Agriculture and Future Climate in Latin America and the Caribbean: Systemic Impacts and Potential Responses

Walter Vergara
Ana R. Rios
Paul Trapido
Hector Malarín

Inter-American Development Bank

Climate Change and Sustainability Division

Environment, Rural Development, Disaster Risk Management Division

DISCUSSION PAPER

No. IDB-DP-329

February 2014

Agriculture and Future Climate in Latin America and the Caribbean: Systemic Impacts and Potential Responses

Walter Vergara
Ana R. Rios
Paul Trapido
Hector Malarín

Inter-American Development Bank
2014

http://www.iadb.org

Authors would like to acknowledge the contribution of Alba Collart (Mississippi State University). Special thanks are due to Lester Brown (Earth Policy Institute); José Joaquín Campos (CATIE); Andrew Jarvis (CIAT); Alejandro Deeb, Carlos Ludeña, Alfred Grunwaldt and Tomás Serebrisky (Inter-American Development Bank) for their comments to an earlier draft of this document.

Agriculture and Future Climate in Latin America and the Caribbean: Systemic Impacts and Potential Responses

Introduction

Agriculture plays a key role in the economy and the social fabric of Latin America and the Caribbean (LAC). The sector contributed 5% of the region's gross domestic product (GDP) in 2012. It also accounted for 19% of male and 9% of female employment during 2008-2011 (World Bank 2013). In addition, exports from Latin America represent a growing contribution to global agriculture trade –from 8% in the mid-1990s to about 13% in 2011 (World Bank 2012)– and now account for about 23% of the region's exports.[1] Therefore, the region's ability to produce and export agricultural commodities is expected to play an increasingly important role in global food security. At the same time, an estimated 49 million people are under-nourished in LAC (OECD-FAO 2012) and the agricultural share of total household income is more than 50% among poor rural households in some Latin American countries.[2]

Within this context, climate changes anticipated during this century may exert additional pressure on environmental conditions under which agriculture activity has developed, and –if not properly addressed– may ultimately result in significant economic and social impacts. Physical changes anticipated by commonly used future climate scenarios, of relevance for agricultural activity, include: increases in air and soil temperatures, changes in CO_2 concentrations in the atmosphere, sea level rise, changes in the hydrological cycle and in water quality and availability, intensification and increase in frequency of extreme weather events, including droughts and floods, changes in the altitudinal level of dew points, and others. Some of these changes are gradual and unidirectional, that is, they will show over time at a rate still uncertain but with a known direction. That is the case of increased temperatures, levels of CO_2 in the atmosphere and sea level rise. This document focuses on the implications for agriculture of those changes; other changes are more uncertain and variable (e.g. weather and rainfall patterns) and more research is still required to ascertain –with a higher degree of accuracy– their systemic implications on agriculture. The objective of this report is to highlight the need to better understand future climate implications for, and to plan for climate change adaptation actions in, the LAC agricultural sector. For this purpose, an overview of the sector's climate challenge[3] is presented, including the consequences of projected impacts and possible responses.

---

[1] Latin America has the second world largest remaining rain-fed crop production potential area (363 million ha), as well as the world's highest endowment of renewable water resources (13,500 km^3) and potential arable land (Alexandratos and Bruinsma 2012).

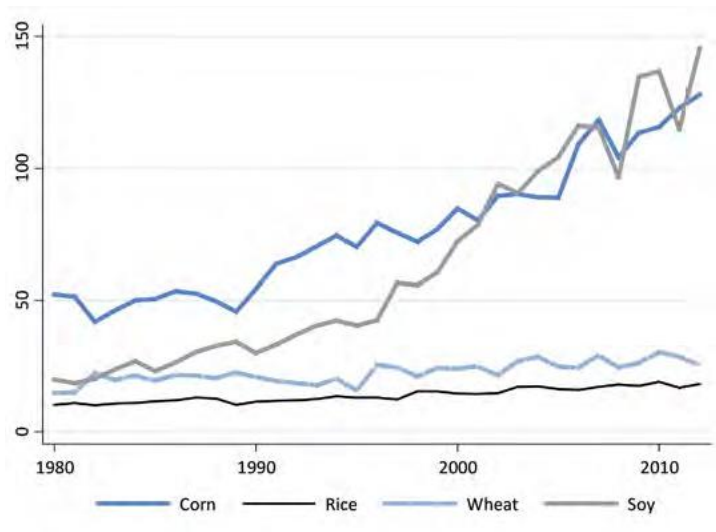
[2] These include –among others– Nicaragua (IFAD 2010), Brazil (World Bank 2003), and El Salvador (World Bank 1998).

[3] There may be some instances where climate change present opportunities rather than challenges. For instance, Magrin et al. (2005) indicate that increased precipitation in the Argentinean Pampas regions led to higher soybean, maize, wheat and sunflower yields (38%, 18%, 13% and 12% respectively).

LAC's agriculture sector

While, as of lately, there has been a great deal of sector diversification in the region, agriculture production remains a back bone of economic activity. The sector accounted for 5% of LAC's GDP in 2012, but contributed to more than 10% of total GDP in several countries (World Bank 2013).[4] LAC's aggregate output of agriculture is estimated to have surpassed US$300 billion in 2012, driven in large part by increases in the value of agricultural commodities (figure 1), but also gains in productivity and area under production. The region is also the main source of sugar, soybeans and coffee, supplying over 50% of worldwide exports for these commodities (FAO 2014).

