LCSAR – The World Bank

Climate Change and Agriculture in Latin America (2020–2050)

R. Confalonieri, M. Donatelli, S. Bregaglio, F.N. Tubiello, D. van der Mensbrugghe, J. Nash A. Soliman, and E.C.M Fernandes [Co-TTLs]
Contents
Figures.................................................................................................................................................. 6
Tables.................................................................................................................................................... 6

Executive Summary .............................................................................................................................. 6
The AZS biophysical results.................................................................................................................. 6
  Wheat .................................................................................................................................................. 7
  Soybean .............................................................................................................................................. 7
  Maize .................................................................................................................................................. 8
  Rice .................................................................................................................................................... 8
  Economic impacts .............................................................................................................................. 9
Major findings and conclusions ............................................................................................................ 10

Chapter 1. Introduction .......................................................................................................................... 10

Chapter 2. The Knowledge Base on Climate Change Projections and Assessments of Agricultural Impacts and Economic Implications ................................................................. 10
Climate change and agriculture ............................................................................................................ 10

Chapter 3. An Open-Access Climate-Crop Impact Agroecological Zone Simulation Modeling Platform for Latin America and the Caribbean ........................................................................ 10
AZS conceptual framework ................................................................................................................ 10
The AZS-BioMA and applications ....................................................................................................... 10
AZS-BioMA inputs .............................................................................................................................. 10
  Climate data and weather generation .............................................................................................. 10
  Soils .................................................................................................................................................. 10
The AZS-BioMA modeling platform ..................................................................................................... 10

Chapter 4. Estimates of Climate Change Impacts for Wheat, Soybean, Maize, and Rice in Latin America (2020 and 2050) ........................................................................................................ 10
Limitations ........................................................................................................................................... 10
  Weather data .................................................................................................................................. 10
  Model calibration ............................................................................................................................... 10
  Soils .................................................................................................................................................. 10
  Effects of elevated carbon dioxide .................................................................................................. 10
  Production systems .......................................................................................................................... 10
  Adaptation strategies ....................................................................................................................... 10
Results ................................................................................................................................................ 10
  Wheat ............................................................................................................................................... 10
  Soybean ......................................................................................................................................... 10
  Maize ............................................................................................................................................. 10
  Rice ............................................................................................................................................... 10
  Agromanagement adaptation ......................................................................................................... 10

Chapter 5. Conclusions and Policy Implications .................................................................................. 10
Helping policy makers assess the best options .................................................................................... 10
Next steps for World Bank and other donor agency investments, operations, and research ............ 10

Bibliography ......................................................................................................................................... 10

Annex I. The Agroecological Zone Simulator and Applications ......................................................................................................................................................................................... 10
Annex II. Crop Yield Simulation Results .............................................................................................. 10
## Glossary of terms and abbreviations

