Inter-American Development Bank

Environmental Safeguards Unit (VPS/ESG)

TECHNICAL NOTES

No. IDB-TN-383

Climate Change and Agricultural Production

Rodomiro Ortiz

February 2012

Climate Change and Agricultural Production

Rodomiro Ortiz

Inter-American Development Bank

2012

Rodomiro Ortiz is Professor of Genetic and Plant Breeding at the Swedish University of Agricultural Sciences in Alnarp. Over the years he has worked as researcher with Universidad Nacional Agraria La Molina, the Centro Internacional de la Papa in Peru, Rutgers University, the International Institute of Tropical Agriculture (IITA) in Nigeria, and as Nordic Professor in the Royal Veterinary and Agricultural University of Denmark. Previously he served as program director at the International Crops Research Institute for the Semi-Arid Tropics in India, at IITA, and at the Centro Internacional de Mejoramiento de Maíz y Trigo in Mexico.

Acronyms

GHG	Greenhouse gas
ENSO	El Niño-Southern Oscillation
IPCC	Intergovernmental Panel on Climate Change

Contents

1. Global and Continental Overview of Climate Change in Agriculture

Extreme temperatures, water scarcity, and floods are expected as a result of global climate change, due to mainly an anthropogenic-led increase of greenhouse gas (GHG) emissions. The sizes of some animals and plants may shrink due to high temperatures and less rainfall,[1] thereby reducing the availability of food sources needed for human nutrition. This change of climate will severely affect agriculture worldwide.[2] Under most global warming scenarios (see Table 1), crop yields are likely to decline due to increasing temperature and declining rainfall, thereby raising food insecurity. Other expected changes are reduced crop quality, intensified nitrogen leaching and soil erosion, and shrinking land and water resources for farming.

Table 1. Main features of climate change scenarios

Scenario	Main features
A1	Rapid demographic and economic growth linked to the introduction of new and more efficient technologies
A1F1	Intensive use of fossil fuel
A1T	Predominant non-fossil energy
A1B	Appropriate use of all energy types
B1	Includes some mitigation level of emissions through the use of more efficient use of energy and improved technologies
B2	Includes some mitigation level of emissions through the use of more efficient use of energy and better localized solutions

Governments and farmers worldwide—particularly smallholders—will have to adapt their agro-ecosystems to unstable, variable weather patterns because climate change will affect food availability, stability, use, and access.[3] For example, the prices for main staples may increase between 30 percent (for rice in an "optimistic" scenario) and 100 percent (for maize in baseline scenario) by 2050 due to declining crop yields.[4] Hence, the main challenges for agriculture in this century will be to increase the supply of food, improve its distribution and access, and enhance resilience of the whole food system while reducing GHG emissions as well as getting rid of air and water pollution from agriculture and land use, avoiding biodiversity and habitat losses, and phasing out unsustainable water withdrawals.[5]

[1] Sheridan and Bickford 2011.
[2] Tubiello et al. 2007.
[3] Schmidhuber and Tubiello 2007.
[4] Nelson et al. 2010.
[5] Foley et al. 2011.

Global Warming and Impacts on Agriculture

The Earth warmed between 1850 and 2010 at a rate of 0.5 ºC per century, but that increased to 0.7ºC per century from 1900, to 1.3ºC per century since 1950, and to 1.8ºC per century for the last 35 years. The last two decades are among the warmest since temperature recording started. Annual losses in barley, maize, and wheat output due to global warming since 1981 amount to 40 million tons (or US$5 billion as of 2002),[6] although these were offset by yield gains due to crop breeding and other agro-technology advances.

It appears that high seasonal temperatures, beyond what has been already noted in the last 50 years, may become further widespread in several Mesoamerican and South American locations in the remainder of this century.[7] The temperature increase could vary between 0.4°C and 1.8°C for 2020, being more severe in tropical locations. High temperatures (particularly >3°C) will dramatically affect agricultural productivity, farm incomes, and food security. Several crops that are important staples for large numbers of food-insecure people will be negatively affected in their yields, although scenarios seem to be more uncertain for some crops than for others.[8] For example, rice's grain yield declines by 10 percent for each 1°C increase in minimum temperature during the dry growing season,[9] while a 10 percent loss in maize production may be expected by 2055.[10] Likewise, global warming may favor wheat in some regions but this grain crop could reduce its productivity significantly in areas where optimal temperatures already occur, or it may expand to cool, temperate environments where wheat does not yet grow.[11] Many insects and mites affecting some crops may increase due to increasing temperatures and atmospheric carbon dioxide (CO2).

Climate Change in Latin America and the Caribbean

Changes in extreme temperatures, which affect agriculture, have been observed over the last 50 years in the American continent. (See Figure 1.) The average temperature increased by 1ºC in the twentieth century in Mesoamerica and South America, although it showed a great spatial and seasonal variability. For example, an increase in the frequency of warm nights occurred during 1960–2000 everywhere in South America below 10°S.[12,13] Likewise, there were positive trends in extreme rainfall events in southeastern South America, north central Argentina, and northwest Peru and Ecuador, and a negative trend in southern Peru and

[6] Lobell and Field 2007.
[7] Battisti and Naylor 2009.
[8] Lobell et al. 2008.
[9] Peng et al. 2004.
[10] Jones and Thornton 2003.
[11] Ortiz et al. 2008.
[12] Marengo et al. 2010.
[13] Vincent et al. 2005.

Chile.[14] (See Figure 2.) The number of consecutive dry days was also noticed in a large part of southeastern South America and, to a smaller extent, in southern Peru, northern Argentina, and Bolivia. Moreover, there has been a significant summer drying trend—as noted on rainfall datasets—for the Caribbean and Central America regions.[15] Honduras, Nicaragua, Haiti, and the Dominican Republic are among the countries most affected by extreme weather events, according to the long-term climate risk index 1990–2008.[16]

Latin America and the Caribbean are vulnerable to changes in climate due to their geography.[17] Mesoamerica and the Caribbean islands are within the hurricane belt, which has shown more volatility and strength in recent years.[18] Likewise, some of South American agriculture depends on water flows from the Andes glaciers, which are retreating due to global warming and could disappear within the next two decades.[19] Water availability and hydroelectric generation will therefore be seriously affected due to reduction of the glaciers. El Niño–Southern Oscillation (ENSO) is another important phenomenon affecting climate variability in Latin America. El Niño was the name given to this weather by Peruvian fishers after the Christ child. It is characterized by an increase of water temperature in the eastern Pacific Ocean, which reverses weather patterns, thereby resulting in more rainfall at the coast and drought in the mid to high altitudes. La Niña—its cold counterpart—may follow El Niño with the opposite patterns.

ENSO was labeled twice in the twentieth century as the "El Niño of the century" due to the unprecedented warming in 1983 and 1998 in the eastern Equatorial Pacific. Intense rainfalls caused landslides and floods, whereas drought was noted in other areas due to dry spells. Agriculture accounted for anywhere from 17 percent (Peru) to 47 percent (Ecuador) in the Andean Community of the total damage of the 1997–1998 El Niño, or US$2.2 billion (29 percent of the total damage), because of water stress and temperature extremes.

Anthropogenic-led changes could influence the increasing frequency and magnitude of El Niño.[20] However, any further increases due to climate change remain open to debate, though ENSO will continue affecting agriculture in the continent. For example, during El Niño 1998 farmers observed shortenings of the crop cycle length, for instance for cotton and

[14] Haylock et al. 2006.
[15] Neelin et al. 2006.
[16] Harmeling 2009.
[17] Isbell 2011.
[18] Vergara et al. 2007.
[19] Bradley et al. 2006.
[20] Bronnimann et al. 2004.

mango in northern Peru. Likewise, insect pests increased under drought while fungal diseases benefited from excess rainfall or changes in temperature.

Other Extreme Weather Events

Floods, droughts, freezing, heat waves, and hailstorms, as well as variation in balance between temperature and rainfall or hurricane intensity and frequency, are the most important extreme events that may occur due to climate change. Some of them—particularly more periods of warm nights, intense rainfall, and consecutive dry days—have severely affected Latin America and Caribbean in recent years: for example, intense rainfalls in Venezuela (1999, 2005); flooding in the pampas of Argentina (2000–2002), Bolivia (2006), Guyana (2006), and Colombia (2011); drought in the Amazon (2005), Ecuador (2004), and Guatemala (2004); frosts in Peru (2005) ; hailstorms in Bolivia (2002) and the Great Buenos Aires area (2006); the unprecedented Hurricane Catarina in the South Atlantic of Brazil (2004); and the record hurricane season of 2005 in the Caribbean Basin.

