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Climate Change Impacts on Agriculture across Africa

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Summary and Keywords

Confidence in the projected impacts of climate change on agricultural systems has increased substantially since the first Intergovernmental Panel on Climate Change (IPCC) reports. In Africa, much work has gone into downscaling global climate models to understand regional impacts, but there remains a dearth of local level understanding of impacts and communities' capacity to adapt. It is well understood that Africa is vulnerable to climate change, not only because of its high exposure to climate change, but also because many African communities lack the capacity to respond or adapt to the impacts of climate change. Warming trends have already become evident across the continent, and it is likely that the continent's 2000 mean annual temperature change will exceed +2°C by 2100. Added to this warming trend, changes in precipitation patterns are also of concern: Even if rainfall remains constant, due to increasing temperatures, existing water stress will be amplified, putting even more pressure on agricultural systems, especially in semiarid areas. In general, high temperatures and changes in rainfall patterns are likely to reduce cereal crop productivity, and new evidence is emerging that high-value perennial crops will also be negatively impacted by rising temperatures. Pressures from pests, weeds, and diseases are also expected to increase, with detrimental effects on crops and livestock.

Much of African agriculture's vulnerability to climate change lies in the fact that its agricultural systems remain largely rain-fed and underdeveloped, as the majority of Africa's farmers are small-scale farmers with few financial resources, limited access to infrastructure, and disparate access to information. At the same time, as these systems are highly reliant on their environment, and farmers are dependent on farming for their livelihoods, their diversity, context specificity, and the existence of generations of traditional knowledge offer elements of resilience in the face of climate change. Overall, however, the combination of climatic and nonclimatic drivers and stressors will exacerbate the vulnerability of Africa's agricultural systems to climate change, but the impacts will not be universally felt. Climate change will impact farmers and their agricultural systems in different ways, and adapting to these impacts will need to be context-specific.

Current adaptation efforts on the continent are increasing across the continent, but it is expected that in the long term these will be insufficient in enabling communities to cope with the changes due to longer-term climate change. African famers are increasingly adopting a variety of conservation and agroecological practices such as agroforestry, contouring, terracing, mulching, and no-till. These practices have the twin benefits of lowering carbon emissions while adapting to climate change as well as broadening the sources of livelihoods for poor farmers, but there are constraints to their widespread adoption. These challenges vary from insecure land tenure to difficulties with knowledge-sharing.

While African agriculture faces exposure to climate change as well as broader socioeconomic and political challenges, many of its diverse agricultural systems remain resilient. As the continent with the highest population growth rate, rapid urbanization trends, and rising GDP in many countries, Africa's agricultural systems will need to become adaptive to more than just climate change as the uncertainties of the 21st century unfold.

Keywords: climate change, agriculture, Africa, adaptation

African Agricultural Systems

Sub-Saharan Africa is a rapidly developing region with a population of about 900 million, with wide ecological, climatic, and cultural diversity (CDKN, 2014). Africa has six of the ten fastest growing countries' economies in the world, but as growth in these economies started from a relatively low base, the current rate of economic growth needs to be seen against a background of three decades of poor development, conflict, and economic marginalization; it is critical to recognize that Africa's growth story needs to be nuanced and context specific (Barton & Leke, 2016). Economically, many Africans depend for food, fiber, and income on primary sectors such as agriculture and fisheries, and some of Africa's vulnerability to climate change lies in the fact that its recent development gains have been in these exact climate-sensitive sectors that continue to be affected by increasing temperatures, rising sea levels, and increasingly variable rainfall (CDKN, 2014).

Agriculture is an extremely important sector on the African continent, on average accounting for 70 percent of the labor force and over 25 percent of GDP (UNECA, 2009).

Despite this importance, it has been relatively low on the political agenda, with the poststructural adjustment era resulting in a legacy of policy failures and little investment by either public or private sector (UNECA, 2009; Hoeffler, 2011). In sub-Saharan Africa in general, stagnant agricultural yields, relative to the region's population growth, have led to a fall in per capita food availability since the 1970s (Niang et al., 2014). Although agricultural production improved during 2000–2010, most of this improvement was the result of countries recovering from the poor performance of the 1980s and 1990s, along with high domestic prices (Nin-pratt et al., 2012). However, in order to meet food security and nutrition requirements for a growing population on the continent, as well as fulfill the targets of the Sustainable Development Goals (SDGs), improving the economic performance of the agricultural sector is of vital importance.

Climate change adds a layer of complexity to this challenge. Africa is one of the continents that is most highly affected by climate change for two reasons: its geographical characteristics of having a majority of land lying across the warming tropics, and the limited human, social and economic capacity that African countries have to adapt to the impacts of climate change (Leal Filho et al., 2015). Demographic and economic trends in Africa mean that climate impacts will be intensified; for example, growing populations will increase the demand for water and food, but prolonged extreme events such as droughts will put additional pressure on already scarce water resources and will reduce crop yields (CDKN, 2014). Already the region suffers from recurring risks to food production, and without adequate measures to adapt, these risks could become more intense under a changing climate; for scenarios approaching 4°C warming, the risk to food security in Africa would be extremely severe, with limited potential for reducing risk through adaptation (Niang et al., 2014). African women are especially vulnerable to the impacts of climate change because they shoulder an enormous, but imprecisely recorded, burden of responsibility for subsistence agriculture, whose productivity can be expected to be adversely affected by climate change and overexploited soil (Viatte et al., 2009).

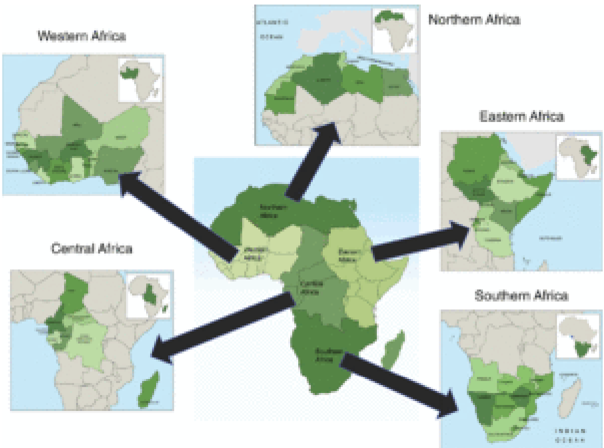
Much of African agriculture's vulnerability to climate change lies in the fact that its agricultural systems remain largely rain-fed, with few technological inputs, as the majority of Africa's farmers work on a small-scale or subsistence level and have few financial resources, limited access to infrastructure, and disparate access to information. Persistent poverty and socioeconomic inequality, low levels of development, limited economic capacity as well as governance challenges have further contributed to the continent's limited capacity to adapt to climate change (Shackleton et al., 2015). New risks from climate change are expected to have major negative impacts on agriculture, fisheries, and food security across the region and feedback into development, thereby undermining any progress that has been made to deal with poverty and inequality (Shackleton et al., 2015).

