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Productive capacity of Brazilian agriculture: a long-term perspective

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Summary

The overall objective of this study is to contribute to developing an approximate view of the productive capacity of Brazilian agriculture to meet the national requirements and contribute to the world supply of food, fibres and biofuel by 2030. Specifically, it addresses the following questions: (a) What is the outlook for Brazil´s agricultural production, harvested area, consumption and trade of main crops in the next 20 years? (b) How did agricultural production move spatially in the Brazilian territory during the 1978-2008 period? (c) Where should most of the expected production take place and how much land will be necessary to produce sustainably the estimated levels of production without affecting negatively the biodiversity? (d) What could be the impact of climate change on the estimated harvested area and production of major producing states? (e) What are the prospects to expand agricultural production via greater utilisation of irrigation? (f) What implications does the productive capacity of the country bring to Brazil´s public policy, technology generation and investments to enhance agricultural productivity and sustainable production in the medium and long term? These questions are addressed based on the following selected products: rice, wheat, edible beans, cassava, cotton, soybeans, maize, sugar cane, sorghum, coffee and cattle beef.

Outlook for Brazil´s production, harvested area, consumption and trade of selected agricultural products, 2010-30. Looking towards the future, it is assumed that the past will largely shape the prospects of Brazil´s agricultural sector structure and performance in the next two decades. In this context, in 2030 the domestic production of coffee should be 4.3 million tons; sugar cane and soybeans would reach respectively 1,051 million and 101 million tons; and beef would total approximately 14 million tons equivalent carcass. Rice output should expand from 13 million tons in 2010 to 18 million in 2030, while that of maize would increase from 56 million to 77 million tons. Cotton production is expected to be about 5 million tons at the end of this period vis-à-vis 3.8 million in 2010.

Agricultural production in Brazil comes from the activities of three main classes of producers: i.e. small, medium and large, defined according to specific levels of annual production. The domestic production of agricultural products has been following a concentration path towards classes of producers with larger annual output. This trend, which is similar to that observed in several developed countries, is expected to continue in the next decades. This brings several implications, including the need to identify policy alternatives capable of making the option of living in rural areas attractive to members of the small producers' class.

The outlook for harvested area at the national level suggests that the total area harvested with the selected crops should expand approximately 13 million hectares between 2010 and 2030, increasing from 62 million to 75 million hectares. This expansion is associated with a significant boost in the harvested area with sugar cane, soybeans and sorghum, a moderate increase in the area of maize, and a fall in the area of rice and wheat. The harvested area with cotton, coffee, edible beans and cassava is expected to remain roughly unchanged, experiencing annual averages growth rates between -0.3% and 0.2% depending on the crop.

The domestic consumption of soybeans, maize, sugar, coffee and beef in 2010-30 is expected to grow at annual average rates between 1.7% and 2% per year, depending on the product. The national consumption of rice, wheat, edible beans and cotton is also expected to expand in 2010-30. However, due in part to the low income elasticity of demand for these products, especially of the first three, their estimated increase should be lower than those of the previous group of products.

Between 2010 and 2030 the exports of soybeans and beef should increase approximately 70% and 65% respectively. The first would expand from 29.6 million tons to 50.5 million and the second from 1.9 million to 3.1 million tons. Cotton exports should almost double during this period and the foreign sales of maize should increase approximately 50%. The exports of sugar are estimated to expand at an annual average growth rate of 1.7% in 2010-30 reaching 33.5 million tons at the end of the period. Coffee exports are estimated to increase from 1.6 million tons to 1.9 million during this period.

Wheat imports are estimated to increase 27% between 2010 and 2030, resulting in foreign purchases of 7 million tons in the last year of this period. Edible beans imports are expected to expand at an annual average growth rate higher than wheat (i.e. 2.2% compared with 1.2%), achieving an import level of 343,000 tons in 2030. Rice imports should fall sustainably from 832,000 tons in 2010 to 707,000 in 2030.

Spatial dynamics and geographic concentration of agricultural production and livestock raising in Brazil. Regarding these aspects, crop production and livestock raising in Brazil have at least two main characteristics: (a) in general they are dynamic with respect to the geographic location of the production processes; and (b) this dynamism has contributed to concentrating agricultural production in the Centre West, South and Southeast regions of the country along the 1978-2008 period.

Soybeans, cotton and sorghum experienced major dislocations at both regional and state level. Soybean production followed a geodesic trajectory (that is, a terrestrial 'straight line') moving from the South region towards the Centre West of the country. Sorghum production followed a similar trajectory as soybeans, moving from the South to the Centre West. In 1978 and 1988, the gravity centre of cotton production was located in the Southeast region. In 1998, it moved to the south of the Centre West region, and in 2008 it was located in the north of that region, more specifically in the state of Mato Grosso. Wheat and edible beans registered movements of less magnitude, and the other selected crops showed significant spatial dislocations, sometimes larger at regional level and others at state level.

Concerning the geographic concentration of agricultural production, the analysis showed that the Centre West is attracting the production of several commodities as well as livestock. It also indicated that some states in other regions, such as São Paulo, Minas Gerais and Paraná, are main producers of several commodities. These results reveal that there is an important degree of concentration of production in this geographical area. This geographic concentration of production was corroborated by the Gini coefficients, which were calculated for the regional distributions of volume in the years of 1978, 1988, 1998 and 2008.