This increase in extreme events led to a 2.4-fold increase in flooding, droughts, and landslides, although some of them could be related to ENSO. These changes in the intensity and frequency of extreme events will increase the vulnerability of Latin American and Caribbean agriculture to climate change—for instance, 120,000 cattle were lost in Chaco (Argentina) and soybean and maize production were down by 65 and 56 percent respectively in Rio Grande do Sul (Brazil) during the 2004–2006 droughts in the Southern Cone.

These extreme events make clear the need to identify better ways for managing agro-ecosystems sustainably. In this regard, indigenous traditional knowledge for agro-ecosystem management needs to be taken into account. For example, indigenous knowledge could provide adaptation measures in the Andes for the decrease of irrigation water due to glacial retreat or the increase in minimum altitude for planting crops, while they may offer means for dealing with the low/high water ("aguaje") cycles related to the dry/wet wind cycles, which significantly affect agriculture in the Amazon.

Models for Climate Prediction

Although there may be some questions about the credibility of models for climate prediction (see Table 2),[21] the climate change scenarios for the continent suggest an increase in temperature between 1º and 6ºC (see Figure 3), but the available rainfall forecasts are very

[21] Koutsoyiannis et al. 2008.

heterogeneous.[22] Nonetheless, the consensus among models regarding rainfall changes points toward an increase of summer rainfall in southeastern subtropical South America, a decrease of rainfall across the continent during winter, and reduced rainfall—irrespective of the season—in the southern Andes.[23] (See Figure 4.) Short rainfall periods will decrease the length of the crop cycle, thereby affecting productivity. There will be a shortening of favorable weather for the crop growing cycle and an increase of drought in northeast Brazil. Warm nights will also occur more frequently throughout tropical South America, whereas cold nights will decrease.[24] An increase in temperature and decrease of rainfall will affect crop yields negatively, and an increase of 4ºC will reduce livestock productivity significantly. Hence, adapting crops and livestock to global warming and water stress across diverse agro-ecosystems will be a priority for Latin America and the Caribbean. As already noted by the Inter-American Development Bank, farmers—especially smallholders—will need to adopt profitable, environment-friendly technological innovations and production practices (including crop shifts) to cope with climate change.[25]

Table 2. Some general circulation models used for predicting future climates

Name	Developer	Resolution (°) in latitude and longitude	Grid points latitude × longitude
ECHAM4/OPYC3	Max-Planck-Institute for Meteorology & Deutsches Klimarechenzentrum, Hamburg, Germany	2.8 × 2.8	64 × 128
CGCM2	Canadian Centre for Climate Modelling and Analysis	3.7 × 3.7	48 × 96
HadCM3	Hadley Centre for Climate Prediction and Research	2.5 × 3.7	73 × 96
CGCM3-T47	Canadian Centre for Climate Modelling and Analysis	3.7 × 3.7	48 × 96
ECHAM5-OM	Max-Planck-Institute for Meteorology & Deutsches Klimarechenzentrum, Hamburg, Germany	1.9 × 1.9	96 × 192
PCM	National Center for Atmospheric Research, USA	2.8 × 2.8	64 × 128

[22] PNUMA 2010.
[23] Vera et al. 2006.
24 Marengo et al. 2009.
[25] IDB 2010.

2. Expected Impacts of Shifting Temperatures and Rainfall on Output, Water Resources, Crop Yields, and Rural Livelihoods

Uncertainty remains about the exact impact of climate change on the agriculture of Latin America and the Caribbean, where three countries—Argentina, Brazil, and Mexico—account for at least 70 percent of the total output.[26] Maize, rice, soybean, wheat, and livestock (for beef, dairy, and wool) are among the most important products and are for the most part—with the exception of maize—produced on medium to large farms. The contributions of agriculture to the gross domestic product vary in the region as follows: below 5 percent in most of the Caribbean; 4–8 percent in all but one country of the Southern Cone, Cuba, the Dominican Republic, and Jamaica; 8–15 percent in the Andean Community, Costa Rica, El Salvador, and Panama; and above 15 percent in Belize, Dominica, Guatemala, Guyana, Haiti, Nicaragua, and Paraguay.

The impacts of climate change will vary according to the farming system and its location.[27] For example, farmland values in hot and wet Amazon and Equatorial regions may decrease, while in temperate or high elevation locations and the Southern Cone of South America they may increase.[28] Equatorial regions are very vulnerable to climate change because farming there is close to the limits of tolerating high temperatures.

South American values of farms specialized in crops or livestock and those under mixed crop-livestock systems will fall 19 percent and 34 percent respectively, but this decrease will be smaller in the mixed system (15 percent) by 2060 (considering a temperature increase of 3°C and 10 percent rainfall decrease).[29] Specialized crop farm profit will fall by 20 percent, whereas it will be down by 34 percent for specialized livestock farms and only 13 percent for mixed farms, which may lead to farmers switching to mixed crop-livestock systems in South America. These losses will be 11 percent for crop farms, 22 percent for livestock farms, and 5 percent for mixed farms if temperature increases only 1.7°C and rainfall increases 5 percent by 2060. In Central America, the losses toward the end of this century will range from 1 percent (Costa Rica) to 66 percent (Guatemala).[30]

The impacts in each country will depend on the interaction between weather, topography, soil types, water availability, and the kind of crops, livestock, and trees used by

[26] Baethgen 1997.
[27] Mendelsohn et al. 2007.
[28] Seo and Mendelsohn 2006.
[29] Seo 2008.
[30] CEPAL 2011a.

farmers in their agro-ecosystems. However, less rainfall, increased floods, or temperature extremes (> 2°C) will have a negative impact on food security, particularly in semiarid and arid zones. CO_2 fertilization may balance some of the negative effects of climate change in mid-altitude valleys, but on average crop and livestock productivity may decrease throughout Latin America and the Caribbean by the end of this century. Moreover, about 50 percent of agricultural land in some areas (such as central and southern Chile, the Peruvian coast, and southeast Brazil) will likely be affected by desertification and salinity.[31]

A recent study suggests that revenue losses in Latin American and Caribbean agriculture could range from 12 to 50 percent by 2100, even after some adaptation of crops, livestock, and farming systems to climate change.[32] Another study suggests that the total output for agriculture in the region could fall 12 percent by 2080 if CO_2 fertilization occurs and 24 percent without it.[33] This last report, however, does not consider how water stress will affect crop and livestock production.

Climate Change and Water Availability

Agriculture is the main user of water worldwide, and its competiveness depends on timely water availability for crops, livestock, and trees. Water stress due to climate change plus an increasing demand for water for irrigation, industry, hydropower, and other human uses will exacerbate the competition among sectors for this resource in the region. A decline in groundwater levels and rising energy costs for pumping water will increase farming costs.

The glaciers in the Andes of Argentina, Bolivia, Chile, Colombia, Ecuador, and Peru have lost 20 percent of their volume, which will affect the supply of both water and energy in South America. Hydro-energy from power generation accounts for at least 50 percent of the energy supply in the Andean Community, where farmers in many areas also depend significantly on water from the glaciers. The temperature increases in the Andes are also affecting water cycles and mountain habitats, where rainfall changes will affect water supply as well. Likewise, coastal areas can be affected by climate change due to sea level rising,[34] which may make the water supply unsuitable for both agriculture and human consumption.

Climate Change and Soil Erosion

A potential negative impact of climate change—especially for small farms—may be the loss of soil organic matter. High temperatures accelerate the decomposition of organic matter and

---

[31] Rodríguez 2007.
[32] de la Torre et al. 2009.
[33] Cline 2007.
[34] Ibid.

increase the rate of other processes in the soil that may affect its fertility.[35] Root growth and organic matter decomposition rates reduce significantly in dry soils, thereby diminishing the cover on the soil, which increases its vulnerability to wind erosion. An increase in rainfall may also cause severe soil erosion in hillsides.