This article describes the latest state of knowledge on climate change impacts on agriculture in Africa. It begins by providing an overview of the projected changes in temperature and precipitation on the continent, across the various regions. It then describes the estimated impacts (both positive and negative) of these climatic changes and variability on agricultural production of crops and livestock, also referring to the impact of climate change on the spread of pests, weeds, and diseases. The final section discusses some adaptation options that have been proposed to limit the negative effects of climate change on the agricultural sector in Africa.

Projected Climate Change Impacts

Climate change has a significant impact on agricultural systems as it affects both plant and animal health. Increased temperatures, especially in the number of extreme hot days, as well as changes in precipitation, are the main climatic variables affecting agriculture on the African continent. Although some uncertainty remains in terms of the direction of climatic changes that Africa will face, especially with regard to precipitation projections, confidence in the projected impacts of climate change on agricultural systems has increased substantially since the initial Intergovernmental Panel on Climate Change (IPCC) reports. The IPCC's fourth assessment report (IPCC, 2007) presented 23 general circulation models of climate (GCMs), but the underlying data used to generate information are so highly aggregated to be applicable at the global level that they are difficult to use in projecting regional climate (Ziervogel et al., 2008). However, growing recognition of the need for climate information at finer scales has driven work aimed at downscaling global climate model information for local and regional decision makers; these are regional climate models (RCMs) (Ziervogel et al., 2008). The Climate System Analysis Group (CSAG) at the University of Cape Town operates the longest-standing empirical downscaled output for Africa; other dynamic downscaling techniques are also employed (WRF, Darlam, and PRECIS), although these are computationally and technically expensive, thereby limiting the number of institutions that can afford to employ the approach (Ziervogel et al., 2008). The Coordinated Downscaling Experiment (CORDEX[1]) of the World Climate Research Programme (WCRP), is aiming to overcome these capacity challenges and is being employed on the African continent to improve understanding of the differential climate variability experienced between regions (see Engelbrecht et al., 2015).

As the African continent is large and diverse, second only to Asia in size and population, its regional climate change trends and impacts are more relevant for decision making. Although there are still severe data shortages for some areas on the continent, especially in the Sahel and some parts of central Africa, our knowledge of regional impacts of climate change has improved: there are now more regional climate models available. In the section describing the projected climate change impacts for Africa, reference is made to specific regions shown in the accompanying map (Fig. 1).



Click to view larger

Figure 1. Map of Africa showing regions and countries

(Source: Constructed from African Development Bank maps: http://www.afdb.org/en/countries/).

These regions partly correspond and incorporate the seven African "communities" of nations and peoples used in the IPCC's Fifth Assessment report; namely, the Southern African Development Community (SADC) (Southern Africa), the Economic Community of Central African States (ECCAS) (Central Africa), the East African Community (EAC) (Eastern Africa), the Economic Community of West African States (ECOWAS) (Western Africa), the Arab-Maghreb Union (AMU) (North Africa), and the Community of Sahel-Saharan States (CEN-SAD) (consisting of all western and northern African countries except Algeria, Cape Verde, and the Western Sahara, and includes Chad, Central African Republic, Sudan, Kenya, Eritrea, Djibouti, Somalia, Comoros and São Tomé and Principe). Sub-Saharan Africa refers to all African countries, excluding those in North Africa.

Temperature Impacts

Over the last century, temperatures across the continent have increased by 0.5°C or more, with minimum temperatures rising faster than maximum temperatures (Niang et al., 2014). Most regions within Africa for which data are available have recorded an increase in the number of extreme temperatures (Seneviratne et al., 2012), and there is high confidence that heat waves will last longer, resulting in more persistent hot days approaching the year 2100 (Niang et al., 2014). Subtropical southern and northern Africa have seen temperature rises on the order of twice the global rate of temperature increase —with the most significant warming in southern Africa having been experienced in the last two decades. Models project further temperature increases for the rest of the century (James & Washington, 2013; Niang et al., 2014; Engelbrecht et al., 2015). Similar increases in seasonal mean temperature in areas of Ethiopia, Kenya, South Sudan, and Uganda have been observed over the last 50 years, and extreme warm events in countries bordering the western Indian Ocean have increased in frequency (Niang et al., 2014).

The warming trend experienced toward the end of the 20th century is expected to continue into the future if significant mitigation of climate change is not undertaken. For example, for the period 2071–2100 relative to 1971–2000, temperature increases of 4–6°C are likely to occur in the African subtropics under low mitigation futures (see Box 1), with somewhat smaller increases projected for the tropics (James & Washington, 2013; Engelbrecht et al., 2015). These increases are projected to be associated with drastic increases in the frequency of extreme temperature events such as very hot days (when the maximum temperature exceeds 35°C), heat waves, and high fire-danger days (Vizy & Cook, 2012; Niang et al., 2014; Engelbrecht et al., 2015). High mitigation futures (RCP 2.6) show less drastic temperature increases, with mean temperature changes staying below 2°C for the 21st century (Niang et al., 2014).

The Sahel and tropical West Africa are hotspots of climate change under both RCP4.5 and RCP8.5 pathways, and it is expected that unprecedented climates will occur earliest in these regions; because of the small natural variability in climate that the region currently experiences, even a slight change in climate will surpass existing experiences (Mora et al., 2013; Diffenbaugh & Giorgi, 2012). For both SRES A2 and A1B scenarios as well as RCP 4.5 and RCP 8.5, these climatic changes are expected to manifest as temperature increases between 3°C and 6°C by 2100, and regional downscaled models produce a similar range of projected change (Niang et al., 2014). Projected maximum and minimum temperatures in equatorial eastern Africa show a significant increase in the number of days warmer than 2°C above the 1981–2000 average by 2050 (Anyah & Qiu, 2012), whereas Ethiopia shows a warming in all seasons, which may cause more frequent heat waves (Conway & Schipper, 2011). In southern Africa, mean land-surface warming is expected to exceed the global mean across all seasons, with high warming rates projected especially for Botswana, Namibia, and the areas of South Africa that border these countries (James & Washington, 2013; Engelbrecht et al., 2009).

