Climate change, water and agriculture

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"The complex interrelationship between environmental change and agricultural production will become one of the most significant policy issues, in both developed and developing countries, in the first few decades of the 21st century. Global and regional climate change will modify both agricultural production capacity and its location, and the intensity of agricultural production will contribute to environmental change at both regional and global levels." *(Ruttan 1991: 25)*

KEY WORDS
Climate change
IPCC
Latin America
Agriculture
Water
Adaptation

The latest report of the Intergovernmental Panel on Climate Change (IPCC)[2] is conclusive. It says that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level" (IPCC 2007b: 5). Over 800 scientists and 400 lead authors in more than 130 countries contributed to the report. One of its most important findings is that the increases in temperatures observed since the mid-20th century are due to human activities. It also presents evidence of many long-term changes in climate, such as variations in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones.

This raises two questions: what will be the effects of global warming? And, what urgent actions need to be taken? With regard to the first, the report suggests that climate change will not be neutral in its impacts. The countries most adversely affected will be those in the tropical and subtropical regions, where most developing countries are located and poverty and hunger are widespread. In those regions, the effect on agriculture would be extremely negative. With respect to the second question, the report provides evidence to support the design of public policies. However, since the IPCC is a scientific body, it does not make recommendations.

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2 The report is divided into four volumes, which deal with: a) the scientific evidence; b) impacts, adaptation and vulnerability; c) mitigation; and, d) a synthesis. At the time of writing (mid-April 2007), only the summaries for policymakers of the first two volumes have been made public, namely, IPCC 2007a and IPCC 2007b.

The objective of this article is to highlight the challenges and the opportunities for adapting Latin American agriculture to climate change, considering not only the expected impact on the sector but also the likely impacts with regard to the availability of water.

Table 1. Anticipated impacts of climate change in Latin America.
1. By mid-century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation. There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America.
2. In drier areas, climate change is expected to lead to salinisation and desertification of agricultural land. Productivity of some important crops are projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones soybean yields are projected to increase.
3. Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation.

Source: *IPCC 2007a: 12*

The impacts of climate change on agriculture

The fact that the impacts of climate change are not neutral is evident in the case of agriculture. There are clear winners and losers. Or at least, depending on the scale of climate change, "some losers will lose more than others." The IPCC report (2007a: 8) suggests the asymmetric impacts on agriculture will be as follows:

- Crop productivity is projected to increase slightly at mid to high latitudes for local mean temperature increases of 1-3°C, depending on the crop, and then decrease beyond that in some regions.
- At lower latitudes, especially seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1-2°C), which would increase the risk of hunger.
- At the world level, potential agricultural production is projected to increase with increases in regional average temperatures of 1-3°C, but above this it is projected to decrease.
- Increases in the frequency of droughts and floods are likely to affect local production negatively, especially in subsistence sectors at low latitudes.

Given these regional asymmetries, one of the biggest concerns is how climate change will affect the possibilities of achieving the Millennium Development Goals, especially regarding the efforts to reduce hunger. What, then, will be the effects on the global food supply?

A study published by Bosello and Zhang (2005), with projections through 2050, suggests that climate change will have a limited impact on the world's food supply and well-being. However, it does stress that there will be major distributional consequences and the biggest negative effects will be concentrated in developing countries situated in tropical and subtropical regions. Poverty and hunger are rife in these countries, which were also identified in recent IPCC reports as the most vulnerable to climate change.

The issues involved in adapting agriculture to climate change

The relationship between climate change and agriculture is complex. On the one hand, the effects of climate change - especially changes in temperature, precipitation and water levels, and the increase in extreme weather events - force farmers to take action to adapt to them. On the other, agricultural activities can play a role in mitigating the greenhouse effect that causes climate change.

Where adaptation is concerned, it is important to consider the different ways in which the socioeconomic system can respond to the situation. There are three possible areas on which it can focus: adaptation at the farm level, adaptation at the national level and adaptation at the global level (Bosello & Zhang 2005: 3-5).