Climate Change and Crop Yields in Latin America and the Caribbean

There are various and sometimes contradictory scenarios regarding quantification of climate change's impacts on agriculture. Some authors indicate that these impacts on crop outputs remain unknown and that more research will be needed to further understand the complexity of crop responses to the changing climate due to its variability and what could be the long-term average climate.[36] They differ in their approach, method, and complexity level, which makes it difficult to compare among country estimates. A few authors also question models that say that changes in climate will significantly affect agriculture and food supply in Latin America.[37]

Research about the impacts of climate change on the agriculture of Latin America and the Caribbean is limited to a few crops or production systems and has been restricted to small geographic domains.[38] Moreover, future climate forecasts and modeling approaches are limited to a few platforms, and the region lacks a comprehensive assessment to validate global climate model forecasts, thereby resulting in significant difficulty in decision-making processes regarding adaptation measures for agriculture.[39] Furthermore, there are doubts about what will happen with the climate because there are no scenarios with a level of probability for sound *ex ante* impact assessments. Nonetheless, farmers are known to monitor changes in climate, and they quickly respond to new weather conditions through establishing complex adaptation mechanisms in their agro-ecosystems. Their knowledge will therefore be a valuable source for developing site-specific adaptation measures because farmers consider the cultural and environmental factors of their farming systems. For example, Amazonian high soils occupation, lowland "chinampa," and Andean terraces have been some of the responses of indigenous people in Latin America to changes in climate.

Contrasting scenarios were summarized for the Intergovernmental Panel on Climate Change (IPCC).[40] For example, maize and pasture productivity may rise due to an increase of

[35] Altieri and Nicholls 2008.
[36] Jarvis et al. 2011.
[37] Maletta 2009.
[38] Jarvis et al. 2011.
[39] Ibid.
[40] Magrin et al. 2007.

rainfall in the pampas of Argentina, Uruguay, and southern Brazil, whereas wheat yield will be reduced in the humid pampas of Argentina and will increase in Uruguay and the semiarid pampas of Argentina due to the rising temperature. Rice yield will mostly decrease in Bolivia and Central America, while soybean output may increase in South America. An increase of nematode pests due to climate change is likely to have a negative impact on the productivity of coffee in Brazil,[41] and increasing rainfall will favor wheat scab during the spring season in the southern Cone. The IPCC also suggests that rising temperatures coupled with decreasing water in the soil may lead to a gradual replacement of tropical forest by savannah in eastern Amazon, whereas semiarid vegetation will tend to be replaced by arid-land vegetation in Latin America, and there will be a significant biodiversity loss through species extinction in tropical regions.

Social Impact of Climate Change on Smallholder and Subsistence Agriculture

Climate change adds a new threat to rural livelihoods—especially for subsistence or smallholder farmers—because it affects economic growth and efforts to reduce poverty, thereby jeopardizing many of the development gains made in recent decades in Latin America and the Caribbean[42]—a region that accounts for only 12 percent of the world's CO_2 emissions. Furthermore, rural Latin America is very vulnerable to changes in climate patterns because a significant percentage of its economy and some of its workforce depend primarily on weather-sensitive agriculture. The changing climate could also hurt the productivity of rural workers and the health of their families because it may affect the quality and quantity of farming produce.

Most of the rural poor live in heterogeneous risk-prone areas with marginal resources and fragile ecosystems whose agriculture depends on rainfall. Climate variability will push these poor people, who are the least responsible for climate change, further beyond their capacity to cope with such changes. Many small farmers in the Andes, Central America, and some Caribbean islands—who already live in harsh environments—may become very vulnerable to climate change impacts because of their geographic exposure to extreme events, low incomes, dependence on agriculture, and few options to pursue other livelihoods. Poor rural people may face a growing scarcity of land viable for agriculture, increasing difficulty in obtaining enough food, and a significant reduction of fresh water as the climate becomes more erratic. For example, about 50 million people in the Andes will suffer lack of dry-

[41] Ghini et al. 2008.
[42] Verner 2011.

season water (whose uses vary from drinking, irrigation, and sanitation to hydropower) whereas another 77 million people living in drought-prone areas will be under water stress due to climate change.[43] Women will be among those suffering most because they are the main providers of food, fuel, and water for their households.[44] Rural communities may be negatively affected because of the inability to enjoy their culture due to climate change's impact on lands and ecosystems of historical, cultural, and spiritual significance.[45]

Changes in water quantity and availability due to climate change will affect food availability, stability, access, and use. Furthermore, average per capita food availability may decrease at least 300 calories (12 percent reduction) by 2050 due to climate change, which will eliminate any progress on fighting malnutrition.[46] There will be also about 6.4 million malnourished children in 2050—that is, about 1.4 million more than in a no-climate change scenario. Other social implications due to the changing climate are related to human health, income inequality, rural migration, and conflict. Climate change will also affect how agriculture uses energy and food consumption patterns. Governments should therefore invest now in adapting agriculture to climate change, which should be science-driven due to the uncertainty on the effects of climate change on agriculture in the long term.

3. Individual Cases Using Available Information

Irrespective of the uncertainty associated with crop and climate models used by various research groups, agriculture and food security are clearly threatened by climate change in Latin America and the Caribbean. (See Figure 5.) The impacts in each country will depend on geography, biophysical resources and their management, agro-ecology, farming systems, risk attitudes, investments, and adaptive capacity, among other factors.

Mesoamerica

Agriculture in Central America and Mexico is very vulnerable to climate change due to warming and less rainfall. Main staples such as beans, maize, and rice—the main calorie source in the diets—will be significantly affected by both high temperatures and water scarcity. There may be a loss of 30 percent of grain output by 2080 in Central America, thereby increasing food insecurity in the region.[47] Maize yield may be down due to 15–20

[43] AIDA 2011.
[44] Simms and Reidd 2006.
[45] AIDA 2011.
[46] IFPRI 2009.
[47] Gutiérrez and Espinoza 2010.

percent less rainfall, and there will be further loss if temperature increases by more than 2°C. Bean yields will reduce if temperatures rise by 1–2°C, whereas rice yields may diminish if temperature increases by more than 1.5°C. Without adapting these crops to climate change, expected yields at the end of this century will be 1.4 tons per hectare (t ha^{-1}) for maize (from today's 2 t ha^{-1}), 0.1 t ha^{-1} for beans (vs. > 0.7 t ha^{-1} in 2009), and 2 t ha^{-1} for rice (vs. current 3.5 t ha^{-1}).[48] The total cost of climate change in Central American agriculture may amount to between 13.7 and 18.5 percent of the gross domestic product in 2100.

Climate change will have major impacts on smallholders in Mexico whose livelihoods depend on rain-fed maize. Climate models indicate that there will be a shift in spatial distribution patterns of agro-climate environments due to drying and warming trends. Although maize farmers are used to saving seeds from previous harvests or obtaining them from fellow farmers, some of them (especially those from the highlands) will need to get seed from outside their geographical range.[49] Hence, traditional maize seed systems will be affected by climate change in the main center of crop diversity.

Temperatures have risen by between 0.2 and 1°C and rainfall has declined by 15 percent during the last three decades in coffee-growing areas of Mesoamerica. The suitability for producing high-quality coffee, such as the acidic Arabica, will be affected by heat, which also favors some pests, such as coffee rusts. Likewise, the crop cycle depends on rainfall patterns because first rainfalls trigger flowering, but under low or high rainfall coffee flowers and fruits drop from the tree, thereby reducing the quality and lowering market prices. ENSO has also affected coffee output: for example, 1 million 46-kg sacks were produced during the low rainfall El Niño years (2004 and 2006), whereas there were about 2 million 46-kg sacks in the very high rainfall La Niña years (2005 and 2007).[50] Climate change will affect coffee production in Central America significantly because there will be areas that will stop producing this crop (and growers will need to shift to other crops or even migrate), farmers in other areas will need to adapt the crop to new management practices, and there will be new suitable areas for farmers to grow coffee.[51]

Climate change may affect banana and plantain yields and their host plant resistance to pests. Temperature increases, which limit photosynthesis, will likely damage banana crops

[48] CEPAL 2011b.
[49] Bellon et al. 2011.
[50] Haggar 2008.
[51] Laderach et al. 2009.

in coastal areas but may allow expansion of current *Musa* farming toward higher elevations. Changes in annual rainfall patterns and water scarcity also affect banana and plantain yields. Although high temperatures may also be associated with increased pest pressure, the most damaging pest (black leaf streak or black Sigatoka) of banana and plantain may decrease in producing locations of Central America and other coastal areas in the continent[52] because a switch toward unfavorable environments for the pathogen (low relative humidity and rainfall affect its development adversely). Aphids (which are virus vectors), flower thrips, and mites may however increase their damage in the host plants at dry environments.

