Impacts of Climate Change on Brazilian Agriculture

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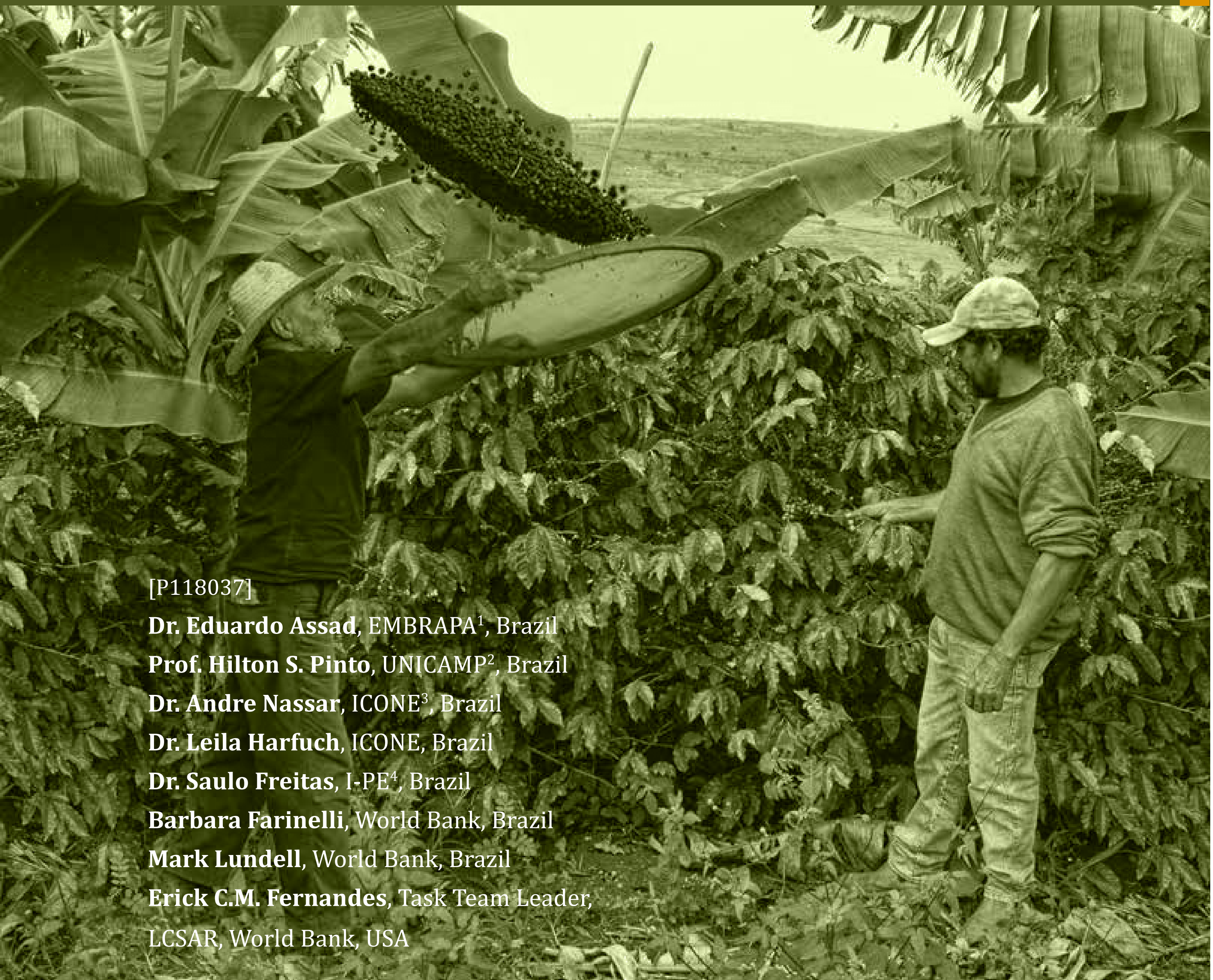
Impacts of Climate Change on Brazilian Agriculture



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Foreword

This study is the result of an exemplary collaborative approach involving leading edge Brazilian agencies - The Brazilian Enterprise for Agricultural Research (EMBRAPA), the University of Campinas (UNICAMP), the Brazilian Institute for International Trade Negotiations (ICONE), and the Brazilian Institute for Space Research (INPE). We are honored to have been associated to this effort.

Agriculture is a major sector of the Brazilian economy and is critical for economic growth and foreign exchange earnings. Between 1996 and 2006 the total value of the country's crops more than quadruple, from 23 billion reais (~U$ 11 billion) to 108 billion reais (~U$ 53 billion). In 2009, agriculture accounted for 19.3 percent of the labor force, or 19 million people, thus strongly contributing to poverty reduction. Agribusiness employs 35 percent of the labor force and accounted for over 38 percent of Brazil's exports, and a $77.5 billion trade surplus in 2011.

Against the backdrop of a vibrant and productive agricultural sector, Brazil continues to pioneer agricultural intensification to increase agricultural productivity even further to meet growing national, regional, and global food demands while at the same time not increasing the agricultural area via deforestation. The Brazilian Government is also concerned about the potential adverse impacts of climate change on Brazilian agriculture and associated livelihoods. For example, the International Panel on Climate Change (IPCC) Assessment Report 4 (2007) noted that climate change in Latin America will affect a number of ecosystems and sectors over the coming decades, with specific impacts on agriculture resulting in:

- Reduction in the quantity and quality of water flows and thus irrigation potential;
- Increasing aridity, land degradation, and desertification;
- Increasing incidence and impacts of crop pests and diseases;
- Decreasing plant and animal species diversity and changes in biome boundaries; and
- Perturbations to ecosystem services (e.g. carbon sequestration, functional biodiversity, environmental flows) needed to sustain the productivity of current agricultural areas.

In order to mitigate the impacts of climate change, the world must drastically reduce global greenhouse gas (GHG) emissions in the coming decades. To date, Brazil has led many key domestic and international initiatives to reduce emissions from deforestation and land use change, aggressively promoted renewable energy, particularly bioenergy, and adopted a National Climate Change Policy, which includes an ambitious voluntary national GHG reduction target for 2020. There is growing concern in Brazil and in the Latin American Region that increasing short term climate variability and medium to long term climate change will have significant negative impacts on the Brazilian landscape and on Brazilian agriculture, national economic growth, and associated livelihoods. The Government of Brazil is developing proactive adaptation measures to counter the emerging risks of climate change impacts on the major sectors underpinning the Brazilian economy with special attention to agriculture.

This study builds on the findings of previous World Bank studies, in particular the 2010 World Development Report to support growth and poverty reduction efforts in the face of climate change, a regional flagship report on Low Carbon, High Growth Latin American Responses to Climate Change (2009), and a regional focused on climate change impacts to Latin America's agriculture (2011). This study also integrates the methods and findings of several other Brazilian studies for example, Impact assessment study of climate change on agricultural zoning (2006), Climate change and extreme events in Brazil (2010), Assessment of regional seasonal predictability using the PRECIS regional climate modeling system over South America (2010). In this study, a range of tested Global and Regional Climate Models as well as significantly better hydro meteorological and land suitability data were used to assess the vulnerability and impacts of climate change on Brazilian agriculture. In addition, the study includes a coupled synthesis of climate-agricultural impacts with robust economic simulations to project economic impacts of climate change on Brazilian agriculture to 2030.

The network of professionals established for this study can now continue to improve and refine the integrated agro-ecological, biophysical, and economic modeling and analysis developed for this study. The inclusion of UNICAMP also lays the foundation for capacity building of the next generation of climate modelers in Brazil and Latin America. The integrated and multidisciplinary expertise and knowledge base strengthened by this study will serve Brazil well as it enhances the productivity and resilience of its agricultural sector that is critical not only for national food security, but also for the global supply of key agricultural commodities.

It is our hope that Brazil will also serve as a model and mentor for many developing countries seeking to enhance their institutional capacities and strategic planning processes to combat climate change and to continue to develop sustainably in the face of looming challenges from climate change.

Deborah L. Wetzel
World Bank Director for Brazil
Región de Latinoamérica y el Caribe

More than ten years ago, the Kyoto Protocol established the tolerable limits for carbon emissions resulting from the economic and social activities of the countries, with a view to slowing down global warming and other climatic changes. Scholars have since demonstrated that the effects of climate change are already being felt as higher average air temperatures and the impacts of extreme temperature and rainfall events on the world's populations.

In the ensuing period the concentration of carbon dioxide, the main greenhouse gas, has risen to four hundred parts per million. Data from the World Meteorological Organization showed that 12 out of the last 13 hottest years since the measurements started in 1850 occurred between 2001 and 2012. Nevertheless, as Professor Ed Hawkins of the University of Reading has demonstrated the average temperature has surprisingly remained the same since 1988, when the Kyoto Protocol was opened to accession by the countries.

Such apparently conflicting data flashes a warning light to the world population because they remind the fact that Earth is much more complex than the human mind can conceive and its climate does not always provide constant and predictable answers. They also forewarn the people that science is entering a nebulous area where current scientific knowledge does not enable to understand the phenomenon and that new scientific breakthroughs are necessary to reduce the uncertainties about Earth's future climate.

Although some scientists believe that global warming proceeds at a lower rate than so far estimated and, thus, that the countries would have more time for corrections and adjustments, most scientists agree that global warming is ocurring. The climate-change scenarios point out to an average temperature rise in excess of 2°C by 2050 and that the impact of such higher temperatures would cause major imbalances in ecosystems essential to humankind survival.

Nevertheless, the significant changes predicted for the Amazon Forest and its biodiversity, the meaningful losses of the glaciers in the Andes and Himalayas and the fast acidification of the oceans and consequent break down of marine ecosystems and death of coral reefs are still plausible events, all of which would condemn countless species to extinction and considerably affect world food supply. The speed and magnitude of the change can doom many species to extinction and significantly affect food supply in the planet. Some people are still sceptical.

Scientist are free to chose the hypotheses in their research, but are enjoined to go beyond the initial evidence and not renounce their duty to delve ever more deeply in the mysteries of Nature. The authors of this book acknowledge and rigorous comply with such tenets.

Ten years ago, Embrapa's Eduardo Assad and Unicamp's Hilton S. Pinto researchers developed a series of studies as an attempt to associate the various global warming scenarios with possible impacts on climatic risks zoning and their ultimate influence on agricultural production in Brazil. They used a single climate model for estimating production area fof each municipality in Brazil. They also showed the different consequences of higher temperatures on various crops cultivated in the regions of Brazil.

Assad and Pinto took up the challenge in this book, with the fruitful and diligent support of André Nassar and Leila Harfuch from the Institute for International Trade Negotiations – ICONE; Saulo Freitas from the National Institute of Space Research – INPE; and from Barbara Farinelli, Mark Lundell and Erick Fernandes, from the World Bank.

A more precise analysis of the vulnerability of Brazilian agriculture is possible using new tools for model climate and the dynamics of soil use. The researchers used seven climate analysis models proposed by the Intergovernmental Panel on Climate Change-IPCC, three of which in a detailed resolution and adapted to tropical conditions. Brazilian Regional Climate Model - RCM - BRAMS developed by CPTEC/INPE was also analysed.

The researchers were then able to reduce the degree of uncertainty of the results by considering the maximum and minimum deviations of the estimated temperatures by the models for both optimistic and pessimistic scenarios considering the temperature ranges obtained by the different models. The most important outcome is the possibility of appraising the degree of uncertainty of the results by using more models.

The results of the simulations pointed out to the same direction, confirming temperature increases predicted for 2030. The climatic-risk agricultural zoning technology was then applied using those results together with information about the land use effectively altered by anthropogenic activities. In a further step the impact on Brazilian agriculture was calculated by means of economic models.

The work makes clear that agriculture is vulnerable to higher temperatures given the predicted levels of global warming. There can be losses in yield and consequently in production. There can have crop migration from one region to another. The regional production profile can change.

The outcome of the current work, which clearly goes beyond previous studies, emphasizes the need to assign priority to biotechnology research, particularly in the regions that will be strongly affected, such as Northeastern and Southern Brazil. The search for genes that increase plant tolerance to high temperatures and water stress should be a routine endeavour in the next few years. The implementation of public policies associated to more balanced production systems should be supported throughout the country in order to reduce the impact of global warming by either mitigating greenhouse gas emissions or integrating production systems better adapted to abiotic stresses.

Only studies like this one, carried out by a consortium of institutions and based on advanced scientific and technological knowledge, can help identify the solutions required by such a challenging future. The possibility of a two-degree Celsius increase in the average temperature of Earth requires that tropical agriculture be prepared for such conditions assuring the guarantee food security during the next few decades.

The first approach to the vulnerability of Brazilian agriculture vis-à-vis global warming relied on material support from the British Government, through the British Council. The more recent study received support from the World Bank, always ready to help in the development of Brazilian agriculture. It is unlikely that we will ever be able to express the true importance and scope of international scientific cooperation in the evolution of Brazilian agricultural science. Embrapa is also greatly indebted to the generosity of institutions such as Unicamp, INPE and ICONE, always willing to contribute to network studies, an asset that guarantees quality work.

Maurício Antônio Lopes
President of Embrapa

Executive Summary

Agriculture is a major sector of the Brazilian economy accounting for about 5.5% of GDP (25% when agribusiness is included) and 36% of Brazilian exports. As per the 2006 agricultural census, Brazil has 5 million farms of which 85% are small holders and 16% are large commercial farms occupying 75% of the land under cultivation. In 2009, Brazil enjoyed a positive agricultural trade balance of $55 billion. In the second quarter of 2010, Brazil's economy recorded 8.8 percent growth with agriculture making a major contribution (11.4 percent) relative to the industrial (13.8 percent) and services (5.6 percent) sectors. Because agriculture is vital for national food security and is a strong contributor to Brazil's GDP growth, there is growing concern that Brazilian agriculture is increasingly vulnerable to climate variability and change.

To meet national development, food security, climate adaptation and mitigation, and trade goals over the next several decades, Brazil will need to significantly increase per area productivity of food and pasture systems while simultaneously reducing deforestation, rehabilitating millions of hectares of degraded land, and adapting to climate change. Because of the projected magnitude of the agricultural impacts and investments required, and the decadal response time of best adaptation options available, there is an urgent need for a state of the art, assessment of climate change impacts on agriculture to guide policy makers on investment priorities and phasing. The current projections of climate change impacts for Brazil are based on climate models that were available prior to 2008. Since then, not only has the science and quality of global, regional, and local modeling advanced significantly, but also improved land quality and climate data are now available.

This study built upon several recent flagship studies on climate change impacts by using a range of tested Global and Regional Climate Models as well as significantly better hydrometerological and land suitability data that were unavailable to previous such studies to assess the vulnerability and impacts of climate change on Brazilian agriculture.

In addition to confirming and the results from previous climate change impact studies that projected significantly negative impacts on Brazilian crops to 2020 and 2030, our findings help to further extend the knowledgebase not only on the extent of impacts to different crops but also the level of impacts in the different regions of Brazil.

For example, this study showed that while for some crops (soybean and cotton) the projected negative climate impacts to 2020 are likely to be more moderate than previously projected, for other crops (beans and corn), however, the impacts could be significantly more severe that than projected in previous studies. These differences illustrate, at least partially, the value of harnessing more complete and geographically distributed climate, terrain characteristics, water, and climate data sets for more nuanced analytical power of climate change modeling approaches.

In the absence of climate change, Brazilian cropland is projected to increase to 17 million hectares in 2030 compared to observed area of cropland in 2009. Due to climate change impacts, however, all the scenarios simulated in this study, result in a reduction of 'low risk – high potential' cropland area in 2020 and 2030. More specifically, our findings suggest that the South Region of Brazil, currently an agricultural powerhouse, could potentially lose up to 5 million ha of its highly suitable agricultural land due to climate change while Brazil as a whole could have around 11 million ha less of highly suitable agricultural land by 2030.

Fortunately, our findings also show that the bulk of the loss of high potential agricultural land could be allocated to currently occupied by poorly productive pastures. The displacement of pastures by grains and sugarcane in the Center-West, and Northeast Cerrado Regions could potentially compensate for the projected loss of suitable cropland and especially the grain losses in the South (~9 million tons) by about half.

It is especially noteworthy that despite the projected reduction in the pasture area, beef production is projected to decrease by a much lower amount due to technological intensification. So although pasture productivity in Brazil might decrease by 7% in all scenarios simulated in 2030 compared to the baseline, our simulations project that beef production may continually grow until 2030 in all scenarios compared to the observed production in 2009, and could increase by more than 2 million tons.

Although pasture intensification potentially compensates for displacement of the pastures by grain and sugarcane in the central regions of Brazil, this study projects that beef producer prices are projected to increase by more than 25% in all scenarios, suggesting that that intensification of pasture use and cattle production might lead to a price increase in order to compensate for the investments to increase yields.

In general, the production declines can be expected to impact prices, domestic demand, and net exports of these products. Relative to 2009 and in the absence of climate change, domestic consumption of all commodities is projected to increase in 2020 and 2030. However, our simulations across all the climate change scenarios suggest that when compared to the 2009 baseline, climate change is likely to reduce consumption of almost all commodities, specially grains and ethanol. The major driver of this projected reduced consumption is the higher real price of all commodities when land availability for agricultural production is reduced as a function of climate change.

The production impact estimates from our study show that unlike previous estimates of declining agricultural production value, the negative impacts on supply of agricultural commodities is expected to result in significantly increased prices for some commodities, especially staples like rice, beans, and all meat products. This will counter the effect of declining productivity on value of agricultural production but could have major negative effects on the poor and their consumption of these staple products. It is noteworthy that beef and soybean oil account for almost 50% of the projected total production value for Brazilian agriculture.

The projected impacts of climate change on rainfall and soil moisture deficits at critical phases of crop growth from this study suggest that there is an urgent need for more detailed analysis for priority crop zones to develop an integrated improved, drought-tolerant (deeper rooted) varieties coupled with good land and water management strategies to mitigate the projected effects. In addition to extending access to efficient irrigation technology, management strategies that conserve and enhance soil carbon will increase soil moisture retention capacity. For example,

a. The Brazilian Government and the private sector have been steadily facilitating the adoption of improved conservation agriculture practices, such as no-till planting, and more resource-efficient systems, such as integrated crop-livestock systems that are inherently more resilient to climate shocks than some intensive cropping systems.
b. The Government is providing credit and financing for the newly-launched "Low Carbon Agriculture" program with approximately US$ 1 billion available for low interest credit in the 2011 season alone.
c. The buildup of agricultural soil carbon may also be eligible for carbon payments in voluntary and (future) formal markets.

In our study, the efforts to access the latest available hydrometeorological and land use data significantly improved our ability to undertake more robust modeling and impact projections. Nevertheless, the lack of good quality and long term climate data continues to hamper regional and local climate modeling efforts as well as the calibration and validation of current projections that are being used to inform policy and investment decisions to 2030 and beyond. Because the climate forcing factors operate both within and external to national frontiers, there is an urgent need for coordinated and targeted climate change investments over the next 1-5 years for instrumentation, data assembly, data sharing and data access systems. National, bilateral, and multilateral investments agencies need to coordinate their investment strategies to support this specific and urgent need.

The need for improved and integrated climate change impact assessments is especially urgent for the agricultural sector. A recent survey carried out by the Brazilian Enterprise for Agriculture and Animal Research (EMBRAPA), revealed that even with advanced breeding techniques, it takes approximately 10 years of R&D and costs at least US$6 million to develop, test, and release a new crop cultivar or variety that is heat and/or drought tolerant.

It is important to note that this study did not simulate the potential impact of technological advances (new varieties, expanded and enhanced access to irrigation, improved land and water management) as adaptation measures to counteract the projected negative impacts of climate change on agricultural productivity. The need for improved and integrated climate change impact assessments is especially urgent for the agricultural sector. A recent survey carried out by the Brazilian Enterprise for Agriculture and Animal Research (EMBRAPA), revealed that even with advanced breeding techniques, it takes approximately 10 years of R&D and costs at around US$6 -7million to develop, test, and release (including 2-3 years for scaling up seed production) a new crop cultivar or variety that is heat and/or drought tolerant. The review synthesis from this report suggests that within the next decade, Brazilian agriculture will already be dealing with a significant level of climate induced crop and livestock productivity stresses. Much of the crop improvement work to date has focused on drought tolerance and a great deal still remains to be done for heat tolerance.

The findings of this study will be incorporated in the EMBRAPA/UNICAMP Agroecozone Model to improve the simulation and climate impact projections that underpin the national rural credit and insurance programs in Brazil. This means that the study will immediately begin having far reaching operational and policy implications in Brazil. The experiences from Brazil are highly relevant for other regions and countries where similar work is on-going.