- **Adaptation at the farm level** refers to any action undertaken by farmers to adapt to changes in the climatic conditions. This includes measures such as changes in the planting time, frequency and location of crops; the adoption of new varieties or combinations of different types of crops; the adoption of technologies and cultivation systems that help preserve the original environmental conditions (e.g., irrigation); and research and development on new varieties that can adapt better to climate change.

- At the **national level**, climate change may lead to changes in the use of agricultural inputs (e.g., land, water, genetic quality of seed) and in output levels (quantity and quality) that spread to the

Table 2. Possible impacts on agriculture of changes in the frequency and intensity of extreme weather events and in the climate, and of increases in sea level.

As a result of …	*it is safe to say that*	*that …*
warmer days and fewer cold days and nights, warmer days and nights and more warm days and nights in most regions,	it is virtually certain,	yields will increase in cold environments and decrease in warm environments, and plagues of insects will increase.
the increased frequency of warm spells/ heat waves in most regions,	it is quite likely,	yields will decrease in cold regions due to heat stress and the danger of wildfires will increase.
the increased frequency of events involving heavy precipitation in most regions,	it is very likely,	crops will be damaged and soil eroded, and land will not usable because water has been extracted from the soil.
the increased frequency of events involving heavy precipitation in most regions,	it is likely,	land will become degraded, yields will fall, crops will be damaged and lost, more livestock will die and there will be a greater risk of wildfires.
the increase in the area affected by drought,	it is likely,	crops and coral reefs will be damaged and the roots of tress will be weakened.
the increase in cyclone activity, the increased frequency of extreme events involving rising sea levels (excluding tsunamis),	it is likely,	irrigation water, estuaries and freshwater systems will become salinized.

Source: *IPCC 2007a: 16*

rest of the economy. The resulting changes in relative prices can lead to crops and inputs being replaced, and to variations in the demand for, and supply of, agricultural and non-agricultural goods. The links between the impacts of climate change and variations in relative prices call for new agricultural technologies and practices to be generated that affect prices. The greater the flexibility of the economic system, the smaller will be the impacts.

- At the **global level**, the impacts of climate change on agriculture will vary from region to region, depending on the latitude where countries are located, the local environmental conditions, the responses from the socioeconomic system and institutional factors. In an increasingly integrated world, this could trigger changes in the flows of factors of production, goods and services, and relative prices. Therefore, the distribution of crops across regions and countries and agricultural trade flows could undergo major modifications in the future.

Mendelsohn (2000: 583-600) distinguishes between private and joint (public) adaptation. Private adaptation is when farmers act individually, meeting their own costs and reaping the benefits. Joint adaptation occurs when all farmers enjoy the benefits but each bears his own costs.

If adaptation to climate change in agriculture has positive externalities[3], then individual actions by farmers (private adaptation) will result in less adaptation than society needs. This justifies public policies to encourage adaptation. Examples of public adaptation in agriculture include research and the development of new species or varieties and species with different structures from current ones, the provision of irrigation infrastructure, agro-hydro-ecological zoning, the delivery of information and the development of public early warning systems.

Studies on the adaptation of agriculture to climate change in Latin America

Few studies have been carried out in Latin America on how farmers are responding to climate change. The World Bank recently undertook a study entitled *Climate Change and Rural Poverty*, with support from the Cooperative Program for Agrifood and Agroindustrial Technology Development in the Southern Cone (PROCISUR) and the Cooperative Agricultural Technological Innovation Program for the Andean Subregion (PROCIANDINO). This study looked at four countries in the Southern Cone (Argentina, Brazil, Chile and Uruguay) and three in the Andean Region (Colombia, Venezuela and Ecuador). Some 2000 farmers on the following five types of farm were surveyed:

- Crops without irrigation.
- Crops with irrigation.
- Crops and livestock without irrigation.
- Crops and livestock with irrigation.
- Livestock only.