A large degree of geographic concentration of production is also observed when analysing the share of the different states in the total production of each of the selected crops and cattle stock. In 2004-08, five or less states were responsible for 80% of the production of seven out of the ten selected crops. In the case of the remaining three crops (i.e. cassava, edible beans and maize) and cattle raising, between 7 and 12 states accounted for 80% of the national production and cattle stock.

’Net area’ required to produce at least 80% of the estimated level of production at groups of major producing states. In Brazil, part of the area used during the cropping year is utilized more than once to grow different crops in successive months of the same period. Therefore, the ‘net area’ utilised to grow the selected crops was approximated by deducting from the total harvested area with these crops the area used by wheat and sorghum, plus the harvested area corresponding to the second crop of maize and to the second and third of edible beans.

The analysis focused also on the groups of states that were responsible for 80% of the domestic production of the selected crops and livestock raising in the 2004-08 period. Moreover, it considered two yield scenarios: one assuming a continuation of past trends (scenario one) and another reflecting the possibility of observing a higher yield scenario (scenario two).

’Net area’ required under scenario one. Under this scenario, the ’net area’ necessary to produce 80% of the total volume of production of the selected crops in the groups of major producing states should be about 50 million hectares in 2030, i.e. an increase of 13.5 million hectares above the 2006 level. This increase is mainly associated with an estimated expansion in the area of soybeans and sugar cane of 8.4 million and 5.2 million hectares respectively in the same period. Part of this expansion should be compensated by a fall in the area of rice and edible beans. However, despite experiencing a reduction in used area, the production of these crops is expected to increase substantially in the group of major producing states in the next decades. Therefore, an expansion in the area of soybeans and sugar cane during this period should not negatively affect the output of these two major food crops. The same applies to the production of the other selected crops. Thus, the threat of a food-fuel competition to food security should continue not being an issue in Brazil.

The fact that under scenario one the ‘net area’ necessary to produce the estimated volume of production of the selected crops in 2010-30 exceeds the area currently used implies a need for additional land. The question then is: from where within the major producing states considered in the analysis this area would come from? In this regard, the study assumes that the future expansion of the selected crops will take place through some dislocation of crops and significant utilisation of pasture area.

It is also expected that the conversion of low productivity pastures to soybeans and sugar cane at the expected rates would not necessarily displace beef and dairy herds from the current main producing groups of states. Several technologies are available and being developed, which can contribute to recovering pasture productive capacity, improve soil fertility and increase the stocking rates and animal productivity. Moreover, the policies that the Brazilian Government is designing to achieve the target of reducing deforestation by 80% until 2020, aim at contributing to avoid that process.

Given the above expectation, an assessment was made about the implications that the additional ’net area’ needed under the first yield scenario would have on the availability of pasture in the 18 major producing states of the selected crops during the next decades. Assuming that the additional ‘net area’ needed would come mainly from degraded pastures, the total area with planted and natural pasture in the 18 major producing states should follow a downward trend in 2006-30 reducing from 142 million hectares to 129 million. This reduction is mainly attributed to an expected expansion in the area with soybeans and sugar cane.

The outlook of the Brazilian production of beef for the next two decades indicates that the national output of this product should increase from 9.2

million metric tons of carcass equivalent (MMTCE) in 2010 to 14 MMTCE in 2030. Given this outlook, the cattle stock needed to produce the estimated levels of beef production for this period was determined through a cattle population dynamics model.

In 2030 the national beef production will be provided by a cattle stock of 249 million animals. In comparison to the existing situation in 2006, this stock represents an increase of 43 million animals. In 2006 the cattle stock located in the 18 major producing states considered in the analysis participated with approximately 92% in the total population of cattle in Brazil. Assuming that this share will remain approximately the same in the next decades, the 18 major producing states of the selected crops should contribute with 228 million animals to the domestic production of beef in 2030. The cattle stock estimated for these states, together with the pasture area that they should have after adjusting for the impact of the expected area expansion of the selected crops, results in stocking rates between 1.31 and 1.78 heads per hectare in 2010-30. The achievement of these rates during this period is feasible.

There are several facts which suggest that cattle-raising in Brazil is in a continuous intensification process, hence moving towards higher stocking rates. This trend towards raising more cattle in relatively less area is corroborated by the expansion in the production of fodder seeds as well as by the increase in the stocking rate during the 1960-2006 period.

There are at least three other elements which suggest an upward trend towards greater intensification of cattle raising in the country: (a) the Government decision to promote an increased use of integrated livestock-crop-forest systems, and the recuperation of degraded pasture as means to meeting its emission reduction targets; (b) the requirement imposed by several importers that the beef exported by Brazil should have a certificate of origin confirming that the product is not coming from a recently deforested area; and (c) a significant expansion in beef cattle feedlots.

'Net area' required under scenario two. In this case, the total 'net area' needed at the major producing states to produce the estimated level of production is expected to increase from 36.3 million hectares in 2006 to 37.6

million in 2030. The difference between these estimates, i.e. an additional 1.2 million hectares, suggests that under this scenario, the 'net area' used by the selected crops in 2006 by the 18 states would be almost sufficient to generate the volume of production estimated for 2030. In other words, substantially less pasture area would be needed to accommodate the expansion of the selected crops.

Assuming that the above would indeed be the case, the area with pasture in the 18 major producing states should fall from 142 million hectares in 2006 to 140.8 million in 2030 under scenario two as compared with 128.5 million in the case of scenario one. This relatively larger availability of pasture area under scenario two implies a lower intensification level, with stocking rates of 1.62 heads per hectare in 2030 against 1.78 heads/ha in scenario one.