Figure 1. Index of Agricultural Commodity Prices for Key Exports from Latin America



Source: OECD-FAO (2012)

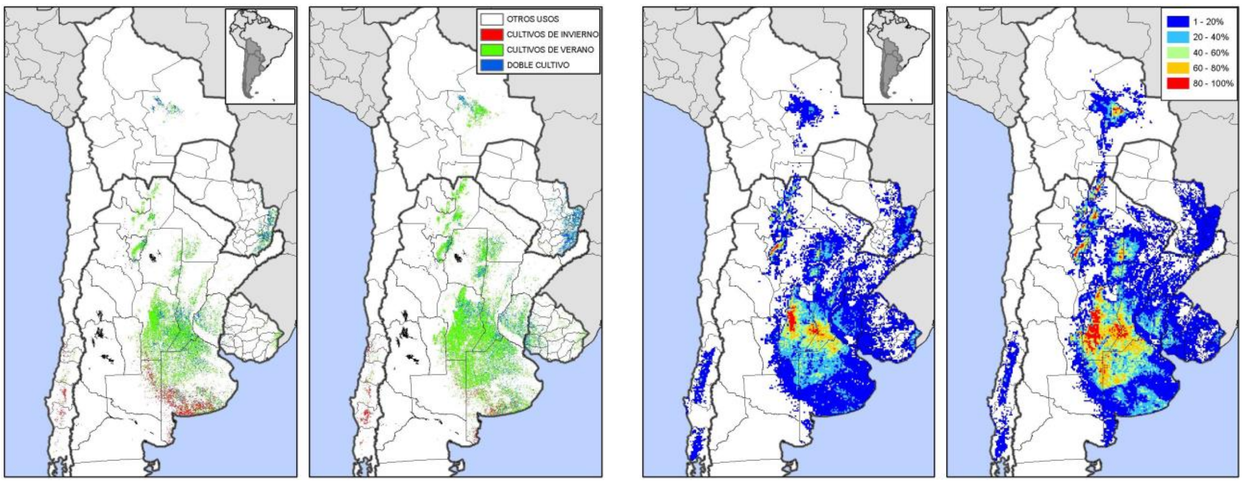
In terms of *area under agriculture*, the region has frequently been characterized as able to enter more of its land into production and, in fact, it placed an additional 31 million ha into agriculture between 2001 and 2011 (FAOSTAT 2013). For example, an overall 43% increase in cultivated land was observed in Argentina, Bolivia, Chile, Paraguay and Uruguay between the cropping cycles 2000/01 and 2010/11 (FONTAGRO-BID 2013). In addition, single-cropping decreased 66% for winter crops while a 59% increase in land planted with summer crops was registered (figure 2). This movement of the agricultural frontier came at the expense of a reduction of natural and cultivated pastures as well as an increase in deforestation. Similarly, an area slightly larger than Costa Rica (54,000 km^2) was converted to soybean cultivation in the agricultural-based states of Goias, Mato Grosso and Mato Grosso do Sul in Brazil (Chomitz et al. 2007). Intact and disturbed forests were the main source of new agricultural land between 1980 and 2000 in Latin America (Gibbs et al. 2010).

[4] The agricultural sector contributed to more than 10% of the total GDP in Uruguay (17%), Bolivia (13%), Nicaragua (19%), Honduras (15%), El Salvador (13%), Guatemala (11%), Guyana (21%), and Dominica (14%).

However, and while there remains a considerable potential for further expansion of agricultural land in the region, both in terms of potential arable land and freshwater availability, further increases of this magnitude may collide with land conservation and avoided deforestation efforts unless these concerns are carefully addressed or expansion of agricultural activity is directed to restore already degraded lands.

Figure 2. Movement of the Agricultural Frontier, Selected South American Countries

A. Annual crops: distribution B. Summer crops: density



2000/01 2010/11 2000/01 2010/11

Source: BID-FONTAGRO (2013)

The region has experienced continuing long term *increases in yields*, resulting from improved practices, better seeds and increased use of fertilizers and pesticides. Although yields may be already reaching a plateau in developed countries for many of the agricultural commodities (Grassini et al. 2013), productivity gaps still leave some room for yield gains in the region (Alston et. al. 2010). There is potential for future productivity gains among small and medium producers where significant efficiencies in the production system can be achieved. This requires enhanced management as well as increased investment in agricultural research, technical assistance and plant genetics.

Irrigation is an important channel to increment agricultural productivity and crop diversification (FAO 2000; Mollinga and Bolding 2004). Today, almost 90% of farmed land in LAC is rain-fed (Wani et al. 2009).[5] Other regions, like the Asia-Pacific region have a much higher rate of irrigated area in agriculture (ECLAC et al. 2012). Expanding the use of irrigation can thus increase LAC's food production, but it will require substantial additional infrastructure and capital.

---

[5] Irrigated land increased by almost 25% from 18 million ha in 1996 to 22 million ha in 2011 (FAOSTAT 2013).