The study explored several aspects of the relationship between climate change and agriculture, including:

- An analysis of crop choices (Seo & Mendelsohn 2007a).
- An analysis of the choice of different types of crops, livestock, a combination of crops and livestock and irrigation, as adaptation options (Mendelsohn & Seo 2007).
- An analysis of the impact of climate change on the net income of farmers and land rents (Seo & Mendelsohn 2007b). The study also looked at three climate change scenarios, based on atmospheric oceanic global circulation models: a moderate scenario, an intermediate scenario and an extreme scenario[4].

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[3] When a person who carries out an action is not the only one to benefit from it, the action is said to have “positive externalities.”

[4] The moderate scenario is based on the Parallel Climate Model (PCM); the intermediate scenario, on a model from the Center for Climate Systems Research (CCSR); while the extreme scenario uses a model from the Canadian Climate Center (CCC).

Not surprisingly, in the first two analyses the empirical evidence shows that the choice of agricultural activities and irrigation is sensitive to climatic variables.

The analysis of the different types of crops chosen as adaptation options revealed that the important climatic variables were temperature and precipitation. The study suggests that climate change will lead to crops being substituted. In particular, there will be a shift away from potatoes and wheat in favor of fruits and vegetables (Seo & Mendelsohn 2007a: 6-11).

The model of possible choices - crops, livestock, crops with livestock and irrigation - is interesting because it includes irrigation. The results with regard to the climatic variables that lead to irrigation being used are not surprising. Among the variables on which farmers base their decision to adopt irrigation are important ones like summer precipitation and winter temperatures. The variables that are of greatest concern to farmers who combine crops with livestock are summer precipitation and winter and summer temperatures (Seo & Mendelsohn 2007a: 10-19).

Other results suggest that the relative rate of return on investment in irrigation declines as temperatures rise and farmers in areas where precipitation is high are less likely to adopt irrigation. The chief limitation of the study is that it does not take the availability of water into account as a key variable in the decision whether to use irrigation.

The analysis of the impacts of climate change on land rents and farmers' net income is based on a model in which farmers maximize their net income, subject to conditions exogenous to their farms, which include climatic variables. The results confirm that net income and land rents are sensitive to those variables (Seo & Mendelsohn 2007b: 10-17). An interesting aspect of the results is that it is possible to differentiate between the impacts for small and large farmers. Both types of farms are sensitive to climate but the negative effect on the income of small farmers[5] is greater.

The results of the study are extrapolated to all Latin American countries for the year 2100, differentiating between small and large farmers (**Table 3**). In general, the results confirm the findings of the recent IPPC report on impacts, adaptation and vulnerability.

Table 3. Impacts of climate change on land rents in Latin America in 2100, under different climate change scenarios.

Farmers	*Moderate scenario*	*Extreme scenario*
Small farmers	Aggregate positive benefits, with changes by location: • Positive for farmers in cold climates, • Negative in hotter regions of Venezuela, Colombia, the northern parts of the Southern Cone and Central America.	Negative results in all locations.
Large farmers	Positive results in general, except in northern South America.	Negative results across the board, with variations in different locations. Possible benefits in Argentina, Chile, Peru and Mexico.

Source: *Seo & Mendelsohn 2007b: 17-19*

5 For the purposes of the study, small farms are those less than 30 ha. in size.

The authors note that the study has several limitations:

a) there is no information about water resources,

b) the effect of carbon fertilization is not considered,

c) the only thing that changes in the future is the climate. The effects of technical change are not considered and it is assumed that the prices of goods and labor do not change with the climate (i.e., relative prices remain the same), and,

d) farmers in the future can adapt as readily as they can in the present. The capital required and other adaptation costs are not considered.

Water in the discussion about adaptation to climate change in agriculture

A study by the Stockholm International Water Institute (SIWI) and the International Water Management Institute (IWMI) presented to the United Nations Commission on Sustainable Development in May 2004 highlighted the importance of water for achieving the Millennium Development Goals regarding the reduction of hunger, and the need to use water more productively in agriculture. The study's projections suggest that the additional water required to produce the food needed to reduce hunger and malnutrition by the year 2025 is equivalent to all the water currently used to support all aspects of life in society. These concerns are also important for the adaptation of agriculture to climate change.