<table>
<thead>
<tr>
<th>Abbreviations and acronyms</th>
<th>Definition</th>
<th>Description (if needed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptation</td>
<td>Adjustment in natural or human systems—in response to actual or expected climatic stimuli or their effects—to moderate harm or exploit beneficial opportunities (IPCC 2007)</td>
<td></td>
</tr>
<tr>
<td>Adaptive capacity</td>
<td>The ability of a system to adjust to climate change (including variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2007)</td>
<td></td>
</tr>
<tr>
<td>AEZ</td>
<td>Agroecological zone</td>
<td></td>
</tr>
<tr>
<td>AR4</td>
<td>Fourth Assessment Report of the Intergovernmental Panel on Climate Change</td>
<td>Published in 2007</td>
</tr>
<tr>
<td>AZS</td>
<td>Agroecological zone simulator</td>
<td>The agroecological zone simulator provides biophysical representations of crop growth as a function of agroclimatology and crop-field management.</td>
</tr>
<tr>
<td>BioMA</td>
<td>Biophysical model applications</td>
<td></td>
</tr>
<tr>
<td>CGE</td>
<td>Computable general equilibrium model</td>
<td></td>
</tr>
<tr>
<td>CH₄</td>
<td>Methane</td>
<td>A greenhouse gas</td>
</tr>
<tr>
<td>Climate change</td>
<td>Climate change refers to a change in the state of the climate that can be identified by changes in the mean or in the variability of its properties and that persists for an extended period—typically decades or longer</td>
<td>Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC 2007).</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
<td>A greenhouse gas</td>
</tr>
<tr>
<td>CO₂-e</td>
<td>Carbon dioxide equivalent</td>
<td>A measure used to compare non-CO₂ gases with CO₂ based on their global warming potential (GWP—see below)</td>
</tr>
<tr>
<td>ECMWF</td>
<td>European Centre for Medium-Range Weather Forecasts</td>
<td></td>
</tr>
<tr>
<td>ENSO</td>
<td>El Niño Southern Oscillation</td>
<td></td>
</tr>
<tr>
<td>ENVISAGE</td>
<td>Environmental impacts and sustainability applied general</td>
<td>See CGE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>equilibrium model</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GCM</strong></td>
<td>General circulation models</td>
<td>A general circulation model is a mathematical model of the general circulation of a planetary atmosphere or ocean and based on equations for a rotating sphere with thermodynamic terms for various energy sources (radiation, latent heat). These equations are the basis for simulating the atmosphere or ocean of the Earth. Atmospheric and Oceanic GCMs (AGCM and OGCM) are key components of global climate models along with sea ice and land-surface components. GCMs and global climate models are widely applied for weather forecasting, understanding the climate, and projecting climate change.</td>
</tr>
<tr>
<td><strong>GHG</strong></td>
<td>Greenhouse gas</td>
<td>Greenhouse gases are gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth’s surface, atmosphere, and clouds. This property causes the greenhouse effect (IPCC 2007).</td>
</tr>
<tr>
<td><strong>GWP</strong></td>
<td>Global warming potential</td>
<td>An estimate of the effectiveness of a gas in trapping heat in the atmosphere relative to CO₂ over a specific time horizon. As per IPCC, over 100 years, methane’s GWP is 21 and nitrous oxide is 310.</td>
</tr>
<tr>
<td><strong>IPCC</strong></td>
<td>Intergovernmental Panel on Climate Change</td>
<td></td>
</tr>
<tr>
<td><strong>LUT</strong></td>
<td>Land utilization types</td>
<td></td>
</tr>
<tr>
<td><strong>N₂O</strong></td>
<td>Nitrous oxide</td>
<td>A greenhouse gas</td>
</tr>
<tr>
<td><strong>NCAR</strong></td>
<td>National Center for Atmospheric Research</td>
<td></td>
</tr>
<tr>
<td><strong>Probabilistic scenarios</strong></td>
<td>The production of large ensembles of climate change scenarios enables the production of probability density functions to represent the range of projected change in a specific event</td>
<td>Specific probabilities may be assigned to individual events or climate change impacts by incorporating model uncertainties within a large model ensemble</td>
</tr>
<tr>
<td><strong>R&amp;D</strong></td>
<td>Research and development</td>
<td></td>
</tr>
<tr>
<td><strong>RCMs</strong></td>
<td>Regional climate models</td>
<td></td>
</tr>
<tr>
<td><strong>SFLAC</strong></td>
<td>Spanish Fund for Latin America and the Caribbean</td>
<td>The Fund is meant to provide resources to enhance the impact of the Bank Group’s development activities</td>
</tr>
<tr>
<td><strong>SRES</strong></td>
<td>Special Report on Emissions Scenarios</td>
<td></td>
</tr>
<tr>
<td><strong>UNFCCC</strong></td>
<td>United Nations Framework Convention on Climate Change</td>
<td>The UN body charged with implementing climate change action globally</td>
</tr>
</tbody>
</table>
**Acknowledgements**

This study was made possible by the generous contribution of the Spanish Ministry of Economy and Finance, through the Spanish Fund for Latin America and the Caribbean (SFLAC).