In summary, yields such as the ones expected under scenario two, contribute to achieving reasonably high levels of crop production in the set of major producing states in the next 20 years without affecting negatively their biodiversity resources. In addition, they lessen the competition for land among the selected crops and put less pressure on increasing the productivity of pastures to carry the estimated cattle stocks required to supply the production of beef envisaged for 2010-30.

Meeting additional 'net area' requirements with conversion of forest areas into cropland. Despite the arguments for assuming that the additional 'net area' needed to produce the estimated level of crop production would come mainly from pasture area and land resulting from the dislocation of some crops, it is legitimate to ask what would be the implications if this assumption is relaxed. In other words, what could be the implications for society´s welfare if in addition to dislocating crops and especially degraded pasture, the additional 'net area' needed comes also from the incorporation of areas with natural cover, particularly forests?

Regarding this question the analysis indicates that the possibility that the additional 'net area' needed to produce the estimated level of crop production may also come from deforestation does not need to affect negatively society´s welfare. The impact of deforestation on society´s welfare depends on several factors such as land vocation - the use that the land will have after being deforested - and the greatest land rent that it can yield. An appropriate policy framework can help the country to assure that only 'good' deforestation, if any, happens. In addition, genetic resources preservation is ecosystem specific and not site specific. Thus, to ensure the preservation of these resources it is not feasible simply to preserve any piece of forest ecosystem regardless of the level of use it has had or its size.

Trade-off between agricultural production expansion and environment quality. The perspective for the next 20 years is that national agricultural production should continue to grow at high rates, placing Brazil in a more notable position in terms of world supply of food, fibres and biofuel feedstocks. This perspective poses several questions: among them, what implication would it bring to the trade-off between production expansion and environment quality?

The response to this complex question is not obvious. It involves the interaction of several elements, including the environmental sustainability nature of agricultural technologies and the orientation of public policies and programmes. Nevertheless, in Brazil there is a growing trend towards the use of environmentally friendly technologies (e.g. zero-tillage, integrated crop-livestock systems and genetically modified crops) and the adoption of policies and programmes (e.g. National Policy on Climate Change, Agro-ecological Zoning for Sugar Cane Production, Low-Carbon Agriculture Programme and Stimulus Programme for Sustainable Agricultural Production) with positive contribution to environmental sustainability. The extension of this trend into the next decades, together with the growing requirements of the Brazilian environmental legislation, should contribute to expand crop and livestock production with reduced pressure on environment quality loss.

Impacts of climate change on the estimated harvested area of the selected crops under yield scenarios one and two. Agricultural production and food security may be severely affected if nothing is done to change the trend towards a global warming. Assuming that despite this warning no actions are taken, the study assessed the impacts which temperature levels expected by scenario A2 of IPCC could have on the estimated harvested area and volume of production.

Under yield scenario one, the impact of a climate change would be to reduce the harvested area with grains[1] by a total of 2.3 million hectares between 2010 and 2030. Fifty four per cent of this reduction would come from reductions in the harvested area with soybeans, 36% from wheat and the rest from the remaining grains considered. Coffee would register a total harvested area loss of 509,000 thousand hectares during that same period, and sugar cane and cassava would experience accumulated increases of 103,000 and 107,000 hectares respectively. Therefore, while wheat and coffee would be the crops most affected by the climate change in terms of reductions on their respective harvested areas, soybeans would be the crop contributing more to the total reduction in the harvested area with grains.

As expected, under yield scenario two the impacts of climate change on harvested area are relatively smaller than those obtained under yield scenario one. Nevertheless, the effects are still quite substantial in the case of wheat, coffee, soybeans and cassava. Under this scenario, the impact of the climate change would be to reduce the harvested area with wheat by 40% during the 2010-30 period compared to 42% if yield scenario one is considered. A similar result is observed in the case of coffee (i.e. an aggregated reduction of 27% and 29% respectively by 2030, under yield scenario two and one) as well as with all other selected crops.

Impacts of climate change on the estimated production level of the selected crops, 2010-30. Besides examining the impacts of climate change on harvested area, an analysis was also carried out to assess the effects which this phenomenon could have on the estimated production of the selected crops in the groups of major producing states.

Mirroring the estimated impacts of the climate change on harvested area, a gradual rise in world average temperatures could reduce substantially the production of several selected crops in the next two decades. Wheat and

[1] The set of grains considered here comprise soybeans, rice, maize, edible beans, cotton and sorghum.

coffee could accumulate aggregated losses in production of 48% and 35% respectively, in the major producing states by 2030 in comparison to 2010. Soybeans, in turn, could experience an accumulated loss of 3.6 million tons by the end of the 2010-30 period. Compared with the estimated production for 2010, this reduction corresponds approximately to 7%.

In contrast to the above, the impact of the climate change on the estimated production of rice and beans in the respective groups of major producing states would be relatively smaller – i.e. an accumulated reduction of about 3.5% by 2030 in both cases. The groups of the major producing states of cotton, maize and sorghum could have their respective levels of production reduced by an accumulated amount of less than 2% at the end of the next two decades in comparison to 2010.

The production of cassava and sugar cane could increase during the next two decades in the respective groups of major producing states. The production of cassava could accumulate a total increase of 7.4% by 2030 vis-à-vis the 2010 level. Sugar cane production in turn is estimated to experience an aggregated increase of 1.5% during the same time period.

Further to the above assessment, the economic impact of the climate change on the production of the selected crops coming from the groups of major producing states was also quantified.

