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Brazil's Climate Adaptation Policies: Impacts on Agriculture

**Constanza Valdes, Christine Arriola, Agapi Somwaru, ERS/USDA
Jose Gasques, MAPA**

Corresponding author: Constanza Valdes
ERS-USDA
1800 M Street, N.W., Room 5138N
Washington, D.C.
Ph. 202-694-5225
Email: cvaldes@ers.usda.gov



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Jose Gasques, MAPA**

Corresponding author: Constanza Valdes
ERS-USDA
1800 M Street, N.W., Room 5138N
Washington, D.C.
Ph. 202-694-5225
Email: cvaldes@ers.usda.gov

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Abstract

Current climate adaptation policies in Brazil are influencing not only the choice of crops but also many agricultural practices at the farm level including changes in planting and sowing periods, use of irrigation-saving technologies, and increased nitrogen fertilization, among others. The shape and content of these adaptation policies and measures for Brazil are not limited to production agriculture, but include also conservation reserve and risk-reducing farm programs. In addition, the decades-old adaptation and management strategies for agricultural production under tropical conditions carried out by EMBRAPA, Brazil's premier agricultural research agency, continue to play a prominent role. As Brazil is one of the world's largest agricultural producers and exporters of agricultural commodities, impacts in Brazil that may occur under different climate scenarios could have broad implications for food supply and prices worldwide. We find that farmers' adoption of adaptation strategies could result in significant increases in agricultural productivity, changes in suitable crop growing areas, reduced vulnerability to temperature changes, and improved income generation for farmers.

1. Introduction

Brazil plays an important role in the discussion on climate change. Agriculture represents a significant share of its Gross Domestic Product and the country is a major food producer and supplier to international markets: a quarter of what Brazil produces in grain, oilseeds and meats is sold in world markets, thus climate-related impacts on Brazil could have broad implications for food supply and prices worldwide. Most importantly for climate change, Brazil has one of the world's largest forest ecosystems: the Amazon. Brazil is also the fifth largest carbon dioxide emitter among developing countries after China, India, Mexico, and Indonesia (EIA, 2010).

Brazil has become a leading voice at climate negotiations, actively participating in developing agreements to address climate change issues. Brazil hosted the 1992 United Nations Conference on Environment and Development (the Rio Earth Summit) and sponsored the *Clean Development Mechanism* of the Kyoto Protocol. More recently, in December 2009 the Brazilian

Parliament adopted a *National Climate Change Policy* which includes a voluntary Green House Gas (GHG) reduction target by 2030 (de Gouvello et al, 2010).

The potential effects of global climate change (i.e. increased temperatures, decreased precipitation) for Brazilian agriculture are prompting Brazilian officials to design and implement climate adaptation policies intended to reduce the negative impacts of climate change on agriculture. Current initiatives include policies and management practices directed at protecting farm productivity as well as those directed at protecting natural resources and the environment.

As Brazil is an important competitor in global agricultural markets and largest world exporter (global market shares in parenthesis) of sugar (48 percent), sugarcane-based ethanol (40 percent), orange juice (39 percent), coffee (30 percent), and beef (18 percent); and second largest exporter of soybeans (32 percent) and poultry meat (27 percent), after the United States, and large importer of selected food crops (wheat, rice), a better understanding of adaptation policies affecting Brazil's farm sector will help in anticipating changes in crop production and effects on trade. With a population of 192 million, it is also one of the world's leading consumers of cereals, oil crops and meats. Domestic demand is projected to grow as Brazil's population gains an estimated 50 million people by 2049 (MAPA, 2010). Brazil's rising food consumption will require continued increases in food supplies.

The primary challenge Brazil is now facing is how to reduce agriculture's vulnerability to climate change and to cope with the expected impacts on agriculture including yields, land use, and farm revenues. Continuous funding for development of heat-resistant crops is needed for

Brazil to be able to sustain production growth in agriculture to meet increasing domestic demand and, at the same time, maintain its position as a major supplier of agricultural products to world markets. A second challenge for Brazil is to reduce and mitigate its GHG from deforestation, land use and land use changes linked to crop and livestock production, and forest management.

This paper discusses Brazil's historical and current adaptation policies directed at protecting farm productivity, natural resources and the environment from detrimental climate change effects. The research also seeks to assess the economic benefits from current adaptation policies using the farm-level optimal crop yields incorporated in MAPA's recently introduced agricultural zoning database (details about this database, commonly referred to as the Agricultural Zoning Program (AZP) to follow). Optimal crop yields are considered for five crops, which together account for more than 90 percent of Brazilian agricultural production: soybeans, corn, sugarcane, wheat, and cotton (MAPA, 2010). These optimal yields –rather than targeted yields, are actual maximum yields currently attainable, under the Brazilian AZP farmer's adaptation initiative, which includes crop technology and growing strategies adapted to local climates and changes in climate to mitigate potential reductions in yields due to climate change. To simulate the market and trade effects of AZP yield changes resulting from Brazil's adaptation policies, these optimal yields for the five crops are introduced in the ERS's PEATSim partial equilibrium, multiple-commodity, multiple-region model of agricultural policy and trade.