The project was developed by a Consortium led by the Consorzio Milano Ricerche, with the participation of the European Commission Joint Research Center (EC-JRC).

Consortium leader: Prof. Roberto Confalonieri

The project was made possible by accessing data and resources of the project EUROCLIMA, granted by DG AIDCO, under the action of the JRC’s Institute of Environmental Sustainability (JRC-IES-MARS).

Scientific leader: Dr. Marcello Donatelli
Executive Summary

The impacts of climate change on agriculture are projected to be significant in coming decades, so response strategies and their likely costs should be evaluated now. Robust crop models are needed to estimate those impacts on agricultural productivity regionally, nationally, and even sub-nationally. But existing crop–climate change modeling platforms are not easily accessible to most stakeholders in developing countries. So there is less testing of those models than there might be, and there are fewer opportunities for further improvements based on local tests and emerging data.

That is why this study produced an open-access crop-climate-economic impact modeling platform for Latin America and the Caribbean that can be extended to other regions—and modified and improved by users as new crop, climate, and economic datasets become available. The new platform projects the likely impacts of agroclimatic factors on crop productivity on the basis of climate projections from two general circulation models and couples it with an economic model to derive and evaluate a range of climate-change scenarios and likely agricultural productivity and economic impacts over the next several decades.

The open-access modeling platform developed in this study, the agroecological zone simulator (AZS), provides biophysical representations of crop growth as a function of agroclimatology and crop-field management. It is based on the biophysical model applications (BioMA) approach used by the European Commission Joint Research Centre to investigate climate-change impacts in the EU. The AZS simulations used:

- The baseline climate (1989 to today) re-sampled to 0.25 degree grid cells (25 kilometers at the horizon).
- Two general circulation models—the U.K. Met Office’s Hadley3 model and the National Center for Atmospheric Research (NCAR) model.
- Two special report on emissions scenarios (SRES), A1b and B1, to represent respectively a high scenario (business as usual) and low scenario (near carbon dioxide stabilization at 550 parts per million).
- Two time horizons for simulating risks to crop production, with little time for adaptation (2020) and with time for adaptation (2050).

The AZS biophysical results

The main results of the AZS simulations suggest that the prevailing and often expressed view that Latin America and the Caribbean will continue to be the breadbasket of the future—stepping in to supply grain to other regions affected by climate change—needs to be tempered and subjected to further rigorous testing. The AZS estimates confirm and extend previous findings indicating that the impacts of climate change on agriculture in the region could be significant even by 2020, with rising risks to maize, soybean, and wheat production in most producing countries by 2050. Encouragingly, however, adaptation interventions such as the targeted use of irrigation, the development and use of improved varieties, and the change of sowing dates could significantly reduce the projected negative impacts of plausible climate shocks. This finding emphasizes the urgency for adequate investments in adaptation strategies to ensure that the
projected shocks to agricultural productivity can be reduced. In most cases, such investments may take several decades to begin having a positive impact.

**Wheat**

For wheat, yields could be significantly affected by climate change, regardless of the emission scenario or general circulation model. Percentage yield declines are projected to be deeper in Mexico, in the Caribbean region, and in the northeastern parts of the continent (Colombia and Brazil). The projected limited water productivity for 2020 and 2050 could be lower than the baseline, with southern and western countries less affected. Yield reductions due to the shortening of the crop cycle leave fewer days to fill grains. The projected yield declines due to disease in 2020 and 2050 could also be significant. Frost damage is expected to affect wheat yields less seriously in Chile, where shorter crop cycles could also reduce the crop exposure to pathogens, thus also reducing the pressure of wheat leaf rust. With few exceptions, insufficient water could affect wheat productivity more than other factors, highlighting the urgent need for developing drought-tolerant wheat varieties (such as deeper rooting).