Caribbean Islands

Some of these islands are very vulnerable to weather-related events. For example, Hurricane Mitch destroyed one-third of the crop area in the Dominican Republic (thereby causing a loss worth US$278 million), and it damaged about 20 percent of crops, 80 percent of banana farms, and 100,000 small livestock in Haiti. The frequency of hurricanes and their intensity may increase in the Caribbean due to the changing climate, thereby affecting agriculture in the storm's path. The Caribbean may also suffer from decreased rainfall that could lead to severe and prolonged droughts. Climate change may also affect soil moisture levels and increase erosion and acidity, with clear impacts on agriculture.

Rising sea level may affect coastal areas by degrading ecosystems, eroding soils, increasing land salinity, and lowering water quality for agriculture. Sea level rise may also affect perennial crops (such as banana) and trees due to washing out of arable land and increased soil salinity. Scenario analyses suggest that the favorable period for the development of black Sigatoka and other foliar plant pathogens affecting bananas may be reduced.[53] However, as noted earlier, some aphids and mites may increase in drier environments, which could lead to higher crop damages.

Andean Community

The temperature has increased by approximately 0.1°C per decade, with only two years of the last two decades below the 1961–1990 mean, whereas rainfall has slightly increased in the last 60 years in the inner tropics but reduced in the outer tropics.[54] Future climate scenarios suggest a continued warming (4.5–5°C) for the tropical Andes by 2100, where temperatures may rise at high altitudes while rainfall will likely increase in the wet season and decrease

[52] CCAFS 2011.
[53] Pérez-Vicente and Porras.
[54] Vuille et al. 2008.

during the dry season, thereby affecting its hydrological cycle and reducing water for irrigation as well as the length of the growing period for crops. The productivity of agriculture may decrease between 12 and 50 percent due to the changing climate. For example, in Ecuador yield losses by 2080 may reach 20 percent for cacao and coffee, and 40 percent for banana and sugarcane.[55] Although maize yields may remain unchanged in Colombia, they are predicted to decline to almost zero in the Venezuelan Piedmont.[56] In Bolivia, rice productivity will decrease between 2 and 15 percent.[57]

Potato will be vulnerable to heat that affects the plant growth and tuber initiation, thereby reducing yield.[58] Rising temperatures will also affect dry matter content and starch formation negatively in this very important tuber crop, whose main center of diversity is the Andes. Warming temperature and humidity will increase late blight—the most damaging potato pest—which may expand above 3,000 m (where it is absent today). Potato tuber moth, which is now in coastal areas and inter-Andean valleys, will also climb due to climate change.

Freezing may become more frequent and intense during the winter, which could increase mortality rates in livestock (particularly sheep), whereas high temperatures during the sunlight may reduce milk production. There may be a slight impact on cattle weight in Bolivia if CO_2 effects are not taken into account, but CO_2 doubling coupled with a rise of 4°C will lead to up to 20 percent weight decrease (depending on the animal genotype and location). A lowering of relative humidity in the highlands (especially the plateau) may be a threat for native vegetation, including natural pastures and medicinal plants.

Southern Cone

In Argentina, rainfall increased while maximum temperature and solar radiation decreased during spring and summer in the last three decades of the twentieth century, and minimum temperature rose throughout the year.[59] As a result, summer crop yields increased, particularly in semiarid areas. Yield increases due to changes in climate were 38 percent in soybean, 18 percent in maize, 13 percent in wheat, and 12 percent in sunflower when comparing 1970–2000 with 1950–1970. Potential wheat yield has however been decreasing since the 1930s, mostly because of winter and spring warming in the central and northern part

[55] CEPAL 2010.
[56] Jones and Thornton 2003.
[57] Jarvis et al. 2011.
[58] Quiroz et al. 2011.
[59] Magrin et al. 2005.

of the pampas of Argentina. Any further temperature increase will lead to wheat yield reductions of 7.5 percent for each 1°C of temperature. Future scenarios suggest that temperature may rise 2–3°C and rainfall could slightly increase during spring and summer, which will lead to 4 percent less wheat yield on average throughout the country but with a great spatial variability. That is, wheat yield will be down by 30 percent in northern locations whereas it will rise by 20 percent in the southwest.[60] Wheat yields will increase by 14 percent in the pampas and will decrease by 10 percent in northern and central locations when CO_2 fertilization is included in the analysis. Depending on the scenario, soybean harvests in the pampas may drop by 22 percent or increase between 3 and 21 percent, whereas maize production may decline by 8–16 percent or increase by 2 percent.[61]

The total economic loss in agriculture due to climate change in Brazil may be R$7.4 billion in 2020 and R$14 billion in 2070.[62] Wheat and maize yields will be reduced by 30 percent and 15 percent respectively in Brazil, whereas soybean yields will be up by 21 percent[63] or down by 40 percent in 2070.[64] Arabica coffee harvests may decrease by 33 percent, especially in São Paulo and Minas Gerais. Bean, cotton, rice, and sunflower may also show yield decreases in the northeast, while sugarcane yields may double. Cassava yields may increase, although there will be a significant lost in the northeast.

The productivity of maize, rice, soybean, and pastures will increase by mid-century in Uruguay due to summer rains, whereas cotton, soybean, wheat, and livestock productivity will be negatively affected by climate change in Paraguay due to rising temperatures and changing rainfall patterns.[65] Bean, cassava, sesame, and sugarcane yields may, however, increase in this country. Whichever model is used, soybean seems to be a more suitable crop than maize for the changing climate in the Southern Cone.

Rainfed wheat yield will decrease 5–10 percent in northern and central Chile due to expected droughts, whereas by Biobío and further south it may increase (>30 percent) because of a rise of minimum temperatures in winter.[66] Bean, maize, potato, and sugar beet yields will be down from the north until Biobío but they will increase in the coast, “pre-

[60] Magrin et al. 2008.
[61] Travasso et al. 2006.
[62] Assad and Pinto 2008.
[63] CEPAL 2011a.
[64] Assad and Pinto 2008.
[65] CEPAL 2010.
[66] Neueschwander Alvarado and Zabaleta Caicheo 2010.

cordillera," and from La Auracania southwards. The productivity of annual pastures will be down in Atacama and from Coquimbo to Los Lagos due to less water availability in their soils, whereas it will be up in central Chile and in El Altiplano. Pastures yields will also decrease in the eastern cordillera due to reduced solar radiation, and from Biobío to Los Lagos due to lengthy dry periods, but these yields will rise up to 10 percent from Valparaíso to Río Maule due to increasing winter temperatures. Grape yields will decrease in northern Chile due to crop earliness thanks to high temperatures during winter and spring and in the Metropolitan zone to the south because of reduced solar radiation, high temperature and rainfall, and late spring frosts. Crop productivity may be up in Maule and Biobío, on the other hand, and from La Araucania southwards. Peach productivity may be affected as well as that of grapes. Apple yields will be down throughout the country until La Araucania because of heat stress (that is, less cold winters and warmer summers), which reduces the fruiting period.

4. Adapting Agriculture to Climate Change: One Size Does Not Fit All

Adapting agriculture to climate change needs to consider increases of temperatures, short growing seasons, and water stress and their impacts at three scale levels: global, national, and farm.[67] There will be global changes in consumers' patterns and food trade, whereas changes in land use, food supply, and prices are expected at the national level. Although there will be negative impacts of climate change in agriculture (as noted), there will be an opportunity to shape productive, competitive, and environmentally friendly agro-ecosystems. The approaches for adapting to climate change at the farm level will depend on farmers' choices of new crops and livestock, the use of climate-resilient cultivars and breeds, eco-friendly practices for crop and livestock production, sustainable intensification and diversification of farming systems, and options for other economic activities (including leaving agriculture when it becomes unprofitable).