In comparison to the respective base-year figures, wheat and coffee are the crops which would suffer the most with a climate change in terms of value of production. Wheat production in the two major producing states, Rio Grande do Sul and Paraná, could accumulate a total loss of US$ 334 million by the end of the 2010-30 period. This economic loss corresponds to 48% of the estimated value of production of this crop in 2010. Regarding coffee, the accumulated loss during that same period would be US$ 820 million, i.e. 35% of the estimated value of production in the base year. Soybeans would be the third most affected crop in economic terms by the climate change. The value of production in the five major producing states of this crop would register a total accumulated loss of US$ 1.5 billion between 2010 and 2030.

Taking all the selected crops together, the economic impact of the climate change on the respective groups of major producing states during the 2010-30 period would be an accumulated reduction of about US$ 3 billion in the value of production of these crops. About half of this economic loss would come from a reduction in the value of soybean production, 27% from coffee, 11% from wheat and the remaining 13% from rice, maize, cotton, edible beans and sorghum.

The climate change could also produce a positive impact, expanding the harvested area with cassava and sugar cane as well as the value of production of these crops by US$ 367 million during that same period. Therefore, the net impact of a rise in the world average temperatures assumed in IPCC´s A2 scenario would be an aggregated loss of US$ 2.6 billion during the next two decades. This loss corresponds to approximately 5% of the total value of production of the selected crops in the base year.

Prospects for expanded irrigated agriculture. The potential for the development of sustainable irrigated agriculture in Brazil is approximately 29 million hectares (Christofidis, 2002). The states with the highest potential for sustainable development of irrigation are Tocantins, Amazonas, Pará, Mato Grosso, Minas Gerais, Rio Grande do Sul, Roraima, São Paulo, Paraná and Goiás. Among these states, the growth of irrigated agriculture should be more significant in the agricultural frontier of Mato Grosso and the states of Minas Gerais, Bahia, Tocantins, Roraima, and the South of Maranhão and Piauí, depending on road improvement and energy storage in these regions (Telles and Domingues, 2006).

Regarding the future use of irrigation by specific crops, Domingues and Gisler (2009) estimated that the expansion of sugar cane cultivation in the next years should require substantial amounts of water for irrigation in the states of Goiás, Mato Grosso and Tocantins. According to these authors, in the next 10 years sugar cane will displace rice as the crop with the largest requirement of water resources in the country.

Projecting the growth of irrigated areas is a complex task. Despite this difficulty, Telles and Domingues (2006) estimated that the total irrigated area in the country should be between 4.4 million and 5.2 million hectares in 2020. However, if the growth rate registered between the 1996 and 2006 Agricultural Census (i.e. 1.8 million hectares per year) is observed in the next years, the irrigated area in Brazil could exceed 6 million hectares by 2020.

Conclusions. The long-term perspective of Brazil´s agricultural productive capacity is quite positive. The production of the selected crops and beef cattle should increase substantially in the major producing states during the next 20 years without putting strong pressure on land expansion, threatening environmental sustainability and enhancing the loss of biodiversity resources.

The outlook of the domestic production of these products points out in the direction of major increases throughout this period, reaching output levels of grains, sugar cane, coffee and beef substantially higher in 2030 than the 2007-2009 average (i.e. between 47% and 68% depending on which of these products). Moreover, it signals that, with the exception of wheat, the growing domestic consumption of these products should be more than met by the expected levels of production. The attendant excess production should enable the country to continue playing a major role in the international markets of soybeans, sugar, coffee, cotton and beef.

A noteworthy aspect behind this performance is that, under a scenario of continued past yield trends, the total 'net area' needed to produce the estimated volume of production of the selected crops in 2010-30 should grow at an annual average rate much lower than that observed in 2000-09, i.e. 1.1% compared with 3.3%, respectively.

The perspective for growing production levels with lower pressure on land expansion, greater environmental sustainability and limited biodiversity loss is further reinforced by several aspects including the possibility for the materialization of a higher crop yield scenario. The total 'net area' needed to produce the estimated volume of production for the selected crops in the set of 18 states in 2030 should be 50 million hectares and 37.5 million hectares respectively, under yield scenarios one and two. The difference between these estimates highlights the sparing-land effect of higher yields.

The analysis carried out here turns on the yellow light concerning the negative impacts that an eventual increase in world temperatures may have on three important crops to Brazil's domestic consumption and foreign trade (wheat, coffee and soybeans). However, this alert is not a reason for alarm. There are various mitigating measures which the countries are taking in order to reduce global warming in the next years. In addition, Brazilian researchers have been developing technologies which enable the adaptation of crops to higher temperatures. These initiatives, together with the proven capacity of man to overcome major challenges, give us an optimistic view of the future, but without lowering the guard in relation to the need to continue strengthening the ongoing efforts.

In summary, Brazil faces a positive perspective regarding the productive capacity of its agricultural sector. The transformation of this perspective into reality however, depends on various factors, some of which can be influenced by public policies, others not. Thus, it is essential that the Government ensures a continued economic stabilisation of the economy, adopts sound macroeconomic and agricultural policies, and succeed in its efforts to reduce the domestic interest rates paid by producers and consumers. Moreover, it is indispensable to further enhance investments on agricultural research and infrastructure development, simplify export procedures, find a solution to the rural credit indebtedness faced by a large number of national farmers, and expand the domestic output of potassium and phosphate for fertiliser production. Above all these elements, it is fundamental that the Government maintains a strong political will to take timely the measures required for a sustained growth of agriculture and the economy.