Several researchers (Tobey et al., 1992; Reilly, 1993) have studied the yield effects in grain producing regions of the world resulting from global climate change and the likely impact on world food production. Others (Stern, 2006; Darwin et al., 1995) have sought to identify

adaptation policies as a response to climate change, providing an economic framework for adaptation and exploring how developing countries can adapt to climate change. Mendelsohn (1999) concludes that tropical regions are more vulnerable to potential damage from change in climate because of existing poor soils. He emphasizes the value of agricultural zoning analysis of climate sensitivity to examine the impact of adaptation by farmers on agriculture.

2. Earlier Adaptation Efforts in Brazilian Agriculture

There is no better country than Brazil to highlight the use of adaptation strategies for its agricultural system. Beginning in the late 1960s and throughout the 1970s, the Government of Brazil (GOB) engaged in the development and implementation of policies whose primary objective was to ensure crop growth under tropical and variable climatic conditions. To that end, increasing government investment in adaptive cultivar's research was carried out through the Brazilian Corporation for Agricultural Research (Empresa Brasileira de Pesquisa Agropecuária, EMBRAPA), a public company created in 1972 and linked to the Ministry of Agriculture and Food Supply (MAPA). EMBRAPA sought to generate and transfer new agricultural technologies for a tropical climate, increase Brazilian farmer's adaptive capacity, and reduce the country's vulnerability to climate change.

EMBRAPA's research has focused on development of high-yielding varieties specifically adapted to the tropics and the frontier lands and the development of pest-resistant/cost-reducing varieties. EMBRAPA's research has also included alternative cultivars with lower fertilizer requirements and higher drought resistance. Through its 39 regional units, EMBRAPA's research has centered on crops (soybeans, sugarcane, corn, rice, cotton, coffee, fruits and

vegetables), livestock activities (beef, pork, poultry, dairy), irrigation agriculture, conversion of degraded pastureland, and conservation of natural resources (MAPA, 2010). EMBRAPA is credited with stimulating the rapid expansion of the land base and increasing agricultural productivity, with the greatest gains for soybeans, cotton and rice (Table 1).

Table 1 Brazil's land use and yields

Commodity	2000-02		2003-05		2006-08	
	Area	Yields	Area	Yields	Area	Yields
	Ha 000	Tons/ha	Ha 000	Tons/ha	Ha 000	Tons/ha
Soybeans	14,628	2.7	20,962	2.5	21,410	2.8
Corn	12,459	2.9	12,319	3.3	13,867	3.6
Cotton	784	1018.7	1,002	1146.3	1,007	1361.7
Wheat	1,482	1.6	2,421	2.0	1,979	1.8
Rice	3,315	2.2	3,613	2.3	2,946	2.7
Sugarcane	5,036	68.5	5,609	73.4	6,739	76.1

Source: Foreign Agricultural Service (FAS), U.S. Dept. of Agriculture. FAS Production, Supply and Distribution Online.

EMBRAPA's research on potassium nutrition for soybeans helped correct nutrient deficiencies in low fertility soils and provided the greatest incentive for soybean cultivation on large tracks of frontier land, propelling Brazil to its current position as the world's second largest soybean producer. Area harvested to soybeans grew 8.5 percent annually from 1962 to 2008, with area increasing from 500 thousand hectares in the 1960s to over 9 million hectares in the 1980s and 21.3 million hectares in 2008. Soybean expansion in the *Cerrados* was even more dramatic with growth of 23 percent per year in 1962-2008. By 2008, the *Cerrados* accounted for 43 percent of total soybean harvested area compared to 0.3 percent in the mid-1960s (IBGE, 2010).

In addition to the varietal improvements attained by EMBRAPA centers, other State government agencies and private enterprises have actively participated in the development of new crop varieties better suited to the tropical areas of Brazil. For example, in the case of sugarcane, Brazil's second most important crop in value terms, EMBRAPA's research has yielded new cultivars with different maturation times, allowing for continuous sugarcane harvesting throughout the year and across the various regions in Brazil. Equally important have been the sugarcane varietal developments by the Campinas Agronomic Institute, the Sugarcane Technology Center, a private NGO which developed the SP (São Paulo) varieties, and Planalsucar (now Ridesa), which developed the RB (República do Brasil) high yielding-heat resistant varieties. The most recent program is CanaVialis created in 2003 –one of the largest cane breeding programs in the world (Macedo, 2005). Harvested area of cane in the Southeast and South regions grew 4.4 percent per year in the 1960-2008 period, increasing from 929 thousand hectares in the 1960s to 2.3 million hectares in the 1980s, 4.0 million hectares in the 1990s and 5.2 million in 2008 (IBGE, 2010).