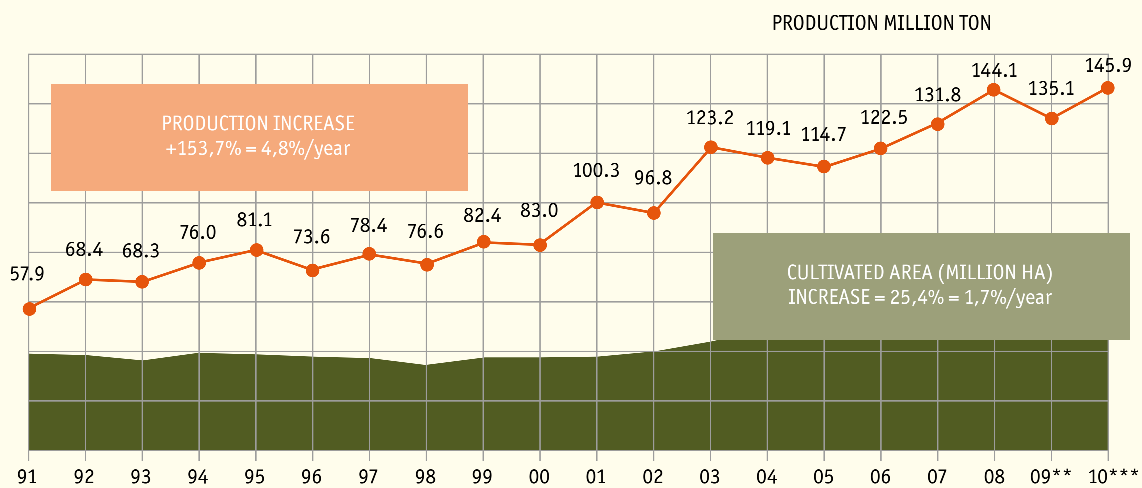
Introduction

Agriculture is a major sector of the Brazilian economy accounting for about 5.5% of GDP (25% when including agribusiness) and 36% of Brazilian exports. Brazil is the world's largest producer of sugarcane, coffee, tropical fruits, frozen concentrated orange juice, and has the world's largest commercial cattle herd at 210 million head. Brazil is also an important producer of soybeans, corn, cotton, cocoa, tobacco, and forest products. Between 1996 and 2006 the total value of the country's crops rose 365 percent from 23 billion reais to 108 billion reais (US$ 64 billion). Brazil accounts for about a third of world soybean exports and supplies a quarter of the world's soybean trade from 6% of the country's arable land. The remainder of agricultural output is in the livestock sector, mainly the production of beef and poultry, pork, milk, and seafood. Brazil is currently the world's largest exporter of beef, poultry, sugar cane and ethanol.

Between 1996 and 2006 the total value of the country's crops rose from 23 billion reais to 108 billion reais, or 365%. Brazil increased its beef exports tenfold in a decade overtaking Australia as the world's largest exporter. It is also the world's largest exporter of poultry, sugar cane and ethanol. Since 1990 its soybean output has risen from barely 15m tons to over 60m. Brazil accounts for about a third of world soybean exports, second only to America. In 1994 Brazil's soybean exports were one-seventh of America's; now they are six-sevenths. Moreover, Brazil supplies a quarter of the world's soybean trade on just 6% of the country's arable land.

From 1991 to 2010 the grain production of the country (cotton, peanut, rice, bean, sunflower, corn, soybean, sorghum, wheat, oat, barley, castor bean, rye and rapeseed) increased 147% and the cultivated area only 25%, or 4,8%/year and 1,7%/year respectively, that represents an strong development of the agriculture technology (Figure 1). In 2009, Brazil enjoyed a positive agricultural trade balance of US$55 billion. In the second quarter of 2010, Brazil's economy recorded 8.8 percent growth with agriculture making a major contribution (11.4 percent) relative to the industrial (13.8 percent) and services (5.6 percent) sectors.

Figure 1. Grain production and area increase in Brazil from 1991 to 2010.



Fonte: CONAB - AGE/Mapa

In recent decades, this growth in the Brazilian agricultural sector has increasingly been driven by productivity gains in cereals, coarse grains, sugarcane, oilseeds and milk sectors. Brazilian production has grown more than 1.5 times the rate of world production (figure 2 and 3). In meat sectors, the average growth has been 1.8 times faster than the world production.

Total output has grown 2.5 times since the 70s while the use of labor is decreased and the use of capital and land has slightly increased. More importantly, the productivity of all production factors has strongly increased for the same period (Figure 4) (Source of data: FAO/FAOSTAT)

Figure 2. World and Brazil Agricultural Production: Expansion from 1990 to 2009 (1990=100)

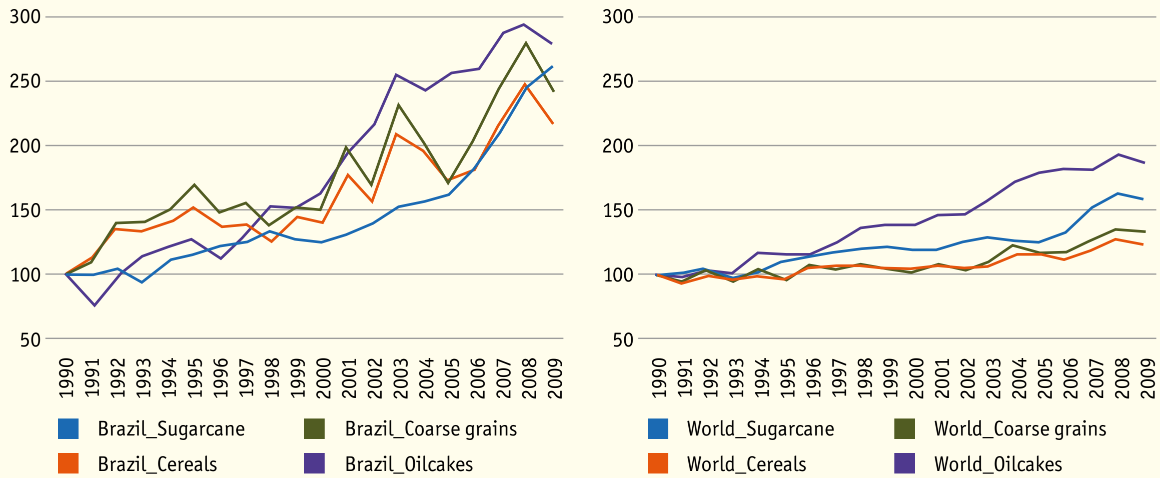


Figure 3. Brazil's and World Meat and Milk Production: Expansion from 1990 to 2009 (1990=100)

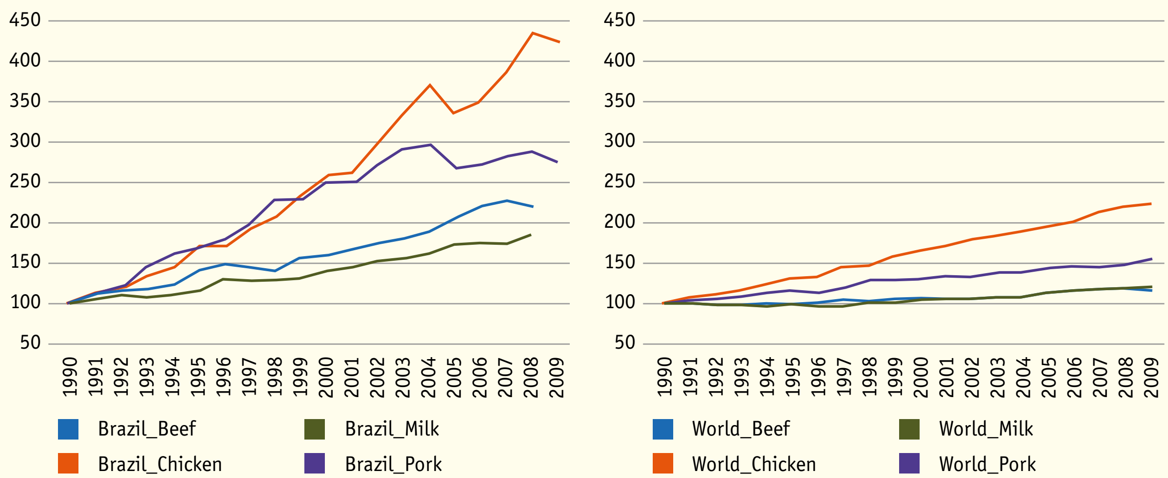
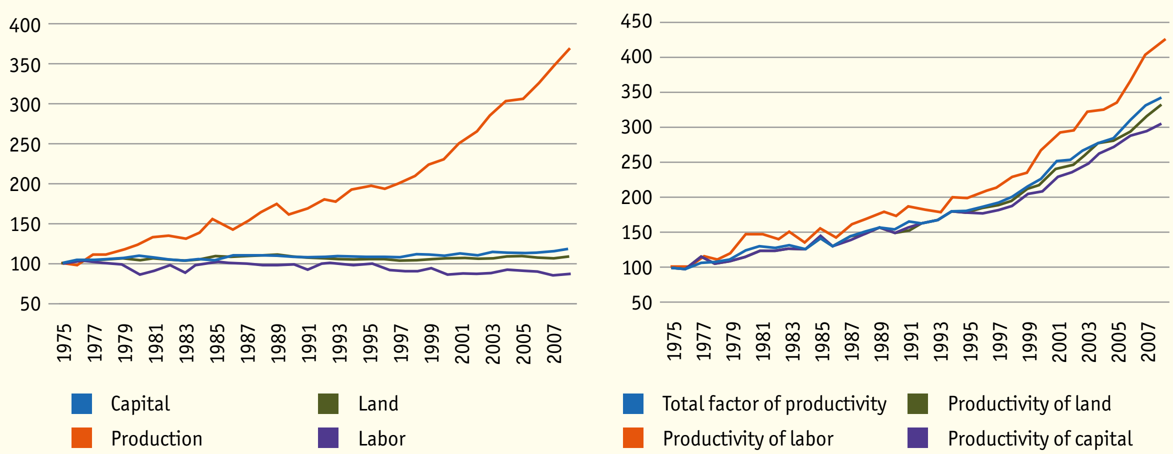


Figure 4. Brazilian Agricultural Sector: Total Production and Use of Labor, Land, and Capital and Total Factor Productivity (1975=100) Source: Gasques et al. (2009)



The Evolution of the Farming Sector in Brazil and Implications to 2030

The 2006 Agricultural Census[5] indicated that the number of rural households is increasing again despite the reduction observed from the 80s to 90s. With respect to the distribution of households according to farm size, the agricultural sector is clearly becoming less concentrated. For example, between 1995 and 2006, the number of smaller households (less than 100 hectares) has increased. In terms of land occupied, both the smallest and the largest size classes have decreased from 1995 to 2006, while the middle classes (10 to 1,000 ha) have increased.

Table 1. Evolution of the Structure of the Brazilian Agricultural Sector

	NUMBER OF RURAL HOUSEHOLDS (units)						LAND OCCUPIED (HA)	
	1970	1975	1980	1985	1995	2006	1995	2006
Total	4,924,019	4,993,252	5,159,851	5,801,809	4,859,865	5,175,489	353,611,246	329,941,393
Less than 10 ha	2,519,630	2,601,860	2,598,019	3,064,822	2,402,374	2,477,071	7,882,194	7,798,607
10 to 100 ha	1,934,392	1,898,949	2,016,774	2,160,340	1,916,487	1,971,577	62,693,586	62,893,091
100 to 1000 ha	414,746	446,170	488,521	517,431	469,964	424,906	123,541,517	112,696,478
More than 1000 ha	36,874	41,468	47,841	50,411	49,358	46,911	159,493,949	146,553,218

Source: IBGE Agricultural Census 2006

The total factor productivity (TFP) of the Brazilian agriculture has increased steadily over the last 35 years. Relative to 1970 (=100), production has increased by 243%, inputs by 53%, and TFP by a corresponding 124%. Investments in R&D have been fundamental for these increases and it has been estimated that a 1% increase in agricultural R&D has resulted in a 0.2% increase in TFP (Gasques et al. 2009). Positive trends in the productivity indices underscore Brazil's effort to prioritize intensification-led productivity gains as opposed to expanding farm areas (Contini et al. 2010).

Will the Brazilian agricultural landscape in 2030 and beyond resemble current agricultural landscapes in Australia, Canada, and the USA that are dominated by few large, technologically advanced farms

5 The last agricultural census for which data is currently available

with national value added derived from land, capital, and skilled labor? The data presented in Figures 2-4 suggest that productivity gains and production growth is taking place in the agricultural sector as a whole. Interestingly, the rural sector in Brazil is becoming more capital and labor intensive across all the scales of farms small and large (see Figure 4 above). It is difficult to envisage the structure of Brazilian farms in 2030 but the above trends suggest that simulations on the long term future of the Brazilian agricultural sector need to focus on the sustainable intensification of the production rather than the likely changes in the structure of the households and the size of farms.

Small holder farmers are generally more vulnerable to economic and environmental shocks and have access to fewer resources to adapt to climate variability and change when compared to large scale farmers. However, relative to large scale producers that rely on one or two crops planted over thousands of hectares, small holder farmers can play a vital role in providing landscape scale resilience through a diversity of production approaches that harness a wider spectrum of agrobiodiversity while also preserving and harnessing ecosystem services and the emerging markets for these services (carbon and biodiversity offsets, hydrological flows for reduced floods and/or improved water quality). In addition to emerging markets for ecosystem services, the increasing global demand for "functional foods" (foods that have direct health benefits like reducing cholesterol, improving liver function, reducing hypertension) could result in major economic windfall for smallholder farmers. Many of the functional foods are "low volume, high value" products that are well suited to smallholder cropping systems in the Brazilian farming landscape.

Another issue that is often overlooked in the discussions on future scenarios for Brazilian agriculture is the prevailing legal and land administration framework in Brazil (Sparovek et al., 2010). The legal framework dictates what can and cannot be done in the rural and agricultural landscape (e.g. maintaining riparian zones, legal (forest) reserves, securing indigenous lands etc.) and the Brazilian Government is aggressively enforcing the legal aspects via a range of monitoring actions, policies, and fiscal instruments. The two main legal frameworks are (a) the Forest Law and (b) Preservation Areas such as state and national parks, and indigenous reserves.

The Forest Law, currently being revised and under discussion in the Brazilian Senate, covers all natural vegetation (the Amazon, the Atlantic Forest, the Cerrado (savanna), the Caatinga (the scrub woodland in northeastern Brazil), the Pantanal, and the Pampas (grassland of southern Brazil). The law delineates rural private land into land for production and land that must be preserved. The land that must be preserved with natural vegetation on all private farmland is further subdivided into (a) conservation areas (Legal Reserves) and (b) Areas for Permanent Preservation (APP) that include (i) riparian zones defined as vegetation strips along rivers and other water bodies with varying width depending on type and size of the water body, (ii) any land with slopes >45°, (iii) hill tops, and (iv) any land above 1800m above sea level.

The goal for the APP is to protect parts of the landscape with strategic value for freshwater recharge and thus the APP cannot be used for any type of production activities and must be maintained with the original native vegetation. Changes to this aspect of the law that allow the planting of exotic tree species (e.g. eucalyptus, African oil palm) and the reduction in the prescribed area to be preserved are currently the subject of intense discussions. Legal Reserves are established to promote biodiversity conservation. Although the primary goal is to maintain the native vegetation, Legal Reserves can be used for some low-impact production systems, such as managed low-impact forest extraction, selected agroforestry systems, and apiculture. These are suitable for smallholder family agriculture and possibly alternative production schemes aiming at niche markets. Conventional mechanized agriculture employing intensive inputs or forestry operations employing complete forest removal are not allowed. Ideally, any proposed changes in the forestry law should also consider the implications of projected impacts from climate change on the agroecological landscapes.

It is possible to envisage a 'paradigm shift' for a productive, resilient, culturally appropriate and inclusive Brazilian rural and farming landscape that has both large farmers ensuring efficient high volume growth and smallholders ensuring resilience to climate change shocks via a range of cropping systems that are productive and profitable on the basis of payments for ecosystem services (e.g. Reduced Emissions from Deforestation and Degradation – REDD plus) and the emerging markets to meet the growing global demand for functional foods and feedstock for industry! Understanding the evolving intensification, vulnerability, resilience, and investment issues and better mapping projected climate change impacts across relevant spatial and time scales, will be critical to enhancing and sustaining Brazil's agriculture and rural sectors and their competitive regional and global advantage. This short section is included to highlight the importance of the legal aspects on future expansion, intensification, and diversification of Brazilian agriculture. The Forest Law (Legal Reserves and APP) is currently under debate in the Brazilian senate with the objective of revising the law. A full discussion of the evolving legal framework and its potential influence on the future structure of Brazilian agriculture is beyond the scope of this report (see Sparovek et al., (2010) for a detailed review and discussion).

Threats to Brazilian Agriculture from climate variability and eventual climate change

There is growing concern in Brazil and in the Latin American Region that increasing short term climate variability and medium to long term climate change will have significant negative impacts on the Brazilian landscape and on Brazilian agriculture, national economic growth, and associated livelihoods (Assad and Pinto, 2008; Margulis and Dubeux, 2010).

- The study by Assad and Pinto (2008) 35 crops were assessed in terms of climate risks but nine major crops (cotton, rice, coffee, sugarcane, beans, sunflower, cassava, maize and soybean, as well as pastures and beef cattle) representing 86% of the planted area in Brazil, received special focus.
- Based on a 2007 baseline, climate risk zone mapping in 5,000 municipalities for these crops, the agricultural scenarios in Brazil were simulated for the years 2010 (closest representation to the current conditions), 2020, 2050 and 2070 and two IPCC Third Assessment Report scenarios: A2 the most pessimistic, and B2, slightly more optimistic. In scenario A2, the estimated temperature rise variation is between 2°C and 5.4°C; and in B2, between 1.4ºC and 3.8ºC.

The results showed that:

i. Projected climate change impacts on all currently produced food grains will amount to US$ 4 billion by 2050 with the soybean sector alone accounting for almost 50% of the losses;

ii. Under a pessimistic Climate Change scenario (A2), the best current coffee production (“low risk”) areas are expected to shrink by at least 30%, which could result in losses of close to US$ 1 billion by 2050. Interestingly, even under a pessimistic A2 scenario, the area suitable for sugarcane could double by 2020.

The study by Margulis and Dubeux (2010) used the Assad and Pinto (2008) study methods based on a single GCM-RCM combination and the A2 and B2 IPCC Third Assessment Report scenarios. The climate modeling outputs were used to drive a computable general equilibrium (CGE) model to better assess the likely economic impacts due to projected climate change to 2020, 2050, and 2070. The simulations showed that Brazil’s GDP in 2050 will approximate US$9.4 trillion and that in the worst case (IPCC Scenario A2) the country could lose about 2.5% every year due to temperature increase impacts. At a discount rate of 1 percent per year, this is equivalent to the loss of one whole year’s GDP over the next 40 years. The study’s findings also projected a significant reduction in the best crop areas currently characterized by low production risk, for 8 of the 9 major food and export crops (Table 1).

Impact of climate change on current "low risk" areas suitable for cultivation (Margulis et al., 2010)

Crops	Variation relative to current productive area (%)					
	SRES B2 (+1.4ºC to +3.8ºC)			SRES A2 (+2°C to +5.4°C)		
	2020	2050	2070	2020	2050	2070
Cotton	-11	-14	-16	-11	-14	-16
Rice	-9	-13	-14	-10	-12	-14
Coffee	-7	-18	-28	-10	-17	-33
Sugar cane	171	147	143	160	139	118
Beans	-4	-10	-13	-4	-10	-13
Sunflower	-14	-17	-18	-14	-16	-18
Cassava	-3	-7	-17	-3	-13	-21
Maize	-12	-15	-17	-12	-15	-17
Soybean	-22	-30	-35	-24	-34	-41

The projected reductions in cultivation area of low risk and associated economic losses to 2050 as summarized by Margulis et al., 2010 are sobering (Table 2 below - 1 US $ = Br$ 1.8)

Crop	Reduction in "low risk" cultivation area (%)	Scenario A2 Annual Economic loss (Millions Reais)*
Rice	-12	530
Cotton	-14	408
Coffee	-17.5	1,597
Beans	-10	363
Soybean	-32	6,308
Maize	-15	1,511
Sugar cane	145	0

The Margulis and Dubeux (2010) study was a pioneering contribution to the Brazilian knowledgebase on climate change impacts on a range of sectors (agriculture, biodiversity, energy, and hydrological resources) and the macroeconomic growth implications at a national scale. The authors nevertheless identified the following opportunities for improving future climate change economic impact assessments:

1. The use of a suite of GCMs and RCMs for improving the robustness of climate change projections rather than the single GCM and RCM used for the study.
2. The improvement in projected rainfall impacts as there was no consensus in the magnitude and direction of the projected rainfall impacts – a problem that continues to plague most other studies.
3. An explicit treatment of uncertainty and the magnitude and frequency of extreme events
4. Improvement in the data density (crop area, land quality, rainfall, temperature, runoff, infiltration, biodiversity, land cover dynamics) and data accessibility for model parameterization, calibration, and validations.

A regional study on climate change impacts to Latin America's agriculture (Fernandes et al. 2011) also found that agricultural productivity is likely to be significantly and negatively impacted, albeit with different sub-regional intensities (BOX 1 below). The study projected that Brazilian soybean, production could decline by as much as 30% in 2020 and even more so by 2050 with significant decreases also likely in maize, and wheat. Encouragingly, however, the study reported that simulation of adaptation interventions (short/long cycle varieties, deeper rooted/drought tolerant varieties, moderate irrigation at critical growth phases, and a shift in planting dates shoed the possibility of mitigating a significant amount of the yield declines in all impacted crops.

BOX 1 - Climate Change and Agriculture in Latin America, 2020-2050

The World Bank's 2011 regional study (Fernandes et al. 2011) reported 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. Key findings include:

- 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, Colombia, and Brazil. Yield reductions due to the shortening of the crop cycle resulting in fewer days to fill grains. The projected yield declines due to disease in 2020 and 2050 could also be significant. With few exceptions, insufficient water could affect wheat productivity more than other factors.
- 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, and likely to result in a markedly reduced soybean grain-filling period.

