotiators of the latest science and the developing crises in agriculture due to climate change impacts.
- An expert meeting, co-organized with FAO, CGIAR CCAFS, and WMO, to identify scientific, technical, data collection and systematic observation gaps and needs regarding slow onset temperature rise and impacts on agriculture.

6.3. Enhanced Action on Mitigation [relevant to both KP and LCA negotiations]

Given the immense threat to agriculture in Africa from climate change, in the context of the objective of the Convention to ensure that food production is not threatened, the priority for mitigation action must fall on Annex I countries to reduce emissions urgently and immediately. Moreover, it makes little sense for African countries to focus on mitigation burdens in the sector given the overriding priority of, and threat to, food security and rural development.

Mitigation commitments by Annex I Parties. The continued emissions from Annex I countries increases risks to African agriculture with every tonne of CO₂ emitted. Given that even a temperature increase of 1.5°C is likely to have serious impacts on agricultural production on the continent, there is no option but rapid and significant emission reductions to ensure temperature rise remains well below 1.5°C.

As offsets allow continued emissions from Annex I Parties, this policy option should be used only in extremely limited circumstances if at all. The vast bulk of emission reductions must come from domestic efforts in developed countries, and offsets within the domestic context provide greater environmental integrity.

Offsets should not be considered a substantial source of climate finance, as dependence of finance on offsets requires continued emissions. While some monetary benefits derived from offsets may be appealing in the short run, in the long run, this is highly problematic.

For example, proposals exist to provide adaptation finance to African countries through soil carbon offsets. Concrete text proposals in the AWG-KP would modify existing CDM rules to expand eligibility to such projects, using discount factors to attempt to address fatal problems of permanence, leakage and additionality. Such proposals undermine the long-term potential to reduce global emissions and thus protect the African agriculture sector and should be rejected.

Cooperative sectoral approaches and sector-specific actions (under Article 4.1(c) and Bali Action Plan 1.b.iv). A facilitator's note on cooperative sectoral approaches currently exists. Given the need for action on agriculture to first and foremost address adaptation, the framing under convention Article 4.1(c) makes the text and discussion problematically focused on mitigation. The path within the negotiations has been to expand the scope of the text, by including provisions related to adaptation. Most recently, some have proposed to try to expand the scope of this particular note to Articles 4.1(d) and (e) as well.

However, given all the difficulties experienced with negotiations to date under 4.1(c) (lasting since well before COP15), other approaches to address agriculture within the UNFCCC framework should be pursued. The most logical home for negotiations on adaptation and agriculture is the Adaptation Committee, once formed, as recommended by AMCEN.

Two general and overarching considerations regarding agriculture and mitigation.

- Africa's agriculture produces a fraction of the greenhouse gas emissions produced by developed country agriculture. Mitigation must remain a secondary concern of African governments, with emphasis given to adaptation.
- Offsets for mitigation through carbon sequestration in soils will not contribute to permanent emission reductions, and thereby further threaten developing country agriculture.

6.4. Means of Implementation

Adaptation can only be carried out with sufficient provision of financial resources, as well as transfer and sharing of relevant technologies and practices and building of indigenous capacity to address the broad range of impacts at levels from local to national.

Finance. As noted above, African governments should carefully assess costs of *adaptation* as a concrete tool for their negotiations on finance. The following discussions on technology transfer and capacity building provide guidance for areas where assessment is necessary, and the types of initiatives and expenses to include in such assessment.

Technology transfer. Adaptation must be a key priority for technology transfer. However single technologies will not be as useful as packages of practices and the efforts to disseminate those practices. Sharing of technologies and practices between and among African countries and other non-Annex I countries with similar climates will be more important than technologies that might be provided by countries with substantially different agricultural systems and climates. For further discussion, see the section below on capacity building.

Intellectual property rights on plant and animal varieties will be a stumbling block to the breeding efforts necessary for agriculture to keep pace with changing climates. An opposition to patents on any life forms is warranted in this regard, but at a minimum compulsory licensing to governments of patented varieties in Africa should be used to make climate-adapted crop varieties and animal breeds freely accessible.

There is likely to be pressure to accept GMOs as necessary for addressing impacts of climate change. A review of scientific literature (not carried out within this report) leads to an opposite conclusion – that the technology of genetic engineering based on single genes for specific stresses is inappropriate for the complex challenges in low-input systems of slow onset temperature rise, global-change-type drought, and extreme heat and precipitation events that farming systems may experience all in a single cropping season.

Capacity building. Agricultural challenges over the coming decades clearly necessitate additional support for capacity building at many levels. Governments should include an assessment of capacity-building needs in their agriculture sectors as part of their overall consideration of capacity

as well as financial resources needed to build that capacity. Such capacity could include, but is certainly not limited to:

- Capacity in meteorological sector, for early warning systems, data collection and interpretation. Early warning systems can provide seasonal rainfall information that can be useful to farmers in their planting decisions.
- Capacity to communicate seasonal weather information and possible responses with farmers. Meteorological information is of little value if there are not dissemination systems in place to communicate with farmers and pastoralists in rural areas.
- Breeding and seed multiplication capacity – climate-change-focused breeding programs, farmer-breeder linkages, seed multiplication systems at the local level are all necessary. As climates rapidly change, it will be difficult to keep pace with breeding for novel climates. Local, regional, national, and African-wide systems of breeding and seed exchange are urgently needed.
- Systems for sharing of traditional and contemporary practices for soil building and water harvesting/management. Many climate-resilient agricultural practices are in use across the African continent, but these must be disseminated more widely. Capacity in farmer-to-farmer knowledge sharing will be key to this effort.

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