3. Adaptation Policies in Brazilian Agriculture

Various empirical studies have documented the observed effects of climate change on many agricultural areas of Brazil. For example, studies focusing on coffee have provided evidence that traditional optimal coffee growing areas in the southeastern region of Brazil (in the States of São Paulo, Minas Gerais, and Goiás) are no longer optimal, as documented increases in temperature –in the order of 1 to 2 degrees over the past 35 years, are making many agricultural areas in these States less productive, pushing coffee farmland into higher latitudes (MAPA, 2010).

With this new evidence on the vulnerability of farmland on tropical climates, Brazilian officials have grown increasingly concerned about the economic impact of climate change on agriculture. In response, Brazilian officials have been recommending adaptation policies which involve changes in agricultural practices in response to a change in climatic conditions and the development of crops suitable to diverse climate changes. The programs that minimize climatic risks for Brazilian agriculture have included the introduction of new cultivars, crop mix, increased nitrogen fertilization, soil PH correction, irrigation-saving technologies (tillage), and changes in planting and sowing dates, among others. These programs have sought to address three principal objectives:

1. Agricultural development and recommended technology -providing new opportunities not just for commercial agriculture (principally in the frontier lands of the Center-West *Cerrados* region), but also for small-holding producers in the arid Northeastern region.
2. Agricultural productivity -increasing crop yields to increase farm incomes, guarantee profits to producers, and reduce farming costs.
3. Agricultural diversification programs –increasing the number of crops produced on farms to increase farm incomes and reduce mono-cropping risk for farmers.

More recently, government programs have been retooled to take into account agricultural losses due to adverse climatic events, adding a fourth objective:

4. Agricultural financing –introducing agricultural zoning as a tool used as a federal farm credit policy by Brazil's Central Bank when supplying federal credit to farmers (total available funding for the 2010/11 crop year now stands at \$54 billion for commercial agriculture and \$10 billion for family farms) to help ensure reduction of agricultural losses from adverse climate events.

A chronological tabulation of major adaptation policies of agricultural production to climate change in Brazil is shown in Table 2. This policy interaction matrix includes a historical inventory represented by policies for productive adaptation to tropical climates and the current adaptation policies (under full implementation since 2006), as represented in the AZP and the focus of this study.

Table 2 Adaptation policies and programs in Brazil

	1965 or earlier	1975	1980	1985	1990	1995	2000	2005	2010
Technology development and adaptation									
New cultivars for tropical agriculture	*	*	*	*	*	*	*	*	*
Use of fertilizers; pesticides	*	*	*	*					
Use of biomass-based energy	*	*	*	*					
Use of irrigation water					*				
Land-use area					*				
Agricultural zoning for optimal yields							*	*	*
Environmental conservation									
Soil productive capacity	*	*	*						
Soil erosion prevention				*	*				
Nutrient leaching				*	*				
Soil compaction				*	*			*	*
Water quality							*		
Biodiversity/natural vegetation								*	*
Environmental restoration									
Degraded soils									*
Set-aside mandatory protection areas									
Expansion of production to frontier lands								*	*
Regulation of territorial expansion									*
Policies for sustainable production:					*				
Labor protection							*		
Mandated use of cleaner technologies							*	*	*
Prohibition of slash and burn of cane									*

Note: The asterisks indicate the approximate date of initial adoption of the adaptation policy designed to minimize climatic risks and increase agricultural productivity.

Source: Prepared by the authors from EMBRAPA and MAPA surveys.

3.1 The Agricultural Zoning Program (AZP)

The Agricultural Zoning Program (AZP), created in 1996 by Brazil's Ministry of Agriculture and Food Supply (MAPA) and EMBRAPA is a policy aimed at adaptation to climate change by explicitly indicating the best geographic distribution of individual crops -accounting for soils and climate, and keeping record of the highest yields attained. Initially, it was setup to provide planting calendars for major crops to decrease climate risk for farmers in the traditional agricultural producing State of São Paulo. The calendar included a *Water Requirement Satisfaction Index* (WRSI), calculated based on historical rainfall data, water evaporation, growing season length, and soil permeability to indicate water supply requirements for various crops during the growing season (Zullo Jr. et al, 2006).

The commodity and regional coverage in the AZP database has been expanded with information on the agronomic characteristics of crops, soil typologies, and climate. The AZP database now covers all 23 Brazilian States, 5,564 counties, and 33 agricultural commodities (including crops, oilseeds, and fruits). An innovation in the program is that since 2006 the AZP has been linked to Brazil's federal farm credit policy as rural lenders obtaining funds from Brazil's Central Bank use the AZP database and planting calendars when supplying federal credit to farmers.