At the local level, adapting to climate change in agriculture basically means being able to adapt, at different points in time, to situations in which there is either too much water or not enough, which will also affect other water uses, such as human consumption and energy production.

Therefore, when we analyze adaptation options such as irrigation it is important to consider their effects on the availability of water, as well as the competing needs of other sectors of the economy.

Rosenzweig *et al.* (2004: 345-360) did a groundbreaking study that deals with these issues. The authors set out to examine the implications for the reliability of irrigation of changes in water availability and the demand for water for crops. The study also explores how effectively different adaptation options maintain the level of reliability.

The authors develop a methodological approach that combines climate change scenarios[6] with agricultural, hydrological and planning models[7]. Based on this, they study the availability of water for agriculture under changing climate conditions and make the corresponding projections for agricultural production, population, technology and economic growth. The study covers large agricultural regions that produce soybean and corn in Northern Argentina, Southeast Brazil, Northeast China, the Hungarian and Romanian parts of the Danube Basin and the Corn Belt in the USA. These regions have different socioeconomic, environmental, technological and climatic conditions; however, with the exception of Northeast China, they all have sufficient water for agriculture under current climatic conditions (Rosenzweig *et al.* 2004: 347-351).

The evidence suggests that in the most water-rich areas studied there will be sufficient water for agriculture in the climate change scenarios analyzed. With respect to the cases studied in Latin America, Northern Argentina occasionally experiences problems with the supply of water for agriculture under current conditions and those problems could be exacerbated and investments required to relieve water stress in the future. The outlook is brighter in the south of Brazil, where it appears that water for agriculture will be plentiful in the future.

6 The study combines information from the following global climate models: a) Geophysical Fluid Dynamics Laboratory (GFDL - Version R30); b) Goddard Institute for Space Studies -NASA; c) Mark Plank Institute; d) United Kingdom Met Office Hadley Center (HadCM2); e) Canadian Climate Model (CGCM2).

7 The models used were: a) the CERES model, to assess the water needed for corn and soybean (i.e., the demand for water); b) the WATBAL model, to assess the impact of climate change on the flow of water in watersheds (i.e., the supply of water); and c) the WEAP model, for projecting, planning and assessing multiple demands for water.

Climate change, population growth and economic development will affect the future availability of water for agriculture

The study includes various simulations to determine whether the area under irrigation could be expanded, as an adaptation option[8]. The results suggest that only Brazil could easily expand the area under irrigation under the climate change conditions studied. The reliability of the water system would be undermined in the other regions.

The authors also point out that even in relatively water-rich areas, changes in the demand for the resource will affect agriculture due to climate change. That, coupled with increased demand from urban growth, will require timely improvements in crop varieties, irrigation and drainage technology, and water management. In short, climate change, population growth and economic development will affect the future availability of water for agriculture (Rosenzweig *et al.* 2004: 345).

The study mentions certain options for agronomic adaptation to climate change, such as variations in planting schedules and the use of varieties with genetic characteristics like heat tolerance, vulnerability to pests and sensitivity to pesticides. It also says that both yield and water use should be taken into consideration when planning adaptation to climate change from a genetic resources perspective (Rosenzweig *et al.* 2004: 357). Other factors are the need to consciously conserve and manage genetic diversity.

With regard to water resources, in some regions, too much water could be more damaging than drought; climate change may even alter the seasonal availability of water. Therefore, where agriculture is concerned the adaptation of water resources must include improvements in irrigation and drainage technologies. Of the cases studied, Brazil is best placed to increase the area under irrigation. In the other regions, it would intensify the stress in the water system (Rosenzweig *et al.* 2004: 356-7) (**Table 4**).