From a *social perspective*, the economic impact of agriculture is small relative to other sectors, but farming activities employ a significant share of unskilled labor –a segment which ranges from 48% of total labor in Argentina to 91% in Nicaragua (Bambrilla et al. 2010)– and are a dominant livelihood strategy among subsistence farmers, accounting along with the rural nonfarm economy, 70% of total income of poor households (World Bank 2007).

Producers in the region are highly heterogeneous, ranging from subsistence farmers, who use few or no external inputs, to commercial farmers who make more intensive use of agrochemicals and are closely linked to international trade (Altieri and Toledo 2011). Smallholder farms are highly relevant for food security purposes. Across the region there are 15 million family farms, covering almost 400 million ha (Berdegué and Fuentealba 2011). These units practice traditional or subsistence agriculture and produce 51% of the maize, 77% of the beans, and 61% of the potatoes consumed in the region (Altieri and Toledo 2011; Altieri 1999). In Mexico, for instance, family farmers account for 70% and 60% of the total land devoted to maize and beans respectively (Altieri and Toledo 2011; Altieri 1999); whereas in Colombia –where coffee represents almost 22% of agricultural GDP– coffee plantations of five hectares or less represent 95% of all producers and 62.2% of the total area (Fonseca 2003).

Agriculture is also relevant from a *climate perspective* on account of its share of regional greenhouse gas (GHG) emissions. Agriculture, land-use, land-use change and forestry accounted for nearly two-thirds of LAC's emissions in 2005 (WRI 2012). This is almost a mirror image of the world's emissions profile dominated by energy use. About one third of the land-use change emissions are linked to net deforestation.[6] There is now hope that this contribution can be quickly reduced as avoided deforestation programs continue to succeed in the region and programs to recover degraded land take hold. The footprint from agriculture activities per se, on the other hand, is linked to practices and technologies representing long-held traditions and might be more difficult to address. Even under aggressive carbon emission reduction scenarios, agriculture will continue to contribute to the regional carbon signal in a significant way (Vergara et al. 2013). The sector is therefore key for any mitigation efforts. Furthermore, interventions in this area have the potential to simultaneously assist towards the achievement of a low-carbon, climate-resilient sustainable development.

Systemic climate impacts in agriculture in LAC

Systemic impacts, those affecting the agriculture sector at large and over time, are linked to the projected unidirectional changes in:

a) atmospheric and soil temperatures;
b) decreases in top soil moisture;
c) sea level rise; and,
d) CO_2 fertilization.

[6] Although the causal links of deforestation are complex, maize and soybean expansion are linked to a decrease in forest area in Latin America during 1990 and 2006 (Opio et al. 2013). In addition, land use change emissions in LAC are attributed to beef and industrial pig production (Opio et al. 2013, MacLeod et al. 2013).

There are also other changes such as modification in rainfall patterns, changes in pests and disease distribution and intensity, and changes in weather variability (incidence of droughts and floods), about which there is less consensus on the magnitude of the impacts and their evolution over time, but that are likely to exert significant pressure on the agriculture sector.

1.1 Atmospheric and soil temperatures

The anticipated changes in atmospheric and soil temperatures are a concern for agricultural yields. The major problem is that key crops might not be able to maintain photosynthesis activity as temperatures continue to rise.[7] While higher temperatures could generally promote growth, photosynthesis activity is known to drop rapidly once its optimum is reached. As the temperature rises above 35°C, photosynthesis slows, dropping to zero when it reaches 40°C (Brown 2004). For example, higher than normal atmospheric temperatures were the main factor for a significant drop in yields –18% for corn and about 10% for soybeans– in the U.S. during the summer of 2012 (Wescott and Jewison 2013).[8]

The average temperature anomaly for this century is now projected in the range of 2-6°C. However, warmer summer temperatures in agricultural areas particularly those in tropical latitudes may reach these thresholds with more frequency and earlier in the coming decades. Also, for some crops –such as grains–, faster growth reduces the amount of time that seeds have to mature, thus reducing their yields (USGCRP 2009). Moreover, climate change is inducing long term changes in the hydrology and ecology of ecosystems that could in turn affect agricultural production. Warmer temperatures are affecting evaporation and evapotranspiration rates, as well as water storage in lakes and reservoirs.[9] They are also changing the altitude of dew points, therefore affecting water balances in mountainous areas (Vergara et al. 2011).