For the African region in particular, a high mitigation scenario (see Box 1) could reduce the possibility of rapid regional temperature increases and its consequent impacts.

Temperature anomalies toward the end of the century are projected to exceed 6°C over large parts of the African subtropics under RCP8.5, with general temperature increases as large as 4°C in this low-mitigation scenario. But in the modest- to high-mitigation scenarios, temperature anomalies are on the order of 3–4°C (for RCP4.5), and general temperature increases are reduced to about 2°C (Engelbrecht et al., 2015, Box 1).

Box 1: Uncertainty and scenarios

In terms of climate change models, Hawkins and Sutton (2009) provide a good overview of uncertainty, noting three sources: the internal variability of the climate system (i.e., natural climate fluctuations without radiative forcing— the cumulative measure of human emissions of greenhouse gases (GHGs) measured in Watts/m^2); model uncertainty (how different models simulate different changes in climate in response to the same radiative forcing); and scenario uncertainty (the uncertainty of future emissions, resulting in uncertainty in future radiative forcing). They show that over small spatial scales and shorter timescales (10–20 years), internal variability contributes the most to uncertainty, but that over many decades and over regional and larger scales, model and scenario uncertainty are the dominant sources of uncertainty (Hawkins & Sutton, 2009). It is uncertainty of the latter category that has implications for understanding climate impacts on agriculture and climate change adaptation.

Although it is known that specific models are better at predicting specific parameters in certain regions, choosing a single model is not advisable owing to the high level of uncertainty in modeling climate change. Rather, an “ensemble” of models is acknowledged as the best way of addressing the uncertainty inherent in making decisions influenced by future climate (Ziervogel et al., 2008; Frame et al., 2007). Ensemble forecasts of alternatives can inform decisions, but climate modeling also contains the “what if” of the changing parameter value of greenhouse gases (GHG) that will be emitted into the atmosphere over time. This is where the IPCC has developed various emissions scenarios based on different driving forces of future emissions. The SRES (Special Report on Emissions Scenarios) scenarios were those used by the IPCC until the fourth Assessment report, and these four narratives (A1, A2, B1, and B2) cover different demographic and technological futures, that is, a fossil-fuel intensive future (A1F1 scenario) versus a predominantly non-fossil-fuel future (A1T) (see IPCC, 2000). For the Fifth Assessment report of the IPCC, new scenarios, the Representative Concentration Pathways (RCPs) were developed. Each pathway represents a set of internally consistent socioeconomic assumptions that result in four levels of radiative forcing: RCP 8.5, RCP6, RCP4.5, and RCP2.6 (see Moss et al., 2008). Hence, RCP 8.5 (the pathway with the highest (8.5) radiative forcing) shows a world with little to no mitigation and an increase in fossil fuels, whereas RCP4.5 assumes continued global development that shifts toward service industries but does not aim to reduce GHG emissions and is similar to SRES scenario B1 (see Table 1). When referring to “low-mitigation futures,” modelers are usually referring to an RCP8.5 or RCP6 world or SRES A1F1 and A2.

Table 1: Project change in global mean surface temperature and global mean sea-level rise for the mid- and late 21st century relative to the reference period of 1986–2005 (*Source*: IPCC, 2013, p. 23).

		2046–2065	**2081–2100**
	Scenario	**Mean and Likely Range**	**Mean and Likely Range**
Global Mean Surface Temperature Change (°C)	RCP 2.6	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.7)
	RCP 4.5	1.4 (0.9 to 2.0)	1.8 (1.1. to 2.6)
	RCP 6.0	1.3 (0.8 to 1.8)	2.2 (1.4 to 3.1)

Rainfall

Precipitation projections for Africa are less certain than the corresponding temperature futures. This is especially due to a lack of observational data and discrepancies between different observed precipitation datasets (Niang et al., 2014). Where there are sufficient data, these show likely decreases in annual precipitation during the 1900s in parts of the western and eastern Sahel region in North Africa, with increases over parts of eastern and southern Africa (Niang et al., 2014). Rainfall has decreased over eastern Africa between March and May/June, probably due to rapid warming of the Indian Ocean, which has resulted in increased precipitation over the ocean and less rainfall on land (Williams & Funk, 2011). As well as modest downward trends in rainfall for Botswana, Zimbabwe, and western South Africa, intraseasonal characteristics, such as the onset, duration, and intensity of rainfall, have changed (Niang et al., 2014). In southern Africa over the period 1961–2000, an increasing frequency of dry spells has been accompanied by an increase in the intensity of daily rainfall, which has implications for run-off (New et al., 2006).

In general, precipitation projections suggest a trend toward wetter tropical regions and drier subtropical regions (James & Washington, 2013). Northern Africa is expected to experience a drier future in both global and regional projections under modest to high warming scenarios, with significant decreases in winter and spring rainfall in the northern basin of Tunisia that is the rainiest part of the country (Bargaoui et al., 2014;

Niang et al., 2014). Downscaled projections indicate drier conditions in southwestern South Africa, but wetter conditions in southeast South Africa during austral summer, although there is a potential delay in the onset of the rainfall season during austral spring (Engelbrecht et al., 2009; James & Washington, 2013; Niang et al., 2014). Central Africa might be expected to see the greatest enhancement in precipitation; however, projected changes are small in comparison to eastern Africa as the area already receives relatively high rainfall (James & Washington, 2013). Projections for eastern Africa show a generally wetter future climate, with more intense rainfall during the wet seasons and less severe droughts, which indicates a reversal of the historical drying trend in the region (Niang et al., 2014; Shongwe et al., 2011). However, GCM projections over Ethiopia indicate a wide range of changes, and in some instances projections do not even agree on the direction of the change in precipitation (i.e., increase or decrease) in areas such as the upper Blue Nile basin late in the 21st century (Conway & Schipper, 2011). Although somewhat counterintuitive, particularly in the subtropics, precipitation is projected to be concentrated into more intense events, with longer periods of little precipitation and increased evapotranspiration (Meehl et al., 2007). A mixed signal of rainfall increases and decreases is also present in the projections for western Africa and the Sahel; that is, there are large uncertainties surrounding the projected rainfall futures in this region (Niang et al., 2014). These regional studies indicate the importance of resolving discrepancies in regional scale atmospheric processes and incorporating local effects on rainfall simulation across the continent, if the data are to be useful for decision making (Niang et al., 2014).