The essential social components to consider for adapting to climate change include organization, social capital, governability, conflict management, education at all levels, capacity strengthening, knowledge sharing, information and communication, research, technology development, traditional and indigenous knowledge, and political incidence.68 Farmers, policy makers, and researchers will therefore need to work together to define a

[67] Rodríguez Vargas 2007.
[68] Arce Rojas 2011.

comprehensive strategy to adapt agriculture to climate change in each country of Latin America and the Caribbean.

It has been suggested that the region will need to invest an additional US$1.3 billion annually to fight malnutrition due to climate change.69 These investments will be mostly for agricultural research, irrigation efficiency and rural road improvements. Better infrastructure will help farmers to raise crop productivity and quality, reduce post-harvest losses, and secure their access to inputs and markets.

Adaptation measures include control of soil erosion, maintenance of soil fertility, changes in fertilizer use and application, dam construction for irrigation, diversification and sustainable intensification of farming systems, introduction of new crops with better adaptation to water stress and temperature extremes, switching to climate-resilient cultivars and breeds, timing of planting and harvest, a conducive policy environment for agriculture to deal with climate change, use of early warning systems, and weather index-based insurances for crops, livestock, and trees.

Farmers tend to modify their household economic portfolio to activities that are less vulnerable to climate in stressful seasons (for example, due to drought, floods, or extreme temperatures). Their access to information and resources, social capital, stage in the life cycle, and wealth all condition their ability to make this shift.[70] Timely, reliable, and relevant weather forecasts can help rural households decide on what livelihood strategy to pursue under a changing climate, such as relying on off-farm income or on agriculture. Diversification plays an important role for managing production risks, particularly in small farms.

Agro-biodiversity at the gene, species, and agro-ecosystem levels increases resilience to the changing climate.[71] Promoting agro-biodiversity remains therefore crucial for local adaptation and resilience of agro-ecosystems. For example, local breeds—which appear to be better than exotic germplasm at coping with climate change—and community-based, participatory breeding could assist in adapting livestock to global warming and drought. Likewise, diverse agro-silvi-pastoral systems may bring stability to the agro-ecosystems that could reach acceptable productivity levels under climate stress.

[69] Nelson et al. 2009.
[70] Valdivia et al. 2000.
[71] Ortiz 2011.

Agro-eco-zoning will help identify where the diverse crops, livestock, and trees could be more appropriate, thereby improving the agro-ecosystems and mapping vulnerable areas. The water requirements for producing any crop or livestock will be also an important factor to consider when selecting what is most suitable for drought-prone environments. Adapting agriculture to climate change will also rely on matching cultivars and breeds to future climates and on genetic enhancement of crops and livestock in order to cope with both climate variability and extremes, but also to promote farmer resilience and adaptability. Heat, drought, salinity, waterlogging, and inundation are among the most important abiotic stresses that will be exacerbated by climate change. Genetic enhancement (including the use of agro-biotechnology)[72] can help enhance crop adaptation to climate change, although it takes time to breed and disseminate newly bred germplasm into target agro-ecosystems. Likewise, host plant resistance will be very important because rising temperatures and variations in humidity may favor emerging pest epidemics. Private and public researchers are therefore breeding new crops that can survive in extreme climates and continue improving their yields in such harsh environments.

The private and public sectors are promoting integrated crop and land management, best practices for using fertilizers, and conservation agriculture in various Latin American farming systems. Conservation agriculture practices help reduce soil erosion and buffer crops against extreme climatic events—for example, reduced tillage and retention of crop residues can increase water harvest and offset shortages that will increase as temperature rises.[73] Farmers will need to adopt other techniques that harvest more rainfall, enhance soil moisture, avoid or reduce irrigation wastes to get "more crop per drop," and grow crops that can still perform and yield under water stress. Enhancing water use efficiency and water productivity at the watershed level through water harvest together with groundwater replenishing will lead to more resources available for crops, livestock, and trees. This could be further advanced by drip irrigation or water-circulating low-cost greenhouses. Alternative sources are also needed to ensure water availability, whereas other energy options (which do not depend on hydropower) should be sought.

The private sector has been researching new crop protection products that can help plants adapt to stresses due to changing climate patterns. For example, a new sprayable formulation blocks plants' natural negative responses to drought stress like wilting leaves and

[72] Ortiz 2008.
73 Reynolds and Ortiz 2010.

poor seed formation, thereby increasing their health and yield potential. Productivity gains of 15 percent were noted in maize and wheat field trials, as well as enhanced yields in cotton and rice plots across some sites in Latin and North America.

Governments should promote traditional knowledge along with new practices for collecting and using water or preserve the soil. (See Figure 6.) Local coping approaches—based on indigenous knowledge—cannot be ignored when adapting agriculture to the changing climate.[74] Examples of this include the "waruwaru," which are raised fields used in the Altiplano of Peru that provide moisture during dry spells, drainage during floods, and a buffer against night frosts; the small dam "qhuthañas" used by Aymaran people in Bolivia to collect and store rainwater; the "Cajete Terrace" agro-ecosystem in the hillsides of Tlaxcala in Mexico that collects water and prevents soil loss; and the use of building barriers made with stone and pine suckers in Central American slopes to cope with drought, conserve soil, and provide edible fruit plus extra income to smallholders. In this regard, the Inter-American Development Bank has provided funding to Peru for restoring "andenes," which is an old pre-Columbus land management system in the steep hillsides of the Andes that makes land available for cropping, increases the efficiency of water use, and avoids soil erosion. Agro-forestry may also be useful for preserving water resources, improving soils, and stabilizing local climates.

Adaptation of agriculture to climate change should be regarded as a public good, which therefore requires sound policy to support farmers, especially smallholders, who at the end will be the main players to adapt the production of their crops, livestock, and trees to the changing climate. They are on the front lines to implement many of the adaptation measures described if they receive sound and reliable incentives. Otherwise, the rural poor—who are among the most vulnerable—will lack the means to break the downward spiral of poverty and to achieve sustainable development. In this regard, access to micro-financing programs can also assist small farms to adapt to climate change. Of course, such micro-credit schemes should be transparent and well regulated to be fully beneficial.

74 UNFCCC 2007.

5. Greenhouse Gas Emissions and Climate Change Mitigation

Agriculture accounts for about one-third of global GHGs, mainly due to tropical deforestation, methane emissions from livestock and rice farming, and nitrous oxide emissions from fertilized soils with nitrogen and manure. Greenhouse gas emissions are, however, relatively low in Latin America and the Caribbean (about 7 percent of total GHG and 12 percent of CO_2). Furthermore, agriculture in the region contributes only 14 percent of the total GHG versus 65 percent for the industry and energy sectors. Nonetheless, most of the GHG emissions in Latin America and the Caribbean derive from land use change, making the region the largest contributor of CO_2 (48 percent) due to this one cause. The main country contributors are Brazil, Mexico, Venezuela, Argentina, Colombia, and Peru, which together account for 83 percent of GHG emissions in the region.

Avoiding deforestation and using appropriate land use management are very important for curbing GHG emissions.[75] Agricultural intensification is a key factor for both ensuring food production and mitigating climate change.[76] Crop productivity gains should be prominent in the strategy to reduce GHG emissions—higher crop yields due to the Green Revolution, for instance, avoided emissions of up to 161 gigatons of carbon (GtC) (590 GtCO2e) since 1961.[77] Increasing yields on existing croplands also helps to curtail the expansion of agriculture into tropical forests. Protected areas in the Amazon forests can further reduce CO2 emissions.[78] Likewise, not burning crop residues and weeds will be very important for mitigating GHG emissions and preserving soils.

The private sector has issued and distributed product-specific codes of best agricultural practices to maximize product efficiency and plant nutrient uptake, while reducing any adverse effects on the environment. The fertilizer industry has been further assessing feasible carbon sequestration practices and urging farmers to engage in best management practices to maximize agriculture's contribution to carbon sequestration. The private sector has also been working on technology options for minimizing pre- and post-harvest losses, because that can reduce GHG emissions. Pre- and post-harvest crop loss due to pests could double without crop protection products. The plant science industry has been researching methods for enhancing food quality and safety as well as for reducing waste

75 Galford et al. 2010.
76 DeFries and Rosenzweig 2010.
77 Burney et al. 2010
78 Soares-Filho et al. 2010

along the food chain. About 30 percent of all food worldwide is wasted today. Some entrepreneurs are further improving safety testing protocols for food-handling and processing equipment, as well as designing new storage techniques, cold-chain systems, and transportation infrastructure to curb GHG emissions. Renewable farm-grown sources are also being used by the industry to produce polymers that replace petroleum-derived materials. They are being used for textile fibers and fabrics, carpeting, packaging (films, sealants, foams, and containers), and personal care.