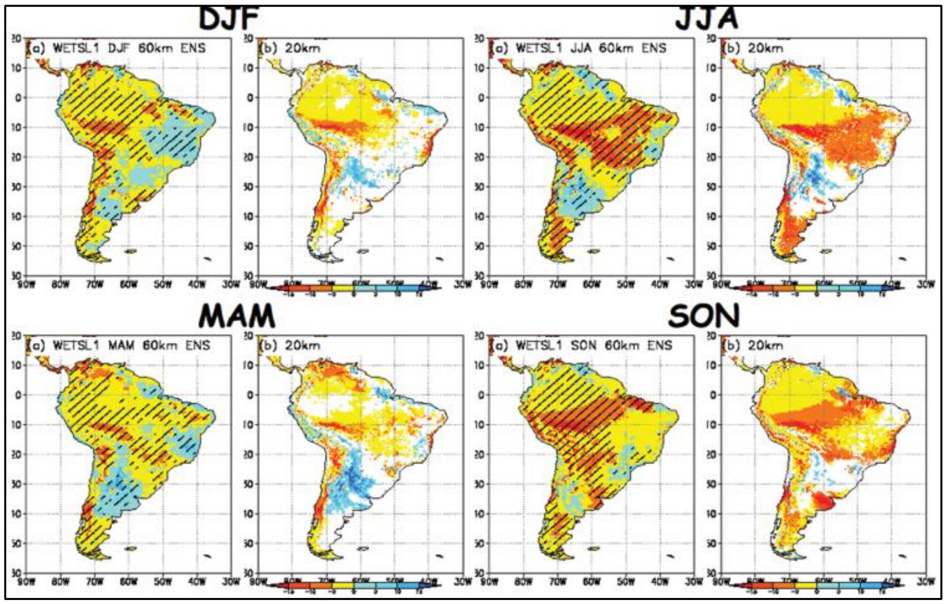
1.2 Decreases in top soil moisture

For most LAC, extended periods of drought and lower moisture levels have been anticipated as a consequence of climate change. A projection for Latin America, made in the context of an assessment of climate temperatures in tropical forests estimates a lengthening of dry periods in most of the region, and a significant decrease in top soil moisture (see figure 3). However, some of the major reductions were found to be forecasted for major food producing areas, such as the south eastern area of the Amazon basin in Brazil, the delta of the River Plate and coastal plains in northern South America.

---

[7] Temperatures higher than 29°C and 30°C are harmful for corn and soybean (Smith et al. 2008).
[8] In 2012, the corn producing region of the United States was 6°F above the average July temperature for the period 1980-2010.
[9] Rapid glacier retreat is affecting water storage and availability in areas where glaciers are the main source of water for human and agricultural consumption.

*Figure 3. Seasonal Changes in Top Soil Moisture in South America between the Present and the End of the 21st Century**



Source: Vergara and Scholz (2010)

* Yellow and red colors indicate largest negative anomalies. Each panel reflects three months in the year. Shaded areas indicate strong correspondence between coarse and fine grid projection using the Earth Simulator.

Water for agriculture already accounts for about 67% of total withdrawals in LAC (FAO 2013). A considerable reduction in land suitable for rain-fed agriculture could be the result of a decrease in top soil moisture and could be exacerbated by extended periods of drought. Irrigation requirements would then escalate placing pressure on existing infrastructure for water supply and increasing production costs. In addition, reductions in top-soil moisture are linked to an increase in soil aridity.[10] This is particularly relevant in LAC given its heavy reliance on rain-fed production systems, and small-scale agriculture in marginal areas.

1.3 Sea level rise

Agriculture in coastal areas and deltas is susceptible to the impact of sea level rise (SLR) through inundation of land, erosion, salinization of wells and land, and loss of ecosystems. Increases in sea water intrusion may affect coastal aquifers, making them unsuitable for use in agriculture and promote gradual salinization of coastal strips. SLR is of significant economic relevance as a number of productive areas are located near the coastline in the region. There is however no comprehensive assessment of the systemic impact that sea level rise would have in agricultural areas in costal zones and deltas.

Low lying areas in the region, where intensive agriculture is practiced, include the northern coastal plains of Colombia and Venezuela; the Gulf of Mexico and coastal areas in the Sea of Cortez, in Mexico; as well as the

[10] An overall rise in aridity is projected for all departments in Central America by 2020, with higher increases in locations that historically have presented more humid conditions CEPAL (2012).

deltas of the River Plate in Argentina, the Magdalena River in Colombia and the state of Maranhao in Brazil. Guyana exemplifies the impacts of sea level rise due to climate change in countries with high concentration of economic activity in their coastal plains. About 25% of the coastal plain territory (142,500 ha) in this country would be affected by sea level rise, including the intensification of storm surges, of which 59% are dedicated to agriculture (Government of Guyana 2012).

1.4 CO_2 fertilization

CO_2 concentrations have increased from about 280 ppm before the industrial revolution to about 400 ppm today and are anticipated to continue to increase under most climate scenarios. The consensus of many studies is that the CO_2 fertilization effect on plants is real: crop photosynthetic rates respond to increased levels of CO_2 until about 700 ppm, depending upon species and other variables (Allen et al. 1996). This effect begins with enhanced CO_2 fixation. Reproductive as well as vegetative biomass growth is usually increased by elevated CO_2. The net result of CO_2 fertilization is expected to be an increase in biomass production and therefore yields. In climate change scenarios, however, temperatures are predicted to increase following CO_2 increases. Temperature increases in a higher CO_2 world could increase vegetative growth; but, the interaction of these two variables may result in opposite effects on yields, if temperature thresholds are reached. Additional analysis is required to ascertain the net impacts on yields in a warmer world with higher atmospheric concentrations of CO_2.

1.5 Other impacts

Cumulative climate change impacts will affect the distribution of plants and animals, phenology, and ecological interactions.