Productive capacity of Brazilian agriculture: a long-term perspective[2]

1. Introduction

There is a major concern among governments, international organisations, researchers and civil society on how the world population can be fed by the middle of this century. This concern involves at least two aspects: the effort that is needed to supply the quantity required; and how this production will be achieved, i.e. if using the available resources in a sustainable manner, preserving the biodiversity and avoiding further deterioration of the environment.

The underlying factors behind the above concern include, among others: the perspective that the world population will increase by 2.5 billion people in the next years, reaching 9.2 billion inhabitants in 2050; the expectation that this increase will further intensify the level of urbanisation and, hence, the changes in consumption pattern; the projections that per capita income in most countries will improve significantly in the next years, and world prices of agricultural products will continue to follow the historic trend observed previously to the 2006-08 price peak; the perception that energy and agricultural markets are becoming more closely linked and further growth in biofuel production is in prospect; and the gradual slowing down of crop yield growth around the world in relation to the rate of food demand growth.

[2] This study has been commissioned as part of UK Government´s Foresight Food and Farming Futures Project. It was prepared by a team of professionals from Embrapa comprising Carlos A. M. Santana (team leader), Danielle A.P. Torres, Rosana do Carmo N. Guiducci, Maria Abadia da Silva Alves, Fernando Luís Garagorry, Geraldo da Silva e Souza, Eduardo Delgado Assad, Giampaolo Q. Pellegrino, Luiz Gustavo Barioni, Mirian Oliveira de Souza, Homero Chaib Filho, Renner Marra and Mierson M. Mota. The study team is grateful to both the Foresight Food and Farming Futures Project and Embrapa for the opportunity to contribute to this project. The team is thankful also to Embrapa's research centres directly related to the products considered in the study for the substantial technical inputs provided. The views expressed do not represent the policy of any Government or organisation.

Brazil is globally important for both food security and environmental sustainability. It meets most of its domestic demand of agricultural products, plays a major role in the international commodity markets, provides vital environmental services to the world and has a large availability of land, water and top agricultural technology.

The growth of agricultural production in the country traditionally has more than exceeded the increase of the national population. The index of agricultural production followed an upward trend increasing from 100 in 1975 to about 360 in 2008, while the index of the national population changed from 100 to approximately 170 during the same period (Barros, 2010). In 2008 the country became the third largest world exporter of agricultural products after the United States and the European Union, exporting US$ 61.4 billion. Brazil, with its several biomes, is notable for having the largest biodiversity reserves in the world. These resources provide important environmental services to the country and to the planet, such as the maintenance of biological diversity and carbon stocks. Therefore, the proper use and protection of this biodiversity is essential for present and future generations.

Given the above aspects, the overall objective of this paper is to contribute to developing an approximate view of the productive capacity of the Brazilian agriculture to meet the national requirements and contribute to the world supply of food, fibres and biofuel by 2030[3]. More specifically, it will address the following questions: (a) What is the outlook for Brazil´s agricultural production, harvested area, consumption and trade of main crops in the next 20 years? (b)How did agricultural production move spatially in the Brazilian territory during the 1978-2008 period? (c) Where should most of the expected production take place and how much land will be necessary to produce sustainably the estimated levels of production without affecting negatively the biodiversity? (d) What could be the impact of climate change on the estimated harvested area and production of major producing states? (e) What are the prospects to expand agricultural production via greater utilisation of irrigation?

[3] The data available is not sufficiently large to obtain reasonable estimates for a long period through the method used here. In addition, the confidence intervals become larger with time. Therefore, the analysis is carried out until 2030.

(f) What implications does the productive capacity of the country bring to Brazil´s public policy, technology generation and investments to enhance agricultural productivity and sustainable production in the medium and long term?

In line with these questions, the study is organised as follows. The next two chapters summarise the recent evolution of the national production, harvested area, consumption and trade of selected agricultural products, and present an outlook for the levels they could achieve during the 2010-30 period. Chapter four analyses the historical trends and perspectives of agricultural production by main groups of producers. Chapter five provides a picture of the dynamics of agricultural production since the end of the 1970s until 2008, and suggests where approximately 80% of the production of ten selected crops[4] is expected to take place in the next 20 years. Building on this analysis, Chapter six estimates the area and production of the selected crops which would be harvested and supplied by the respective groups of major producing states. Chapter seven addresses the trade-off between production expansion and environment quality and Chapter eight assesses the impact which a rise on world average temperatures could have on the estimated harvested area and production obtained in Chapter six. Following this assessment, Chapter nine examines the current situation of agricultural irrigation in the country and addresses the perspective of expanding crop production through its use. Finally, the last chapter draws some conclusions based on these analyses.

2. Recent evolution of production, consumption and trade of selected agricultural products

[4] These products are: maize, soybeans, rice, wheat, edible beans, cassava, sugar cane, sorghum, coffee and cotton. The selection criteria behind this group of products are presented in Chapter 2.

Brazil produces a large number of agricultural products; among them, several are distinguished for their large share in total agricultural production and harvested area of the country. They are also notable for their great importance in terms of participation in the national diet, contribution to the trade balance and production of biofuels, fibres and animal feed. These products, which together contributed approximately 90% of the harvested area and production of temporary and permanent crops in the 2004-08 period are: rice, wheat, edible beans, cassava, cotton, soybeans, maize, sugar cane, sorghum and coffee. They were, therefore, selected to be considered in this study. In addition, in view of its great importance in terms of participation in the group of main products consumed by the national population and the contribution it makes to Brazil´s agricultural trade balance, beef production, consumption and trade is also included in the study.