- 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.
- 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. In low-temperature areas (especially Uruguay and southern Brazil) climate change could reduce the incidence of pre-flowering cold shocks inducing sterility. Except for Brazil and the Caribbean, rice 'blast' disease pressure could ease, because temperature and rainfall conditions become less favorable for the blast causing pathogen *Pyricularia grisea*,

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A key challenge and opportunity for Brazil is the need to better understand, quantify, and map the locations of projected impacts on currently productive agriculture and to better quantify the magnitude and uncertainty associated with current projections of both positive and negative impacts.

In 2011, a World Bank report (Assad et al. 2011) presented a detailed review of the literature and outputs of recent empirical studies that had developed projections of the likely impacts of climate change on Brazilian agriculture. Generally speaking, the empirical evidence suggests that the net impact of climate change on Brazilian agriculture is negative, although there are varying regional consequences. However, most of the studies to assess likely impacts of climate change on Brazilian agriculture were constrained by several of the following limitations:

1. the simulations regarding climate change were based on scenarios of uniform increase in temperature and precipitation and did not use geographically differentiated climate projections.
2. the studies used climate data sets that were significantly less comprehensive in terms of geographical distribution as well as precision than what is currently available.
3. The studies were based exclusively on Global Climate Models (GCMs) for projections of future climate change impacts. Although simulations with GCMs are appropriate tools to address global to sub-continental scale climate change and impacts (Giorgi et al. 2001), the results of long-term multimodel GCM simulations must still be treated with caution as they do not capture the detail required for regional impact assess-

ments, due in part to the coarse resolution (~300 km x 300 km) in the majority of the models used. The concern about the low spatial resolution of GCMs is especially relevant for heterogeneous regions, such as South America, where the distributions of surface variables such as temperature and rainfall are often influenced by local effects of topography, and thermal contrasts, which can have a significant effect on the climate (Alves and Marengo, 2009).

4. To address country, sub-country and local scale climate change consequences or impacts, higher resolution (e.g. 50 km x 50 km) regional climate models (RCMs) have been employed. It is important to note, however, that although the results for Brazil demonstrate that RCMs show good skill in the simulation of the present-day climate, they still require adjustments and calibration (based on local data and field observations) to the settings used by the model in order to correct for the systematic errors inherited from the GCM from which they were derived and ultimately to produce useful estimates of regional, and seasonal to inter-annual climate projections (Marengo et al., 2009b).

Scope of this study

This study builds upon the findings of a decade of research on climate change impacts on Brazilian agriculture and provides the latest findings of new modeling approaches and simulations of:

i. projected climate change in Brazil to 2020 and 2030
ii. the likely impact of climate change on existing agroecological zones and their suitability for major grain crops, sugarcane, cotton, and pastures, and
iii. the economic impacts of changes in agroecological zone suitability for the various crops and the:
   - induced changes in supply and demand of agricultural products at a national level,
   - the economic effects on agricultural production and profitability, and
   - changes in the distribution of land use and production within Brazil for given supply and demand scenarios.

This report highlights the outputs of targeted modeling on major Brazilian crops by regions within Brazil to provide more robust and quantitative information on how and where the drivers of agricultural production growth are more likely to be impacted by changing climate. The goal is to empower policy makers to ensure that the farming sector has access to the knowledge and resources to undertake the adaptation that will be necessary to cope with unavoidable climate changes while simultaneously contributing to mitigating GHG emissions.

Four key integrated and linked interventions were used to attempt to significantly improve currently available assessments of climate change impact on Brazilian agriculture and to guide policy makers with the priorities and phasing of needed investments. This study:

1. Accessed and incorporated the best available hydrometerological data from all calibrated and validated ground stations of the Brazilian Water Agency (ANA) in all the sub-regions in Brazil to significantly reduce the identified **"climate data deficiency"** of previous studies.
2. Refined climate change projections via coupling global, regional and local scale models to provide more robust climate change projections for Brazil. This was achieved via:
   a. An analysis of the best ensemble of global and regional climate models (GCMs and RCMs) that have been tested for Brazilian climate conditions
   b. Integration of the best available GCMs and RCMs with a the state of the art Brazilian developments in Regional Atmospheric Model (BRAMS) that incorporates aerosol and land cover/land use feedbacks for much improved local weather and climate (especially rainfall) projections.
3. Coupled the best GCM, RCM, and BRAMS suite of models identified above with the EMBRAPA/UNICAMP Agro Zoning model and recently available highly disaggregated land (soil) quality data at municipal level to develop an updated EMBRAPA AZM.
4. Coupled the EMBRAPA AZM with the Brazilian Land Use Model (BLUM) for an improved Climate-Sensitive BLUM to assess:
   a. Climate change induced changes in supply and demand of agricultural products at a national level
   b. Changes on the distribution of land use and production within Brazilian territory for given supply and demand scenarios.
   c. Economic effects on agricultural production and profitability

Climate Change and Agricultural Impact Projections in Brazil to 2030 and Beyond

Based on the literature review findings highlighted in the preceding sections, and the emerging outputs of on-going work in Brazil, there are significant opportunities to improve both the quality and the robustness of the currently available projections for climate change impacts on Brazilian agriculture over the next three to four decades. One option has been to develop regional climate models (RCMs) nested within a GCM to facilitate more robust projections at national to sub-national scales (Christensen et al. 2007). Various national and international programs have used RCMs to help quantify better regional climate change and provide regional climate scenarios for assessing climate change impacts and vulnerability. These have all followed a standard experimental design of using one or two GCMs to drive various regional models from meteorological services and research institutions in the regions to provide dynamically downscaled regional climate projections over Central and South America (Marengo et al., 2009; Soares and Marengo, 2009; Urrutia and Vuille, 2009).

Refining climate change impact projections via global, regional and local scale modeling

As discussed in previous sections, the relatively coarse resolutions of GCMs pose limitations to the explicit simulation of mesoscale climate processes and to the representation of topography, land cover, land use, and land–sea distribution. This study undertook the following key steps in refining climate change projections and impact assessments for major Brazilian crops.

Regional and Brazilian Approaches to Selecting and Using Climate Models

We reviewed the ongoing Latin American regional effort (*Cenarios Regionalizados de Clima Futuro da America do Sul (CREAS)* [The Regional Climate Change Scenarios for South America], where three RCMs: (1) **Eta for Climate Change Simulations—Eta CCS**—(Pisnichenko and Tarasova 2009, (2) **RegCM3** (Seth and Rojas 2003, Pal et al., 2007) and (3) the public version 3 of the UK Met Office Hadley Centre **HadRM3P** (Jones et al. 2004; Alves and Marengo 2009) were nested within the public version of the atmospheric global model of the UK Met Office Hadley Centre HadAM3P (Marengo and Ambrizzi 2006; Marengo 2009).

The CREAS effort aims to provide high resolution climate change scenarios in South America for raising awareness among government and policy makers in assessing climate change impact, vulnerability and in designing adaptation measures. The rationale for the choice of global model HadAM3P is because (a) the model adequately reproduces the seasonal distribution and variability of rainfall over large areas of South America, even though some systematic errors persist, (b) the model has been investigated quite thoroughly in various regions in previous downscaling experiences.

Emissions Scenarios Used for this Study

Due to resource (funding and time) constraints, this study refined previous work by Brazil and the World Bank by using similar emissions scenarios and modeling approaches.

Previous work (Assad and Pinto 2008, Margulis and Dubeux, 2010) was based on a 2007 baseline, climate risk zone mapping in 5,000 municipalities for major Brazilian crops, and the agricultural scenarios in Brazil were simulated for the years 2010 (closest representation to the current conditions), 2020, 2050 and 2070 and for two IPCC Third Assessment Report scenarios: A2 the most pessimistic, and B2, slightly more optimistic. In scenario A2, the estimated temperature rise variation is between 2°C and 5.4°C; and in B2, between 1.4ºC and 3.8ºC.

Based on the previous work in Brazil in the context of the A2, B2 scenarios, we selected the A2 emission (more pessimistic with projected temperature rise variation between 2°C and 5.4°C) scenario as most closely resembling the estimated increased future heterogeneity with continued population growth. Economic development is primarily regionally oriented, the per capita economic growth and technological development are more fragmented and slower when compared with other scenarios (IPCC, 2007).

In this study, we focused on refining climate-agricultural impact assessments for the periods 2020-2030 and for the scenario A2 because these decades are of greatest concern to current investments and policy makers. More importantly, the reliability of available data and projection capability is also greatest for the period to 2030. Beyond 2030 and based on available climate and other relevant data, projections become increasingly uncertain.

Climate Models Used for this Study

We used the findings of a study by Macedo (2011) that evaluated GCMs for Brazil, and selected the 4 most appropriate GCMs using IPCC SRES A2 based on climate (temperature) projection congruence for different regions of Brazil. The selected GCMs included:

- **NCCCSM (CCSM3)** – National Center for atmospheric Research – USA
- **GIER (GISS-ER)** – NASA Goddard Institute for Space Studies – USA
- **CSMK3 (CSIRO – Mk 3.0)** – Commonwealth Scientific and Industrial Research Org – Australia
- **INCM3 (INM-CM3.0)** – Institute for Numerical Mathematics – Russia

In addition to the above GCMs, we selected 3 Regional Climate Models (RCMs) that have already been extensively tested and calibrated in Brazil:

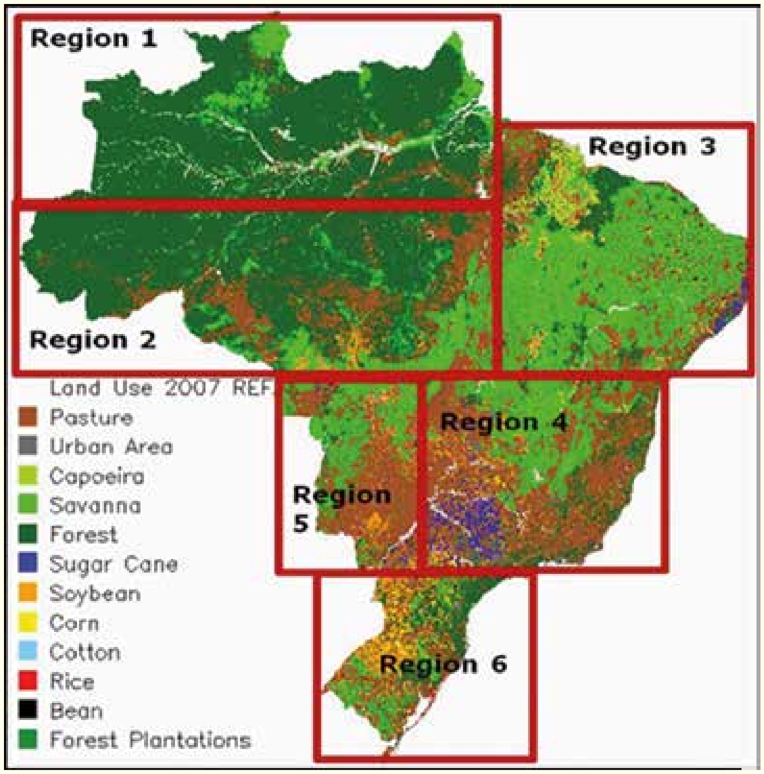
- **PRECIS** (Providing Regional Climates for Impact Studies) developed by the Hadley Center (UK) and was initially denominated HadRM3P. The contour conditions are defined by the projections of the model HadRM3P and HadAM3P. The model is indicated for the South America and adjacent ocean conditions. Previous work developed by EMBRAPA and CEPAGRI showed an excellent suitability for temperature projections to 2050 but with problems in simulating rainfall.

1. **Eta for Climate Change Simulations—Eta CCS—**(Pisnichenko and Tarasova 2009) developed at Belgrade University and implemented by the National Center for Environmental Prediction. The Brazilian Center for Weather Forecasts and Climate Studies (CPTEC) has used the Eta model operationally since 1996 to provide weather forecasts over South America. Due to its vertical coordinate system, the Eta Model is able to produce satisfactory results in regions with steep orography such as the Andes range. The CPTEC GCM forecasts comparisons with Eta showed that the model provided considerable improvement over the driver model. The assessment of the Eta Model seasonal forecasts against climatology showed that, in general, the model produced additional useful infor-

mation over climatology. The Eta Model exhibited better results in simulations of upper- and lower level circulation and precipitation fields.

2. **BRAMS** *Brazilian developments on Regional Atmospheric Modeling System. (Freitas et al., 2009; Longo et al., 2010). The* BRAMS model is based on the Regional Atmospheric Modeling System - RAMS - with specific parameterization for the tropics and sub tropics. The model has a set of modules to simulate processes of radioactive transfer, water and heat exchange between surface and atmosphere, microphysics of clouds and turbulent transfer in the boundary layer.
   a. The BRAMS system is able to incorporate aerosol effects on radiation balance and the hydrological cycle thereby helping to overcome a significant source of inconsistencies in the rainfall projections.
   b. BRAMS has also high resolution and updated topography, land use, soil type and normalized difference vegetative index (NDVI) data sets. The biophysical parameters maximum stomatal conductivity, leaf area index, albedo, roughness, biomass and soil heat capacity, soil porosity, hydraulic conductivity and moisture potential at saturation and root distribution associated with the vegetation and soil parameterizations of RAMS were adapted for tropical and sub-tropical biomes and soils, using observations or estimations obtained in recent Brazilian field campaigns, mostly associated with the LBA (Large Scale Biosphere-Atmosphere Experiment in Amazonia – www.lba.cptec.inpe.br) program.
   c. Overall, the BRAMS model is able to replicate the seasonal cycle of precipitation over Brazil with good skill across most of regions. In Figure x below, for regions 1 and 2 the projection skill is very good, while for regions 3, 4 and 5 it is satisfactory. Region 6 is where the model underestimates rainfall.

Figure 5. The BRAMS land-use map for the analysis of model simulation results

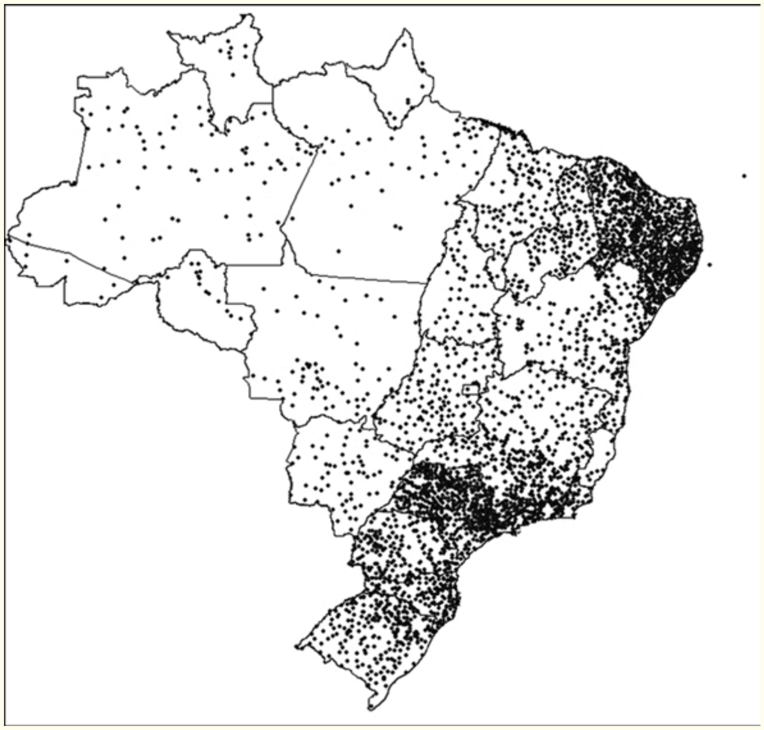


Model Testing, Climate Projections and Model Calibrations

After selecting the seven climate models - four GCMs and three RCMs - the temperature and precipitation were simulated for to 2020 and 2030 with 2010 as the baseline. The detailed methods for climate simulation and the accompanying mathematical treatment of data are available on request.

Once the temperature and precipitation simulations were conducted, they were calibrated against hydrometerological data from a range of Brazilian agencies (ANA, CPETEC, EMBRAPA, INMET, UNICAMP). The AGRIPEMPO hydromet system has a network of 1,200 meterological stations and 4,000 rain gauges nationally (see Figure 6 below) with at least 25 years of data records that have been quality checked to 2007.

Figure 6. Spatial distribution of the Brazilian hydromet stations [Source: EMBRAPA]



In order to derive the variation of temperature across the seven climate models over time we used the method proposed by Gleik (1986). Using 2000 as the baseline we derived the difference of the value for monthly temperatures for each of the target years (2020 and 2030).

1. So for any given spatial coordinate (x, y) in a given climate model M the temperature variation is estimated by:

$$\Delta TM\ M(m,a,x,y) = TMM(m,a,x,y) - TMM(m,2000,x,y)$$

   where TM M(m,a,x,y) is the moving average of 11 years for the month m , year a for the point (x,y).

2. For each hydrometerological station in the national AGRIMET database we were then able to determine the value of ΔTM for each of the climate models and then for each year/month the ΔTM MAX and the ΔTM MIN.

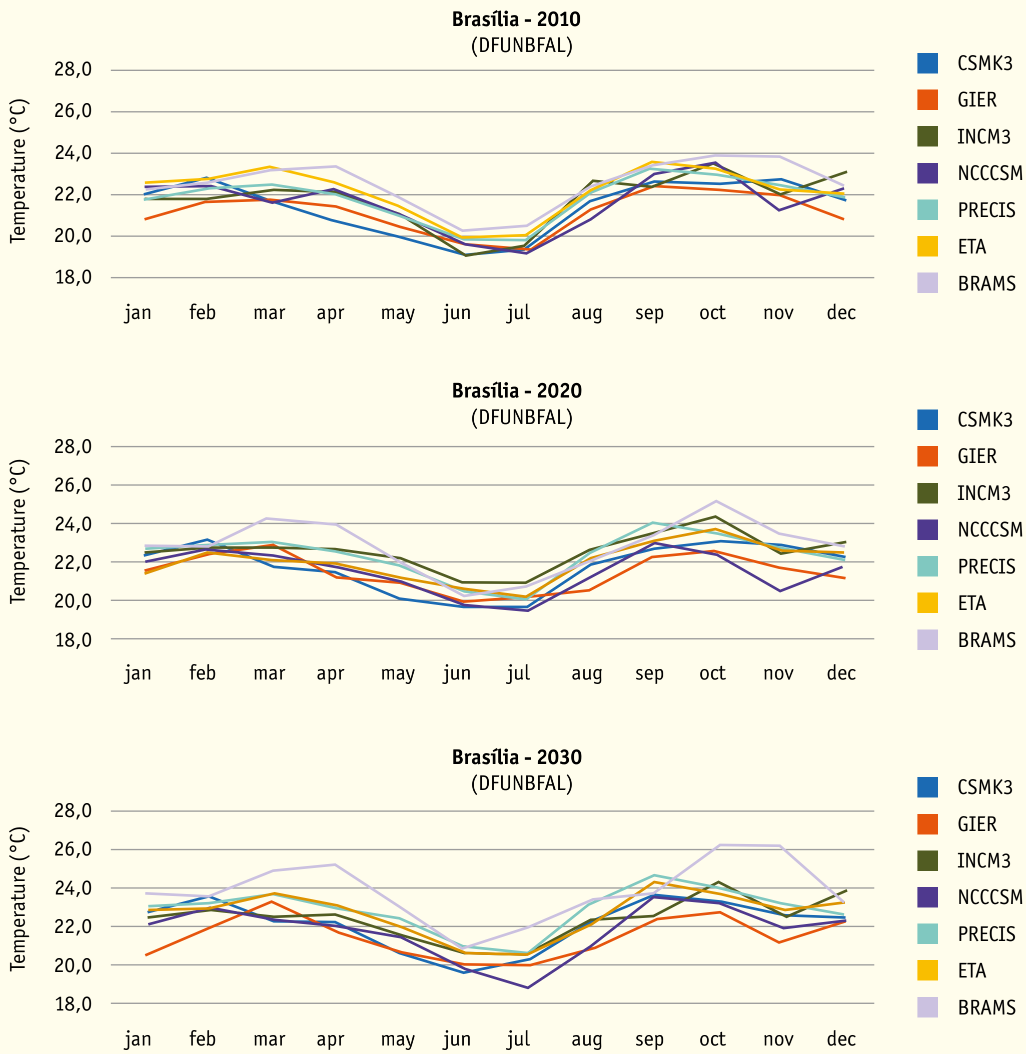
3. To obtain the temperature used in the crop impact simulations (TS) for each geographical coordinate (x,y) corresponding to a hydromet station, TS was calculated as follows

$$TS(m,a,x,y) = TR(m,x,y) + \Delta TMM(m,a,x,y)$$

   Where TR(m,x,y) is the real temperature at the location (x,y) for the month m, and ΔTMM(m,a,x,y) is the variation of temperature for a given model M for the month m and year of interest a.