With adaptation, the projected yield impacts are markedly less negative for all the production levels and scenarios considered, but low water availability still limits wheat productivity. Although the use of genotypes with longer crop cycles could partly compensate for the effect of climate change in reducing the grain-filling period, the longer crop cycle increases water demand because of increased transpiration. Except in Chile, disease pressure is expected to fall everywhere, even without adaptation strategies for leaf rust. Argentina could be most affected by disease pressure, whereas insufficient water availability appears to be the major wheat yield-reducing factor in Brazil and Chile.

**Soybean**

For soybean, yields could be reduced by climate change in 2020 and more so in 2050, though with different magnitudes throughout the region. Yield losses could be large in Brazil (more than 30% from the baseline) but less pronounced in Argentina, Bolivia, Colombia, and Uruguay. This can be explained by the greater impact of climate change in Brazil, where the crop cycle is projected to be shorter than in other parts of Latin America, markedly shortening the soybean grain-filling period. The impact of rust disease would not increase with warming, except in Colombia, where the AZS shows an increase for all combinations of general circulation model (GCM) emission scenarios. This could be explained by the severity of the increase in temperature in an already warm environment, given Colombia’s proximity to the equator, which in turn could lead to more favorable conditions for pathogens.

With adaptation—such as longer crop-cycle varieties, different sowing dates, and irrigation—the impacts across all scenarios and time windows could be reduced, especially in Ecuador and Uruguay. In Argentina the use of varieties with longer cycles could compensate for yield losses due to climate impacts that reduce the period for crop growth and maturity.
Maize

For maize, climate change could reduce yields throughout Latin America, regardless of the emission scenario or GCM. This is mainly due to the shorter grain-filling period not being compensated for by the higher daily biomass accumulation rates and the CO₂ fertilization effect. The countries most affected are likely to be Brazil, Ecuador, Mexico, and Caribbean countries, where maize is one of the main crops. The Hadley GCM produced the highest losses, except for Brazil and Ecuador (and for the latter, only for the B1 scenario). Because the yield impacts of climate change are highly heterogeneous across the region, national adaptation strategies will be critical in mitigating productivity declines.

Adaptation, especially in the 2020 timeframe, could dampen negative impacts of climate change on maize yields in most of the region, though yield declines could still be significant in major maize-producing countries, like Mexico. Higher percentage declines were simulated for the Hadley GCM than the NCAR, with the A1B emission scenario usually leading to the most severe declines. Adaptation strategies could limit but not completely offset the climate-change damage to maize production, even in countries where grey leaf spot disease appears as the most limiting factor.

Rice

For rice, the AZS estimates show that productivity could, on average, increase across the region. A major reason for this positive outlook appears to be related to the fact that rice is a wetland/irrigated crop. Except for Brazil, Mexico, and the Caribbean, the 2020 and 2050 projections are encouraging, with higher productivity projected in most cases. Rice has higher temperature growth requirements than other crops. Under the current climate (the baseline) production is slightly reduced by photosynthesis being limited by suboptimal temperatures. With warmer conditions the negative effect of the shorter grain-filling period would be counterbalanced by higher biomass accumulation rates because of more favorable conditions for photosynthesis.

The result of these two opposite effects is a general increase in productivity, except in countries already experiencing warm climates (where thermal conditions for photosynthesis are already close to optimal and the reduced grain-filling period leads to declines in final yields). In low-temperature areas (especially Uruguay) climate change could reduce the incidence of pre-flowering cold shocks inducing sterility. Except for Brazil and the Caribbean the blast disease pressure on the crop could ease, because of thermal and rainfall conditions less favorable for Pyricularia grisea, the blast disease pathogen.

With adaptation—including the use of different varieties and different sowing dates—future conditions could be decidedly favorable for rice across the region. Long-cycle genotypes allow long grain-filling periods and high daily biomass accumulation rates, because of negligible
temperature limits to photosynthesis and the CO$_2$ fertilization effect, higher for the C3 species than for the C4 (such as maize).\(^1\)

**Economic impacts**

The economic impacts of implementing the climate-induced agricultural productivity shocks in the four focus crops were investigated by coupling of AZS biophysical results to the ENVISAGE platform. (An example in chapter 4 shows the steps for implementing and potentially applying such a powerful coupling.) Results were limited by the focus on Latin America, assuming no impacts in the rest of the world. They thus are relevant to understanding first-order dynamics following a perturbation, but they would need to be updated with more consistent impact signals globally.