Distribution of plants and animals. Alteration in the distribution of plants and animals includes the shift of tropical species and movement of altitude boundaries (Parmesan 2006, Laderach et al. 2009) as temperatures increase. Coffee may undergo a geographical redistribution in Brazil with an overall decrease in suitable land. Haggar and Schepp (2012) estimate that up to 33% of the current coffee area in Sao Paulo and Minas Gerais in Brazil (two main coffee producer states) may be lost while suitable area in Paraná, Santa Caterina and Rio Grande do Sul may increase. Similarly, suitable land for coffee production in Nicaragua may be reduced as the optimum altitude for coffee production rises from 1200 masl to 1400 masl and 1600 masl by 2020 and 2050 respectively (Laderach et al. 2009).[11] This trend towards more intense cultivation at higher elevations is leading in some instances to land use changes in upper water-sheds, displacing critical areas for the conservation of water regulation.

The diversity of the genetic resource pool is being threatened by climate change. Endemic varieties are less capable of moving and surviving as the agro-ecological conditions change. Around 20% of crop wild relatives of three major crops (peanuts, cowpea, and potato) could be threatened by extinctions by 2050 (Jarvis et al. 2008). Seven out of the 25 most critical places with high endemic species concentrations are in Latin America and these areas are undergoing habitat loss (Jarvis et al. 2011). There is a need not only to conserve genetic

[11] There is evidence that higher altitudes in the American Cordillera are experiencing a faster rate of warming (Bradley et al. 2004 and 2006, Ruiz et al. 2012).

resources but to undertake research aimed at identifying genetic traits which are key for adaptation (CGRFA 2011).

Phenology. This aspect includes inter alia, acceleration of growth, flowering and fruit ripening due to warmer temperatures (Root et al. 2003, Menzel 2005, Cleland et al. 2007, Sherry et al. 2011), and alterations in seed germination (Walck et al. 2011). Evidence indicates that spring has been advancing globally since the 1960s (Walther et al. 2002) at a rate between 2.3-5.1 days earlier per decade (Parmesan and Yohe 2003, Root et al. 2003), with observed changes in the timing of seasonal activities of animals and plants (Walther et al. 2002). This may affect production in southern areas of the continent.[12]

Ecological interactions. Warmer temperatures may also result in changes in the geographical range of pests, alterations in population growth rates, extension of the development season, and increased risk of invasion by migrant pests (Porter et al. 1991). As an example, an increase in pests and diseases due to climate change is reported in Colombia for bananas, plantain, coffee, potato, cacao, maize and cassava (Lau et al. 2013). However, management of the impacts of climate on beneficial insects and pests requires further research. Topics that have been suggested include the influence of climatic variables on beneficial and pests insects, long-term monitoring of population levels and possible implications of climate changes for insect management strategies.

Finally, while difficult to ascertain, with the information at hand, climate-induced weather variability and intensification of weather events have an impact on agriculture. Still, according to the OFDA/CRED International Disaster Database (EM-DAT), the frequency of floods and droughts in the Americas has risen 20-fold between the first half of the 20th century and the first decade of the 21st. Changes in extreme weather and climate events have occurred since 1950 including an increase in the frequency and intensity of warm days and nights, heat waves, heavy precipitation, droughts, cyclone activity and sea level (IPCC 2013). For example, in Central America, the frequency of floods more than doubled between 1970-1989 and 1990-2009 (CEPAL 2011). Estimated losses related to climate events in Peru during the period 1995-2007 were 444,707 ha of crop production, equivalent to US$910 million (Ministerio del Ambiente 2010). The agricultural sector in Central America reported estimated losses of US$155 million and over US$355 million from the impact of Hurricane Mitch and the tropical storm Stan respectively (CEPAL 2009).

[12] Climate change effects might extend to qualitative characteristics of agricultural production (Sugiura et al. 2013, Sun et al. 2012) and post-harvest losses (Magan et al. 2011), areas that might have important economic implications.

Possible adaptation actions

Climate change will thus lead to changes in crop production: some areas may become unsuitable for specific crops, while others become suitable for production. Crop yields may be reduced, and the costs of agriculture production could increase. On the aggregate, these changes will impact all agricultural activities, including large agro-industrial concerns as well as smallholder farm families. The latter group, however, may face the most severe impacts and have more limited resources with which to cope.

The financial impacts on agriculture could be significant. Parry et al. (2004), for example, project a yield reduction of around 20% in wheat and barley as a consequence of these impacts. A recent report projects that annual agricultural exports in LAC could be expected to decline by around US$50 billion by 2050 solely on account of climate impacts on crop yields, with an overall regional reduction of maize, soybean, wheat, and rice yields valued as high as US$8-11 billion loss in net export revenues by 2020 (Fernandes et al. 2012).[13] Maize could experience yield declines between 21% and 34% in Honduras, Guatemala, and Panama, while bean yields could drop by about 66% in Guatemala (ECLAC, FAO, and IICA 2012). Besides reductions in agricultural productivity, additional consequences might be triggered, including threats to food security, food market speculation, and possible increases in malnutrition.

Several studies have highlighted the urgency of implementing adaptation actions (e.g. Fernandes et al. 2012; Vergara et al. 2013) to deal with this challenge. It is estimated that the region requires an additional annual investment of USS1.1-1.3 billion[14] to adapt to climate change, with one-third of these resources directed to agricultural research (IFPRI 2009). Similarly, the World Bank (2010) approximates total adaptation needs for the agricultural sector in the region at US$1.2-1.3 billion annually.