The implications for public policy

In Latin America, some countries have made efforts to adapt, particularly through the conservation of key ecosystems, early warning systems, risk management in agriculture, strategies for managing droughts, floods and coastal areas, and disease surveillance systems. However, the effectiveness of these efforts is undermined by the lack of basic information and monitoring systems; insufficient capabilities and appropriate political, institutional and technological frameworks; low incomes; and settlements in vulnerable areas (IPCC 2007b: 12).

The above highlights the need for public policies to support adaptation to climate change in agriculture that promote greater integration of the agricultural and water resource sectors. There are several implications as far as adaptation is concerned:

1. **Government intervention is justified**. A number of factors justify public policymaking to promote adaptation to climate change in agriculture. According to Mendelsohn (2000: 590-59), one is the existence of positive externalities to guide or correct the adaptation actions undertaken by private agents (e.g., by eliminating subsidies that promote the inefficient use of irrigation in agriculture). Another factor is equity in the international context, given the scientific evidence that the poor, tropical countries will be the most affected. Furthermore, the results suggest that small farmers are more sensitive to changes in climate. Yet another factor is timely access, especially for small farmers, to information about future changes in climate, their impacts and possible adaptation options.

   The characteristics of adaptation to climate change in agriculture mark it out as a public good. However, there is no guarantee that joint adaptation will be efficient, since there may be differing views about what kind of adaptation

[8] These exercises did not include the United States.

Table 4. Some facts related to water, agriculture and climate change.
Agriculture is the biggest consumer of water worldwide. In the USA, agriculture uses 87% of all extracted water. In the USA, approximately 68% of all groundwater extracted is used for agriculture.
It takes roughly 100 times more water to produce 1 kg of animal protein than to produce 1 kg of vegetable protein.
Approximately 16% of the world's cropland is irrigated. Around 33% of the world's food is produced on irrigated land. Irrigation, especially using groundwater, uses large amounts of energy to pump the water. In the USA, some 10% of the total energy expended each year in the agricultural sector is used in irrigation.
In the USA, some 12% of farmland is irrigated and produces 27% of the value of all crops. However, this percentage does not include the costs to the government of supplying and subsidizing a large percentage of the water used for irrigation.
The amount of water that reaches plants is put at less than 40% worldwide.
Many things can be done to conserve water, such as: ■ using surge flow irrigation instead of flooding and channel irrigation techniques. Farmers in Texas, USA, are utilizing 38-56% less water for irrigation thanks to this innovation. ■ irrigating at night to reduce evaporation. This technique can improve efficiency by 200-300%. ■ using low-pressure sprinklers, which improves water efficiency by 60-70% compared with high-pressure sprinklers. ■ using the low-energy precision application (LEPA) technique, which can enhance efficiency by 88-99%. ■ using drip or micro-irrigation techniques, which are up to 95% more efficient. However, this technology is expensive and requires very clean water.

Source: *Pimentel et al. 1997: 97-106*

is desirable, and disputes about the payment mechanism for public adaptation; while private agents may expect to be remunerated for their efforts (Mendelsohn 2000: 593).

At the national level, policies and strategies that strengthen or correct the responses of farmers and other private agents may be relevant to influence developments at the farm level. At the global level, actions should be channeled through multilateral international cooperation mechanisms, such as the environmental conventions.

2. **Better technologies are required to manage both too little and too much water in agriculture.** The study by Rosenzweig *et al.* (2004) points to the growing importance of both irrigation and drainage technologies. This is important in wet areas, since analyses of the relationship between climate change and agriculture tend to focus on the impacts on dry areas and irrigation as an adaptation option.

3. **Efficient water management.** Efficient water management is essential for agriculture to adapt to climate change. It calls for policies such as the reduction of subsidies for the water used in agriculture, the development of water markets, the introduction of controls on the demand for water, investment to ensure that water is available when and where it is needed and, in general, the design of incentives to encourage farmers to conserve water and soil resources (Rosenzweig *et al.* 2004: 357; Pimentel *et al.* 1997: 107).