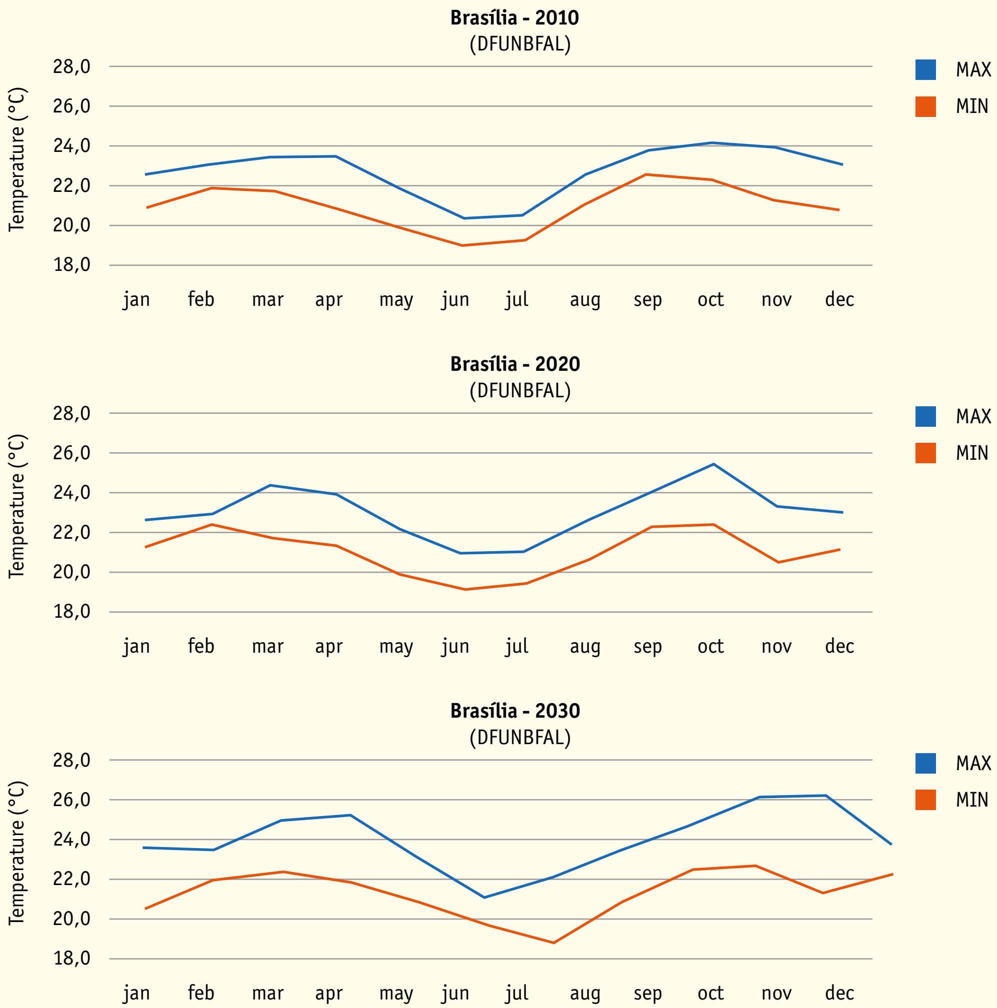
To assess the representativeness of the simulated temperatures Ts with observed values at hydrometerological stations, we simulated the 2010 temperatures for selected stations across Brazil. Figure 7 below shows the good congruence of the simulated Ts across the 7 models (4 GCMs and 3 RCMs) for a hydromet station located in Brasilia.

Figure 7. Variation of the temperature estimated by the seven models for the weather station "DFUNBFAL", located in Brasila, DF, Brazil (lat: -15,79; long: -47,9227).



In addition to deriving ΔTM we also obtained the maximum and minimum values for the models (ΔTM MAX e ΔTM MIN) that when averaged over the 7 climate models were consistent for the Brasilia hydromet station (Figure 8). The pattern was repeated at all other stations tested across Brazil thereby allowing the development of an **OPTIMISTIC** (ΔTM MIN) and **PESSIMISTIC** (ΔTM MAX) temperature increase scenarios 2010-2030.

Figure 8. Monthly maximum and minimum temperatures estimated from the seven models for the weather station "DFUNBFAL", located in Brasília, DF, Brazil. (Lat:-15,79; Long:-47,9227).



The Agro Climatic Risk and Vulnerability Zoning Model

In Brazil, zoning of agricultural risks is a public policy since 1996 and each of the 5,564 municipalities in the country has been zoned for suitability of crop cultivation in terms of at least 80% probability for harvesting an economically viable crop yield. The zoning is based on the growth phases of each crop (phenology), drought stress, flood risk, and extreme temperatures at critical phases of crop growth. For example, drought stress at flowering or grain filling can significantly impact yields. Excessive rain at harvest time can ruin a crop. The incidence of extreme temperatures can cause the loss of production due to flower loss in the case of high temperatures or frost by low temperatures.

In 2001, EMBRAPA and UNICAMP developed a simulator to project the agricultural risks as a function of climate and soil. The simulator was then used to produce 500,000 simulated observations for beans, 600,000 for soybean, 400,000 for rice, 2,500,000 for maize and 450,000 for wheat. These simulations to reflect the different soil, plant, climate characteristics of the different municipalities in Brazil resulted in an advanced knowledge base of the agricultural geography of the country.

In addition to information on crop needs, terrain characteristics, soil quality, and weather data, the zoning has been further fine-tuned to include specific indices of sensitivity of crops to extreme temperature and moisture events during critical growth phases of crop growth based on known agricultural calendars. For example, the crop risk indices are based on agro-meteorological water balance, calculated from crop evapotranspiration, which is the sum between leaf transpiration and soil evaporation. Each crop has optimal soil moisture characteristics for optimal levels of photosynthesis, growth, and yield. Critical climate factors for this process are temperature and soil moisture that can be used to delineate the area in which any crop could be produced in Brazil and the associated climate related risks.

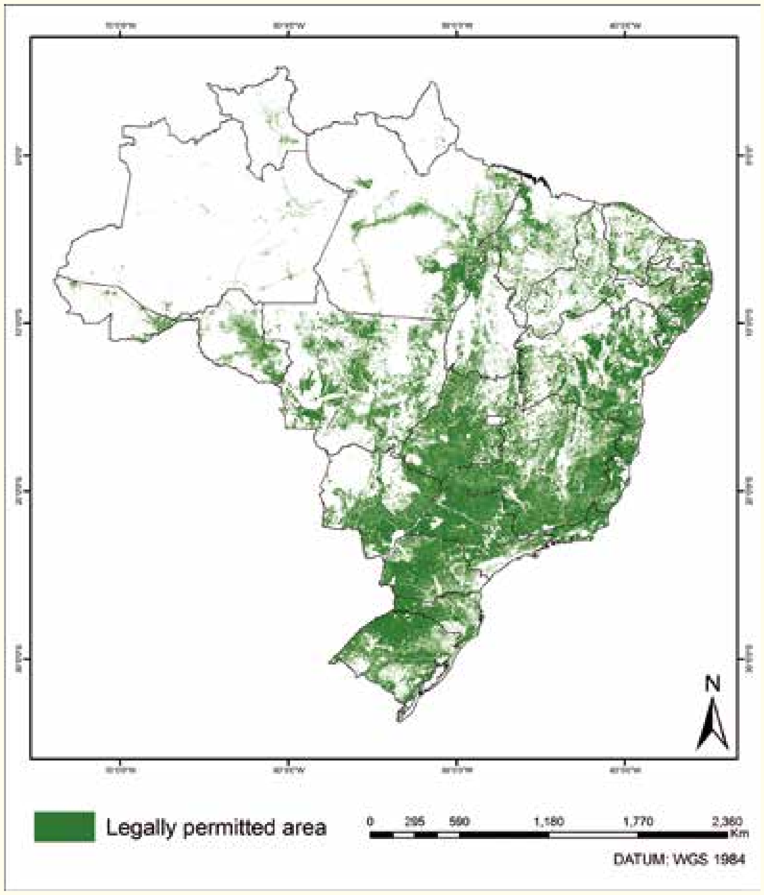
By incorporating IPCC global warming scenarios, the projected temperature and any rainfall/soil moisture impacts can be introduced in the simulations on the basis of temperature and moisture risk indices for any given crop. The areas of lowest risk are those where there is water stress, which guarantees seed germination and especially flowering and grain filling – factors that are critical to final crop yield. This risk must not exceed 20%.

This study is contributing to upgrade the current Brazilian agricultural zoning system to include future climate scenarios and projections of climate and once completed will begin to have an immediate operational and policy impact nationally.

The Agro Climatic Risk and Vulnerability Zoning Model (Assad and Pinto, 2008) developed by EMBRAPA and UNICAMP currently underpins all financial lending to the agricultural sector in Brazil. The Central Bank of Brazil requires mandatory agricultural zoning throughout the country for access to rural credit and the EMBRAPA/UNICAMP model indicates “what, where and when” to plant a crop variety according to a zoning system. Three types of zoning are defined:

a. **Agro-ecological** - uses the data base of soil, topography, climate, and the current land and environmental legal framework. For example, Figure 9 below is the available land area (in green) for agriculture at municipal scale resolution that can be legally accessed for farming. This study used high resolution soils, vegetation, and terrain characteristics data sets and included all restrictions on the types of land use that can be practiced as mandated in Brazil’s legal framework to produce this high resolution map as a baseline for analyzing future climate change impacts.

Figure 9. Legally permitted area for agriculture based on land and environmental legal frameworks and landuse restrictions



b. Agroclimatic – based simply on climate information without evaluating the potential crop risk.

c. Climatic - uses climate, soil, and crop culture by assessing the risk analysis taking into account mainly the information about rainfall, temperature and water balance of derivatives that indicate the deficiencies and surpluses of water for agricultural crops.

Agro Climatic Zoning integrates crop growth models with refined climate simulations described above and uses a crop risk matrix based on a *state of the art* soil and land quality typology, weather data, crop water needs, and crop phenology (see Figure 10).

The Water Needs Index (ISNA) of the Agro Climatic Zoning Approach

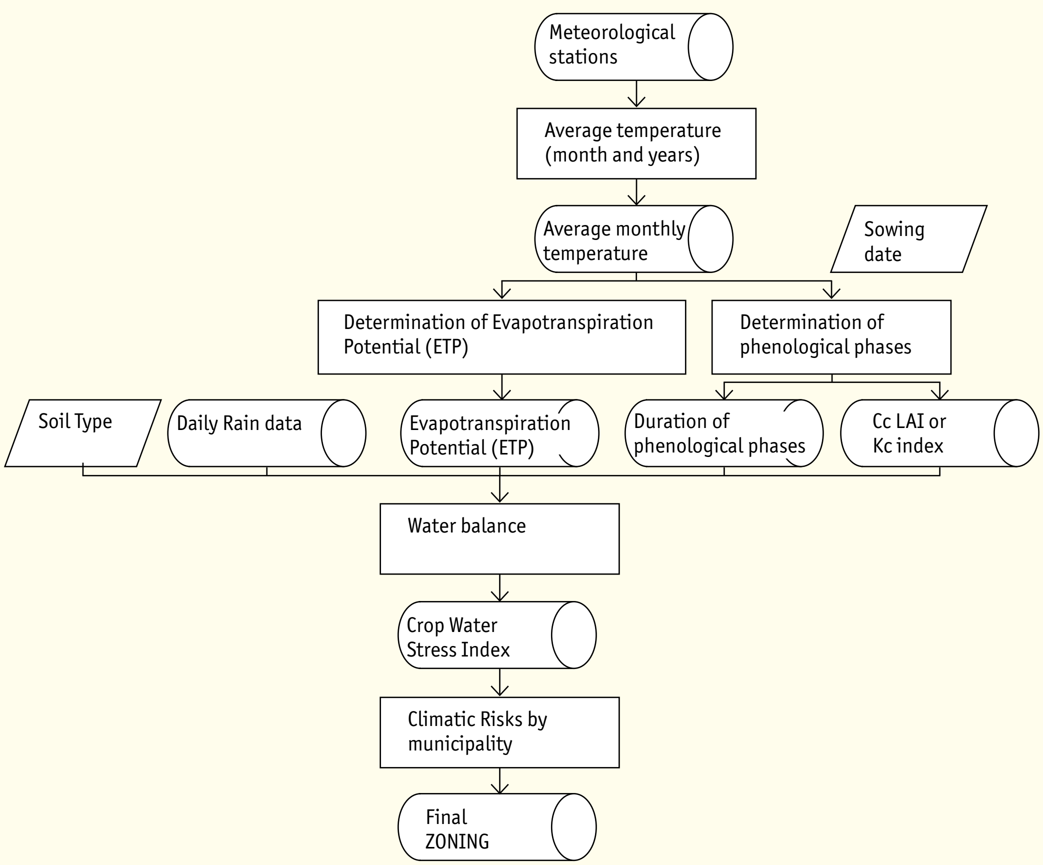
The basis for the zoning is a crop water supply (Vulnerability) index based on the ratio of actual to maximum evapotranspiration per crop is used to derive a crop risk and suitability zoning. The risk zones set for each municipality in the country indicate which of the 9 major food and export crops that are at least 80 percent likely to provide an economically acceptable harvest.

Each crop or variety has a pre-defined set of climate conditions based on long term research and field observations. The complete length of a crop cycle is divided into four phenological (growth) phases (Initial Development, Vegetative Growth, Reproduction and Maturity) where the third phase is normally considered as critical mainly due to the high sensitivity of flowering to dry spells and/or high temperatures. The length of each phenological phase is defined by degree-days or heat units. The incidence of extreme temperatures can cause the loss of production due to flower loss in the case of high temperatures or frost by low temperatures.

Soil Classification and Map of the Agro Zoning Approach.

The soils are classified into three types - sandy, medium and clayey – or with low, medium or high capacity for water retention capacity respectively. The crop coefficient (Kc) is defined according to the typical soil and is a measure of water consumption for each phase of the crop development. The ISNA values are based on the rainfall stations and estimated by a specific sowing period produced by the water balance for a fixed combination of soil type and phenological cycle.

Figure 10. Flowchart of components and biophysical, climatic, and plant growth processes used for zoning



Identifying Cropping Areas that are less Vulnerable to Climate Change Impacts

Based on temperature effects to 2020, 2030 vulnerable areas are identified and the area quantified. The principles for determining climate risk are as follows:

a. Areas with the least risk are those that do not have a soil water deficiency that results in good germination as well as flowering and grain filling. This risk should not exceed 20%. The risk is based on an evapotranspiration index of the crops.

b. Using the above criteria, it is possible to assess the risk of planting any crop within Brazil. In addition to soil moisture, the projected temperatures for 2020, 2030, and 2050 are also used to refine risk assessments.

c. The major advance of the above approach relative to the previous studies is that each low risk agroecological zones are also screened for soil types, steep slopes, legal reserve area, riparian zones (APPs), indigenous areas, and protected areas thereby greatly increasing the precision of the estimates of crop productivity and likely climate impacts.

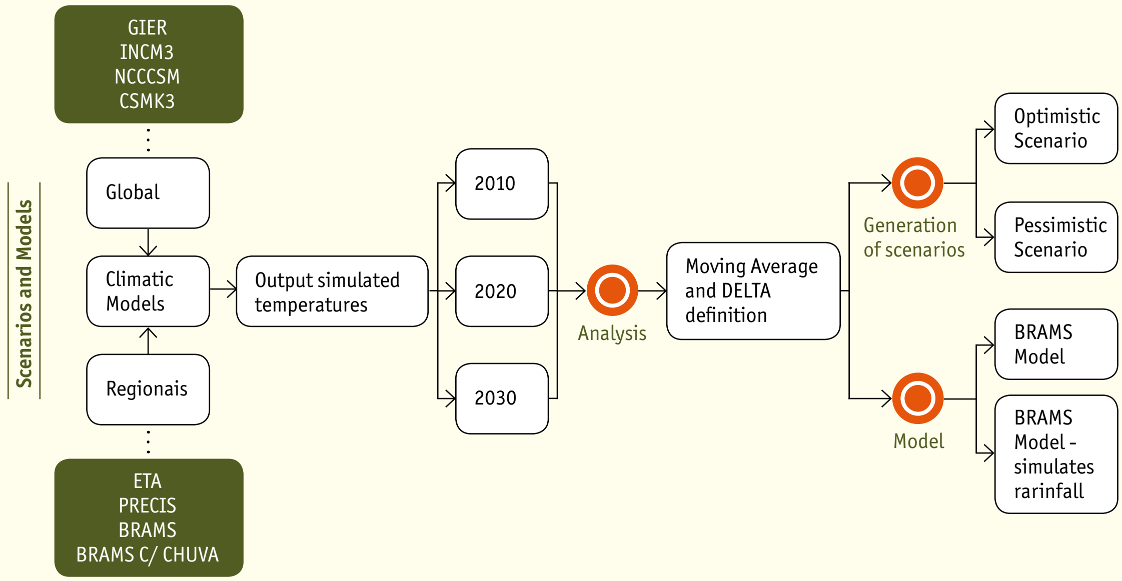
d. For current modeling efforts, the baseline for the crops planted, area planted, and value of production is the 2009 IBGE survey (Table 2 below).

Table 2. Crops and Area Planted in Brazil (2009)

Crop	Planted Area (ha)
Cotton	814,700
Rice	2,905,700
Sugarcane	8,845,650
Bean Summer Season	1,201,600
Bean Autumn Season	675,000
Maize Summer Season	9,463,200
Maize Autumn Season	4,799,650
Soybean	21,761,800
Rainfed Wheat	2,345,500

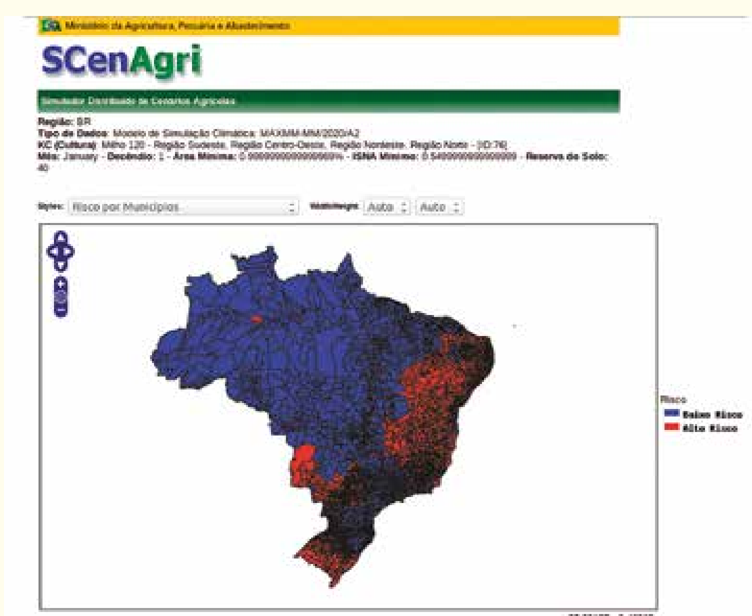
The process of integrating the GCM and RCM outputs to generate optimistic and pessimistic climate scenarios to 2020 and 2030 is highlighted below (Figure 11).

Figure 11. Representation of the process of handling models to the generation of scenarios.



To obtain the impact of projected climate change impacts on temperature and precipitation to 2020 and 2030 on target crops and pastures, we used EMBRAPA (C-PTIA's) Simulator of Agricultural Scenarios (SCenAgri) that integrates climate data, land, water, and crop characteristics/requirements based on nationally tested field tested datasets. SCenAgri can be used to simulate future agricultural production scenarios based on regional climate projections (Figure 12 below).

Figure 12. Example of low and high risk areas for planting corn in Brazil considering the sowing date in the first ten days of January, considering the pessimistic scenario.



Projected Climate Change Impacts on Area of Crop Suitability to 2020 and 2030

This study assessed the likely impacts of climate change projected by an ensemble of GCMs and RCMs on the major grain (soybean, maize, wheat, and beans) and biofuel (sugarcane) crops as well as cotton and pastures. In addition to an innovative approach that allowed a high resolution disaggregation not only of agroecologically suitable but also legally accessible farmland, this study also developed optimistic and pessimistic (temperature increase) scenarios of climate change thereby facilitating a more nuanced interpretation of likely risks to and impacts on the major Brazilian crops. Table 3 below presents the results of our climate impact projections on suitable area (relative to 2010 baseline) for major Brazilian grain crops. The values for pasture are estimated decreases in the productivity of pastures.

Table 3. Percent change in area at low risk from climate change

Crops	2020		2030	
	Optimistic %	Pessimistic %	Optimistic %	Pessimistic %
Cotton	-4.6	-4.8	-4.6	-4.9
Rice	-10	-7.4	-9.1	-9.9
Sugarcane[1]	107	101	108	91
Soybean	-13	-24	-15	-28
Rainfed wheat	-41	-15.3	-31.2	-20
Bean (summer season)	-54.2	-55.5	-54.5	-57.1
Bean (autumn season)	-63.7	-68.4	-65.8	-69.7
Maize (summer season)	-12	-19	-13	-22
Maize (autumn season)	-6.1	-13	-7.2	-15.3
Pasture[2]	-34.4	-37.1	-34.9	-38.3

[1]Sugarcane includes potential (new) areas not just current areas of production
[2]Pasture value = productivity.

For soybean, bean (summer and autumn seasons), maize (summer and autumn seasons), and cotton the results indicate a significant loss in the low risk area due to increasing temperature. As expected, more pronounced losses were observed in the pessimistic scenario where the temperature increase is projected to be higher than in the optimistic scenario.

Interestingly, for rice and rain fed wheat, the pessimistic temperature scenario seems to have less severe impacts than in the pessimistic scenario. This could be due to the higher temperatures in the pessimistic scenario offsetting damage to these crops from cold temperatures and/or frost. For example, it is well known that cold temperatures can result in flower sterility in rice.

For sugarcane, we included 'potentially suitable areas' rather than just the current area where it is grown, which resulted in a significant increase in areas low risk (or high suitability) suggesting that sugarcane is naturally better adapted to cope with increasing ambient temperatures. Unlike for sugarcane, however, our simulations suggest that pasture productivity with be increasingly negatively impacted with increasing temperatures.