In terms of extreme events, regional model studies suggest an increase in the number of extreme rainfall days (days experiencing rainfall near the upper end of observed values) over western Africa and the Sahel during May and July, and more intense and more frequent occurrences of extreme rainfall over the Guinea Highlands and Cameroon Mountains (Niang et al., 2014; Vizy & Cook, 2012). Extreme precipitation events over eastern Africa, including droughts and heavy rainfall, have been experienced more frequently during the last 30 to 60 years, and projections of general rainfall increases over eastern Africa also indicate an expected increase in large-scale flood events (Seneviratne et al., 2012; Niang et al., 2014; Shongwe et al., 2011; Williams & Funk, 2011). Over southern Africa, an increase in extreme warm indices (very hot days, hot nights, hottest days) and a decrease in extreme cold indices in recent decades is consistent with the general warming trend. There is a greater likelihood of heat waves associated with reduced rainfall conditions that tend to occur during (but are not limited to) El Niño events (Niang et al., 2014; New et al., 2006). In the near- to long-term future, southern Africa, and especially the southwestern regions, are at a high risk of severe droughts and a higher frequency of dry spells (Shongwe et al., 2011; Engelbrecht et al., 2015; Niang et al., 2014).

Diverse Impacts on Agriculture

In addition to appropriate farming practices, agriculture is dependent on biophysical characteristics such as soil type and fertility, water and temperature. In the mainly rain-fed agricultural systems in Africa, the prevailing climate is responsible for providing sufficient rainfall for plants as well as ensuring that temperatures remain within the bounds required by certain crops. For example, maize is a warm weather crop and grows optimally with mean daily temperatures above 15°C (but not exceeding 45°C) and is easily killed by frost (FAO Water, 2016). Tuber growth in potatoes is severely limited below 10°C and above 30°C (FAO Water, 2016). Climate also plays an important role in livestock farming as conditions influence the growth of forage, the availability of water for the animals, and conditions such as heat stress (Thornton et al., 2009). Furthermore, under current projections, existing water stress will be amplified, putting even more pressure on already stressed agricultural systems, especially in semiarid areas (Niang et al., 2014). Below are some key findings on the potential impacts of climate change on agriculture, although these should not be seen as predictions but rather as indicators of trends as the modeling of climate impacts on crops and livestock is a highly uncertain process (see Box 2).

Box 2. A brief introduction to climate-crop models

One of the most widely used tools for assessing the relationship between climate change and food production are climate crop models. These aim to assess the relationship between climate variables and crop production or yield and can therefore be used to project possible future crop systems under different scenarios. In their simplest form, climate crop models involve a climate model, which produces the climate input variables (temperature and precipitation) for a crop model that defines the relationship of these inputs with the final output of crop yield or production within a set of parameters (see Pereira, 2012). However, the first major challenge is that climate models and crop models were designed separately and function at different scales. This can lead to scale mismatch. On one hand, traditional crop models were originally designed for use at the field level, at a high spatial resolution where many input variables and parameters are known, or they can be directly measured, making the crop model very specific. On the other hand, climate models focus mainly on the global and sometimes at the regional scale. This disparity can either be ignored and dealt with through postprocessing or solved through downscaling, but in both cases it means that the traditional suite of crop models for field-scale simulations are not all suitable for regional climate crop projections under climate change, and so models with low-input data must be designed or selected for (Challinor et al., 2009).

There are two main types of climate crop models (Tubiello & Ewert, 2002). (1) Statistical models are used to predict large-scale agricultural yields from regression analyses based on monthly or annual variables (e.g., Lobell et al., 2008). However, they have no power to explain why certain changes have occurred. This led to the development of (2) process-oriented regional-scale (large-area) models. These stem from process-based models that are designed to compute crop dynamics at smaller spatial scales (e.g., the leaf or canopy level) and are based on deterministic equations and simulation of underlying processes at timescales of minutes to days (Tubiello & Ewert, 2002).

As well as having to deal with the problem of scale mismatch between climate and crop models, the levels of uncertainty within the models themselves as well as the scenarios being modeled mean that in order to paint a realistic picture of possible future projections, this uncertainty needs to be accounted for. This has led to the development of multiple climate simulations (or ensembles) that can be used to sample the inherent uncertainties in the modeling process (e.g., Lobell et al., 2008; Tao et al., 2009). Although the ensembles are usually run to account for differences within climate models, the response of crops to any projected climate also contains uncertainties. Inputs (e.g., planting date and variety) can also be varied to create an ensemble (Challinor et al., 2009).

Many model-based predictions of climate change across Africa exist, the results of which vary across a considerable range owing to the problems listed above. Another factor affecting food security aspects of crop climate modeling is that the plant experiments informing the process-based crop model simulations are focused on the world's major food crops. Common African crops such as sorghum, millet, and yams are often left out, as is the simulation of intercrops (Challinor et al., 2007), though this is improving. Although it is important for models to be able to simulate the impacts of unprecedented changes in mean climate, the impact of extreme events can act as an indicator of vulnerability to climate change by assessing people's ability to deal with extremes of climate and climate variability (Challinor et al., 2007). Stochastic models are most appropriate for these types of analyses. An integrated assessment study by Furuya and Kobayashi (2009) uses a stochastic version of the International Food and Agricultural Policy Simulation Model to study the impact of crop production variations on the world food market. Similar models could be used to incorporate extreme stochastic weather events into standard crop climate models.

Finally, the impact of socioeconomic factors on food production cannot be overlooked if a holistic picture of food security includes access to as well as availability of food crops. Challinor et al. (2009) call for more integrated studies (e.g., Fischer et al., 2005; Parry et al., 2004; Rosegrant et al., 2008) in order to get a better understanding of how socioeconomic processes influence climate–crop relationships and trends in production at the regional scale. Ensemble methods can also be used in integrated studies to quantify uncertainties in socioeconomic and behavioural factors (Pereira, 2012).