Appropriate amounts and timing of nitrogen applications may help lower emissions without affecting crop yields. Resource-conserving technology can further reduce GHG emissions by enhancing precision when applying fertilizers (especially nitrogen) and water; for instance, optical hand-held sensors are increasingly used in precision agriculture for the site-specific estimation of nitrogen fertilizer requirements. Conservation agriculture practices such as direct seeding and decreasing tillage have additional benefits, such as improving nitrogen use efficiency and reducing use of fossil fuels, thereby reducing GHG emissions. Furthermore, herbicide-tolerant crops provided by the private seed sector to farmers worldwide have been helping with the adoption of no-till farming practices, which plays a major role in curtailing GHG emissions, sequestering soil carbon, and preserving soil and field biodiversity. Soil carbon sequestration gains associated with decreasing tillage when using biotech crops saved about 16.3 billion kg of CO2 in 2009, which is the equivalent of removing 7.2 million cars from the road.

Genetic enhancement of crops shows great potential for reducing N2O emissions from soils into the atmosphere. Crops are therefore being bred for nitrogen use efficiency because this trait will be a key factor for reducing nitrogen fertilizer pollution as well as for improving yields in nitrogen-limiting environments. Emissions during the rice-growing season can be reduced by various practices, such as by keeping the soil as dry as possible and avoiding waterlogging, by incorporating organic materials in the dry period rather than in flooded periods, by composting the residues before incorporation, or by producing biogas for use as fuel for energy production.

Livestock is a key driver of environmental change.[79] Managing livestock to make the most efficient use of feeds often reduces amounts of methane produced. For example, forage

79 Pelletier and Tyedmers 2010.

legumes with low tannin content can improve the diet quality in ruminants. Adoption of improved pastures, intensifying ruminant diets, changes in land use practices, and changing breeds of large ruminants on the production of methane and CO2 may account for 7 percent of the global agricultural mitigation potential to 2030.[80] The objective will be therefore to minimize emissions per unit of animal product when managing livestock with the aim of increasing their productivity. The use of biodigestors will be another approach for mitigating emissions for animals confined in small areas (such as swine and dairy). The processing of their waste and capturing of methane will be of further use for flaring (thereby generating carbon credits because they are less potent as GHGs than methane) or for generating electricity on-farm or for local use.[81] Silvi-pastoral systems combining productive forage grasses and trees can also be used to recover degraded pasturelands, because they can capture significant amounts of carbon from the atmosphere and retain it in their deep root systems. They can be a more efficient and less destructive alternative to cattle ranching.

6. Outlook

The impacts of climate change in agriculture can be measured by productivity loss due to extreme temperatures, which affect growth cycles, and water stresses that reduce yield. Solar radiation changes can also influence biomass accumulation, whereas CO_2 concentration levels will affect photosynthesis, water, and nitrogen efficiency. Climate change will cause further declines in water runoff, which may affect the water supply for agriculture.

Climate change is already happening, as noted by the increased frequency and intensity of storms, drought, flooding, other extreme weather events, salinity, altered hydrological cycles, and rainfall. Although the models for predicting climate may provide contradictory scenarios, most of them indicate that the most vulnerable areas in the continent are the South American Andes, Central America, and the Caribbean islands.

The impacts of the changing climate on agro-ecosystems and food availability and prices depend on the farming system, size, and location. The challenges that farmers and consumers will face relate to food supply, distribution, and access. How to adapt agriculture to climate change will remain the main challenge of next decades. Some adaptation options are given in Table 3. For example, farmers will need better weather forecasts combined with sound information to select climate-resilient crops, breeds, and trees capable of withstanding

80 Thornton and Herrero 2010.
81 Rodríguez 2007.

the new climates. Improving farmers' ability to use water and fertilizers efficiently, as well as their management of fragile soils, is essential for adapting agriculture to the shocks of climate change.

Agriculture needs to reduce GHG emissions to mitigate climate change, as well as to phase out water and air pollution, eliminate unsustainable water withdrawals, and avoid biodiversity and habitat losses. A more efficient use of land, water, and other natural resources by agriculture will be very important. Table 3 summarizes some mitigation actions needed to succeed in this endeavor. They include, among others, avoiding deforestation, appropriate land management, agricultural intensification to curtail expansion to forests, protected areas (for example, in Amazon forests), not burning crop residues and weeds, proper amounts and timing of nitrogen fertilizers, the use of resource-conserving technology, crop breeding for input efficiency, managing livestock feeds and diets, and silvi-pastoral systems.

Table 3. Summary of some adaption and mitigation options to address climate change and its impacts on or from agriculture

Adaptation

- Develop sound forecasts that facilitate farmers' adoption of climate-resilient technologies
- Improve land and water management
- Use climate-resilient seeds and breeds
- Re-value indigenous and traditional knowledge for addressing climate change
- Strengthen interdisciplinary research on adaptive capacity of agriculture
- Provide incentives to farmers for engaging practices to adapt to climate change
- Offer risk management tools to help farmers manage weather and market variations
- Invest in infrastructure (such as roads) that gives farmers better access to inputs and markets

Mitigation

- Intensify agriculture sustainably to enhance productivity of agro-ecosystems
- Promote conservation agriculture and other resource-conserving technology
- Reduce emissions by minimizing pre- and post-harvest losses and waste on food systems
- Lessen livestock- and rice-related emissions
- Avoid deforestation and promote reforestation and afforestation
- Reward farmers and the food industry for mitigating climate change
- Ensure agriculture becomes eligible for voluntary carbon credits for greenhouse offsets
- Extend carbon markets' scope to include the critical role of soil as a carbon sink

Governments should use planning and management tools to adapt to and mitigate climate change in agriculture. They should provide incentives for farmers to engage in practices toward adapting their farming to climate change. Likewise, farmers will benefit from risk management tools to manage weather and market variations. Rewards should also be given to farmers and food industry companies whose practices help mitigate climate change. Knowledge management systems—at both national and regional levels—for sharing information on best practices and relevant technology will help address the challenges brought to agriculture by the changing climate.

Integrated approaches are needed to adapt agriculture to climate change and mitigate its GHG emissions. The agenda should therefore focus on livelihood improvements coupled with agro-ecosystem resilience, eco-efficiency, and sustainability rather than just on productivity gains. Intensifying agro-ecosystems sustainably by producing more food with lower inputs, adapting agriculture to climate change (as well as mitigating climate change through eco-efficiency in agriculture), conserving agro-biodiversity through its use, adding value throughout the food chain, improving the nutritious quality of the human diet, and making markets work for smallholders are all key steps needed to address climate change and vital development issues.

References

AIDA (Asociación Interamericana para la Defensa del Ambiente). 2011. *The Human Rights Impacts of Climate Change in the Americas*. Oakland, CA, Mexico D.F., and Bogota, Colombia.

Altieri, M., and C. Nicholls. 2008. Los impactos del cambio climático sobre las comunidadescampesinas y de agricultores tradicionales y susrespuestas adaptativas. *Agroecología* 3: 7–28.

Arce Rojas, R. 2011. *Adaptación al Cambio Climático. Una Perspectiva Regional. Sistematización del Diálogo Regional de Adaptación y de Aprovechamiento de Aguas de la Agricultura al Cambio Climático en los Andes*. Serie Documentos de ReferenciaPrograma AACC Adaptación de la agricultura y del aprovechamiento de aguas de la agricultura alcambio climático en los Andes. Paísesandinos 2010–2013. Bonn, Germany: Deutsche GesellschaftfürInternationaleZusammenarbeit.

Assad, E. D., and H. S. Pinto (eds.). 2008. *Aquecimento Global e a nova Geografia da Produçãoagrícola no Brasil*. Empresa Brasileira de Pesquisa Agropecuaria, Brazil.