Agricultural losses resulting from rainfall and temperature variability have been estimated to represent on most crop years about 20 percent of all planted crops (CONAB, 2008). About 60 percent of agricultural losses in Brazil are the result of drought conditions during formative and grand crop-growth phases and close to 30 percent of the losses are estimated to result from very humid conditions at harvesting (Zullo Jr. et al, 2006).

3.2 The Cost of Brazilian Adaptation Policies

Adaptation policies tend to involve significant public and private investments in infrastructure and financial services needed to build adaptive capacity. Measures to build adaptive capacity range from understanding the potential impacts of climate change and the options for adaptation (i.e., undertaking impact studies and identifying vulnerabilities), to implementing specific actions, and obtaining the resources necessary to implement the actions (Stern Review, 2006).

Adaptation policies in Brazil include federal subsidized credit provided through Brazil Central Bank, and the agricultural zoning, and extension services programs provided by EMBRAPA. Under current credit conditions, individual producers and farm cooperatives receive subsidized loans (now at 6.25 percent per year compared to markets rates of about 20 percent), with the maximum loan amount varying with the farmer's annual income and geographical location. Other government subsidized investment credit programs charge interest rates of between 8.75 and 10.75 percent per year for large producers. Subsidized credit has been made available to low-income small farmers (producers with less than 10 hectares) and agrarian reform settlers who have received a plot of land to farm but lack access to credit and markets (MAPA, 2010).

Subsidized credit for adaptation programs has been increasing in real terms since 2000 as a result of two factors geared toward reducing climatic risks: a GOB initiative to provide subsidized credit (8.75 percent subsidized loan rates) to producers in degraded pastureland (up to 2 million hectares annually) introducing livestock farming systems with heat and disease tolerant breeds; and new credit programs (with participation of the GOB and private investors) to increase agricultural production of heat-tolerant crops.

By 2010, credit available for adaptation programs had reached over \$700 million (in constant 2000 prices), with 93 percent of that amount allocated to operating capital, and the remaining 7 percent for investment and aforestation programs. Individual agricultural producers and farmer's cooperatives receive operating capital credit to fund soil preparation, protection, and correction, pastureland conversion and restoration, and adaptation extension services. In 2010, operating credit of \$664 million (in real terms) benefited 18.6 million hectares (Table 3). Other adaptation programs included funding for investment for conversion to pastureland, and restoration of degraded pastureland and adaptation extension services. The value of these loans for agriculture in 2010 was about \$34 million (in constant 2000 prices), mostly under the restoration of degraded pastureland and pastureland conversion programs. Investment credit for aforestation and reforestation programs to protect crops from high temperatures was \$20 million (in real terms) in 2010 (Table 3).

Table 3. Subsidized credit for adaptation programs for Brazilian farmers, 2010

	2010
<i>(thousand US\$, constant 2000 prices)</i>	
Operating Capital -Heat-Resistant Crops	664,023
Agricultural zoning	440,096
Soil correction	46,643
Pastureland conversion and restoration	71,977
Heat-resistant crops	105,306
Investment –Heat-Resistant Livestock Breeds	33,605
Pastureland conversion and restoration	26,881
Adaptation extension services	6,724
Aforestation and reforestation- Heat Protection	20,111
Total	717,739

Source: Banco Central do Brasil. *Anuario de Credito Rural*. ERS calculations.

4. Market and Trade Effects of the Adaptation Policies

Agronomic simulation models predict that increases in mean temperatures will reduce grain yields as the cool crop-growing areas get warmer. An impact assessment of climate change on agriculture considers that if higher temperatures are not followed by adaptation and /or development of heat-resistant cultivars, the suitable areas for grain and oilseed production will most likely decrease. The exception appears to be sugarcane, where the sucrose metabolism enzymes in the sugarcane stalk at higher temperatures would favor an increase in suitable areas for harvesting sugarcane. Factors such as farming practices, regional infrastructure, soil types (suitability decrease in regions with sandy soils as opposed to clay or medium soils, as temperature increase), will also determine the economic suitability for crop production.

4.1 Modeling Methodology

To analyze the impact on agriculture of Brazilian climate adaptation policies we follow the agricultural zoning approach recommended by Mendelsohn (1999) taking advantage of the recently completed Brazilian AZP database which includes sugarcane production in the various regions of Brazil. In this approach, we selected five individual crops (soybeans, corn, sugarcane, wheat, and cotton) assigned to each agricultural zone and disaggregated at the county level. The database identifies the most suitable areas for farming at the county-level, and where maximum (optimal) yields could be attained when farmers implement adaptation technologies recommended under the agricultural zoning program (AZP) (MAPA, 2010). These selected counties in the AZP database are linked to crop production in each on the 5,564 counties in the crop year 2009-10, as reported by IBGE (IBGE 2010). The optimal yield representing a

maximum for a region that, when applied to the entire country, may overstate the yield that is obtainable, and thus represents the upper end of a possible range of outcomes. The optimal yields were then entered into the ERS's PEATSim economic model to project overall supply and market effects, including crop outputs, prices, and net revenue.