Crops

As illustrated in the previous section, a changing climate will impact temperature and precipitation, two very important variables for crop growth. Warming trends have already become evident across the continent, and it is likely that the continent's mean annual temperature will increase by more than 2°C by the end of this century (Niang et al., 2014). Added to this warming, changes in precipitation patterns are also of concern for agricultural systems on the continent. In general, high temperatures and changes in rainfall patterns are likely to reduce cereal crop productivity across sub-Saharan Africa, ranging from a 2 percent decrease for sorghum to a 35 percent decrease for wheat (Nelson et al., 2009). Maize-based systems in southern Africa are particularly vulnerable to climate change, with yield losses for South Africa and Zimbabwe predicted to be in excess of 30 percent (Lobell et al., 2008; Schlenker & Lobell, 2010). An exception is eastern Africa where maize production could benefit from warming in high-elevation locations, although this would require a shift in the distribution of maize production as most cropping presently happens in low-elevation areas (Thornton, Jones et al., 2009). Wheat production in northern Africa is expected to be vulnerable to warming trends, and in western Africa the positive effects on millet and sorghum from increased precipitation are likely to be counteracted by temperature increases above 2°C (Niang et al., 2014). In Nigeria, results from the EPIC (Environmental Policy Integrated Climate) model show an increase in yields of maize, sorghum, rice, millet, and cassava across all lowland ecological zones as the climate changes toward 2050, but toward the end of the 21st century the rate of yield increase is expected to slow (Adejuwon, 2006). It is important to note, however, that these model projections are based on a variety of assumptions about GHG (greenhouse gas) emissions, how these emissions will impact the climate, how the change in climate will impact crops, and then, finally, the financial implications if they are included in the model. Even within a single county, it is possible to get conflicting information (see Box 3).

With regard to noncereal crops, there is less conclusive evidence on the impact of climate change on yields. Cassava yields are expected to increase into the 2030s, assuming that there is a CO_2 fertilization effect,[2] but by midcentury negative impacts from climate change are expected to occur (Schlenker & Lobell, 2010; Lobell et al., 2008). Under climate change, suitable conditions for cassava are expected to be greatest in Central and eastern Africa, and due to cassava's hardiness at high temperatures and sporadic rainfall, it could prove to be a good substitute for cereal crops as an adaptation response to climate change (Jarvis et al., 2012). Yields of beans are estimated to decrease by the mid-21st century (Jarvis et al., 2012; Thornton et al., 2011), while for peanuts some studies show a positive effect from climate change, especially in rain-fed systems (Tingem & Rivington, 2009; Dube et al., 2013) and a negative effect in other studies (Schlenker & Lobell, 2010; Lobell et al., 2008). Although the effects can be highly variable across varieties, Bambara groundnuts (*Vigna subterranea*) are projected to benefit from moderate climate change (Tingem & Rivington, 2009; Niang et al., 2014). In western Africa and the lowlands of eastern Africa, banana and plantain production could decline, but in the highlands of eastern Africa it is expected to increase due to higher temperatures, but much more research is required to better establish climate change impacts on these two crops (Niang et al., 2014). While there is generally a negative impact on African crops under climate change, some positive impacts on production are projected (see Table 2).

Table 2: Comparison of relative production changes for a variety of African crops under climate change in different regions. The results are probabilistic projections of production impacts in 2030 as a percentage of 1998 to 2002 yields. Negative changes are highlighted in orange (*Source*: data from Lobell et al., 2008).

	West Africa			**Sahel**			**Central Africa**			**Eastern Africa**			**Southern Africa**		
	worst	**median**	**best**	**worst**	**median**	**best**	**worst**	**median**	**best**	**worst**	**Median**	**best**	**worst**	**median**	**best**
wheat	−11,03	−1,26	9,00	−14,53	−7,71	−2,72	−8,33	−1,76	4,82	−4,75	5,45	17,73	−32,34	−15,79	−4,78
rice	−5,92	−1,91	0,75	−6,62	−1,73	3,70	−6,52	−1,90	1,23	−3,24	3,31	12,27	0,39	5,23	12,05
maize	−9,64	−3,51	1,09	−6,79	−1,11	7,42	−4,18	−1,39	0,70	−5,78	−0,97	4,42	−46,56	−28,49	−12,27
millet	−4,33	0,79	6,17	−2,86	3,48	12,46	−34,17	−13,32	0,77						
sorghum	−5,51	−0,19	4,65	−15,33	−4,29	6,18	−16,69	−4,02	5,56	−7,17	0,84	6,23	−16,86	−1,49	14,66

cassava	−2,95	0,73	4,71				−2,89	−0,27	2,01	−5,63	1,98	8,33	−2,91	0,20	3,93
yams	−13,82	−5,14	0,75												
groundnut	−16,60	−7,32	−2,01	−9,19	−0,38	8,77	−8,14	−2,54	1,51	−2,52	2,90	10,72	−8,09	2,21	13,29
cowpea				−4,56	11,84	39,53				−34,44	−17,04	−7,05			
oil palm							−6,01	−2,22	0,89						
barley										10,16	27,79	54,74			
sugarcane										−10,83	−3,34	1,57	−19,42	−5,54	6,70

beans										−7,99	−2,80	1,67			
soybean													−17,82	−8,02	−0,87

Box 3: Climate change impacts on maize in South Africa

A range of studies have been conducted on the impacts of climate change on maize in South Africa—the staple food crop of the country which millions of people rely on to meet their food security needs (Carter & Gulati, 2014). Most studies confirm the regional and global models' findings that climate change will cause a decrease in maize yields. Akpalu et al. (2008) find that a 10 percent reduction in precipitation reduces the mean maize yield by approximately 4 percent and that the gain in maize yields from increased temperature begins to diminish as temperatures start to reach thresholds. Another study showed significant impacts of climate change on maize production and estimated that the financial losses would vary between R46 million (3 million USD) with the CO_2 fertilization effect and R681 million (46 million USD) without the CO_2 fertilization effect (Turpie et al., 2002). However, this finding contradicts the study by Dube et al. (2013), which projects gains between 5 and 25 percent for rain-fed maize.

Much of the uncertainty lies in the fact that the amount of land under maize cultivation is unknown in the future, as some areas become unsuitable for production. Johnston et al. (2013) find that, until 2035, although the harvested area of maize is expected to decline, yields are expected to rise, thereby increasing total production, but that after this production will succumb to the decline in planted area and South Africa will become a maize importing country. These impacts will be even more severe if the expected increase in yields does not materialize and during years of extreme weather (Johnston et al., 2013). As is clear from the diverse findings of these models, it is impossible precisely to predict the impact of climate change on future crop yields, but it is possible to detect trends against which one can start to implement adaptive policies.