Baethgen, W. E. 1997. Vulnerability of the agricultural sector of Latin America to climate change. *Climate Research* 9: 1–7.

Battisti, D. S., and R. L. Naylor. 2009. Historical warnings of future food insecurity with unprecedented seasonal heat. *Science* 323: 240–44.

Bellon, M., D. Hodson, and J. Hellin. 2011. Assessing the vulnerability of traditional maize seed systems in Mexico to climate change. *Proceedings of the National Academy of Sciences* 108: 13432–37.

Bradley, R. S., M. Vuille, H. F. Diaz, and W. Vergara. 2006. Threats to water supplies in the tropical Andes. *Science* 312: 1755–56.

Bronnimann, S., J. Luterbacher, J. Staehelin, T. M. Svendby, G. Hansen, and T. Svenoe. 2004. Extreme climate of the global troposphere and stratosphere in 1940–42 related to El Nino. *Nature* 431: 971–74.

Burney, J. A., S. J. Davis, and D. B. Lobell. 2010. Greenhouse gas mitigation by agricultural intensification. *Proceedings of the National Academy of Sciences* 107: 12052–57.

CCAFS (Climate Change, Agriculture and Food Security). 2011. *Banana Boom and Bust as Climate Changes*. Copenhagen, Denmark.

CEPAL (Comisión Económica para América Latina y el Caribe). 2010. *La Economía del Cambio Climático en América Latina y el Caribe - Síntesis.* Santiago, Chile.

———. 2011a. Agricultura y cambio climático: instituciones, políticas e innovación. *CEPAL Serie Seminarios y Conferencias* 65. Santiago, Chile.

———. 2011b. *La Economía del Cambio Climático en Centroamérica. Reporte Técnico 2011.* Mexico D.F.

Cline, W. R. 2007. *Global Warming and Agriculture: Impact Estimates by Country*. Washington DC: Center for Global Development and Peterson Institute for International Economics.

DeFries, R., and C. Rosenzweig. 2010. Toward a whole-landscape approach for sustainable land use in the tropics. *Proceedings of the National Academy of Sciences* 107: 19627–32.

de la Torre, A., P. Fajnzylber, and J. Nash. 2009. *Low Carbon, High Growth: Latin American Responses to Climate Change – An Overview*. Washington, DC: International Bank for Reconstruction and Development/ World Bank

Foley J. A., N. Ramankutty, K. A. Brauman, E. S. Cassidy, J. S. Gerber, M. Johnston, N. D. Mueller et al. 2011. Solutions for a cultivated planet. *Nature* 478: 337–42.

Galford, G. L., J. M. Melillo, D. W. Kicklighter, T. W. Cronin, C. E. P. Cerri, J. F. Mustard, and C. C. Cerri. 2010. Greenhouse gas emissions from alternative futures of deforestation and agricultural management in the southern Amazon. *Proceedings of the National Academy of Sciences* 107: 19649–54.

Ghini, R., E. Hamada, M. J. P. Júnior, J.A. Marengo, and R. Ribeiro do Valle Gonçalves. 2008. Risk analysis of climate change on coffee nematodes and leaf miner in Brazil. *Pesquisa Agropecuaria Brasileira* 43: 187–194.

Gutiérrez, M. E., and T. Espinoza. 2010. Vulnerabilidad y adaptación al cambio climático: Diagnóstico inicial, avances, vacíos y potenciales líneas de acción en Mesoamérica. *Notas Técnicas* IDB-TN-144. Washington, DC: Inter-American Development Bank.

Haggar, J. 2008. *Impact of ClimateChange on Coffee Farming Households in Central America and Steps for Adaptation in the Future.* Turrialba, Costa Rica: Centro Agronómico Tropical de Investigación y Enseñanza.

Harmeling, S. 2009. *Global Climate Risk Index 2010*. Berlin: Germanwatch e. V.

Haylock, M. R., T. C. Peterson, L. M. Alves, T. Ambrizzi, Y. M. T. Anunciação, J. Baez, V. R. Barros et al. 2006. Trends in total and extreme South American rainfall 1960–2000 and links with sea surface temperature. *Journal of Climate* 19:1490–512.

IDB (Inter-American Development Bank). 2010. *IDB Integrated Strategy for Climate Change Adaptation and Mitigation, and Sustainable and Renewable Energy*. Washington, DC.

IFPRI (International Food Policy Research Institute). 2009. *Impact of Climate Change on Agriculture – Factsheet on Latin America and the Caribbean*. Washington, DC.

Isbell, P. 2011.What climate change means for Latin America. *Hemisphere* 20:19–21.

Jarvis A., J. Ramìrez, O. Bonilla-Findji, and E. Zapata. 2011. Impacts of climate change in crop production in Latin America. In S. S.Yadav, R. J. Redden, J. L. Hatfield, H. Lotze-Campen, and A. E. Hall (eds.), *Crop Adaptation to Climate Change*, 44–56. New York: John Wiley & Sons, Ltd and Blackwell Publishing Ltd.

Jones, P. G. and P. K. Thornton. 2003. The potential impact of climate change on maize production in Africa and Latin America in 2055. *Global Environmental Change* 13: 51–59.

Koutsoyiannis, D., A. Efstratiadis, N. Mamassis, and A. Christofides. 2008. On the credibility of climate predictions. *Hydrological Sciences* 53: 671–84.

Laderach, P., A. Jarvis, J. Ramirez, A. Eitzinger, and O. Ovalle. 2009. *The Implications of Climate Change on Mesoamerican Agriculture and Small-farmers Coffee Livelihoods.* Hamburg, Germany: Tropentag 2009, 6–8 October.

Lobell, D. B., and C. B. Field. 2007. Global scale climate–crop yield relationships and the impacts of recent warming. *Environmental Research Letters 2* DOI:10.1088/1748-9326/2/1/014002.

Lobell, D. B., M. B. Burke, C. Tebaldi, M.D. Mastrandrea, W. P. Falcon, and R. L. Naylor. 2008. Prioritizing climate change adaptation needs for food security in 2030. *Science* 319: 607–10.

Magrin, G. O., M. I. Travasso, and G. R. Rodríguez. 2005. Changes in climate and crop production during the 20th century in Argentina. *Climatic Change* 72: 229–49.

———. 2008. Global warming and wheat production in Argentina. In *Proceedings of the Global Conference on Global Warming –2008 (GCGW-08)*, Istanbul, Turkey, 6–10 July.

Magrin, G., C. Gay García, D. Cruz Choque, J. C. Giménez, A. R. Moreno, G. J. Nagy, C. Nobre et al. 2007. Latin America. In Intergovernmental Panel on Climate Change, *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, 581–615.Cambridge, U.K.: Cambridge University Press.

Maletta, H. 2009. El pan del futuro: cambio climático, agricultura y alimentación en América Latina. *Debates en Sociología* 34: 117–76.

Marengo, J., R. Jones, L. M. Alves, and M. C. Valverde. 2009. Future change of temperature and precipitation extremes in South America as derived from the PRECIS regional climate model system. *International Journal of Climatology* DOI: 10.1002/joc.186.

Marengo, J. A., M. Rusticucci, O. Penalba, and M. Renom. 2010. An intercomparison of model-simulated in extreme rainfall and temperature events during the last half of the twentieth century: part 2: historical trends. *Climate Change* 98: 509–29.

Mendelsohn, R., A. F. Dias Ávila, and N. Seo. 2007. *Proyecto: Incorporación del Cambio Climático a las Estrategias de Desarrollo Rural – Síntesis de los Resultados en América Latina.* Montevideo, Uruguay: Programa Cooperativo para el Desarrollo Agroalimentario y Agroindustrial del Cono Sur.

Neelin, J. D., M. Münnich, H. Su, J. E. Meyerson, and C. E. Holloway. 2006. Tropical drying trends in global warming models and observations. *Proceedings of the National Academy of Sciences* 103:6110–15.

Nelson, G. C., M. W. Rosegrant, J. Koo, R. Robertson, T. Sulser, T. Zhu, C. Ringler et al. 2009. *Climate Change Impact on Agriculture and Costs of Adaptation*. Washington, DC: International Food Policy Research Institute.