PEATSim is a partial equilibrium multiple-commodity, multiple region economic model of global agricultural policy and trade. The model accounts for the simultaneous interaction between major crops and livestock activities and contains individual countries' domestic and trade policies (Stout et al, 2004). The model is calibrated to the USDA's 10-year projections for global agricultural production and trade. The USDA baseline projections are a conditional, long-run, scenario: a Departmental consensus about what would be expected to happen under a continuation of current policies, normal weather, and specific assumptions about global macroeconomic conditions and agricultural productivity growth (USDA, 2010).

PEATSim Production/Yield Block

Area harvested for each crop i in year t (AH_{it}) is modeled as a constant-elasticity function of the crop's own producer price and producer prices of other crops, which may in general be complementary or competing for land. Because the model permits partial adjustment factors that cause short-run supply response to be some reduced proportion of the long-run response, harvested area in one year also depends in general on harvested area in the previous year:

$$AH_{it} = consah_i \cdot AH_{it-1}^{\lambda_{ah}} \cdot \prod_{j \in crops} PP_{jt}^{(1-\lambda_{ah})\sigma_{ah_{ij}}} \text{ for } i \in crops,$$

where AH_{it-1} is area harvested in the previous year and PP_{jt} is the producer price for crop j .

The σah_{ij} are elasticity parameters and λah is a partial adjustment parameter satisfying

$0 \leq \lambda ah < 1$. The $consah_i$ are constant terms set so that the model reproduces base-year data on area harvested. Crop yield (YLD_{it}) is modeled as a constant-elasticity function of the own producer (yield) price (PYP_{it}) and the yield in the previous year:

$$YLD_{it} = consyld_i \cdot YLD_{it-1}^{\lambda yld} \cdot PYP_{it}^{(1-\lambda yld)\sigma yld_i} \quad \text{for } i \in crops$$

where YLD_{it-1} is yield in the previous year, σyld_i is an elasticity parameter, and λyld is a partial adjustment parameter satisfying $0 \leq \lambda yld < 1$. The $consyld_i$ are constant terms set so that the model reproduces base-year data on crop yield. The producer yield price (PYP_{it}) is the price that producers receive at the margin for additional output. Farmers adjust usage of non-land inputs (machinery, labor, fertilizer, etc.) per acre in response to changes in PYP_{it} .