According to Table 1, in the last three decades the domestic production of the selected crops expanded substantially, placing Brazil among the ten top world producers of rice, soybeans, sugar cane, maize, coffee, cotton, cassava and sorghum. Examining the data provided in this table, it can be observed that with the exception of soybeans and sugar cane, the main factor behind the production growth of the selected products was yield increase vis-à-vis area expansion. However, all selected crops have experienced substantial increase in yield. Currently, Brazil is among the main producing countries[5] with the highest yield level of soybeans, cotton, sorghum, coffee and maize. In addition, it is also noteworthy that in the case of rice, cotton, cassava and edible beans the level of production increased significantly while the harvested area fell.

Table 1: Brazil: production, harvested area, yield, consumption and trade – selected agricultural products, 1978 - 2008

[5] The group of countries which together are responsible for 80% of the world production of the products under consideration.

Products	1978	1988	1998	2008
Cassava				
Production (ton)	25,459,408	21,673,849	19,502,717	26,703,039
Harvested area (ha)	2,148,707	1,752,026	1,578,879	1,888,859
Yield (kg/ha)	11,849	12,371	12,352	14,137
Coffee				
Production (ton)	1,267,662	1,368,830	1,689,366	2,796,927
Harvested area (ha)	2,183,673	2,975,245	2,070,409	2,222,224
Yield (kg/ha)	581	460	816	1,259
Consumption (ton)	n.a.	348,419	732,000	1,059,600
Exports (ton)	621,301	904,357	995,833	1,566,921
Cotton				
Production (ton)	1,108,396	2,435,487	1,172,017	3,983,181
Harvested area (ha)	1,471,092	1,822,868	825,029	1,063,817
Yield (kg/ha)	753	1,336	1,421	3,744
Consumption (ton)	n.a.	838,000	782,900	1,009,200
Exports (ton)	n.a.	35,000	3,100	532,900
Edible beans				
Production (ton)	2,193,977	2,808,639	2,191,153	3,461,194
Harvested area (ha)	4,617,259	5,781,248	3,313,621	3,781,908
Yield (kg/ha)	475	486	661	915
Consumption (ton)	n.a.	2,600,000	2,500,000	3,650,000
Imports (ton)	n.a.	10,000	211,300	209,700
Maize				
Production (ton)	13,569,401	24,748,036	29,601,753	58,933,347

Harvested area (ha)	11,124,827	13,169,003	10,585,498	14,444,582
Yield (kg/ha)	1,220	1,879	2,796	4,080
Consumption (ton)	15,028,500	25,320,000	35,000,000	44,500,000
Exports (ton)	21,485	740	1,783	6,370,665
Rice				
Production (ton)	7,296,142	11,809,467	7,716,090	12,061,465
Harvested area (ha)	5,623,515	5,959,100	3,062,195	2,850,670
Yield (kg/ha)	1,297	1,982	2,520	4,231
Consumption (ton)	n.a.	10,500,000	11,750,000	12,800,000
Imports (ton)	n.a.	190,000	2,009,000	589,900
Sorghum				
Production (ton)	227,502	302,001	589,827	2,004,005
Harvested area (ha)	104,361	195,427	349,547	844,662
Yield (kg/ha)	2,180	1,545	1,687	2,373
Soybeans				
Production (ton)	9,540,577	18,016,170	31,307,440	59,242,480
Harvested area (ha)	7,782,187	10,519,972	13,303,656	21,057,302
Yield (kg/ha)	1,226	1,713	2,353	2,813
Consumption (ton)	n.a.	14,626,000	22,400,000	34,750,000
Exports (ton)	658,527	2,597,364	9,189,576	24,493,693
Sugar cane				
Production (ton) – (1)	129,144,950	258,412,865	345,254,972	645,300,182
Harvested area (ha) – (1)	2,391,455	4,117,375	4,985,819	8,140,089
Yield (kg/ha)	54,003	62,762	69,247	79,274
Sugar consumption (ton)	n.a.	n.a.	9,150,000	11,400,000

Sugar exports (ton)	1,347,416	2,575,289	8,371,312	19,472,458
Wheat				
Production (ton)	2,690,888	5,737,971	2,269,847	6,027,131
Harvested area (ha)	2,811,189	3,467,556	1,408,852	2,363,893
Yield (kg/ha)	957	1,655	1,611	2,550
Consumption (ton)	n.a.	n.a.	8,367,000	9,418,000
Imports (ton)	4,334,832	941,273	6,395,200	6,032,691
Beef (equivalent carcass)				
Production (ton)	n.a.	3,993,500	5,794,300	8,834,100
Consumption (ton)	n.a.	3,716,300	5,513,100	6,944,600
Exports (ton)	n.a.	302,200	382,600	1,919,500

Sources: selected crops - IBGE for production, harvested area and yield; CONAB for consumption and trade;

Beef - data from CONAB. n.a. = not available

(1) Refer to sugar cane used in the production of sugar, ethanol and other uses (e.g. production of fodder and brandy).

Table 1 also shows that the domestic consumption of the selected crops and sugar expanded significantly in the last decades reaching very high levels in 2008. The increase in the consumption of soybeans, maize and sorghum is due largely to the expansion in the local livestock and oilseed industries. On the other hand, the main factors behind the expansion in the consumption of the other products include population growth, economic stability and relatively higher income levels, especially of less favourable income groups.