Evidence is emerging that high-value perennial crops will also be negatively impacted by rising temperatures as currently suitable agroclimatic zones become marginal for plants by the 2050s (Niang et al., 2014). While the intentional translocation of perennial crops to high altitudes may mitigate these impacts to a certain extent, this option is limited to those geographic areas where this is possible; the loss of productivity of high-value crops such as tea, coffee, and cocoa will have detrimental impacts on export earnings for those countries that produce these commodities (Niang et al., 2014). Furthermore, crops' wild relatives provide an important source of genetic diversity for crop improvement, but their survival is threatened by climate change (Jarvis et al., 2008). In a study that looked at the wild relatives of peanuts, potatoes, and cowpeas under three migration scenarios (unlimited, limited, and no migration), Jarvis et al. (2008) found that climate change negatively affected all taxa, with 16–22 percent expected to go extinct and most species losing over 50 percent of their range size. It is therefore extremely important, not only to consider the vulnerability of existing crops under cultivation to climate change, but also those taxa that are necessary for maintaining genetic diversity.

Livestock

Livestock systems in Africa face multiple stressors that can amplify the vulnerability of communities to climate change (Niang et al., 2014). These stressors include rangeland degradation; increased variability in water access; fragmentation of grazing areas; sedentarisation; immigration of nonpastoralists into grazing areas; lack of opportunities for livelihood diversification; conflict and political crises; weak social safety nets; changes in land tenure and insecure access to land, markets, and other resources (Niang et al., 2014). Combining these existing pressures with natural, and climate-change-induced, variability in precipitation and temperature increases makes pastoralism one of the most vulnerable sectors to climate change. Climate change can impact livestock in three key areas (pests and diseases are discussed in the following section): water availability, heat stress, and the quality and quantity of feed.

Extensive rangeland in Africa is already drought-prone, and regions like North Africa and southern Africa, which are projected to become drier, will become even more vulnerable to livestock losses from prolonged drought conditions (Niang et al., 2014). Although minimal in comparison to the water needed for crop production, drinking water for animals is crucial and could become difficult to provide under climate change (Niang et al., 2014). Results from a study in Botswana show that, due to the increased need to pump groundwater to supply livestock, an increase of 23 percent in the cost of water supply is expected due to climate change (Masike & Urich, 2009). Furthermore, deterioration of pastures during droughts and periods of overgrazing can result in the poor health and sometimes death of livestock. In northwest Kenya, recurring droughts have led to increased competition for grazing land, livestock losses, and conflict, all of which negatively impact the food and livelihood security of livestock owners (Ziervogel et al., 2008). In times of water scarcity, humans are forced to share their water sources with livestock, and this situation can lead to the transfer of diseases (Ziervogel et al., 2008). Attempts to quantify the impacts of climate change on water resources in livestock systems in developing countries are highly uncertain, particularly where groundwater accounts for a substantial portion of the supply of water to livestock, which is the case in many grazing systems; thus, there is a need for further research in this area (Thornton et al., 2009).

Climate change is also projected to have an impact on the quantity and quality of feeds for livestock. For example, it is estimated that maize stover availability per head of cattle will decrease in several East African countries by 2050 (Thornton et al., 2010). Hopkins and Del Prado (2007 in Thornton et al., 2009, p. 115) identify the following impacts on feed:

- Changes in plant growth brought about by changes in atmospheric CO_2 concentrations and temperature;
- Changes in the composition of pastures, for example, in the ratio of grasses to legumes;
- Changes in plant quality as concentrations of water-soluble carbohydrates and nitrogen change;
- Greater incidences of drought, which may offset yield increases;
- Greater intensity of rainfall, which may increase nitrogen leaching in certain systems.

Other negative impacts on livestock farming include greater water requirements for livestock from temperature increases as well as impacts on livestock from heat stress (Archer & Tadross, 2009). Although the exact extent to which increased heat stress will affect livestock productivity has not been well established in the tropics and subtropics, a few studies indicate that keeping heat-tolerant livestock will become more prevalent as a response to warming (Thornton et al., 2009). These studies indicate that as it gets hotter in the lowlands areas of Africa, farmers might shift from stocking dairy cows and sheep to stocking beef cattle and goats, as well as decreasing numbers of poultry (Kabubo-Mariara, 2008; Seo & Mendelsohn, 2008).

Pests and Diseases

Under climate change, pressures from pests, weeds, and diseases are also expected to increase, with detrimental effects on crops and livestock (Niang et al., 2014). In the highlands regions of eastern Africa, warming trends could lead to the expansion of crop pests into previously cold-limited areas; for example, the coffee berry borer (*Hypothenemus hampei*) could become a serious threat in coffee-growing regions of Ethiopia, the Ugandan part of the Lake Victoria and Mount Elgon regions, Mount Kenya and the Kenyan side of Mount Elgon, and most of Rwanda and Burundi (Jaramillo et al., 2011). Threats to banana production could come from the altitudinal range expansion of the burrowing nematode *Radopholus similis*, and warming trends could expand the range of black leaf streak disease (*Mycosphaerella fijensis*) in Angola and Guinea that also threatens bananas (Niang et al., 2014).

Striga weed (*Striga hermonthica*) is a major cause of cereal yield reduction in sub-Saharan Africa and changes in temperature, rainfall and seasonality could result in more suitable habitats for this weed in Central Africa, but the Sahel might become less suitable (Niang et al., 2014; Cotter & Sauerborn, 2012). Good news for cassava is that climate change could result in an overall decrease in the suitable range of major cassava pests-whitefly, cassava brown streak virus, cassava mosaic geminivirus and cassava mealybug (Jarvis et al., 2012), although an increase in whiteflies, mites and mealybugs is projected for Southeast Africa and Madagascar where cassava is currently cultivated (Bellotti et al., 2012).

In the case of livestock, models of the distribution of the main tick vector (*Rhipicephalus appendiculatus*) of East Coast fever disease (*Theileriosis*), under changes in mean, minimum, maximum temperature and rainfall in January and July, show an increased suitability in the Northern Cape and Eastern Cape provinces of South Africa, Botswana, Malawi, Zambia, and eastern Democratic Republic of Congo (Olwoch et al., 2008).

Athough this section has shown the diverse impacts that climate change is projected to have on agriculture in Africa, it is important to acknowledge the diversity of farming systems evident on the continent, ranging from pastoralists like the Maasai in Kenya to large-scale commercial farmers in South Africa and Egypt. Climate model projections are starting to take into account regional differences, but as yet they do not significantly differentiate at the farming system level. Climate change will impact these different farmers and their agricultural systems in different ways, and adapting to these impacts will need to be context-specific.