Figures 13-21 (below) show the geographical distribution and extent of the climate change impacts on "low risk" agricultural land across Brazil for the crops in Table 3.

Maps of projected climate change impacts on major grain crops, sugarcane, and pastures in Brazil to 2020 and 2030

Figure 13. Impact of climate change on area suitable for soybean (2010 – baseline and 2030 optimistic and pessimistic)

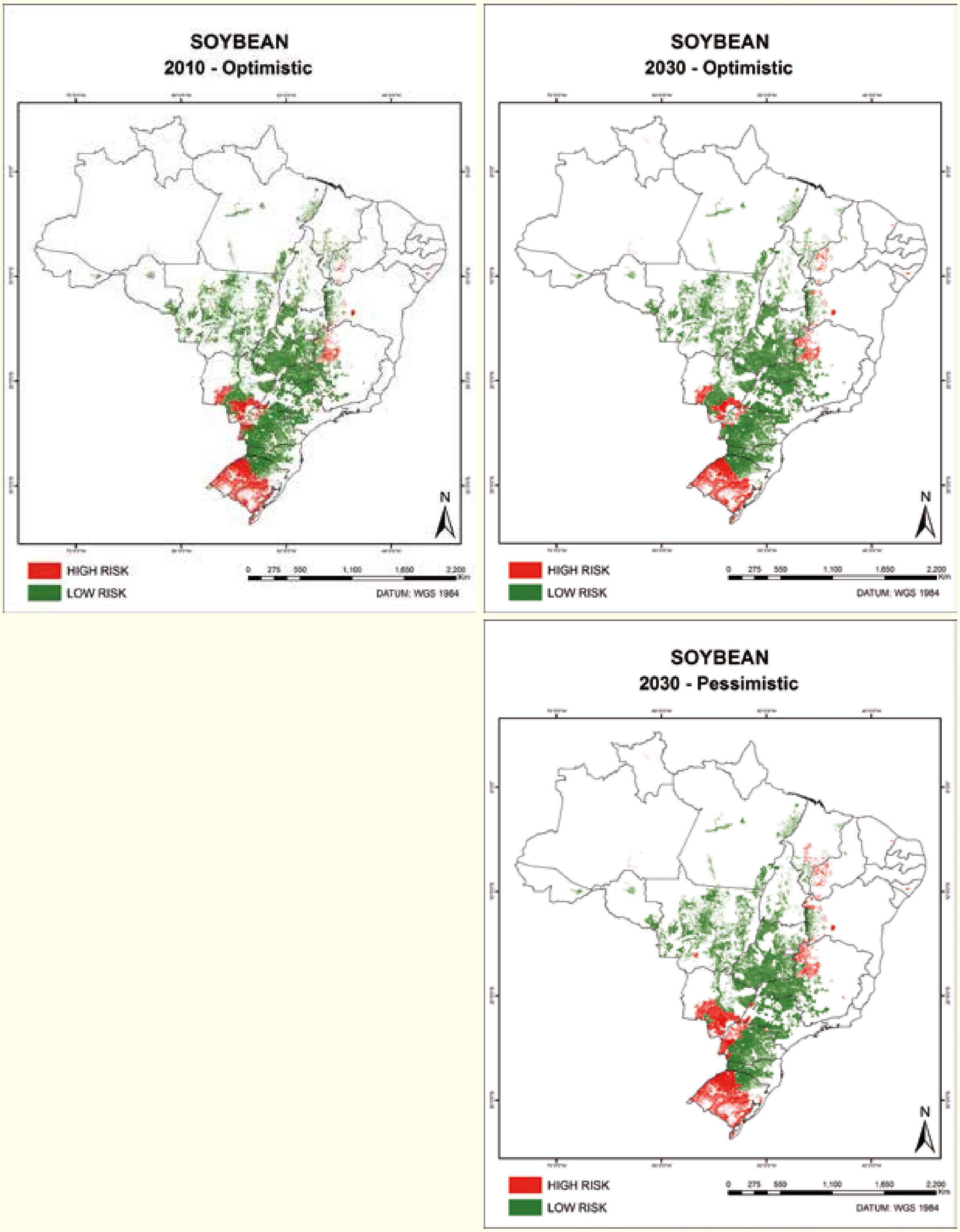


Figure 14. Projected losses in pasture productivity (%) relative to 2010 baseline under optimistic and pessimistic scenarios (2020 & 2030)

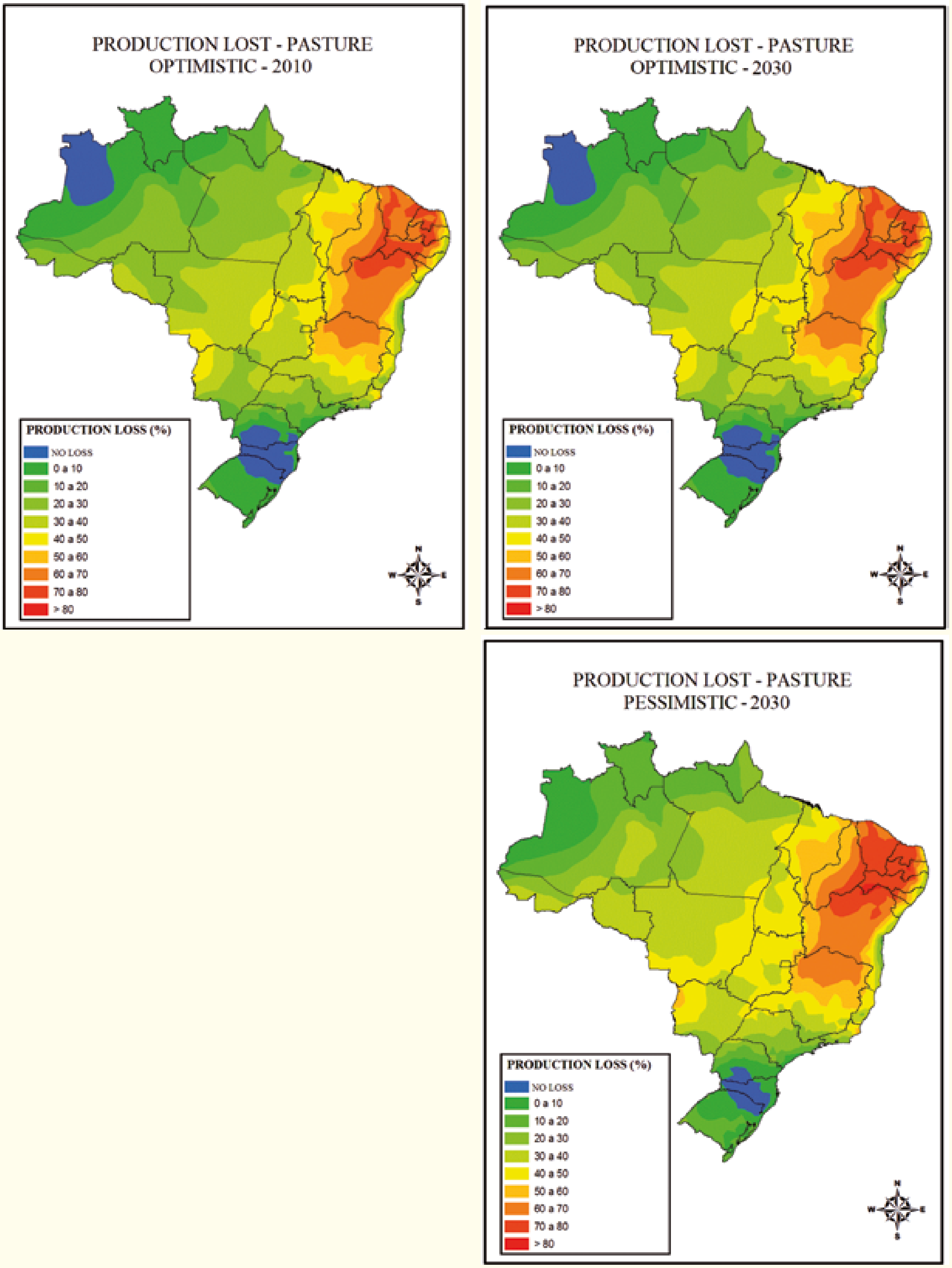


Figure 15. Impact of climate change on area suitable for beans – summer season (2010 – baseline and 2030 optimistic and pessimistic)

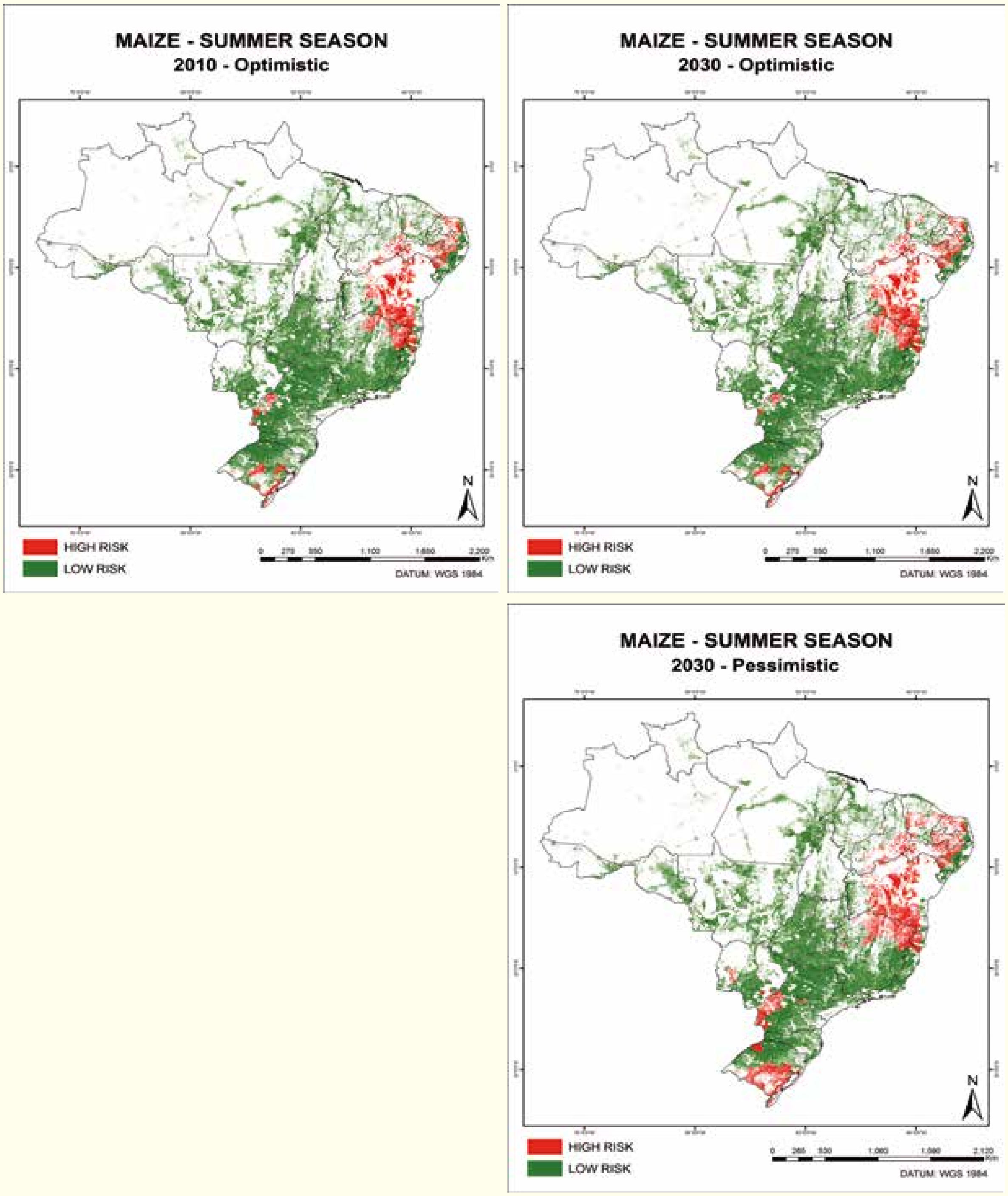


Figure 16. Impact of climate change on area suitable for beans – autumn season (2010 – base-line and 2030 optimistic and pessimistic)

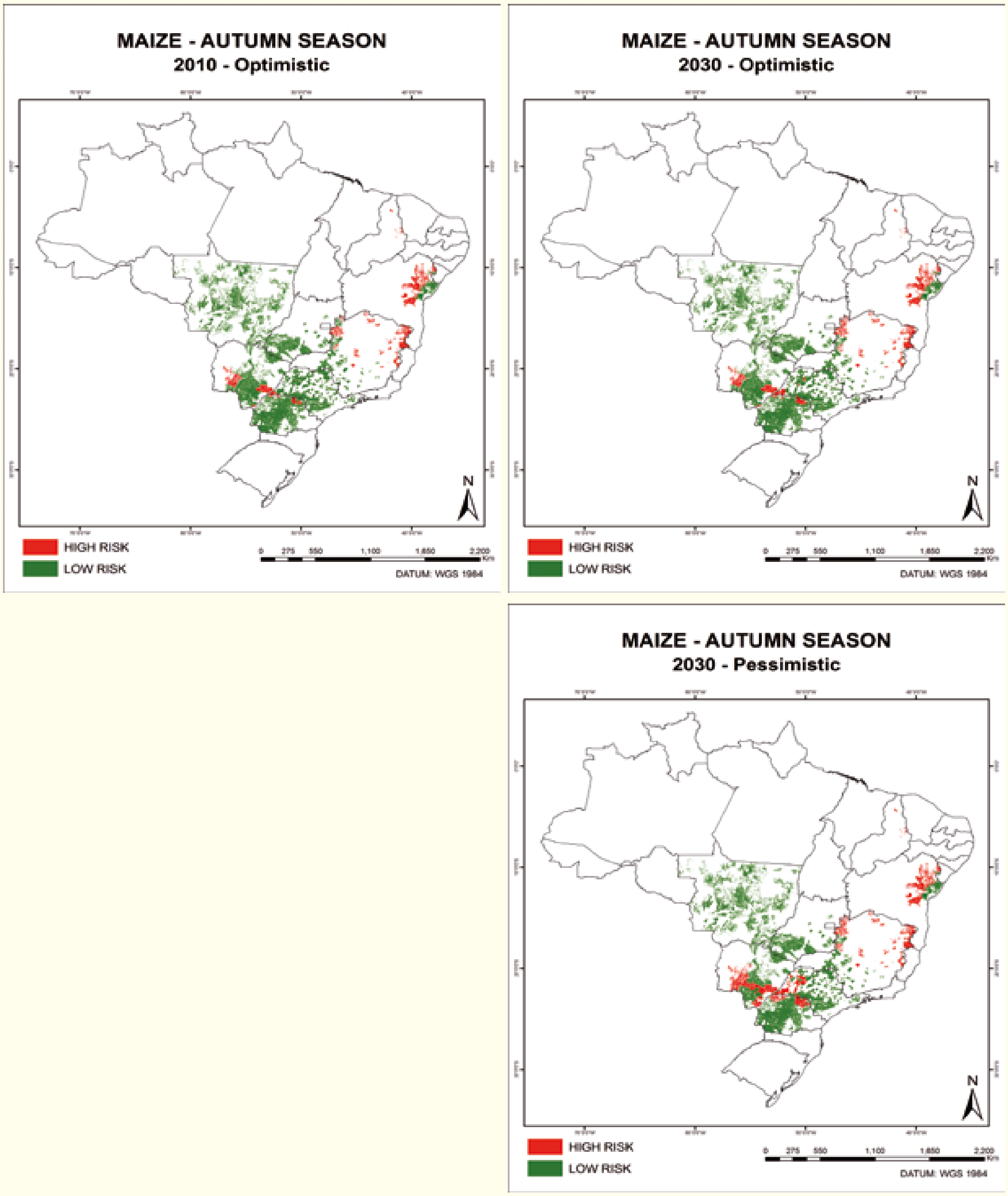


Figure 17. Impact of climate change on area suitable for wetland rice (2010 – baseline and 2030 optimistic and pessimistic)

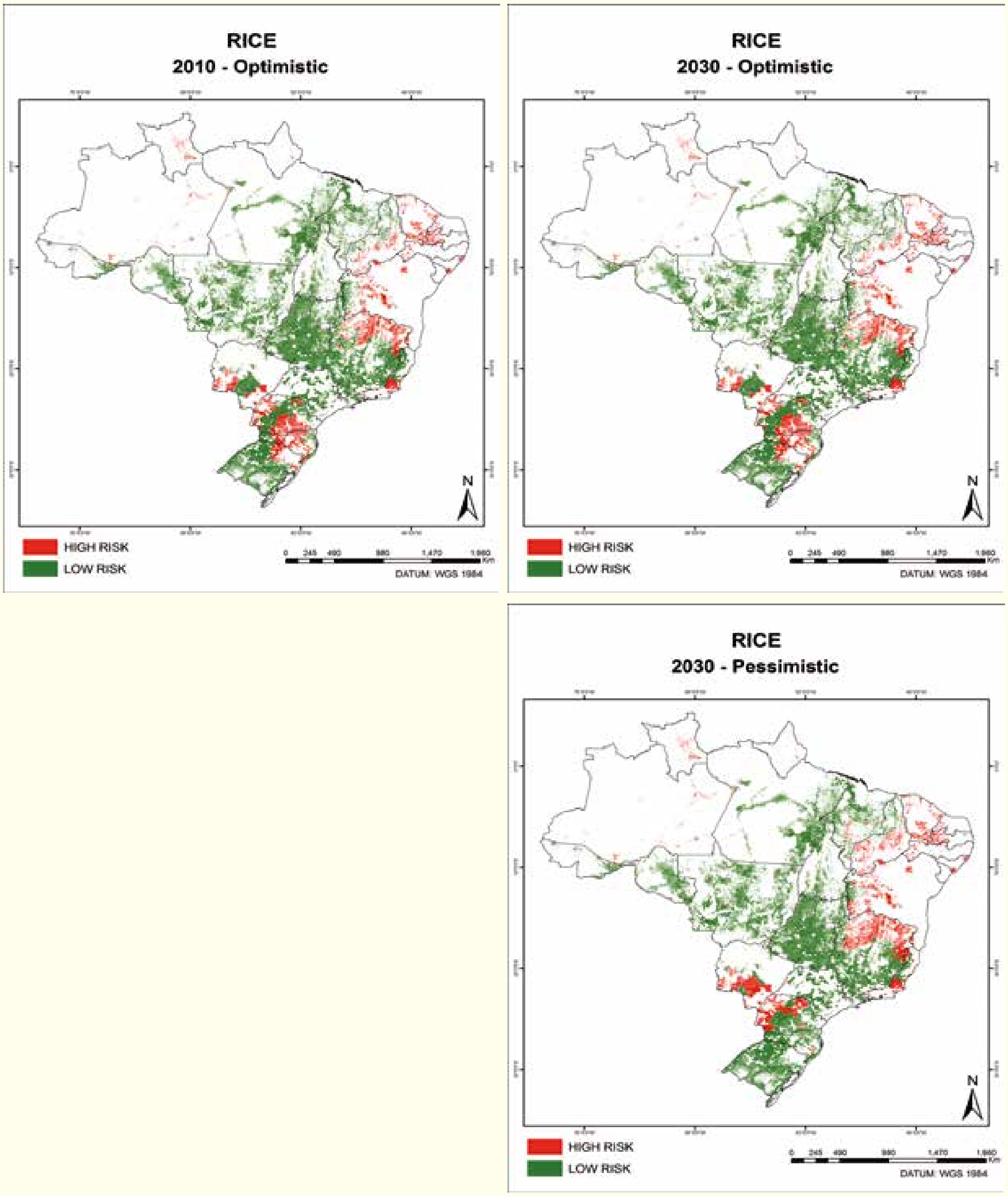


Figure 18. Impact of climate change on area suitable for sugarcane (2010 baseline and 2030 optimistic and pessimistic)