4.2 Results to 2049: Crops Supply, Demand, and Trade

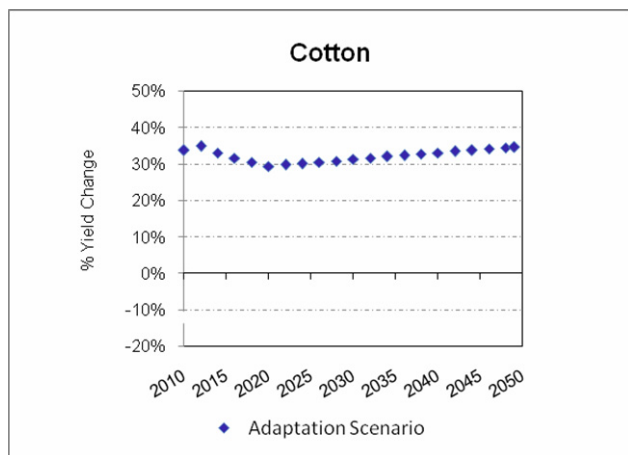
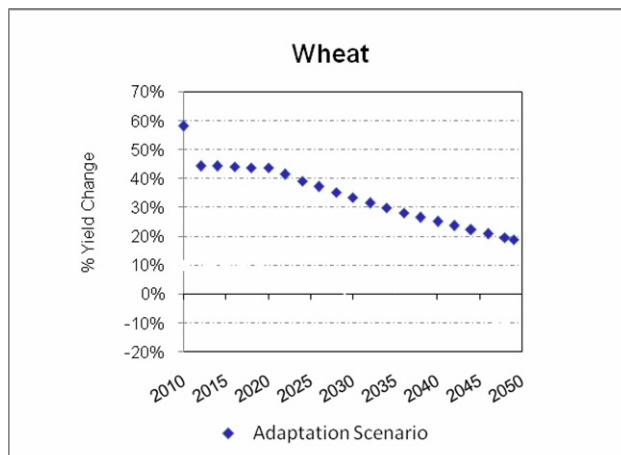
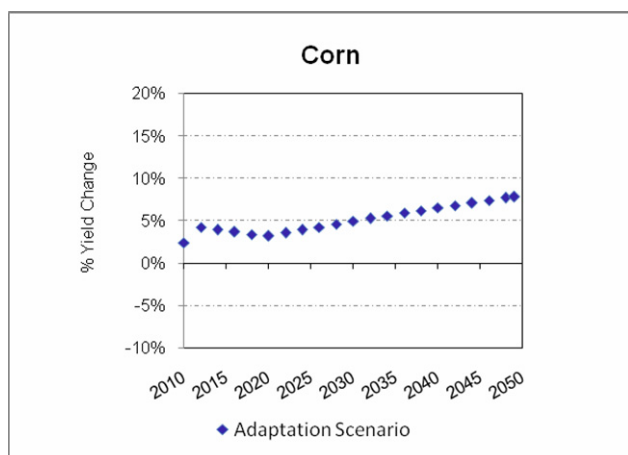
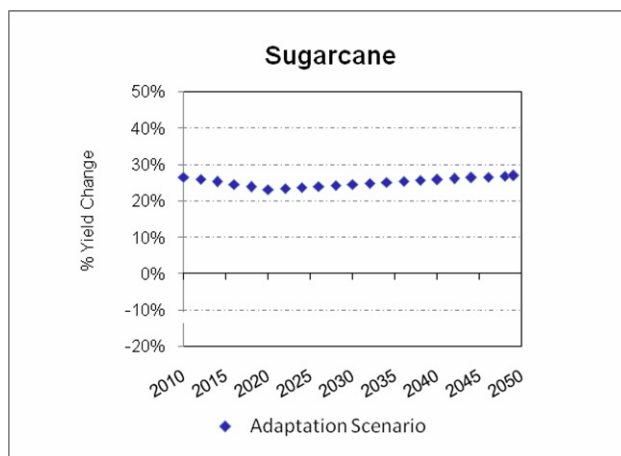
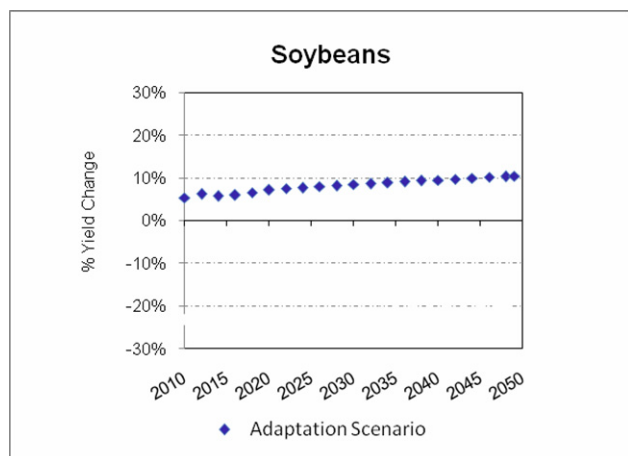
The time path for the dynamic PEATSim model is 2009-2019, calibrated to the results from the USDA baseline projections. Base data for crops on area, yield, production, consumption, stocks, and trade are from the 2009 crop year and are drawn from USDA PS&D database. In the base scenario, USDA baseline projections for Brazil already include estimates of expected increase in corn yields so that the maximum (optimal) agricultural zoning yields represents an increase in yields above the current expectations.

To analyze the dynamics of adaptation for Brazilian agriculture we consider a continuous sequence of 40 years or growing seasons for the base model run. A scenario of implementation of adoption strategies is simulated introducing the optimal yield outcomes from the agricultural zoning county database aggregated at the national levels, to determine how the various agricultural sectors adjust. The outcomes are presented as changes from the 2009-2049 baseline.

We set a simulation to assess the effects of the maximum (optimal) yields attained by Brazilian farmers incorporating adaptation strategies in soybeans, corn, sugarcane, wheat, and cotton. The model's time path is extended to 2049. We modeled the adaptation scenario of an increase in yields, incorporating the real yields obtained from the county-level commodity yield data in the production database from 2009-10, lined up (at the county-level) with the AZP (adaptation) database.

The resulting first year yield increase from baseline (percent increase in parenthesis) include: soybeans (5.3 percent), corn (2.5 percent), sugarcane (26.6 percent), cotton (33.8 percent), and wheat (58.1 percent) (Figure 1). This initial growth in crop yields leads to 0.1 percent higher average annual growth rate for soybeans, corn, sugarcane, and cotton, but a 0.5 percent reduction in the annual growth rate for wheat in 2009-49. Impacts on supply, demand, and trade differ across commodities and the livestock sector, based on how changes in crop productivity affect feed supplies and costs.