Adaptation measures –for example, improved varieties and production practices including irrigation, soil conservation, minimum o no tillage, and water management– may prove to be effective in reducing the magnitude of the damage and losses resulting from the long-term, systemic impacts of climate change. Recent adaptation investments in the region include: improvements of climatic and oceanographic surveillance and deployment of early warning systems and use of climate change scenarios to plan adaptation measures (Mexico and the Caribbean); use of ancient knowledge to maximize soil water infiltration (Central and South America); conservation of high mountain ecosystems as an element to retain water (Colombia, Ecuador, Peru, Bolivia); identification, development and /or use of climate resilient varieties or breeds. However, there is still a long road ahead to ameliorate the socio-economic impacts of climate change in the agricultural sector.

Adaptation to long term, unidirectional impacts, will require the development of different types of programs and activities. This process should include at least the following elements:

a) Policy makers, farmers, private sector institutions, and investors must recognize that the region's agriculture faces an unprecedented challenge that will require a sustained adaptation effort to avert

[13] Reductions in yields are associated with moisture limitations during grain-filling and shortening of the crop cycle.
[14] Measured in 2000 US$.

long-term, systemic impacts of the types discussed above. That is, there is a need for a campaign to raise awareness of the anticipated impacts, timetables for these impacts and the associated economic and social effects.

b) Current agricultural policies, developed over time and without regard to the climate challenge, should be revised to channel public resources in new ways which are consistent with a low carbon climate resilient agriculture, as well as to promote investment in public goods such as agricultural research and extension services.

c) A major scale-up of collaboration efforts between research and extension institutes, the private sector, and governments is required to speed up adaptation aiming at: (i) the identification, production and commercialization of climate-resilient crop varieties, (ii) the systematization and dissemination of the use of traditional and local knowledge, (iii) the assessment of the long term implications of sea level rise and soil temperature for agriculture; and (iv) the evaluation of linkages to international trade and supply chains.

d) Strengthen data collection, monitoring, and forecasting as well as to build capacity for providing and using climate information services that target long-term trends.

e) Leverage public, private and international funding to maximize benefits within the agricultural sector through the implementation of climate resilient practices.

References

Alexandratos, N. and J. Bruinsma. 2012. World Agriculture towards 2030/2050: the 2012 Revision. ESA Working paper No. 12-03. Rome: FAO.

Allen L., J. Baker, and K. Boote. 1996. "The CO_2 Fertilization Effect" in *Global Climate Change and Agricultural Production: Direct and Indirect Effects of Changing Hidrological, Pedological and Plan Physiological Processes*. Edited by Fakhri Bazzaz and Wim Sombroek. FAO and John Wiley & Sons.

Altieri, M.A. 1999. "Applying Agroecology to Enhance Productivity of Peasant Farming Systems in Latin America." *Environment, Development and Sustainability* 1:197–217.

Altieri, M.A., and V.M. Toledo. 2011. "The Agroecological Revolution in Latin America: Rescuing Nature, Ensuring Food Sovereignty, and Empowering Peasants." *Journal of Peasant Studies* 38(3):587-612.

Bambrilla, I., R.D. Carneiro, D. Lederman, and G. Porto. 2010. "Skills, Exports, and the Wages of Five Million Latin American Workers." Policy Research Working Paper, The World Bank, Washington, DC.

Berdegué, J.A., and R. Fuentealba. 2011. "Latin America: The State of Smallholders in Agriculture." Conference on New Directions for Smallholder Agriculture, Rome, Italy, 24-25 January.

Bradley, R.S., F.T. Keimig, and H.F. Diaz. 2004. "Projected Temperature Changes Along the American Cordillera and the Planned GCOS Network." *Geophysical Research Letters* 31: L16210.

Bradley, R.S., M. Vuille, H.F. Diaz, and W. Vergara. 2006. "Threats to Water Supplies in the Tropical Andes." *Science* 312:1755–56.

Brown L. 2004. *Plan B: Rescuing a Planet Under Stress and a Civilization in Trouble*. Washington DC: Earth Policy Institute.

CEPAL. 2012. *La Economía del Cambio Climático en Centroamérica: Síntesis 2012.* Santiago, Chile.

—. 2011. *La Economía del Cambio Climático en Centroamérica.* Santiago, Chile.

—. 2009. *El Salvador: Efectos del Cambio Climático sobre la Agricultura*. Santiago, Chile.

CGRFA. 2011. "Coping with Climate Change: The Importance of Genetic Resources for Food Security." Rome: FAO.

Chomitz, K. M., P. Buys, G. De Luca, T.S. Thomas, and S. Wertz-Kanounnikoff. 2007. *At Loggerheads? Agricultural Expansion, Poverty Reduction, and Environment in the Tropical Forests*. Washington, DC: World Bank.

Cleland, E. E., I. Chuine, A. Menzel, H.A. Mooney, and M.D. Schwartz. 2007. "Shifting Plant Phenology in Response to Global Change." *Trends Ecol. Evol.* 22(7): 357-65.