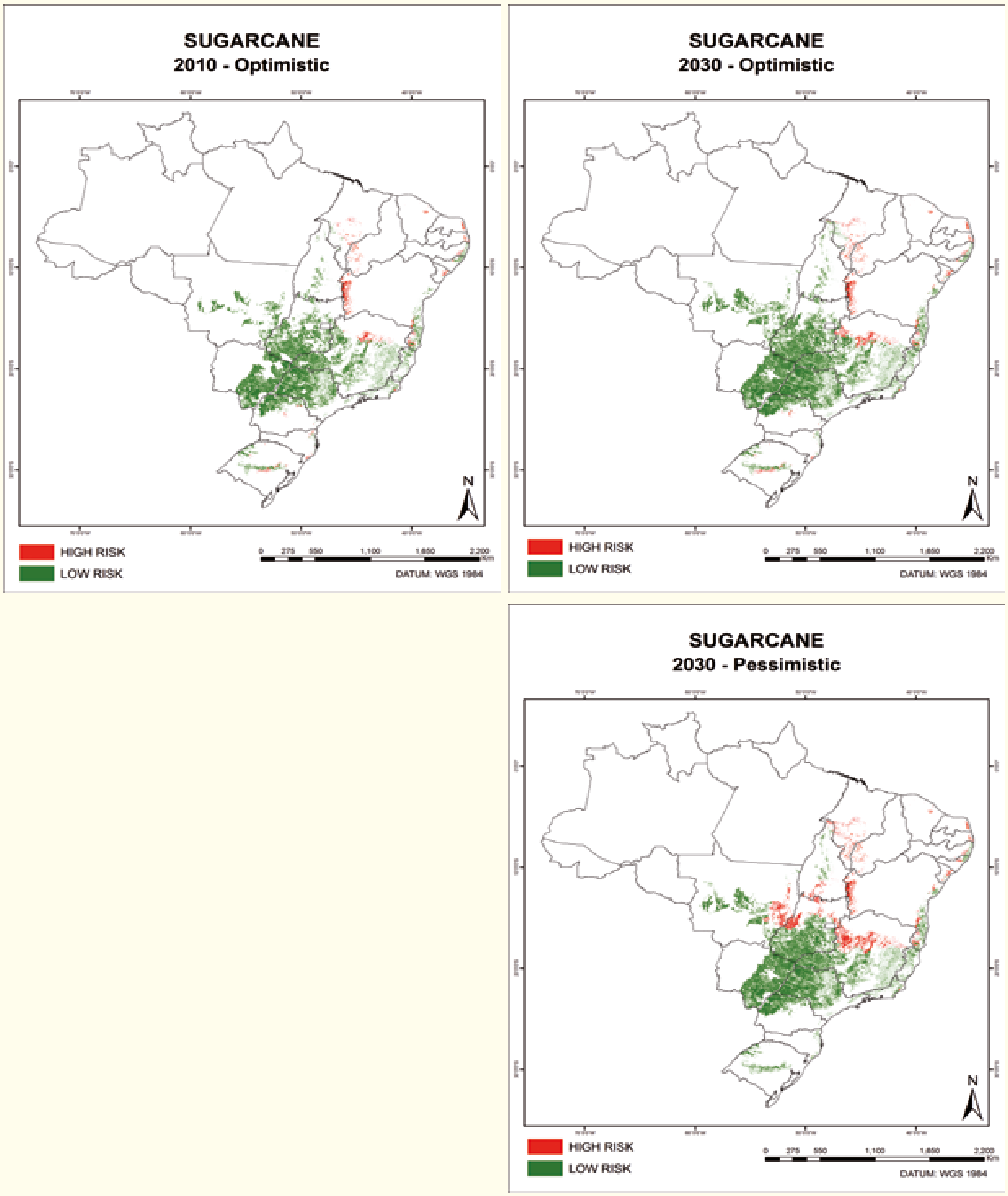


Figure 19. Impact of climate change on area suitable for cotton (2010 baseline and 2030 optimistic and pessimistic)

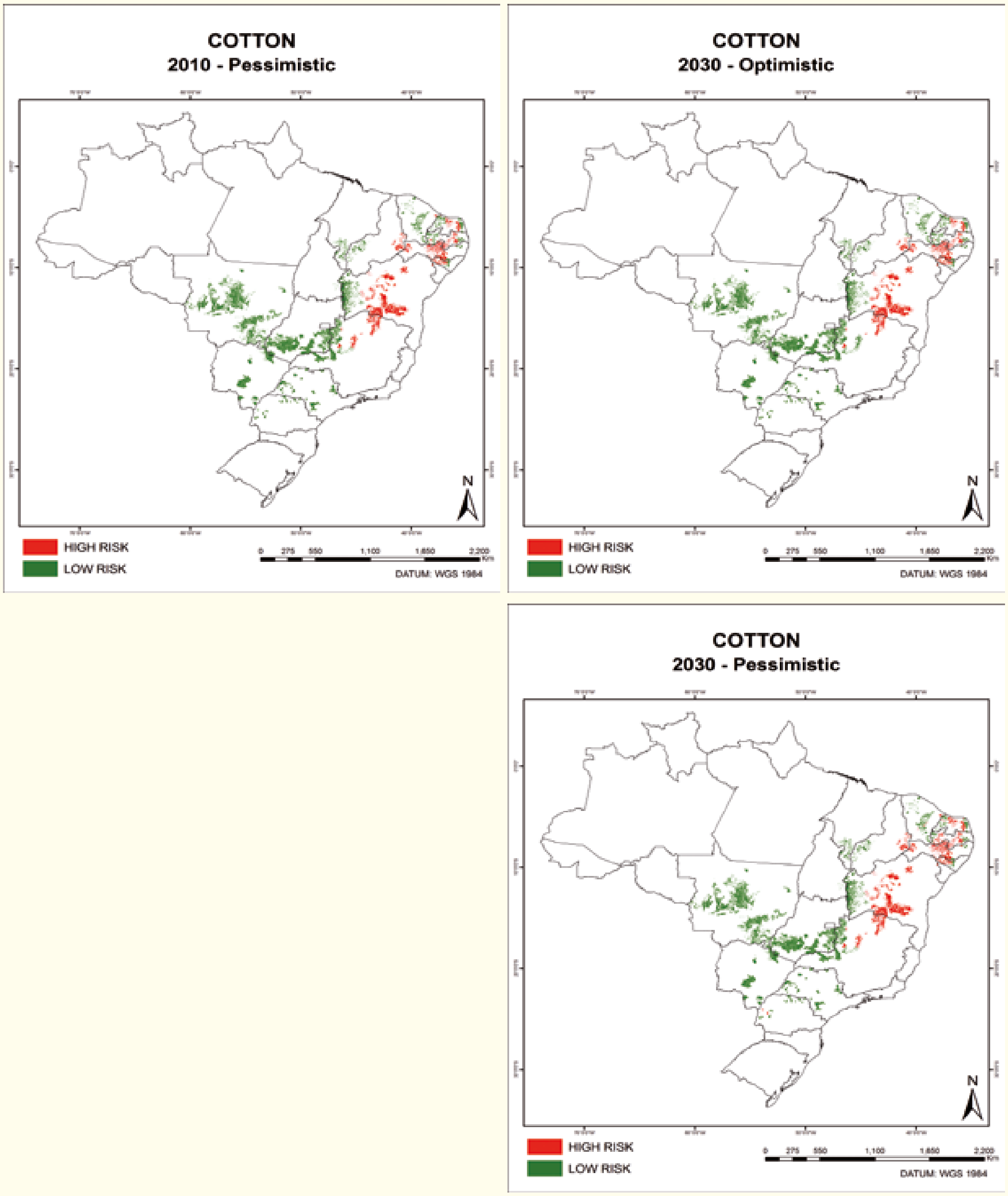


Figure 20. Impact of climate change on area suitable for beans – summer season (2010 – baseline and 2030 optimistic and pessimistic)

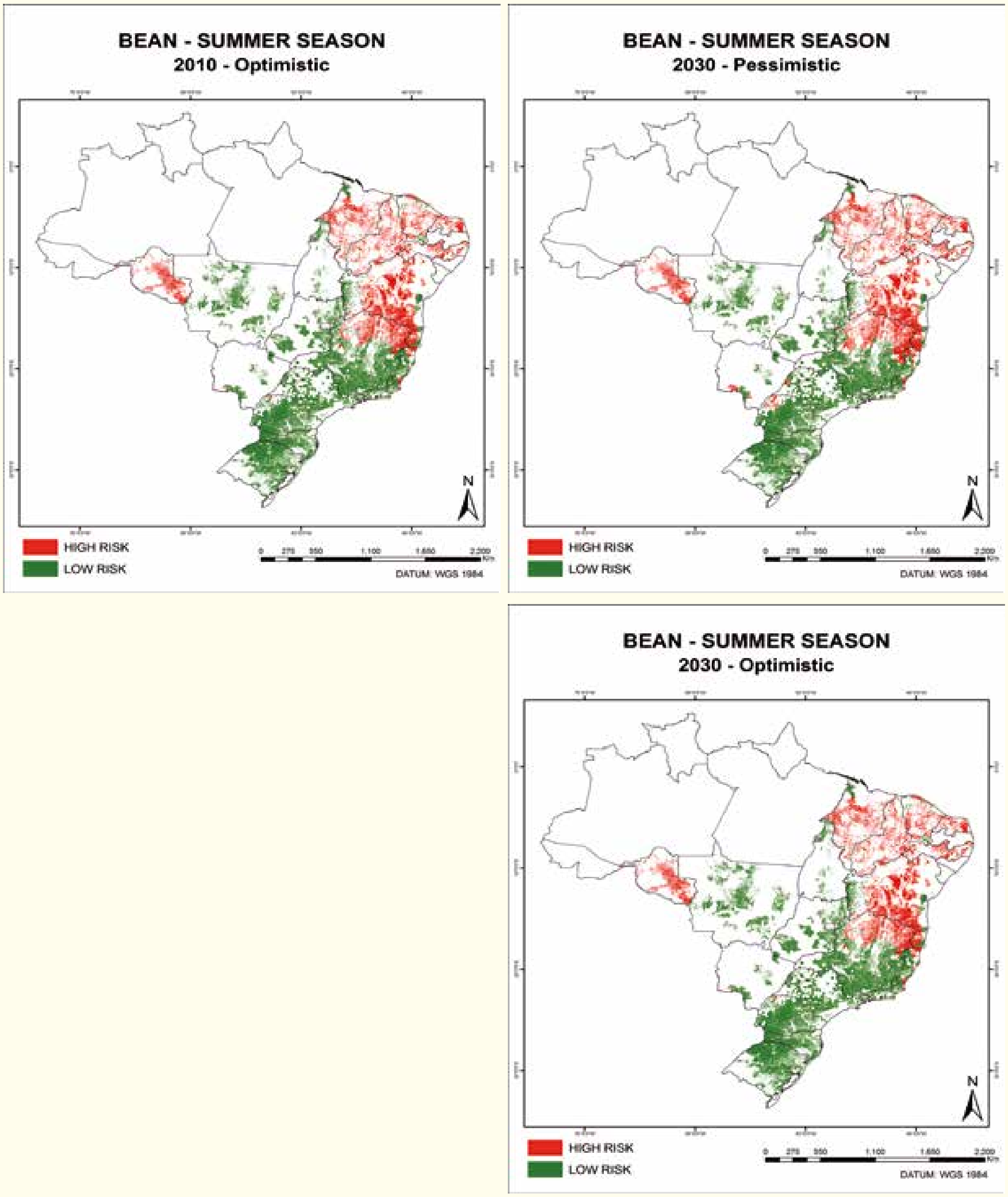
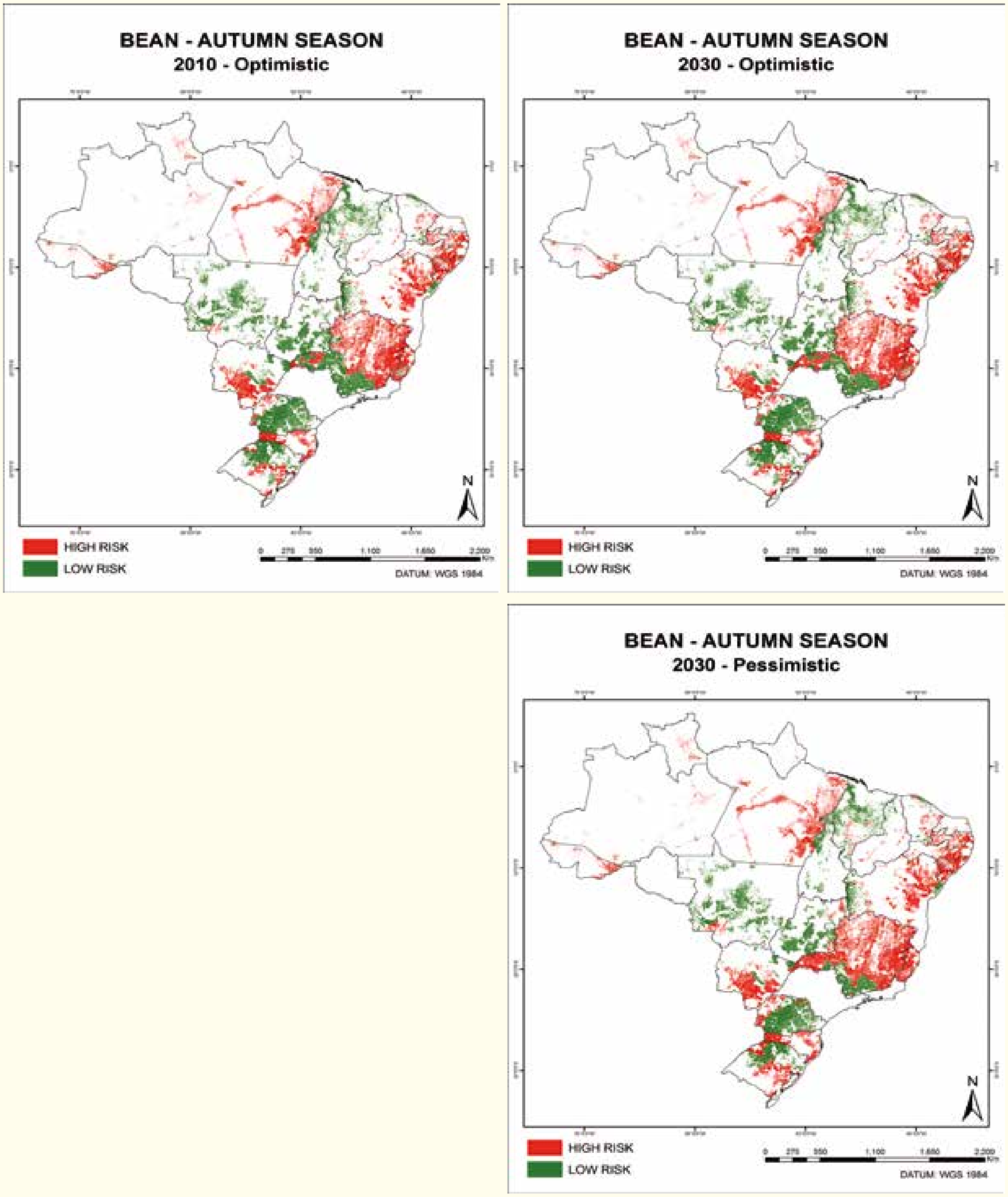


Figure 21. Impact of climate change on area suitable for beans – autumn season (2010 – baseline and 2030 optimistic and pessimistic)



Projected climate change impacts on commodity supply and demand and land use dynamics

In order to estimate the economic impacts of the simulated yield effects as a function of different climate change scenarios on the agricultural sector, ICONE used EMBRAPA's suitable area or yield impact results for crops and pasture as i-Puts to the Brazilian Land Use Model (BLUM). The following sections highlight the methodology used to integrate the scenarios in the models and also describe the results of four scenarios simulated: (i) the baseline projections (without any climate change impact); (ii) the pessimistic, (iii) the optimistic, and (iv) BRAMS without precipitation scenarios.

Methodology for the economic simulations of climate change scenarios and projected agricultural impacts.

This section describes the methodology used to simulate the economic impacts of climate change scenarios. The Brazilian Land Use Model – BLUM was the main tool used for the simulations. EMBRAPA's agricultural impact projections were adapted as i-Puts to the BLUM model and an allocation model was then used to distribute the BLUM outputs across 558 micro-regions nationally.

The Brazilian Land Use Model – BLUM

BLUM is a one-country, multi-regional, multi-market, dynamic, partial equilibrium economic model for the Brazilian agricultural sector which comprises two sections: supply and demand and land use. The model includes the following products: soybeans, corn (two crops per year), cotton, rice, dry beans (two crops per year), sugarcane, wheat, barley, dairy, and livestock (beef, broiler, eggs and pork). Commercial forests are considered as exogenous projections. In total, the selected products account for 95% of total area used for agricultural production in 2008. Although second (winter) crops, such as corn, dry beans, barley and wheat do not generate additional need for land (they are smaller and planted in the same fields as first season crops, in double cropping areas), their production is accounted for in the national supply.

The supply and demand projections

In the supply and demand section, the demand is projected at the national level and formed by domestic demand, net trade (exports minus imports) and final stocks (which are not considered for dairy and livestock sectors and sugarcane), which respond to prices and to exogenous variables such as gross domestic product (GDP), population and exchange rate. The supply is formed by national production (which is regionally projected) and beginning stocks (again considered only for grains and final sugarcane-based products) and responds to expected profitability of each commodity, which depends on costs, prices and yields.

Land allocation for agriculture and livestock is calculated for six regions[6], as showed in Figure 22 (below).

- South (states of Paraná, Santa Catarina, and Rio Grande do Sul);
- Southeast (states of São Paulo, Rio de Janeiro, Espírito Santo, and Minas Gerais);
- Center-West Cerrado (states of Mato Grosso do Sul, Goiás and part of the state of Mato Grosso inside the biomes Cerrado and Pantanal);
- Northern Amazon (part of the state of Mato Grosso inside the Amazon biome, Amazonas, Pará, Acre, Amapá, Rondônia, and Roraima);
- Northeast Coast (Alagoas, Ceará, Paraíba, Pernambuco, Rio Grande do Norte, and Sergipe);
- Northeast Cerrado (Maranhão, Piauí, Tocantins, and Bahia).

National supply and demand and regional land use of each product respond to prices. Consequently, for a given year, equilibrium is obtained by finding a vector of prices that clears all markets simultaneously. Year by year, a sequence of price vectors are found, which allows the market trajectory to be

6 The main criteria to divide the regions were agricultural production homogeneity and individualization of biomes with especial relevance for conservation.

followed through time. The outputs of the model are: regional land use and change, national production, prices, consumption and net trade.

Annual production in each region comes from the product of allocated land and yields. National production is the sum of all regions' production, in addition to beginning stocks. This relationship guarantees the interaction between the land use and supply and demand sections of the model, considering that the following identity must be satisfied:

Beginning stock + Production + Imports = Ending Stock + Consumption + Exports

or, considering that Net Trade = Exports - Imports:

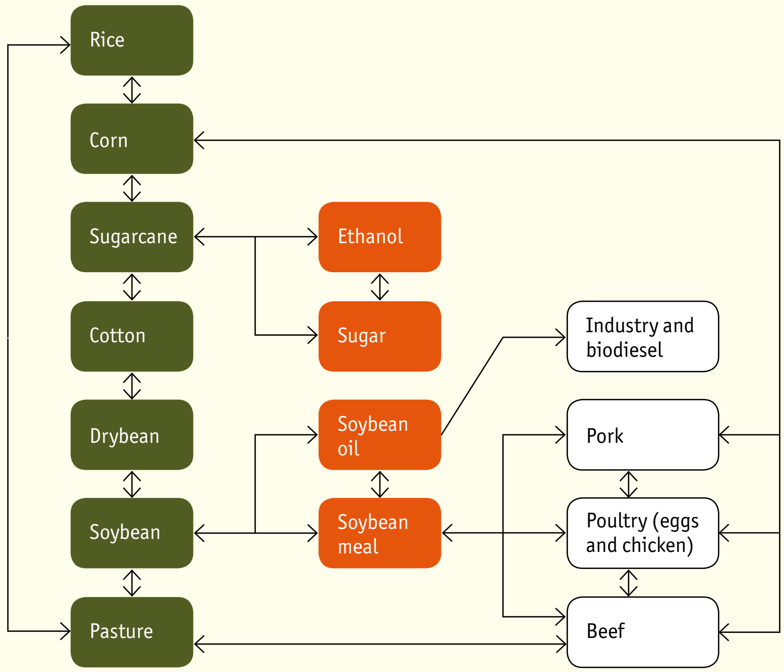
Beginning stock + Production = Ending Stock + Domestic Consumption + Net Trade

Figure 22. Regions considered in the Brazilian Land Use Model – BLUM

Source: ICONE, IBGE and UFMG.

BLUM also takes into account interactions among the analyzed sectors, and among one product and its sub-products. For example, the interaction between the grain and livestock sectors is the feed consumption (basically corn and soybean meal) that comes from the supply of meat, milk and eggs, which is one component of the domestic demand for corn and soybeans. In the case of the soybean complex, the components soybean meal and soybean oil are parts of the domestic demand for soybeans and are determined by the crush demand. Similarly, ethanol and sugar are the components of sugarcane demand (Figure 23).

Figure 23. Interactions between BLUM sectors



Source: ICONE

The Components of Land Use Dynamics

The land use dynamics is divided in two effects: *competition* and *scale*. Intuitively, the competition effect represents how the different activities compete for a given amount of available land, and the scale effect refers to the way that the competition among different activities generates the need for additional land. This need is accommodated by the expansion of total agricultural area over natural vegetation.

The competition effect is accounted for via a set of equations that allocates a share of agricultural area to each crop and pasture in each region as a function of its own and "cross" price-profitability. It establishes that, for a given amount of agricultural land, the increase in the profitability of one activity will result in an increase in the share of area dedicated to this activity and reduce in the share of area of competing activities.

The regularity conditions (homogeneity, symmetry and adding up) are imposed so that the elasticity matrices (and associated coefficients) are theoretically consistent. For any set of these coefficients we calculate individual, cross impacts, and competition among activities. Then, using this structure, simulations in BLUM allow the calculation not only of land allocation, but also land use changes. In other words, the conditions allow the identification of the exchanged area for each activity, considering the amount of total allocated agricultural area.

In order to ensure coherence of the above mentioned conditions, pasture area is regionally and endogenously determined, but modeled as the residual of total agricultural area minus crop area. In the context of the Brazilian agriculture, it is particularly relevant to project pasture both endogenously and regionally, since it represents around 77% of total land used for agricultural production.

Although the competition among activities may represent regions where the agricultural area is stable and near its available potential, this is an insufficient analysis for Brazil. Recent Brazilian agricultural trends show that crops, commercial forests and pastures all respond to market incentives by contributing to an expansion of the total area allocated to agriculture (Nassar et al., 2010a)[7]. This effect is captured in the scale section of the BLUM. This methodological improvement is essential to adjust the model skills to the specific reality of the Brazilian agricultural land use dynamics.