Nelson, G. C., M. W. Rosegrant, A. Palazzo, I. Gray, C. Ingersoll, R. Robertson, S. Tokgoz et al. 2010. *Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options*. Washington, DC: International Food Policy Research Institute.

Neueschwander Alvarado, A., and J. F. Zabaleta Caicheo. 2010. *El Cambio Climático en el Sector Silvoagropecuario de Chile*. Santiago, Chile: Fundación para la Innovación Agraria.

Ortiz, R. 2008. Crop genetic engineering under global climate change. *Annals of Arid Zone* 47: 343–54.

———. 2011. Agrobiodiversity management for climate change. In J. Lenné and D. Wood (eds.), *Agrobiodiversity Management for Food Security: Critical Review*, 189–211. Wallingford, U.K: CAB International.

Ortiz, R., K. D. Sayre, B. Govaerts, R. Gupta, G. V. Subbarao, T. Ban, D. Hodson et al. 2008. Climate change: Can wheat beat the heat? *Agriculture, Ecosystems & Environment* 126: 45–58.

Pelletier, N., and P. Tyedmers. 2010. Forecasting potential global environmental costs of livestock production 2000–2050. *Proceedings of the National Academy of Sciences* 107: 18371–74.

Peng, S., J. Huang, J. E. Sheehy, R. C. Laza, R. M. Visperas, X. Zhong, G. S. Centeno et al. 2004. Rice yields decline with higher night temperature from global warming. *Proceedings of the National Academy of Sciences* 101: 9971–75.

Pérez-Vicente, L., and A. Porras. 2011. Potential impact of climate change on banana and plantain pests and diseases in Cuba. In ISHS/Pro*Musa* symposium *Bananas and plantains: Toward sustainable global production and improved uses. Program and Abstracts*, 39. Bahia Othon Palace Hotel, Salvador, Brazil, 10–14 October, International Society of Horticultural Science, Pro*Musa*, Bioversity International, Empresa Brasileira de Pesquisa Agropecuária, Salvador, Brazil.

PNUMA (Programa de las Naciones Unidas para el Medio Ambiente). 2010. *Gráficos Vitales del Cambio Climático para América Latina y El Caribe*. Comisión Económica para América Latina y el Caribe, Panama City, Panama.

Quiroz, R., A. Posadas, C. Yarlequé, H. Heidinger, C. Barreda, R. Raymundo, C. Gavilán et al. 2011. *Challenges to Sustainable Potato Production in a Changing Climate: A Research Perspective*. Conference at the 95th Annual Meeting of the Potato Association of America, 15 August, Wilmington, N.C.

Reynolds, M. P., and R. Ortiz. 2010. Adapting crops to climate change: A summary. In M. P. Reynolds (ed.), *Climate Change and Crop Production*, 1–8. Wallingford, U.K.: CAB International.

Rodríguez, A. G. 2007. Cambio climático y agricultura: implicaciones para la adaptación y las políticas públicas. VIII Reunión del Foro Regional Andino para el Diálogo y la Integración de la Educación Agropecuaria y Rural, Universidad Nacional Agraria La Molina, Lima, Perú. 27 November – 1 December.

Rodríguez Vargas, A. 2007. Cambio climático, agua y agricultura. *ComunIICA* 1 (II Etapa): 13–23.

Schmidhuber ,J., and F. N. Tubiello. 2007. Global food security under climate change. *Proceedings of the National Academy of Sciences* 104: 19703–08.

Seo, S. N. 2008. Agricultural systems in South America under climate change: A microeconometric analysis. Working Paper Series. Available at SSRN: http://ssrn.com/abstract=1192922.

Seo, S. N., and R. Mendelsohn. 2006. Climate change impacts on Latin American farmland values: The role of farm type. *Revista de Economia e Agronegócio* 6: 159–76.

Sheridan, J. A., and D. Bickford. 2011. Shrinking body size as an ecological response to climate change. *Nature Climate Change* 1: 401–06.

Simms, A., and H. Reid (compilers). 2006. *Up in Smoke? Latin America and the Caribbean. The Threat from Climate Change to the Environment and Human Development.* The Third Report from the Working Group on Climate Change and Development. Oxford: Oxfam Publishing.

Soares-Filho, B., P. Moutinho, D. Nepstad, A. Anderson, H. Rodrigues, R. Garcia, L. Dietzsch et al. 2010. Role of Brazilian Amazon protected areas in climate change mitigation. *Proceedings of the National Academy of Sciences* 107: 10821–26.

Thornton, P. K., and M. Herrero. 2010. Potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics. *Proceedings of the National Academy of Sciences* 107: 19667–72.

Travasso, M. I., G. O. Magrin, W. E. Baethgen, J. P. Castaño, G. R. Rodríguez, J. L. Pires, A. Giménez et al. 2006. Adaptation measures for maize and soybean in Southeastern South America. *AIACC Working Paper* 28. Washington, DC: Assessments of Impacts and Adaptations to Climate Change.

Trenberth, K. E., P. D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker et al. 2007. Observations: surface and atmospheric climate change. In Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC*, 235–336. Cambridge, U.K.: Cambridge University Press.

Tubiello F. N., J.-F. Soussana, and S. M. Howden. 2007. Crop and pasture response to climate change. *Proceedings of the National Academy of Sciences* 104: 19686–90.

UNFCCC (United Nations Framework Convention on Climate Change). 2007. *Climate Change: Impact, Vulnerabilities and Adaptation in Developing Countries.* Bonn, Germany.

Valdivia, C., C. Jetté, R. Quiroz, J. L. Gilles, and S. Materer. 2000. *Peasant Households Strategies in the Andes and Potential Users of Climate Forecasts: El Niño of 1997–1998*. Selected Paper at 2000 American Agricultural Economics Association Annual Meeting, 30 July – 2 August, Tampa, FL.

Vera, C., G. Silvestri, B. Liebmann, and P. González. 2006. Climate change scenarios for seasonal precipitation in South America from IPCC-AR4 models. *Geophysical Research Letters* 33: L13707.

Vergara, W., H. Kondo, E. Pérez Pérez, J. M. Méndez Pérez, V. Magaña Rueda, M. C. MartínezArango, J. F. Ruiz Murcía et al. 2007. *Visualizing Future Climate in Latin America: Results from the Application of the Earth Simulator*. *LAC Region Sustainable Development Working Paper* 30. Washington, DC: World Bank.

Verner, D. 2011. Social implications of climate change in Latin America and the Caribbean. *Economic Premise* 61. Washington DC: World Bank.

Vincent, L., T. Peterson, V. R. Barros, M. B. Marino, M. Rusticucci, G. Miranda, E. Ramirez et al. 2005. Observed trends in indices of daily temperature extremes in South America, 1960–2002. *Journal of Climate* 18: 5011–23.

Vuille, M., B. Francou, P. Wagnon, I. Juen, G. Kaser, B. G. Mark, and R. S. Bradley. 2008. Climate change and tropical Andean glaciers: Past, present and future. *Earth-Science Reviews* 89: 78–96.

Figure Captions

Fig. 1.Trends in annual temperature, 1979–2005
Source: CEPAL 2010, after Trenberth et al. 2007.

Fig. 2. Drought intensity index, 1990–2002: From driest (red) to wettest (dark blue)
Source: CEPAL 2010, after Trenberth et al. 2007.

Fig. 3. Changes of temperature as per scenarios A2 (left) and B2 (right)
Source: CEPAL 2010.

Fig. 4. Rainfall forecasts (%) per scenarios A2 (left) and B2 (right)
Source: CEPAL 2010.

Fig. 5. Climate change impact in agriculture of Central America, Ecuador, Chile, Argentina, Paraguay, and Uruguay
Source: CEPAL 2010, according to selected national sources.

Fig. 6. Andean farmers always face the challenges of climate. In the past they used various technology options such as "andenes" (upper left) for making land available for cropping, improving the efficiency on the use of water, and avoiding soil erosion in the steep hillsides, or artificial lagoons known as "cochas" (lower left) for storing water after the rains in the highlands—which were used for irrigating crops or for drinking by livestock—as well as built "waruwaru" or raised beds (right) for managing water after floods and used thereafter for rehabilitating marginal soils, improving drainage, storing water, using optimally available radiant energy, and attenuating frost.

Photos source: www.incas.info/incan-agriculture.html.