The aggregate impact of this partial shock could be as high as 1.7% of regional GDP in 2050 under the A1B emission scenario for the Hadley GCM, which produces the most severe yield shocks in the AZS projections. Although the impact signal is strong, this seems a fairly large decline in regional GDP, considering that the four affected crops would represent only about 1.3% of regional GDP in 2050 under the baseline scenario. Two reasons for such an outcome could be climate change affecting other sectors and agriculture having a big (multiplier) effect on other sectors. The projected impacts tend to accelerate between 2020 and 2050. They are larger for the Hadley model than the NCAR model, and they tend to be higher for the A1B emission scenario than the B1 emission scenario. The impacts on global output are negligible.

Most affected across all scenarios and GCMs are Argentina and Brazil, two of the region’s largest agricultural producers. Uruguay would be the only country that would see gains in most of the scenarios—though under the more severe Hadley A1B scenario, even Uruguay could experience a 2.3% loss. Among those least affected are Chile, Ecuador, and Peru. Chile’s agricultural sector, small as a share of the total economy in the base year, declines over time—particularly for the four focus crops. Ecuador and Peru have low production shares in the affected crops. Because this study focuses on four crops, the impacts for other crops—such as tropical fruits, coffee, and sugar, which are potentially important parts of GDP—are not included in the estimates.

The within-country distribution between agriculture and the rest of the economy would tend to worsen in all countries in the region. In Argentina agricultural value added could drop by 7% in 2020 in the best case and by 32% in 2050 in the worst. The loss in agricultural value added is significantly less in Brazil than in Argentina in 2050, even though the 2020 impacts are similar. Some countries (such as Uruguay) may see a rise in agricultural value added.

\(^1\) C3 photosynthesis is called C3 because the CO$_2$ is first incorporated into a 3-carbon compound. It is more efficient than C4 and CAM plants under cool and moist conditions and under normal light because requires fewer enzymes and no specialized anatomy. Most plants are C3. C4 photosynthesis is called C4 because the CO$_2$ is first incorporated into a 4-carbon compound. It photosynthesizes faster than C3 plants under high light intensity and high temperatures. Examples of C4 plants include maize, sugarcane, millet, and Brachiaria pasture grass.
In a worst case scenario for the four focus crops in Latin America and the Caribbean, the loss in net export revenues could be $8–11 billion in 2020 and $30–52 billion in 2050. Brazil could bear the greatest absolute burden followed by Argentina and then Mexico.

Major findings and conclusions

The ability to test dynamic interactions between agroclimatic factors and field management is critical for policy makers assessing economically efficient investment options. This study produced a robust set of linked modeling tools and a coherent set of linked databases to facilitate the evaluation of dynamic interactions of high-resolution agroclimatic and field management factors affecting crop growth and development. It allowed interactions with a detailed general equilibrium model to include and test the constraints of realistic socioeconomic factors on production and welfare.

For Latin America and the Caribbean the projected yield shocks on wheat, maize, and soybean generated by the AZS platform could result in substantial negative economic impacts in the aggregate—particularly for Argentina and Brazil, which are heavily invested in the focus crops of this study.

The findings have several major policy implications.

1. The estimated negative impacts could be significantly larger than what has previously been predicted for Latin America and the Caribbean—and for precisely the two major agricultural producers (Brazil and Argentina) expected to play a major role in the global food supply chain. This should be a red flag for policy makers deciding on both mitigation and adaptation investments to combat global warming via greenhouse gas emissions reductions in the LCR countries and globally.