The scale effect refers to the equations that define how the returns of agricultural activities determine the total land allocated to agricultural production. More precisely, total land allocated to agriculture is a share of total area available for agriculture, and this share responds to changes in the average return of agriculture regionally.

Scale and competition effects are not independent. In conjunction, they are the two components of the return elasticities of each activity. Considering a *ceteris paribus* condition, the increase in profitability of one activity has three effects: increase in total agricultural area (through average return), increase in its own share of agricultural area and, therefore, reduction in the share of agricultural area of other activities. For competing activities, cross effects of profitability on area are negative.

As mentioned previously, the elasticities of each crop are the sum of competition and scale elasticities. At the same time, regional elasticity of land use with respect to total agricultural returns (total Agland elasticity) is the sum of the scale elasticities of each activity. Therefore, competition elasticities can be calculated directly after total Agland elasticity while total individual elasticities were obtained through econometric analysis and literature review.

Accounting for Land Use Dynamics in BLUM

In the BLUM land use section, the area a of crop i of each region l (l=1,...,6) in year t is defined by the following equation:

$$a_{ilt} = A_l^T * m_{lt} * s_{ilt} \qquad (1)$$

A_l^T is the total area available for agricultural production in the region l; m_{lt} is the share of A_l^T that is currently used for agricultural production (all crops and pasture), and is the share of the area used by agriculture that is dedicated to crop i. A_l^T is an exogenous variable defined by GIS modeling.

The variable m_{lt} is endogenous to the model and responds to the average agricul-

7 Nassar, A. M.; Antoniazzi, L. B.; Moreira, M. R.; Chiodi, L.; Harfuch, L. 2010a. An Allocation Methodology to Assess GHG Emissions Associated with Land Use Change: Final Report. ICONE, September 2010. Available at <http://www.iconebrasil.org.br/arquivos/noticia/2107.pdf>.

tural market return (profitability) index of region l (r_{lt}), so the share of area allocated to agriculture can be defined as:

$$m_{lt} = \frac{A_{lt}}{A_l^T} = kr_{lt}^{\alpha_{lt}\varepsilon_{rl}^{A_l}} \qquad (2)$$

where k is a constant parameter; ε_{rl}^{Al} is the land supply elasticity (with respect to the average return) for region l (results for the Brazilian average is presented in Barr et al. 2010). The parameter α_{lt} is positive, higher or lower than one and can be defined as:

$$\alpha_{lt} = 1 - \frac{A_{lt} - A_{l0}}{A_l^T} \qquad (3)$$

where A_{l0} is the land used for agriculture in a defined base period. When agricultural land in period t is close to the base period, α_{lt} is close to 1 and it does not affect ε_{rl}^{Al}. However if agricultural land in t is larger than in the base period, the parameter α_{lt} is smaller than one and reduces the effect of ε_{rl}^{Al}. The opposite occurs when current agricultural land is smaller than (A_{lo}), increasing the land supply elasticity.

The r_{lt} is calculated through evidences that indicate which activities most expand in the agricultural frontier defined as:

$$r_{lt} = \sum_{i=1}^{n} r_{it} * d_{li} \qquad (4)$$

where d_{li} is a weighting vector of deforestation rate caused by each agricultural activity obtained by satellite imagery and GIS modeling. We can then calculate the weighting vector d_{li} as follows:

$$d_{li} = \frac{D_{li}}{D_l^T}; \text{where } D_l^T = \sum_{i=1}^{n} D_{li} \qquad (5)$$

According to Holt (1999) the cross area elasticity of crop i with respect to the return of other crops j can be defined as:

$$\varepsilon_{r_{lj}}^{l,i} = \frac{\partial a_{ilt}}{\partial r_{jlt}} \frac{r_{jlt}}{a_{ilt}} = A_l^T \left(\frac{\partial m_l(r_{lt})}{\partial r_{lt}} \frac{\partial r_{lt}}{\partial r_{jlt}} s_{ilt}(r_{ilt}, r_{jlt}) + m_l(r_{lt}) \frac{\partial s_{ilt}(r_{ilt}, r_{jlt})}{\partial r_{jlt}} \right) \frac{r_{jlt}}{A_l^T m_l(r_{lt}) s_{ilt}(r_{ilt}, r_{jlt})} \qquad (6)$$

Which by rearranging terms leads to:

$$\varepsilon_{r_{lj}}^{l,i} = \frac{\partial m_l(r_{lt})}{\partial r_{lt}} \frac{\partial r_{lt}}{\partial r_{jlt}} \frac{r_{jlt}}{m_l(r_{lt})} + \frac{\partial s_{ilt}(r_{ilt}, r_{jlt})}{\partial r_{jlt}} \frac{r_{jlt}}{s_{ilt}(r_{ilt}, r_{jlt})} \qquad (7)$$

The first term on the right hand side of equation (6) can be defined as the scale effect of the cross area elasticity $\varepsilon_{r_{lj}}^{s_{l,i}}$:

$$\varepsilon_{r_{lj}}^{s_{l,i}} = \frac{\partial m_l(r_{lt})}{\partial r_{lt}} \frac{\partial r_{lt}}{\partial r_{jlt}} \frac{r_{jlt}}{m_l(r_{lt})} \qquad (8)$$

The competition effect of the cross area elasticity $\varepsilon_{r_{lj}}^{c_{l,i}}$ is the last part in the right hand side of equation (6):

$$\varepsilon_{r_{lj}}^{c_{l,i}} = \frac{\partial s_{ilt}(r_{ilt}, r_{jlt})}{\partial r_{jlt}} \frac{r_{jlt}}{s_{ilt}(r_{ilt}, r_{jlt})} \qquad (9)$$

By analogy, the area elasticity of crop i related to its own return is also formed by the scale and competition effects and can be written as:

$$\varepsilon_{r_{li}}^{l,i} = \frac{\partial m_l(r_{lt})}{\partial r_{lt}} \frac{\partial r_{lt}}{\partial r_{ilt}} \frac{r_{ilt}}{m_l(r_{lt})} + \frac{\partial s_{ilt}(r_{ilt}, r_{jlt})}{\partial r_{ilt}} \frac{r_{ilt}}{s_{ilt}(r_{ilt}, r_{jlt})} = \varepsilon_{r_{li}}^{s_{l,i}} + \varepsilon_{r_{li}}^{c_{l,i}} \qquad (10)$$

Where $\varepsilon_{r_{li}}^{s_{l,i}}$ is the scale effect and $\varepsilon_{r_{li}}^{c_{l,i}}$ is the land competition component of the area elasticity of crop i with respect to its own return[8].

The land competition component can then be calculated as:

$$\varepsilon_{r_{li}}^{c_{l,i}} = \varepsilon_{r_{lt}}^{l,i} - \varepsilon_{r_{li}}^{s_{l,i}} \qquad (11)$$

The link between the regional land supply elasticity ($\varepsilon_{r_l}^{A_l}$) and the scale effect of each activity ($\varepsilon_{r_{li}}^{s_{l,i}}$) can be observed. The land supply elasticity can be defined as:

$$\varepsilon_{r_l}^{A_l} = \frac{\partial m_l}{\partial r_l} \frac{r_l}{m_l} \qquad (12)$$

And, rearranging:

$$\frac{\partial m_l}{\partial r_l} = \frac{\varepsilon_{r_l}^{A_l} m_l}{r_l} \qquad (13)$$

The elasticity with respect to the variation in return of a given crop i in region l is:

$$\varepsilon_{r_{li}}^{s_{l,i}} = \frac{\partial m_l}{\partial r_l} \frac{\partial r_l}{\partial r_{li}} \frac{r_{li}}{m_l} \qquad (14)$$

Which, from equation (14) and with some calculation, can be rewritten as:

$$\varepsilon_{r_{li}}^{s_{l,i}} = \varepsilon_{r_l}^{A_l} \frac{\partial r_l}{\partial r_{li}} \frac{r_l}{r_{li}} \qquad (15)$$

From equation (4), equation (15) can be rewritten as:

$$\varepsilon_{r_{li}}^{s_{l,i}} = \varepsilon_{r_l}^{A_l} d_{li} \frac{r_l}{r_{li}} \qquad (16)$$

Using equation (15), if the land supply elasticity is known, the scale effect of activity i can be easily calculated. As a result, the vector containing all land competition component elasticities $\varepsilon_{r_{li}}^{c_{l,i}}$ represents the diagonal of the competition matrix (one for each region l). Along with other restrictions (such as the regularity conditions and negative cross elasticities) the diagonal terms are then used to obtain the cross elasticities in the competition matrix, as represented in equation (9).

8 Also explained in Nassar *et al.* (2009) available at http://www.iconebrasil.com.br/arquivos/noticia/1872.pdf

EMBRAPA's Agricultural Impact Projections as Inputs to BLUM

We used the results for each crop and pastures from simulated scenarios by EMBRAPA as i-Puts in the Brazilian Land Use Model. The baseline for the EMBRAPA projections is the cropped area in 2009 and the simulations project the area that will continue to be suitable for future production activities. Thus, for each simulated scenario there is a set of results for pasture and the following crops: rice, cotton, corn (1st and 2nd crop), soybeans, dry beans (1st and 2nd crops), sugarcane and wheat.

However, in order to adapt EMBRAPA results to BLUM and the micro-regional allocation models, we made some assumptions. The database received was for total planted area for each activity considered in the models and for each scenario by municipality, for 2009, 2020 and 2030.

In the case of BLUM model, we aggregated the results in terms of impacts on areas for each activity into the six Brazilian regions (BLUM regions). Since EMBRAPA used the planted area for crops from the Municipality Agricultural Survey, IBGE – Brazilian Institute of Geography and Statistics, we calculated the impacts in percentage points over the planted area used in BLUM (from CONAB – Companhia Brasileira de Abastecimento) for 2009.

As an example of the set of data simulated by EMBRAPA, Table 4 below shows the results for soybeans.

Table 4. Simulated scenarios for soybeans, aggregated in BLUM regions (in 1,000 ha)

	Planted area	Pessimistic		Optimistic		BRAMS (- precipitation)		BRAMS (+precipitation)	
Region	2009	2020	2030	2020	2030	2020	2030	2020	2030
South	8.286	4.626	4.272	6.196	5.826	4.824	4.233	8.285	4.233
Southeast	1.424	1.161	1.156	1.233	1.233	1.162	1.160	1.160	1.160
Center-West Cerrado	7.676	6.676	6.540	7.307	7.296	6.690	6.540	6.540	6.540
North (Amazon)	2.422	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420
Northeast Coast	1	0	0	0	0	0	0	0	0
Northeast Cerrado	1.953	1.589	1.247	1.727	1.659	1.589	1.264	1.264	1.264
Brazil	21.762	16.473	15.634	18.883	18.434	16.686	15.617	15.617	15.617

Source: IBGE and EMBRAPA. [Source: EMBRAPA and ICONE]

Comparing the results for each scenario with the observed planted area in 2009 (baseline), the impact of climate change to 2030 is evident as a reduction of suitable area for soybeans in all scenarios. Importantly, the most severely impacted region is the South (a major soybean producing area) where the projected suitable area decline is almost 50% by 2030. On average, the area that can be used to produce soybeans in Brazil reduces by 28% in the simulated pessimistic and BRAMS (no precipitation) scenarios in 2030.

In order to use suitable area projections as inputs in BLUM we combined all crops and pasture results that had negative impacts on area for the scenarios. Some municipalities presented positive impacts on pastureland and sugarcane, due to climate change scenarios. In the case of the impacts on pastureland, EMBRAPA simulated the impacts in terms of percentage change related to a starting point to 2010, 2020 and 2030 for each climate change scenario. BLUM has a mixed source for pasture area, which was used to derive impact values as a proportion of the EMBRAPA results. Table 5 shows the compiled results for each crop and each scenario simulated by EMBRAPA and used as inputs in BLUM.

Table 5. Simulated planted area for crops and pasture for Brazil (in 1000 ha)

	BLUM	Pessimistic	Optimistic	BRAMS (-P)	BRAMS (+P)
	2009	2030	2030	2030	2030
Soybean	21.743	15.634	18.434	15.617	21.588
Corn 1st crop	9.463	7.620	8.361	7.796	9.135
Rice	2.909	2.617	2.640	2.614	2.560
Cotton	843	776	777	776	812
Sugarcane	8.846	16.922	18.419	17.125	11.997
Dry Beans 1st crop	2.894	1.122	1.188	1.137	1.923
Wheat	2.396	1.877	1.614	1.561	0
Corn 2nd crop	4.901	4.064	4.456	4.122	4.500
Dry Beans 2nd crop	1.254	519	587	525	970
Pasture	183.485	183.320	183.489	183.478	162.915

Note: BRAMS (-P) refers to the BRAMS scenario with no precipitation change; BRAMS (+P) includes precipitation changes [Source: EMBRAPA and ICONE]

The BRAMS (with precipitation) scenario results were found to have an anomaly that was traced to a programming error that has since been rectified but in this version of the report, the results relating to the BRAMS +P observations are omitted. They will be included as soon as the recalculated values are available in a week or so.

Because BLUM is an annual projection model, the impacts on planted area for 2020 and 2030 computed by EMBRAPA were distributed along the period from 2013 to 2030. An assumption was made in order to calculate the impacts of each scenario on land available and suitable for agricultural expansion (remaining vegetation). We assumed that the land available for expansion will have the same impact of that considered on crops and pasture for each scenario simulated. In other words, we used the share of each crop on total area used for agriculture and its percentage variation for each scenario in order to calculate the impact over natural vegetation available and suitable for agriculture, as shown in Table 6 for the pessimistic and optimistic scenarios.

Table 6. Land available and suitable for agricultural expansion for each scenario (1000 ha)[i]

	Original Database in BLUM	Pessimistic		Optimistic		BRAMS (- precipitation)	
		2020	2030	2020	2030	2020	2030
South	2.081	1.788	1.763	1.924	1.898	1.816	1.761
Southeast	4.324	4.256	4.272	4.289	4.288	4.276	4.275
Center-West Cerrado	8.872	8.686	8.697	8.815	8.814	8.723	8.698
North Amazon	16.108	15.949	15.997	16.051	16.051	16.049	16.047
Northeast Coast	68	56	56	58	57	57	56
Northeast Cerrado	12.066	11.555	11.474	11.672	11.643	11.605	11.482
Brazil	43.519	42.289	42.258	42.809	42.751	42.525	42.318

[i]Considering only the impacts on the following products: soybeans, corn (1st crop), rice, dry beans (1st crop), sugarcane and pasture. [Source: ICONE]

This assumption is necessary because it is unrealistic to expect that total area allocated for agriculture will be reduced and there will be no deforestation in areas suitable for expansion.

For the pessimistic scenario, total area available for agricultural expansion is projected to decrease by more than 1 million hectares. This impact is much lower than that presented for crops in Table 5. The explanation is that pasture area considered separately will have a much lower impact on area reduction. On the other hand, when the impacts on crops and pasture are considered together, the impacts are significantly higher, as shown in Table 7. Out of approximately 230 million hectares used for grains (first crop), sugarcane and pasture in 2009, climate change scenarios could reduce this amount by more than 10 million hectares in the Pessimistic and BRAMS (without precipitation) scenarios, while in the optimistic scenario, the area reduction could amount to 7 million hectares in 2030.

Table 7. Land used in 2009 and potential projected for 2030 for each scenario (in 1000 ha)

		Baseline	Pessimistic	Optimistic	BRAMS (-P)
Region	2009	2030	2030	2030	2030
South	30.281	29.823	25.084	27.031	25.114
Southeast	37.193	37.317	36.784	36.963	36.835
Center-West Cerrado	58.998	59.678	58.698	59.396	58.725
North Amazon	51.629	58.688	58.003	58.054	58.165
Northeast Coast	14.790	14.911	12.672	14.384	12.725
Northeast Cerrado	37.100	38.255	36.871	37.224	36.903
Total	229.990	238.671	228.112	231.640	228.467

Note: Only first crops for corn and dry beans and excluding winter crops (wheat and barley)
Source: ICONE

In terms of total land available and suitable for agriculture, which is the sum of areas with natural vegetation suitable for production and land currently used for these activities, as also presented in Table 2, the South region will be the most affected in all scenarios. According to Table 8, more than 50% of total reduction on land available for agriculture will be in the South. Brazil is likely to have 12.5 and 12.2 million hectares less land suitable for agricultural production in the pessimistic and BRAMS (-P) scenarios in 2030. For the optimistic scenario, the potential area for agriculture could be reduced by 8 million ha compared to the original baseline.

Table 8. Land available and suitable for agricultural production, comparing scenarios for 2030 (1000 ha)

	Original	Pessimistic	Optmistic	BRAMS (-P)
South	32.362	27.412	29.513	27.380
Southeast	41.517	41.015	41.169	41.044
Center-West Cerrado	67.870	66.535	67.425	66.536
North Amazon	67.737	67.271	67.495	67.480
Northeast Coast	14.859	12.066	12.475	12.128
Northeast Cerrado	49.165	46.753	47.445	46.787
Brazil	273.509	261.053	265.523	261.357

Source: ICONE

Based on past trends for land use and especially pasture dynamics, it is very likely that a significant proportion of current pasture land could be converted to cropland under all climate change scenarios. In BLUM projections, for example, beef production increases even with less land allocated to pasture in the future. Currently, Brazil has 42.2 million hectares of pastureland suitable for crop production, where 32% is concentrated in the Center-West Cerrado, 22% in the South, 16% in the Southeast, 16% in the North Amazon, 9% in the Northeast Cerrado and 4% in the Northeast Coast, as shown in Table 9.

Table 9. Pastureland suitable for crop production, comparing scenarios for 2030 (1000 ha)

	Original	Pessimistic	Optimistic	BRAMS (-P)
South	8.528	3.870	5.856	3.841
Southeast	6.043	5.593	5.729	5.618
Center-West Cerrado	12.306	11.134	11.915	11.134
North Amazon	5.983	5.850	5.850	5.850
Northeast Coast	1.652	-63	247	-45
Northeast Cerrado	3.547	1.644	2.172	1.669
Brazil	38.060	28.028	31.769	28.067

Source: Sparovek and ICONE

Despite the projected reduction in the area of pastureland highly suitable for crop production by almost 10 million hectares relative to the 2009 baseline, pastureland can continue to be converted to crop production in all scenarios via increased intensification of beef production in all the simulated scenarios.

The next section presents the preliminary results for three scenarios in BLUM: baseline, pessimistic, optimistic and BRAMS (without precipitation). As described above, the dynamic variable in the model for each scenario in 2020 and 2030 was the land available and suitable for agriculture, combined with the amount of pastureland that can be converted into cropland.

Simulation Results from the Brazilian Land Use Model (BLUM)

The results are presented in three sub-sections: land use and production, domestic consumption, production value, and international trade and prices. We compared the results of the pessimistic, optimistic and BRAMS (no precipitation) scenarios for 2020 and 2030 with the baseline scenario (without climate change).

Land Use and Production

Table 10 shows the results for land allocated to agricultural production, considering crops and pastureland together, for each scenario in 2009, 2020 and 2030.

Table 10. Land used by pasture and first season crops[i] (1000 ha)

	Baseline			Pessimistic		Optimistic		BRAMS (-P)	
Region	2009	2020	2030	2020	2030	2020	2030	2020	2030
South	30.281	29.807	29.823	25.369	25.084	27.353	27.031	25.766	25.114
Southeast	37.193	37.317	37.317	36.650	36.784	36.978	36.963	36.843	36.835
Center-West Cerrado	58.998	59.442	59.678	58.402	58.698	59.165	59.396	58.617	58.725
North Amazon	51.629	55.629	58.688	54.421	58.003	54.486	58.054	54.697	58.165
Northeast Coast	14.790	14.912	14.911	12.772	12.672	13.023	14.384	12.861	12.725
Northeast Cerrado	37.100	37.752	38.255	36.584	36.871	36.800	37.224	36.692	36.903
Total	229.990	234.858	238.671	224.198	228.112	227.804	231.640	225.476	228.467

[i]Only first crops for corn and dry beans and excluding winter crops (wheat and barley)
Source: ICONE

In the baseline scenario, total area allocated to crops and pasture in Brazil increases by 2% in 2020 and 4% in 2030, relative to 2009.

Comparing the results from the pessimistic scenario with the baseline for 2020 and 2030, in terms of total area allocated to agriculture, the South region is likely to be the most affected, due to the climate change restrictions for this scenario. In 2020, total area might be reduced by 4.4 million hectares compared to the baseline, increasing to 4.7 million hectares in 2030. In general, Brazil might have 10.6 million hectares less land allocated to agriculture in 2030. BRAMS scenario without precipitation presented similar results as the pessimistic scenario.

For the optimistic scenario the impacts were much lower. The South region reduced total area used by agricultural production by 2.5 and 2.8 million hectares in 2020 and 2030, respectively, relative to the baseline. Similarly for Brazil as a whole, the total area reduction is projected to be around 7.1 million hectares for 2030 compared to the baseline. Interestingly, however, most of this reduction was allocated to pasture area, as shown in Table 11. This is the result of cattle raising intensification, since there is pastureland with high suitability for crops.