Figure 1 Percent Yield Changes from Baseline, Under Scenario Implementation of Adaptation by Farmers in Brazil, 2010-2050



Scenario Results

Scenario results for the implementation of adaptation strategies for the individual crops are reported as deviations from the baseline and the results are presented in Table 4 and Figure 2. Aggregated results under the adoption of the adaptation scenario are reported in Table 5 and include land use area, aggregated crop production, aggregated livestock and products production, and the total value of agricultural production variables.

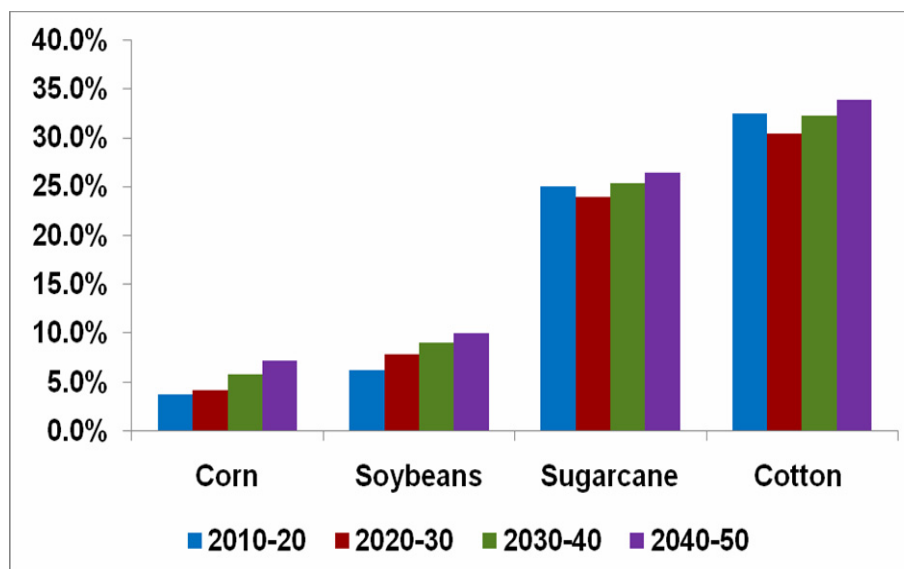
We first examine the maximum (optimal) increase in soybean, corn, sugarcane, wheat, and cotton yields in Brazil compared to the baseline. This is the initial shock we introduce to the model. The increase in yields causes production in Brazil, primarily sugarcane, cotton and soybeans to increase. Sugarcane production in Brazil increases slightly less than 15 percent, cotton production increases 31 percent, and soybean production increases about 8 percent (along the optimal yield guidelines). As a result of the gains in yields, area harvested for all crops – except for corn, decreases 1.4 percent per year. The slight increase in corn area reflects the fact that relative corn prices do not change sufficiently to shift land out corn production. The increased in soybean yields combined with the increase in feed demand from the livestock sector leads to increased soybean use, which is sufficiently met by production, leading to rapid gains in soybean exports. The increase in sugarcane yields combined with increase in domestic demand for ethanol leads to increased sugarcane use. Sugarcane prices decline about 18 to 22 percent over the baseline period, lower than world prices. As a result, sugarcane increases its relative competitiveness in export markets (Table 4).

Table 4. Impact of a hypothetical optimal yield increase, deviation from the baseline