Adaptation

Successful adaptation is in essence the reduction of vulnerability to a specific impact (e.g., climate change) through the realization of adaptive capacity within a system (Adger et al., 2004). Leichenko and O'Brien (2002, p. 3) propose a working definition of such dynamic vulnerability as "the extent to which environmental and economic changes influence the capacity of regions, sectors, ecosystems and social groups to respond to various types of natural and socio-economic shocks." Resilience is the opposite of vulnerability; it is about having the capacity to respond to diverse stresses and not be worse off. Furthermore, in order to be resilient under different pressures, it is important to be adaptive or to have adaptive capacity to these pressures. Adaptive capacity can be defined as "the ability or capacity of a system to modify or change its characteristics or behaviour so as to cope with existing or anticipated external stress" and thereby also increase its resilience (Adger et al., 2004, p. 34). This capacity to undergo the requisite changes to maintain resilience under future impacts includes an ability (1) to adjust to a change, (2) to buffer potential damages, and (3) to take advantage of opportunities offered by this change (IPCC, 2007).

The IPCC's definition of adaptation is "the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate harm or exploit beneficial opportunities. In natural systems, human intervention may facilitate adjustment to expected climate and its effects" (Noble et al., 2014, p. 838). The key here is that there should be a degree of purposefulness to the act of adaptation, as the ability to cope with climatic impact can also be increased by actions that are not anticipatory or undertaken in direct response to observed or anticipated climate change (Noble et al. 2014). For example, diversifying livelihoods in response to immediate economic factors could increase long-term ability to cope with a changing climate, but these actions are more reactive to climate impacts than anticipatory of them and so they might not be seen as adaptation to climate change (Noble et al., 2014). Successful adaptation will also depend on humans' ability to allow and facilitate the adjustments of natural systems (through migration, compositional changes, etc.) to a changing climate (Noble et al., 2014).

Challenges and Lessons Learned

The African continent is vulnerable to the impacts of future climate change partially because of its relatively low capacity to adapt (adaptive capacity) to climate effects and partially because of the relatively strong climate-change signal that is projected for Africa (Niang et al., 2014). However, Africa does have some inherent adaptive capacity, including its wealth of natural resources, well-developed social networks, and longstanding traditional mechanisms of managing climate variability through crop and livelihood diversification, migration, and small-scale enterprises, many of which are underpinned by local or indigenous knowledge systems for sustainable resource management (Niang et al., 2014). The ability of these strategies to address multiple and often mutually reinforcing risks—for example, climate variability and fluctuating input costs—are improving across the continent (see the OPPORTUNITIES AND POTENTIAL SOLUTIONS section), but it is expected that in the long term they will be insufficient in enabling communities to cope with the variability of longer-term climate change combined with development processes across the continent (Niang et al., 2014).

Africa is exposed to a range of multiple stressors (e.g., poverty, youth unemployment, lack of infrastructure) that interact in complex ways with climate change; therefore, the adaptation needs of the continent are broad, including institutional, social, physical, and infrastructure needs, ecosystem services and environmental needs, and financial and capacity needs (Niang et al., 2014). Successful adaptation in the African context is dependent on building systemic resilience, often to uncertain impacts (Adger et al., 2011). In some instances, significant implementation challenges related to complex cultural, political, and institutional factors have led to a deficit of adaptive capacity on the continent, thereby reinforcing the need for strong links between adaptation and development plans—in essence, the need for low-regrets adaptation strategies that not only buffer impacts from climate change but that also produce long-term development benefits (Niang et al., 2014). No single adaptation strategy exists to meet the needs of all communities and contexts in Africa, and the focus in the 2000s on technological solutions is evolving toward a broader view that highlights the importance of building resilience, through social, institutional, and informational approaches (Chambwera & Anderson, 2011). There is a growing recognition that the poverty and complex livelihood-vulnerability risks faced by many people in Africa are a challenge for adaptation (Tschakert & Dietrich, 2010), and that there is an urgent need to take into account local norms and indigenous knowledge when devising adaptation strategies (Nyong et al., 2007).

Another lesson that has been learned is that climate change adaptation often fails to contextualize climate change risks within the set of other climate information such as historical data, real-time data, and traditional knowledge, all of which are available to support decision making but which can sometimes be contradictory, making decision making difficult (Ziervogel et al., 2008). By focusing on existing climate variability, on one hand, some climate change professionals argue that agricultural decision makers might be caught off-guard by significant and abrupt climate change; on the other hand, those who focus on climate variability claim that African farmers need to be able to cope better with existing variability so that they will be better able to adapt effectively to future climate change (Ziervogel et al., 2008). Rather, both information about future climate change and existing climate variability should be available as a continuum of climate information across scales so that it can be used within the specific decision-making context in which it is needed (Ziervogel et al., 2008). A small-scale farmer will be interested in accessing information about rainfall in the following season—in which case seasonal climate forecasts are appropriate. In contrast, a crop breeding scientist might prefer to have an understanding of climate change patterns in the next 20 years in order to develop an appropriate product—in which case climate change scenarios might be more beneficial (Ziervogel et al., 2008). Both farmer and scientist would be subjected to climate variability, but one would be more susceptible to the longer range climate than the other.

Barriers

Knowledge of barriers that hamper adaptation in developing countries also remains limited, especially with regard to vulnerable households that are dependent on agriculture (Antwi-Agyei et al., 2014; Shackleton et al., 2015). While this is a complex issue that spans multiple governance levels, some key barriers have been identified (see Antwi-Agyei et al., 2014; Shackleton et al., 2015):

1. Inadequate infrastructure and finance prevent the use of cutting-edge equipment in meteorological departments, which means that decision makers do not have enough appropriate data/information available on climate variability and change, as well as their impacts.
2. Weak governance structures and institutions, coupled with a lack of human resources and capacity, results in poor coordination among organizations and departments involved in climate change adaptation, as well as a breakdown in, or even a complete lack of, communication of climate information to farmers.
3. At the household level, financial barriers often hinder adaptation, including the lack of acceptance, availability, and ready markets for drought-tolerant crops, which are linked to sociocultural barriers, as people maintain their preferences for existing staple crops.