In addition to meeting the growth in the domestic consumption, the expansion in the production of the above-mentioned products enabled Brazil to increase further its participation in the export market during the 1978-2008 period. According to the USDA, in 2008 Brazil was the leading exporter of coffee, the number two foreign seller of soybeans seed, and a major participant in the largest five export group of maize, cotton and sorghum. The country, however, is not self-sufficient in wheat, rice and edible beans; rather, it has relied on the international market to meet part of its domestic requirements (Table 1). Among these products, wheat is notable for the large quantities imported by Brazil. Despite following a downward trend in 1998-2008, the imports of this product reached 6 million tons at the end of this period, keeping the country among the two largest importers in the world.

The Brazilian production, consumption and exports of beef have also grown remarkably in the last decades. Beef production jumped from 4 million tons equivalent carcass in 1988 to 8.8 million tons in 2008; several factors contributed to this expansion including: major technological developments (e.g. introduction of new fodder cultivars, better herd management systems, artificial insemination and improved sanitary measures); economic stabilisation of the national economy; greater availability of certified fodder seeds and good marketing opportunities. This expansion enabled the local consumption and exports of this product to record similar performance during the same period: domestic consumption increased from 3.7 million to 6.9 million tons equivalent carcass and exports grew from 302,000 to 1.9 million tons.

3. Outlook for Brazil´s production, harvested area, consumption and trade of selected agricultural products, 2010-30[6]

Looking towards the future, it is assumed that the past will largely shape the prospects of Brazil´s agricultural sector structure and performance in the next two decades. In this regard, the context which is expected to influence future developments is as follows: global economic growth will continue to recover in the next years; world population growth should follow a downward trend in the next decades reaching approximately 8 billion people in 2030 (United Nations,

[6] This chapter was developed by Carlos A. M. Santana, Geraldo da Silva e Souza and Mirian Oliveira de Souza.

2009). In the specific case of Brazil, there is also expected to be a relatively lower rate of population growth during 2010-2030, and a population of about 216 million people at the end of this period (IBGE, 2008).

Given the results of major long-run projections, most commodity prices are expected to remain at or above the 1997-2006 level (OECD/FAO, 2009; and USDA, 2010). Crop yield and livestock productivity will, in general, continue to increase at long-term trends. In addition, a higher crop yield scenario is also considered, in order to take into account the perspective of a wider use of better technologies available to farmers. Agricultural and trade policies in Brazil and in major agricultural producers and importing countries should not suffer drastic changes. Similarly, there should be no major shocks affecting world agricultural supply and demand. Average weather conditions should predominate.

Considering the above contextual aspects, an outlook for Brazil´s agricultural production, harvested area, consumption and trade of the selected crops was established for the period 2010-30. Specifically, a non-causal forecasting method consisting of univariate time series models was used (i.e. Statespace, Box & Jenkins [Arima] and Exponential Smoothness).

The reasons for using this method instead of partial equilibrium models included the difficulty of predicting the evolution of key macroeconomic variables like per capita income, inflation, interest rates and exchange rates far into the future. Moreover, in the specific case of Brazil, the existing partial equilibrium models are rarely supported by the national data; elasticities are computed elsewhere and freely used to specify equations (Souza *et al.*, 2008). In this regard, a detailed analysis carried out by Gazzola *et al.* (2006) of OECD/FAO´s Outlook 2006-15 for the meat market showed that elasticities estimated from regressions differ markedly from the ones used in the specification of the meat market models. These authors also observed that there were frequent sign inversions, indicating probable specification errors.

Given the above, univariate time series models were identified and estimated through SAS software procedures for each of the selected crops and variables. The selection of the most appropriate model was based on statistical tests, analysis of how well the model fitted to the observations, coherence of the results obtained, growth potential, and consultation of specialists. In addition, the general approach followed was to choose models which provided more conservative (lower) estimates.

The outlook for each of the above-mentioned variables was constructed based on single time series. Attempts were made to obtain estimates for more than one variable simultaneously; nevertheless, due to estimation problems univariate models were employed. The data used to obtain the estimates for crop production and harvested area of the selected crops consisted of 34 annual observations (1975-2008). Similarly, relatively long time series[7] were utilised in establishing the outlook for imports and exports. However, due to limited data availability, the estimates for domestic consumption were based on a smaller number of observations (between 16 and 31 depending on the crop).

The same method as the one indicated above was employed by Brazil´s Ministry of Agriculture, Livestock and Supply (MAPA) when carrying out its recent 'Projeções do Agronegócio: Brasil 2009-10 to 2019-20' (Projections of Brazilian Agribusiness for the period 2009-10-2019-20). The products considered in the Ministry´s analysis includes nine of the eleven covered in this study[8]. The estimates provided by MAPA are in general, similar to those obtained here (Table 2). Regarding the present study, it should be noted that the estimates reported in this table are not a forecast about the future; rather they are an outlook of what could be expected given past historical trends and the expectation of researchers.

Given the above understanding, the estimates presented in Table 2 show that the domestic production of the selected products should continue to grow in the next 20 years, especially coffee, sugar cane, soybeans, sorghum and beef cattle. The production of these products, taken individually, is expected to increase at annual average growth rates above 1.9% during the 2010-30

[7] Between 25 and 49 observations.