2. Despite the projected severity of climate change impacts for maize, soybean, and wheat, some findings were encouraging. For example, the study simulated the response to the use of simple adaptation strategies such as improved varieties, change of sowing dates, and modest irrigation and found that these strategies did not overcome the projected damages from climate change but did dampen the yield shocks to a significant degree for some crops. Policy-relevant interventions related to adaptation strategies include:
   a. Allocating adequate research and development (R&D) resources to generate improved and adapted plant varieties—currently estimated to take at least a decade and to cost US$5–7 million for each new variety).
   b. Expanding high-efficiency irrigation to overcome moisture limitation during grain-filling, a major yield-limiting factor in the region for maize, soybean, and wheat. Less than 6% of Brazil’s agriculture and less than 2% of Argentina’s are irrigated yet these are the two countries projected to be hit most severely by climate change and moisture limitations for their major commodity crops.

3. One surprise from the study is the estimated positive impact of climate change on rice productivity in the region, which highlights to the potential for increasing rice production, especially since rice now feeds about 3 billion people worldwide, and global supplies expected to tighten significantly in coming years. The key policy-relevant issues for rice futures in LCR include:
   a. Raising the current low yield levels of irrigated rice in LCR. Most of the region’s rice is produced in the rainy season to ensure adequate supplies of water for most of
the growing season. The yield plateau for rainy season rice is about 5 tons per hectare because sunlight is often reduced by clouds. If the rice could be produced during the dry season with adequate water capture and irrigation, the rice yield plateau could rise to between 8 and 12 tons per hectare.

b. **Ensuring adequate water supplies and water control in the landscape.** Most of the region’s countries have plans to expand hydroenergy as a part of national low-carbon growth strategies. Ensuring that new hydroenergy programs also include irrigation would enhance the adaptation capacity for agriculture. Policies that promote multipurpose hydro would also permit relocating rice and other agriculture in coastal and low-lying areas to areas less vulnerable to major floods and rising sea levels—an adaptation-mitigation win-win.

c. **Reducing the environmental footprint of rice.** Because flooded rice is a major source of methane (a powerful greenhouse gas), adequate R&D funding and policy instruments will be needed to catalyze public-private partnerships to develop and extend rice field management strategies and the use of improved biological and new-generation “high efficiency-low emissions” synthetic fertilizers.

4. The study finding that moisture limitations are likely to strongly influence the reduction of future crop yields further emphasizes the importance of current discussions at the global level to include soil carbon sequestration in any post-2012 climate agreement. The available empirical evidence for a wide variety of soil and agroecosystem types confirms that an increase in soil carbon can also result in significant improvements in soil moisture holding capacity and thereby reduce the need for irrigation. Appropriate policy and market signals are urgently needed to encourage land-based carbon sequestration to facilitate better soil and water use and result in more resilient agroecosystems. Sequestration above and below ground could also increase rural income opportunities through more diverse ecosystem services.

5. The AZS estimates of climate impacts on agricultural productivity at relatively high spatial resolution could provide key information to reduce uncertainty for risk-reducing insurance and microfinance instruments. Insurance (risk-sharing) is likely to be important in future adaptation decisions, whether through traditional indemnity-based insurance or through other options that may be more suitable for climate-based insurance, such as index-based schemes, weather derivatives, and catastrophe bonds.

6. If a large share of world agriculture faces similar impacts to the AZS projections for the region and the four crops studied, initial economic simulations project higher food prices than the baseline. So, investments and grants are urgently needed to expand the current portfolio of crops in the AZS platform to include subsistence crops, biofuels crops, and horticultural crops beyond wheat, soybean, maize, and rice. This will allow more robust assessments of the intrasectoral impacts and economic implications in the region and across regions.

7. Policy makers in the region and elsewhere need more realistic assessments of their relative comparative advantages in agriculture and their priorities for investments in adaptive strategies. All regions should urgently conduct similar CC-agriculture impact assessments to allow a more robust cross-regional comparison of climate change’s impacts on food security, trade, and GDP. To help facilitate participatory and robust analyses, the open-access AZS platform developed in this study is now available for further refinement, scaling up, and testing in the Latin American and Caribbean Region as well as for rapid deployment to and use by other regions.