ECLAC, FAO and IICA. 2012. *The Outlook for Agriculture and Rural Development in the Americas: A Perspective on Latin America and the Caribbean 2013.* Santiago, Chile: FAO.

EM-DAT. The OFDA/CRED International Disaster Database. Brussels, Belgium: Université Catholique de Louvain.

FAO. 2014. *Panorama de la Seguridad Alimentaria y Nutricional en América Latina y el Caribe 2014.* Rome.

—. 2013. AQUASTAT FAO Information System of Water and Agriculture. 2013. Rome

—. 2000. *Irrigation in Latin America and the Caribbean in Figures*. Rome.

FAOSTAT. 2013. FAOSTAT Database. Accessed December 2013.

Fernandes, E. C. M., A. Soliman, R. Confalonieri, M. Donatelli, and F. Tubiello. 2012. *Climate Change and Agriculture in Latin America, 2020–2050: Projected Impacts and Response to Adaptation Strategies*. Washington, DC: World Bank.

Fonseca, L.A. 2003. *Colombia: Escenario Social, Económico, e Institucional de la Actual Crisis Cafetalera*. Bogotá, Colombia: ECLAC.

FONTAGRO-BID. 2013. Informe Final del Componente 1: Caracterización de la Expansión Agrícola. Análisis Espacial. Coordinación, José Norberto Volante.

Gibbs, H.K, A.S. Ruesch, F. Achard, M.K. Clayton, P. Holmgren, N. Ramankutty, and J.A. Foley. 2010. "Tropical Forests were the Primary Sources of Key Agricultural Land in the 1980s and 1990s." *PNAS* 107(38):16732-37.

Government of Guyana. 2012. *Guyana Second National Communication to the United Nations Framework Convention on Climate Change*.

Grassini P., K.M. Eskridge and K.G. Cassman. 2013. "Distinguishing between Yield Advances and Yield Plateaus in Historical Crop Production Yields." *Nature Communications* 4:2918.

Haggar, J. and K. Schepp. 2012. *Coffee and Climate Change: Impacts and Options for Adaptation in Brazil, Guatemala, Tanzania and Vietnam.* NRI Working Paper Series: Climate Change, Agriculture and Natural Resources.

IFAD. 2010. *Rural Poverty Report 2011. New Realities, New Challenges: New Opportunities for Tomorrow's Generation.* Rome, Italy: International Fund for Agricultural Development.

IFPRI. 2009. *Climate Change: Impact on Agriculture and Costs of Adaptation.* Washington DC: IFPRI.

IPCC. 2013. *Climate Change 2013: The Physical Science Basis. Summary for Policymakers.* Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by T. F. Stocker, D. Qin, G. Plattner, M.M.B. Tignor, S.K. Allen. J. Boschung, A; Nauels, Y. Sia. V. Bex, P.M. Midgley.

Jarvis, A., A. Lane, and R.J. Hijmans. 2008. "The Effecgt of Climate Change on Crop Wild Relatives." *Agriculture, Ecosystems & Environment* 126(1-2):13-23.

Jarvis, A, H. Upadhyaya, C.L.L. Gowda, P.K. Aggarwal, S. Fujisaka, and B. Anderson. 2011. "Climate Change and its Effect on Conservation and Use of Plant Genetic Resources for Food and Agriculture and Associated Biodiversity for Food Security." FAO Thematic Background Study.

Laderach, P., A. Jarvis and J. Ramirez. 2009. "The Impact of Climate Change in Coffee-Growing Regions: The Case of 10 Municipalities in Nicaragua." Cooperación Público-Privada "AdapCC" Adaptación al Cambio Climático para los Pequeños Productores.

Lau, C., A. Jarvis, and J. Ramirez. 2013. Colombian Agriculture: Adapting to Climate Change. CIAT Policy Brief No. 1 Centro Internacional de Agricultura Tropical (CIAT). Cali, Colombia.

MacLeod, M., P. Gerber, A. Mottet, G. Tempio, A. Falcucci, C. Opio, T. Vellinga, B. Henderson, and H. Steinfeld. 2013. "Greenhouse gas emissions from pig and chicken supply chains – A global life cycle assessment." Food and Agriculture Organization of the United Nations (FAO), Rome.

Magan, N., A. Medina, and D. Aldred. 2011. "Possible climate-change effects on mycotoxin contamination of food crops pre- and postharvest." *Plant Pathology* 60(1):150–63.

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.

Menzel, A. 2005. "A 500 Year Pheno-climatological View on the 2003 Heatwave in Europe Assessed by Grape Harvest Dates." *Meterorol. Z.* 14: 75-77.

Ministerio del Ambiente. 2010. *Segunda Comunicación Nacional del Perú a la Convención Marco de las Naciones Unidas sobre Cambio Climático 2010.* Lima, Perú: Impresiones & Ediciones Aguilar S.A.C.

Mollinga, P.P., and A. Bolding, eds. 2004. *The Politics of Irrigation Reform*: *Contested Policy Formulation and Implementation in Asia, Africa, and Latin America*. Burlington VT: Ashgate Publishing Company.

OECD-FAO. 2012. *Agricultural Outlook 2013-2022*. Rome.