Opportunities and Potential Solutions

Despite these barriers, a variety of conservation and agroecological practices such as agroforestry, contouring, terracing, mulching, and no-till are increasingly being adopted by African farmers (Nyasimi et al., 2014; Tittonell et al., 2012; Mbow et al., 2014; Kaczan et al., 2013). These practices have the benefits of being both mitigation and adaptation strategies (see Box 4), as well as broadening sources of livelihoods for poor farmers, but there are constraints to their widespread adoption, including challenges varying from land tenure to knowledge-sharing.

Box 4: Climate-Smart Agriculture

Climate-smart agriculture (CSA) is a somewhat contested term promoted by the Food and Agriculture Organization of the United Nations (FAO) and the CGIAR (Consultative Group on International Agricultural Research) research group on Climate Change, Agriculture and Food Security (CCAFS). They define CSA as [BEXT]an integrative approach to address these interlinked challenges of food security and climate change, that explicitly aims for three objectives:

1. sustainably increasing agricultural productivity, to support equitable increases in farm incomes, food security and development;

2. adapting and building resilience of agricultural and food security systems to climate change at multiple levels; and

3. reducing greenhouse gas emissions from agriculture (including crops, livestock and fisheries). (CCAFS 2016).

Agroforestry is one of the most promising climate change adaptation strategies for Africa, as it provides the opportunity to produce assets for farmers, offers climate change mitigation opportunities, and has the potential to promote sustainable production that enhances agroecosystem diversity and resilience (Mbow et al., 2014). Agroforestry is a land-use practice in which trees are cultivated in conjunction with crops or pasturelands. A number of successful agroforestry technologies exist that can meet “climate-smart” requirements, such as trees that improve soil, fast-growing trees for fuel wood, indigenous fruit trees to provide added nutrition and income, and trees that can provide medicinal plant products (Molua, 2005; Mbow et al., 2014). However, Mbow et al. (2014) emphasize that there is a need to differentiate between simple agroforestry systems (such as alley cropping, intercropping, and hedgerow systems) and complex agroforestry systems that function like natural forest ecosystems but are integrated into agricultural management systems (Rice, 2008; Oke & Odebiyi, 2007).

Unfortunately, as with other adaptation strategies, agroforestry faces challenges. Structural barriers include the failure of extension services in poor African countries to help scale up innovations in agroforestry and limited investments in agroforestry compared to intensified monoculture systems, which have seen strong support during the postcolonial era, mostly for export as cash crops (e.g., peanut, cocoa, cotton) (Mbow et al., 2014). Furthermore, despite intensive modeling efforts, the effects of climate change on agroforestry systems (and vice versa) are not well understood, which means that it is not known which trees and management options are the most suitable for future climates nor how to best minimize negative climate change impacts on farming systems (Mbow et al., 2014). There is an urgent need to improve climate change knowledge for agroforestry systems, and not just conventional cropping systems.

Ultimately, Africa faces many challenges when it comes to adapting to climate change because adaptation is not a process that can be undertaken in isolation from other development processes. Although the continent is vulnerable to climate change due to its geography and relatively low adaptive capacity, it is also culturally and ecologically diverse, which provides it with some resilience in the face of a changing climate. Furthermore, because it is still in a phase of high economic growth, it is, in many cases, able to develop with mitigation and adaptation in mind, unlike many developed regions that are locked-in to a fossil-fuel intensive development out of which they need to transition. Critical to effective adaptation are the producing and sharing of climate information with decision makers at all levels, and ensuring that constant learning takes place.

Conclusion

Although African agricultural systems are highly reliant on their environment, their diversity, context specificity, and the existing generations of traditional knowledge offer elements of resilience in the face of climate change. The combination of climatic and nonclimatic drivers and stressors will likely exacerbate the vulnerability of Africa's agricultural systems to climate change, but the impacts will not be universally felt. There remains a dearth of local-level understanding of impacts and communities' capacity, willingness, and motivation to adapt, especially in remote areas of the continent. It is well understood that Africa is vulnerable to climate change, not only because of high exposure to specific changes in, for example, temperature and rainfall, but also because many African communities lack the capacity to cope with, or adapt to, the negative impacts of climate change.

In this article, the current status of research on climate change impacts on agriculture in Africa has been outlined. Much good information exists in the IPCC Fifth Assessment report (see Niang et al., 2014), but there are still gaps with regard to the confidence in climate change projections (especially rainfall) on the continent and the impact that these projections will have on agricultural production. More research, especially on producing good regional climate models, needs to take place, and more good quality data are required, especially in countries from Central Africa and parts of the Sahel that currently lack instruments, analytical tools, and capacity to capture and analyse these data. Adaptation efforts are by necessity context-specific, although some practices, like agroforestry, are applicable in many different cases, although the specific mix of species is dependent on environmental as well as socio-cultural and economic factors within each community.

This article has not covered the impact of climate change on food security because it deserves its own dedicated piece. All the same, it is important to emphasize the important links between climate change impacts, agricultural production, and food security. Climate change provides both an impediment to food security owing to its generally negative impacts on staple crop production and an opportunity to transform African food systems into more adaptive, more affordable, and more nutritious systems that rely more on indigenous crops and traditional knowledge that are adapted to the local context rather than on mono-cropping systems that tend to be more vulnerable to climate extremes.

While African agriculture faces exposure to climate change as well as broader socioeconomic and political challenges, many of its diverse agricultural systems remain resilient. As the continent with the highest population growth rate, rapid urbanization trends, and rising GDP in many countries, Africa’s agricultural systems will need to become adaptive to more than just climate change as the uncertainties of the 21st century unfold. This article captures this complexity and shows that decision making under the threat of climate change is not a straightforward process, but that our knowledge and coping mechanisms are improving. What the evidence reveals is that it is critical to ensure that multilateral agreements to keep global warming under a 2°C increase are kept and that sufficient funding and capacity for adaptation goes to those who most need it; many of whom are underresourced African farmers.

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Notes:

(1.) http://www.cordex.org/

(2.) The CO_2 fertilization effect is the potential increase in plant growth that will occur from excess CO_2 in the atmosphere as plants use CO_2 during photosynthesis to grow. Plants that are more likely to benefit are those with a C3 photosynthetic pathway, such as wheat and potatoes, rather than those with a C4 pathway, such as maize, cassava, and sugarcane, but the fertilization effect varies between species and also between regions, and research has shown that the variability in yield due to the response to elevated CO_2 is about 50–70% of the variability in yield due to the response to climate (McGrath & Lobell, 2013).

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