Table 11. Land allocated to pasture (million hectares)

		Baseline		Pessimistic		Optimistic		BRAMS (-P)	
Region	2009	2020	2030	2020	2030	2020	2030	2020	2030
South	16.19	14.64	13.79	12.13	11.31	13.24	12.32	12.36	11.33
Southeast	27.47	25.67	24.29	24.96	23.68	25.29	23.89	25.13	23.72
Center-West Cerrado	49.00	45.66	42.78	44.20	41.39	45.08	42.18	44.44	41.42
North Amazon	47.83	51.08	53.62	49.64	52.58	49.81	52.74	49.93	52.74
Northeast Coast	10.85	10.70	10.44	9.11	8.82	9.31	9.05	9.18	8.86
Northeast Cerrado	32.15	30.69	29.44	29.43	27.99	29.74	28.42	29.55	28.02
Total	183.48	178.44	174.36	169.47	165.78	172.46	168.61	170.58	166.09

Source: ICONE

The projections show that for Brazil, total pastureland could decrease by 8.6 and 8.3 million hectares in the pessimistic and BRAMS (no precipitation) scenarios in 2030, and 5.8 million ha in the optimistic scenario for the same year, compared to the baseline. Despite the high level of reduction, in relative terms the impacts were 5% for the pessimistic and BRAMS scenarios and 3% for the optimistic scenario, compared to the baseline.

Regionally, as expected due to climate change impacts, the South region was the most affected in terms of pastureland displaced by crops. For both pessimistic and BRAMS (no precipitation) scenarios, pastureland reduced by 2.5 million hectares, which represent 18% reduction compared to the baseline in 2030. However, even for the baseline scenario area allocated to pasture reduced by 2.4 million hectares compared to observed pastureland in 2009. This shows the decrease trend of pastureland in the South region, which have been displaced by crops. All other regions, except the North Amazon, also present a decrease trend on pastureland in the baseline scenario.

Table 12 shows that total crop area was reduced, but not as substantially as pasturelands. Again, most of the reduction was concentrated in the South, since this region was the most affected by the climate change scenarios. That is, it will not be possible to displace pasture in the same amount of crop demand for area in the South region, which requires a regional reallocation of production. The Center-West Cerrado and the Northeast Cerrado increased crop area in the simulated climate change scenarios, compared to the baseline.

Table 12. Land allocated to crops[i] (1000 ha)

		Baseline		Pessimistic		Optimistic		BRAMS (-P)	
Region	2009	2020	2030	2020	2030	2020	2030	2020	2030
South	14.090	15.171	16.034	13.236	13.771	14.116	14.710	13.405	13.783
Southeast	9.727	11.646	13.030	11.687	13.104	11.690	13.071	11.716	13.115
Center-West Cerrado	9.994	13.779	16.901	14.204	17.305	14.088	17.214	14.178	17.302
North Amazon	3.798	4.553	5.065	4.778	5.419	4.677	5.310	4.771	5.429
Northeast Coast	3.945	4.213	4.468	3.661	3.850	3.711	3.921	3.681	3.867
Northeast Cerrado	4.951	7.059	8.810	7.159	8.878	7.061	8.805	7.144	8.880
Total	46.506	56.421	64.308	54.726	62.328	55.343	63.031	54.896	62.376

[i]Only summer season crops corn and dry beans and excluding winter crops (wheat and barley)
Source: ICONE

The baseline (in the absence of climate change) shows that cropland is projected to increase to 17 million hectares in 2030 compared to observed cropland in 2009. Due to climate change impacts, however, all the scenarios simulated, result in a reduction of cropland in 2020 and 2030 compared to the baseline. It is important to note, however, that the displacement of pastures by grains and sugarcane partially compensates for projected cropland losses hence the lower initial impacts presented in Table 2. As a result, as presented in Table 12, land allocated to crops is projected to decrease by almost 2 million hectares in 2030 for the pessimistic and BRAMS scenarios and 1.3 million ha for the optimistic scenario.

The cropland simulations (Table 12) present an interesting trend in regional land use change dynamics in Brazil. While cropland is projected to decrease in the South and Northeast (coastal) regions, cropped area in all other regions is projected to increase thereby partially compensating for the potential climate change impacts. In essence these land use trends appear to represent autochthonous adaptation strategies – displacement of less suitable cropping systems and relocation of cropping systems to more favorable areas relative to current locations.

With respect to Brazilian grain production, as shown in Table 13, our simulations project a reduction of around 4.6 million tons in 2030 in the pessimistic and BRAMS (no precipitation) scenarios relative to the baseline. As expected, the optimistic scenario projects a reduced impact from climate change with production projected to decline by 2.7 million tons in 2030 compared to the baseline. In general, the production declines can be expected to impact prices, domestic demand, and net exports of these products.

Table 13. Grain production, first season crop only* (thousand tons)

	Baseline			Pessimistic		Optimistic		BRAMS (-P)	
Region	2009	2020	2030	2020	2030	2020	2030	2020	2030
South	42.160	59.428	67.849	52.159	58.973	55.476	62.687	52.788	58.996
Southeast	14.622	17.900	23.372	18.042	23.775	17.985	23.574	18.082	23.793
Center-West Cerrado	28.853	41.175	50.561	42.905	52.634	42.338	51.979	42.769	52.601
North Amazon	10.323	14.609	18.301	15.461	19.748	15.083	19.286	15.424	19.779
Northeast Coast	2.310	3.197	3.671	2.781	3.178	2.815	3.226	2.795	3.190
Northeast Cerrado	10.222	20.471	30.247	21.091	31.079	20.650	30.557	21.007	31.063
Total	108.492	156.781	194.001	152.440	189.389	154.346	191.310	152.865	189.422

*Only summer crops (corn and dry beans) and excluding winter crops (wheat and barley)
Source: ICONE

Despite the projected decrease in grain production in the South region by around 8.9 million tons in 2030 under the pessimistic scenario relative to the baseline, the Center-West, North Amazon and Northeast Cerrado regions will increase grain production by 4.4 million tons in 2030 under the same scenario, compared to the baseline. That is, regional production re-allocation will reduce the climate change negative impacts on grains by almost half.

It is especially noteworthy that despite the projected reduction in the pasture area of pasture, beef production will decrease by a much lower amount due to technological intensification as shown in Table 14. So although beef production in Brazil might decrease by 7% in all scenarios simulated in 2030 compared to the baseline, our simulations project that beef production will continually grow until 2030 in all scenarios compared to the observed production in 2009, and could increase by more than 2 million tons.

Table 14. Beef production (thousand tons)

	Baseline			Pessimistic		Optimistic		BRAMS (-P)	
Region	2009	2020	2030	2020	2030	2020	2030	2020	2030
South	1.072	1.596	1.942	1.453	1.700	1.492	1.748	1.460	1.700
Southeast	2.483	2.894	3.292	2.823	3.158	2.820	3.144	2.824	3.157
Center-West Cerrado	2.997	4.473	4.927	4.349	4.594	4.367	4.629	4.353	4.597
North Amazon	1.381	1.474	1.891	1.404	1.733	1.403	1.725	1.408	1.736
Northeast Coast	388	532	627	511	588	512	590	512	588
Northeast Cerrado	839	911	1.012	886	954	887	956	887	954
Total	9.161	11.881	13.691	11.426	12.726	11.482	12.793	11.443	12.733

Source: ICONE

Domestic Consumption, Prices and International Trade

In terms of domestic consumption, Table 15 summarizes the results for each product and scenario analyzed.

Table 15. Domestic consumption of each product analyzed (1000 tons and billion liters)

	Baseline			Pessimistic		Optimistic		BRAMS (-P)	
Activities	2009	2020	2030	2020	2030	2020	2030	2020	2030
Grains	106.940	143.375	175.286	141.488	173.643	142.386	174.466	141.713	173.665
Ethanol	23.960	40.891	67.599	39.809	65.260	40.211	66.024	39.954	65.321
Soybeans meal	12.000	16.022	18.922	15.826	18.807	15.929	18.898	15.854	18.810
Soybeans oil	4.341	6.783	8.260	6.739	8.220	6.761	8.240	6.745	8.220
Sugar	10.341	14.288	19.055	14.185	18.975	14.225	19.003	14.200	18.977
Beef	7.433	9.400	10.089	8.997	9.250	9.045	9.304	9.012	9.255
Broiler	7.294	10.791	12.088	10.695	12.160	10.770	12.216	10.715	12.161
Pork	2.598	3.017	3.434	3.006	3.401	3.015	3.449	3.009	3.440

Source: ICONE

In the absence of climate change, domestic consumption of all commodities is projected to increase in 2020 and 2030 compared to 2009. However, our simulations across all the climate change scenarios suggest that when compared to the 2009 baseline, climate change is likely to reduce consumption of almost all commodities, specially grains and ethanol. The main cause of this reduction is the higher real prices faced by all commodities when land availability for agricultural production is reduced as a function of climate change. The pessimistic and BRAMS scenario project the most severe reductions of domestic consumption compared to the baseline.

The Projected Real Prices of Commodities to 2020 and 2030 as Impacted By Climate Change

The real prices of commodities are presented in Table 16. Competition among crops and pasture lead to higher prices in the scenarios with land availability for agriculture restriction. As expected, the pessimistic scenario presented the higher impacts on prices than other scenarios.

Table 16. Commodities' real prices (2011=100)

			Baseline	Pessimistic	Optimistic	BRAMS (-P)
Region	Unit	2011	2030	2030	2030	2030
Corn	R$/ton	395.79	359.29	385.58	374.91	385.08
Soybeans	R$/ton	712.41	815.42	865.34	843.37	864.88
Cotton	R$/ton	1,667.91	1,415.15	1,454.70	1,437.42	1,453.63
Rice	R$/ton	420.10	571.22	671.88	629.49	671.07
Dry Beans	R$/ton	1,178.37	1,523.41	1,691.32	1,638.99	1,688.96
Soybean meal	R$/ton	568.52	814.73	841.80	832.22	841.65
Soybean oil	R$/ton	2,427.65	2,463.22	2,558.26	2,510.82	2,556.95
Wheat	R$/ton	420.04	480.60	480.60	480.60	480.60
Barley	R$/ton	496.33	368.41	368.41	368.41	368.41
Sugar	R$/ton	986.40	343.08	374.25	363.54	373.38
Ethanol	R$/liter	1.35	0.66	0.71	0.69	0.71
Beef	R$/kg	6.35	9.43	12.09	11.83	12.07
Broiler	R$/kg	1.64	2.57	2.80	2.74	2.80
Pork	R$/kg	2.13	3.90	4.21	4.12	4.20

Source: ICONE

Interestingly, beef producer prices increased more than 25% in all scenarios, showing that intensification of pasture use and cattle production might lead to a price increase in order to compensate for the investments to increase yields. Costs of production increase with increasing intensification of livestock production.

Projected Production Value of Agriculture as Impacted by Climate Change 2020 and 2030

Based on the above price projections, climate change impacts are likely to lead to higher values of production in the climate change scenarios due to higher prices and impacts on production (Table 17). So as production declines in one region, supply will be lower than demand, prices will increase and production in other regions will respond positively. It is noteworthy that beef and soybean oil account for almost 50% of the projected total production value for Brazilian agriculture.

Table 17. Production Value in R$ million (2011=100)

	Baseline			Pessimistic		Optimistic		BRAMS (-P)	
	2009	2020	2030	2020	2030	2020	2030	2020	2030
Corn (total)	16,678	24,675	31,889	26,020	33,717	25,459	33,037	25,854	33,684
Soybeans	47,550	68,639	96,181	73,162	101,625	71,048	99,258	72,620	101,577
Cotton	3,413	8,168	10,047	8,338	10,266	8,263	10,171	8,314	10,260
Rice	7,831	6,812	9,254	7,485	10,131	7,207	9,789	7,427	10,124
Dry Beans (total)	4,562	5,829	9,268	6,517	10,138	6,303	9,870	6,466	10,126
Soybean meal	18,350	20,673	33,022	21,255	33,832	21,009	33,589	21,196	33,830
Soybean oil	71,615	128,603	150,100	132,665	155,060	130,581	152,464	132,171	155,002
Wheat	2,819	4,452	3,600	4,362	3,516	4,182	3,463	4,215	3,452
Barley	86,208	78,166	42,852	77,813	42,658	77,949	42,726	77,862	42,665
Sugar	28,248	29,066	20,906	30,806	22,684	30,142	22,076	30,563	22,634
Ethanol	28,102	55,802	52,179	57,824	54,621	57,053	53,787	57,542	54,553
Beef	51,963	85,111	129,121	93,785	153,907	92,198	151,305	93,306	153,678
Broiler	19,287	30,448	50,568	32,674	54,999	31,942	53,994	32,463	54,938
Pork	6,897	11,862	18,843	12,599	20,298	12,347	19,926	12,526	20,270
Total	393,523	558,304	657,832	585,304	707,454	575,683	695,453	582,526	706,794

Increasing prices also explain domestic consumption decrease, as showed in Table 15, and also on net trade (Table 18). Climate change scenarios increased prices and, consequently, reduced the demand.

Table 18. Net trade results for each scenario (1,000 tons and billion liters for ethanol)

	Baseline			Pessimistic		Optimistic		BRAMS (-P)	
Region	2009	2020	2030	2020	2030	2020	2030	2020	2030
Grains	30,471	50,218	68,654	48,629	67,044	49,013	67,556	48,582	66,932
Ethanol	2,897	9,944	11,983	9,944	11,855	9,879	11,924	9,806	11,859
Soybeans meal	12,210	17,569	21,722	17,382	21,540	17,474	21,622	17,304	21,384
Soybeans oil	1,579	1,613	1,885	1,559	1,834	1,585	1,856	1,576	1,862
Sugar	24,088	32,674	41,814	32,370	41,588	32,553	41,710	32,415	41,595
Beef	1,728	2,517	3,549	2,428	3,477	2,510	3,536	2,431	3,478
Broiler	3,635	5,570	7,479	5,570	7,479	5,543	7,409	5,544	7,481
Pork	592	2,598	3,439	2,598	3,439	913	1,378	913	1,386

Source: ICONE

Net trade had lower effects than the domestic consumption, but grain exports were the most affected by more than 1 million tons in 2030, relative to the baseline, for all simulated scenarios.

Conclusions

The value added of this study relative to the other studies carried out in the region over the last decade can be summarized as follows:

1. The study was conceptualized in the context of an on-going national-regional-global *Cenarios Regionalizados de Clima Futuro da America do Sul* (CREAS) effort to improve robustness of climate change projections and likely impacts on agriculture. We used some of the same Global and Regional Climate Models (GCMs and RCMs) used in CREAS so the results from this study will both contribute to and benefit from the on-going CREAS effort.
2. Whereas previous studies had used a single Global Climate Model and single RCM to project national and sub-national impacts, this study used a combination of global and higher resolution regional models and long term hydrometerological and land use data sets to improve calibration of the climate model outputs. The integration of the different climate models and data sources allowed a more refined analysis and synthesis at sub-national scales and also allowed the identification of key data (e.g. hydromet density) gaps.
3. The implementation of this study required active collaboration among researchers, agronomists, and professors and students from leading Brazilian national agencies (EMBRAPA-Agriculture, UNICAMP-climate modeling, INPE-mesoscale weather and spatial modeling, ICONE-economic modeling).

The network of professionals can now continue to improve and refine the integrated agroecological, biophysical, and economic modeling and analysis developed for this study. The inclusion of UNICAMP also lays the foundation for capacity building of the next generation of climate modelers in Brazil and the LCR region.

4. This study assessed the vulnerability and impacts of climate change on Brazilian agriculture by building on valuable work done in the last decade in Brazil and in the LAC region. The results from this study confirm and extend the findings of pervious work that climate change is likely to have increasingly significant and mostly negative impacts on the major grain and pasture systems in Brazil. For example, in comparison with the previous study by Assad and Pinto (2008) that used one GCM and RCM and projected substantial negative impacts to soybean, wheat, maize, and pasture systems, this study using a range of GCMs and RCMs and significantly better hydrometerological and land suitability data, showed that while for some crops (soybean and cotton) the projected climate impacts are likely to be more moderate, for other crops (beans and corn) the impacts could be significantly more severe that than projected in the 2008 study. The Table below highlights for 2020, these differences and illustrates, at least partially, the value of harnessing more robust climate, land, water, and climate data sets for more nuanced analytical power of climate change modeling approaches.

COMPARISON low risk area (%)	**2020**			
	PRECIS model by Assad and Pinto (2008)		Series of GCM & RCMs	
	Optimistic	Pessimistic	Optimistic	Pessimistic
Cotton	-11.4	-11.7	-4.6	-4.8
Rice	-8.41	-9.7	-9.9	-7.4
Sugarcane	170.9	159.7	107	101
Soybean	-21.62	-23.59	-13	-24
Bean (summer season)	-4.3	-4.3	-54.3	-55.5
Bean (autumm season)			-63.7	-68.4
Maize (summer season)	-4.3	-4.3	-12	-19
Maize (autumm season)			-6.1	-13

5. Coupling the above climate impact on agriculture data with an econometric simulation tool – the Brazilian Land Use Model (BLUM), revealed the following likely outcomes at sub-regional scales and geographic locations:

a. In the absence of climate change, cropland is projected to increase to 17 million hectares in 2030 compared to observed area of cropland in 2009. Due to climate change impacts, however, all the scenarios simulated, result in a reduction of cropland in 2020 and 2030.

b. In the pessimistic scenario Brazil could have 10.6 million hectares less land allocated to agriculture in 2030 as a result of climate change with the South Region being the worst impacted losing close to 5 million ha by 2030.

c. It is important to note, however, that the displacement of pastures by grains and sugarcane partially compensates for the projected cropland and grain losses. Framers and the market will partially drive adaptation to loss of suitable crop land due to climate change via displacement of current, poorly producing pastures with grain crops and sugarcane. The projections suggest that there could also be a regional relocation with some of the grain crops moving out of the south to the central regions of Brazil.

d. With respect to Brazilian grain production, our simulations project a reduction of around 4.6 million tons in 2030 in the pessimistic scenarios relative to the baseline. As expected, the optimistic scenario projects a reduced impact from climate change with production projected to decline by 2.7 million tons in 2030 compared to the baseline.

e. Despite the projected decrease in grain production in the South region by around 8.9 million tons in 2030 under the pessimistic scenario relative to the baseline, the Center-West, Northeast Cerrado and North Amazon regions are projected to increase grain production by 4.4 million tons in 2030 under the same scenario, compared to the baseline. That is, regional production re-allocation will reduce the climate change negative impacts on grains by almost half.

f. Although the pasture area is projected to be reduced, beef production is projected to decrease by a much lower amount than the pasture area due to technological intensification. Pasture productivity in Brazil might decrease by 7% in all scenarios simulated to 2030, but our simulations project that compared to the 2009 baseline, beef production may continue to increase until 2030 in all scenarios, and could increase by more than 2 million tons.

g. Beef producer prices are projected to increase by more than 25% in all scenarios, showing that intensification of pasture use and cattle production might lead to a price increase in order to compensate for the investments to increase yields.

h. In general, the production declines can be expected to impact prices, domestic demand, and net exports of these products. In the absence of climate change, domestic consumption of all commodities is projected to increase in 2020 and 2030 compared to 2009. However, our simulations across all the climate change scenarios suggest that when compared to the 2009 baseline, climate change is likely to reduce consumption of almost all commodities, specially grains and ethanol. The main cause of this reduction is the higher real prices faced by all commodities when land availability for agricultural production is reduced as a function of climate change. The pessimistic and BRAMS scenario project the most severe reductions of domestic consumption compared to the baseline.

i. Our estimates show that unlike previous estimates of declining agricultural production value, the negative impacts on supply of agricultural commodities is expected to result in significantly increased prices for some commodities, especially staples like rice, beans, and all meat products. This will counter the effect of declining productivity on value of agricultural production but could have major negative effects on the poor and their consumption of these staple products. It is noteworthy that beef and soybean oil account for almost 50% of the projected total production value for Brazilian agriculture.

6. It is important to state that our study did not simulate the potential impact of technological advances (new varieties, expanded and enhanced access to irrigation, improved land and water management) as adaptation measures to counteract the projected negative impacts of climate change on agricultural productivity. For example,

   a. The Brazilian Government and the private sector have been steadily facilitating the adoption of improved conservation agriculture practices, such as no-till planting, and more resource-efficient systems, such as integrated crop-livestock systems that are inherently more resilient to climate shocks than some intensive cropping systems.

   b. The Government is providing credit and financing for the newly-launched "Low Carbon Agriculture" program with approximately US$ 1 billion available for low interest credit in the 2011 season alone.

7. In our study, our efforts to access the latest available hydrometerological and land use data significantly improved our ability to undertake more robust modeling and impact projections. Nevertheless, the lack of good quality and long term climate data is hampering regional and local climate modeling efforts as well as the calibration and validation of current projections that are being used to inform policy and investment decisions to 2050 and beyond. Because the climate forcing factors operate both within and external to national frontiers, there is an urgent need for coordinated and targeted climate change investments over the

next 1-5 years for instrumentation, data assembly, data sharing and data access systems. National, bilateral, and multilateral investments agencies need to coordinate their investment strategies to support this specific and urgent need.

8. The need for improved and integrated climate change impact assessments is especially urgent for the agricultural sector. A recent survey carried out by the Brazilian Enterprise for Agriculture and Animal Research (EMBRAPA), revealed that even with advanced breeding techniques, it takes approximately 10 years of R&D (including 2-3 years of scaling up and distribution of seed) and costs in the range of US$6-7 million to develop, test, and release a new crop cultivar or variety that is heat and/or drought tolerant.

9. The findings of this study will be incorporated in the EMBRAPA/UNICAMP Agroecozone Model to improve the simulation and climate impact projections that underpin the national agricultural credit and insurance programs in Brazil. This means that the outputs of the study will begin having immediate and far reaching operational and policy implications in Brazil. The experiences from Brazil are highly relevant for other regions and countries where similar work is on-going and could both enrich and benefit from other regional experiences via south-south exchange programs.

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