The study by the SIWI and the IWMI (2004: 4) highlights five challenges related to public policies that are relevant in this regard.

a) Productivity: close the productivity gap between what is being produced now and what could be produced, through interventions that enhance water productivity. This is undoubtedly a major challenge. As the title of the report suggests, it means obtaining more nutrition for each drop of water used.

b) Technology: facilitate the dissemination and use of new technologies for enhancing water productivity.

c) Cultural practices: identify and influence unsustainable consumption patterns that increase the demand for water-intensive foods.

d) Ecological issues: identify the minimum criteria for ecological services to protect aquatic ecosystems against water depletion.

e) Economic concerns: identify unsustainable agricultural subsidies and trade barriers, especially those that affect regions where water is scarce.

4. Institutional management and development. No provisions exist at the international level keyed to the need for adaptation to climate change. The Kyoto Protocol, the principal international climate change agreement, focuses strongly on mitigation. Therefore, as Rosenzweig *et al.* (2004) emphasize, institutional adaptation is essential, along with continued technological improvement and investment in the water and agriculture sectors. This calls for greater coordination between institutions in the environment sector, especially those responsible for water management, and the different institutional bodies in the agricultural sector.

Corollary

The IPCC document points up the need for public policies to support private efforts to adapt to climate change in agriculture that explicitly address the repercussions for water resources. This has major implications for the agenda of international cooperation agencies, especially for the countries that will be most affected by climate change. The agencies should provide support in at least five areas:

a) the development of policy frameworks;

b) he development of institutional frameworks that make it possible to address the problems using an integrated approach;

c) the formulation of investment projects required in the water and agricultural sectors;

d) capacity building; and,

e) the generation and transfer of relevant knowledge.

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Resumen / Resumo / Résumé

Cambio climático, agua y agricultura

El informe reciente del Panel Intergubernamental sobre el Cambio Climático (IPCC) presenta evidencia científica concluyente acerca de la certeza del cambio climático y sus efectos asimétricos entre países desarrollados y en desarrollo, especialmente en el sector agrícola. El objetivo de este artículo es destacar retos y oportunidades para la adaptación de la agricultura latinoamericana al cambio climático, y considerar no sólo los impactos esperados en dicho sector, sino también los impactos previstos en la disponibilidad de agua. En el documento se enfatiza el carácter de bien público que tiene la adaptación en la agricultura. También se presentan implicaciones de política pública, derivadas de conocimiento actual sobre los vínculos entre cambio climático, agua y agricultura.

Mudança climática, água e agricultura

O recente relatório do Painel Intergovernamental sobre Mudanças Climáticas (IPCC) apresenta evidência científica conclusiva acerca da certeza das mudanças climáticas e seus efeitos assimétricos entre países industrializados e países em desenvolvimento, especialmente no setor agrícola. O objetivo deste artigo é apontar desafios e oportunidades para a adaptação da agricultura latino-americana às mudanças climáticas, considerando não apenas os impactos esperados no setor, mas, também, os efeitos previstos na disponibilidade de água. O documento enfatiza a natureza de bem público da adaptação na agricultura. Também apresenta as implicações para as políticas públicas, decorrentes do conhecimento atual sobre os vínculos entre mudança climática, água e agricultura.

Changement climatique, eau et agriculture

Le rapport du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC), publié récemment, présente des preuves scientifiques concluantes au sujet de la certitude du changement climatique et de ses effets asymétriques dans les pays développés et les pays en développement, en particulier dans le secteur agricole. Le but du présent article est de mettre en évidence les défis et les possibilités qui attendent l'agriculture latino-américaine dans son adaptation au changement climatique, en considérant non seulement les impacts prévus dans ce secteur, mais aussi les répercussions anticipées sur les ressources en eau. Dans cet article, l'accent est mis sur le caractère de bien public que revêt l'adaptation dans le secteur agricole. Sont également présentées les implications, pour les politiques publiques, des connaissances actuelles sur les liens entre le changement climatique, l'eau et l'agriculture.