Opio, C., P. Gerber, A. Mottet, A. Falcucci, G. Tempio, M. MacLeod, T. Vellinga, B. Henderson, and H. Steinfeld. 2013. "Greenhouse gas emissions from ruminant supply chains – A global life cycle assessment." Food and Agriculture Organization of the United Nations (FAO), Rome.

Parmesan, C. 2006. "Ecological and Evolutionary Responses to Recent Climate Change." *Annu. Rev. Ecol. Evol. Syst.* 37: 637-69.

Parmesan, C. and G. Yohe. 2003. "A Globally Coherent Fingerprint of Climate Change Impacts Across Natural Systems." *Nature* 421: 37-42.

Parry, M.L., C. Rosenzweig, A. Iglesias, M. Livermore, G. Fischer. 2004. "Effects of Climate Change on Global Food Production under SRES Emissions and Socio-economic Scenarios." *Global Environmental Change* 14:53–67.

Porter J. H., M.L. Parry, and T.R. Carter. 1991. "The Potential Effects of Climatic Change on Agricultural Insect Pests." *Agricultural and Forest Meteorology* 57(1-3): 221-40.

Root, T. L, J.T. Price, K. R. Hall, S.H. Schneider, C. Rosenzweig, and J.A. Pounds. 2003. "Fingerprints of Global Warming on Wild Animals and Plants." *Nature* 421: 57-60.

Ruiz, D., D.G. Martinson and W. Vergara. 2012. "Trends, Stability and Stress in the Colombian Central Andes." *Climatic Change* 112:717-32.

Sherry, R.A., X. Zhou, S. Gu, J.A. Arnone, D.W. Johnson, D. S. Schimel, P.S.J. Verburg, L.L. Wallace and Y. Luo. 2011. "Changes in Duration of Reproductive Phases and Lagged Phenological Response to Experimental Climate Warming." *Plant Ecology and Diversity* 4(1):23-35.

Smith S., N. Golborne, L. Gohar, J. Lowe, and J. Davey. 2008. "Projecting Global Emissions, Concentrations and Temperatures." In *Building a Low-carbon Economy - The UK's Contribution to Tackling Climate Change*. Norwich, UK: The Stationary Office.

Sugiura T., H. Ogawa, N. Fukuda, and T. Moriguchi. 2013. "Changes in the Taste and Textural Attributes of Apples in Response to Climate Change." *Scientific Reports* 3(2418):1-7.

Sun, P., N. Mantri, H. Lou, Y. Hu, D. Sun, Y. Zhu, T. Dong, and H. Lu. 2012. "Effects of Elevated CO2 and Temperature on Yield and Fruit Quality of Strawberry (Fragaria × ananassa Duch.) at Two Levels of Nitrogen Application." *PLoS ONE* 7(7):1-12.

USGCRP. 2009. *Global Climate Change Impacts in the United States.* Edited by Thomas R. Karl, Jerry Melillo, and Thomas C. Peterson. New York: Cambridge University Press.

Vergara W., A. Deeb, I. Leino, A. Kitoh, and M. Escobar. *Assessment of the Impacts of Climate Change in Mountain Hydrology.* 2011. Washington DC: World Bank

Vergara, W., A. R. Rios, L. M. Galindo, P. Gutman, P. Isbell, P. H. Suding, and J.L. Samaniego. 2013. *The Climate and Development Challenge for Latin America and the Caribbean*. Washington, DC: Inter-American Development Bank.

Vergara W., and S. Scholz. 2010. *Assessment of the Risk of Amazon Dieback*. Washington DC: World Bank.

Walck, J.L., S. N. Hidayati, K.W. Dixon, K. Thompson, and P. Poschlod. 2011. "Climate Change and Plant Regeneration from Seed." *Global Change Biology* 17: 2145-61.

Walther, G., E. Post, P. Convet, A. Menzel, C. Parmesan, T.J.C. Beebee, J. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. "Ecological Responses to Recent Climate Change." *Nature* 416:389-95.

Wani, S.P., T.K. Sreedevi, J. Rockstrom, and Y.S. Ramakrishna, eds. 2009. "Rainfed Agriculture – Past Trends and Future Prospects." In S.P. Wani, J. Rockstrom, and T. Oweis, eds. Rainfed Agriculture: Unlocking the Potential. Cambridge MA: CABI North American Office, pp. 1-35.

Wescott P and M. Jewison. 2013. *Weather Effects on Expected Corn and Soybean Yields*. Washington DC: USDA Economic Research Service FDS-13g-01.

World Bank. 2013. *World Development Indicators 2013.* Washington, DC: World Bank.

—. 2012. *Agriculture Exports from Latin America and the Caribbean.* Washington, DC: World Bank.

—. 2010. *The Cost to Developing Countries of Adapting to Climate Change: New Methods and Estimates.* Washington, DC: World Bank.

—. 2007. *World Development Report 2008: Agriculture for Development.* Washington, DC: World Bank.

—. 2003. *Rural Poverty Alleviation in Brazil: Toward an Integrated Strategy.* Washington, DC: World Bank.

—. 1998. *El Salvador: Rural Development Study.* Washington, DC: World Bank.

WRI. 2012. CAIT (Climate Analysis Indicators Tool) Version 9.0. Washington, DC: WRI.

www.iadb.org/climatechange | twitter: @BIDcambioclima