	2010	2015	2020	2025	2030	2035	2040	2045	2050
<i>Adaptation Scenario</i>									
Soybeans									
Area Harvested	-0.08%	-0.05%	-0.26%	-0.29%	-0.36%	-0.39%	-0.41%	-0.43%	-0.44%
Yields	5.30%	5.83%	7.17%	7.84%	8.43%	8.99%	9.50%	10.01%	10.40%
Production	5.22%	5.78%	6.89%	7.52%	8.04%	8.57%	9.05%	9.54%	9.91%
Exports	9.73%	10.91%	13.32%	14.75%	16.02%	17.29%	18.48%	19.67%	20.60%
Price	-3.80%	-4.24%	-4.78%	-5.06%	-5.40%	-5.71%	-5.97%	-6.23%	-6.42%
Corn									
Area Harvested	0.64%	0.56%	0.81%	0.89%	1.03%	1.05%	1.07%	1.10%	1.12%
Yields	2.45%	3.82%	3.23%	4.10%	4.95%	5.76%	6.54%	7.25%	7.83%
Production	3.11%	4.40%	4.06%	5.03%	6.03%	6.87%	7.68%	8.43%	9.04%
Imports	2.19%	2.63%	2.63%	2.71%	2.79%	3.01%	3.19%	3.36%	3.48%
Price	-2.55%	-3.04%	-3.04%	-3.14%	-3.22%	-3.46%	-3.67%	-3.85%	-3.99%
Sugarcane									
Area Harvested	-7.39%	-7.67%	-7.48%	-8.01%	-8.41%	-8.62%	-8.87%	-9.17%	-9.39%
Yields	26.63%	24.96%	23.16%	23.91%	24.60%	25.25%	25.89%	26.48%	26.93%
Production	17.27%	15.38%	13.95%	13.98%	14.12%	14.46%	14.72%	14.89%	15.01%
Exports	41.06%	32.66%	27.33%	25.93%	25.03%	24.72%	24.41%	24.02%	23.75%
Price	-17.54%	-18.37%	-18.08%	-19.28%	-20.18%	-20.70%	-21.30%	-21.96%	-22.47%
Cotton									
Area Harvested	-1.01%	-0.79%	-0.59%	-0.53%	-0.54%	-0.54%	-0.54%	-0.55%	-0.55%
Yields	33.75%	32.40%	29.37%	30.36%	31.31%	32.24%	33.13%	34.00%	34.66%
Production	32.40%	31.34%	28.61%	29.67%	30.60%	31.52%	32.41%	33.27%	33.92%
Exports	67.96%	63.64%	56.34%	58.52%	60.43%	62.34%	64.15%	65.86%	67.10%
Price	-6.72%	-6.50%	-6.23%	-6.36%	-6.69%	-6.94%	-7.18%	-7.42%	-7.62%
Livestock Production									
Beef	0.13%	0.20%	0.04%	0.06%	0.05%	0.08%	0.10%	0.14%	0.16%
Pork	-0.09%	0.03%	0.03%	0.06%	-0.01%	-0.01%	0.00%	0.01%	0.02%
Poultry	0.21%	0.23%	0.27%	0.31%	0.23%	0.25%	0.26%	0.27%	0.28%

Source: Simulation results, ERS calculations

**Figure 2. Impacts on Brazil's commodity yields, percent change from baseline
Adaptation Scenario**



The increases in crop productivity (yields) lead to significant gains in crop production by 2049 (an 11.7 percent increase compared to the baseline scenario). Crop area is reduced between 0.8 and 1.3 percent over the period as optimum management strategies for crop production result in positive changes in crop productivity compared to the baseline and allow farmers to minimize the negative impacts of higher temperatures (Table 5). The increase in crop yields combined with increase in demand for food and feed grains leads to increased use, which is more than offset by increased production. Domestic grain prices decline about 3 to 7 percent over the baseline period, due to increased supply, and more than global prices. As a result, Brazil increases its relative competitiveness in feed and export markets. Domestic feed use increases moderately while Brazilian exports of grains increase sharply. The Brazilian livestock sector benefits from increased production and the lower grain prices. Livestock production expands between 0.1 and 0.2 percent over the period with lower feed costs (Table 5).

Table 5. Aggregated results for agriculture –Adaptation Scenario

	2010	2020	2030	2049
Land Use				
		<i>(thousand hectares)</i>		
Base gross cropped area	50,600	52,987	55,161	58,827
Scenario gross cropped area	50,193	52,511	54,570	58,048
% change from base	-0.8	-0.9	-1.1	-1.3
Aggregate Crop Production				
		<i>(thousand tons)</i>		
Base production	193,459	221,580	247,510	297,656
Scenario production	211,897	242,062	272,652	332,568
% change from base	9.5	9.2	10.2	11.7
Livestock and Products Production				
		<i>(thousand tons)</i>		
Base production	53,178	62,211	70,452	83,677
Scenario production	53,199	62,263	70,517	83,835
% change from base	0.0	0.1	0.1	0.2
Value of Agricultural Production (Million US\$)	107,002	236,758	467,251	1,381,076

Source: Simulation results, ERS calculations.

Conclusions

Brazil has already engaged in agronomic research to better adapt crops and livestock to its climatic conditions, which are tropical and vary across the country. This research and related investment could be extended or intensified to deal with climate change. Through earlier adaptation efforts encouraged by EMBRAPA, Brazil has managed to increase output five-fold since the 1970s with agronomic adaptation to tropical climate, cost-saving technological improvements, expansion of cultivated area in frontier lands in the *Cerrados* region, and shifting production from smallholders to large scale farming to achieve economies of scale.

The use of adaptation policies in Brazilian agriculture to deal with climate change would lead to yield increases and changes in the location of production to other regions more suitable for crop production. Further, adaptation solutions, such as the development of cultivars adapted to higher temperatures, have proven very effective in assisting Brazilian farmer decisions to plan for the effects of climate change. The results of the scenario analysis indicate that the increases in crop productivity of 5-10 percent would reduce pressure on agriculture commodity prices, particularly for soybeans and corn. An increase in corn yields would increase supply of livestock feed without significantly reducing the production of other crops. Further research is needed to investigate the impact on Brazilian agriculture from increases in average temperatures, reduced precipitation and greater variability and the likely impacts on diverse growing conditions in the various regions of Brazil.

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