[8] These products are: cotton, rice, edible beans, maize, wheat, cassava, soybeans, coffee and beef cattle. In addition to these products the Ministry´s document covers also the following products: soybean meal and oil, potato, milk, ethanol, orange and orange juice, tobacco, cellulose, poultry and pork meat.

period. In this context, in 2030 the supply of coffee[9] should be 4.3 million tons, sugar cane and soybeans would reach respectively 1,051 million and 101 million tons, and beef production would total approximately 14 million tons equivalent carcass.

The production of rice, cotton and maize should also grow in the period of analysis;, however, at annual average growth rates lower than those expected for the previous group of crops[10]. Rice output should expand from 13 million tons in 2010 to 18 million in 2030 while that of maize would increase from 56 million to 77 million tons. Cotton production is expected to be about 5 million tons at the end of this period vis-à-vis 3.8 million in 2010.

Table 2: Outlook - Brazil: production, harvested area, yield, consumption and trade of selected crops, 2010-30

Products	2010	2015	2020	2025	2030
Cassava					
Production (ton)	27,139,440	28,230,444	29,321,448	30,412,451	31,503,455
Harvested area (ha)	1,894,972	1,910,255	1,925,538	1,940,821	1,956,104
Yield (kg/ha)	14,322	14,778	15,228	15,670	16,105
Coffee					
Production (ton)	2,758,697	2,869,368	3,375,966	3,738,888	4,258,702
Harvested area (ha)	2,218,909	2,210,622	2,202,334	2,194,047	2,185,759
Yield (kg/ha)	1,243	1,298	1,533	1,704	1,948
Consumption (ton)	1,133,567	1,249,941	1,361,938	1,473,908	1,585,877

[9] The Brazilian production of coffee presents a bi-annual pattern in the sense that a good production year is immediately followed by a poor one. This characteristic brings serious difficulties to outlook construction through time series analysis. Given this difficulty, the outlook for coffee production presented in this study was obtained by estimating the expected yield of this product at national level for the period 2010-30 and multiplying it by the estimated harvested area.
[10] Specifically, cotton production would grow at 1.4% per year and rice and maize at 1.7%.

Exports (ton)	1,630,070	1,701,256	1,766,254	1,831,298	1,896,341
Cotton					
Production (ton)	3,808,850	3,651,767	4,435,887	4,413,051	4,901,924
Harvested area (ha)	1,035,761	921,804	1,039,407	959,873	989,718
Yield (kg/ha)	3,677	3,962	4,268	4,598	4,953
Consumption (ton)	987,335	1,066,536	1,146,362	1,220,198	1,293,853
Exports (ton)	482,700	659,823	751,965	838,553	933,563
Edible beans					
Production (ton)	3,379,825	3,678,867	3,871,827	4,058,366	4,256,742
Harvested area (ha)	3,759,750	3,706,582	3,653,815	3,601,033	3,548,251
Yield (kg/ha)	899	993	1,060	1,127	1,200
Consumption (ton)	3,723,706	3,964,008	4,209,292	4,454,520	4,699,748
Imports (ton)	221,836	252,175	282,514	312,854	343,193
Maize					
Production (ton)	55,586,945	60,259,219	65,747,311	71,230,705	76,714,127
Harvested area (ha)	13,928,794	14,198,774	14,612,101	15,023,704	15,435,328
Yield (kg/ha)	3,991	4,244	4,500	4,741	4,970
Consumption (ton)	46,507,726	51,426,355	56,344,984	61,263,613	66,182,242
Exports (ton)	7,451,341	8,383,391	9,315,440	10,247,490	11,179,539
Rice					
Production (ton)	12,577,080	13,866,117	15,155,154	16,444,192	17,733,229
Harvested area (ha)	2,728,899	2,424,451	2,120,003	1,815,555	1,511,107
Yield (kg/ha)	4,609	5,719	7,149	9,057	11,735
Consumption (ton)	13,104,483	13,865,690	14,626,897	15,388,103	16,149,310
Imports (ton)	831,571	731,085	728,260	717,085	706,585

Sorghum					
Production (ton)	2,133,804	2,458,303	2,782,802	3,107,300	3,431,799
Harvested area (ha)	897,969	1,031,235	1,164,502	1,297,769	1,431,036
Yield (kg/ha)	2,376	2,384	2,390	2,394	2,398
Soybeans					
Production (ton)	67,791,589	76,062,815	84,334,041	92,605,267	100,876,493
Harvested area (ha)	24,364,032	26,223,104	28,619,121	31,122,566	33,644,408
Yield (kg/ha)	2,782	2,901	2,947	2,976	2,998
Consumption (ton)	31,931,217	35,837,304	39,743,391	43,649,478	47,555,565
Exports (ton)	29,591,903	34,811,989	40,032,074	45,252,159	50,472,245
Sugar cane					
Production (ton) – (1)	711,598,008	799,115,843	883,032,569	966,938,002	1,050,843,399
Harvested area (ha) – (1)	8,927,911	9,920,790	10,856,078	11,791,059	12,726,038
Yield (ton/ha)	79,7	80,5	81,3	82,0	82,6
Sugar consumption (ton)	12,350,678	13,620,565	14,890,453	16,160,340	17,430,228
Sugar exports (ton)	23,626,145	26,267,065	28,667,269	31,067,785	33,468,300
Wheat					
Production (ton)	6,030,527	6,311,865	6,646,633	6,928,722	7,165,875
Harvested area (ha)	2,329,492	2,243,490	2,157,488	2,071,485	1,985,483
Yield (kg/ha)	2,589	2,813	3,081	3,345	3,609
Consumption (ton)	10,631,200	11,472,200	12,313,200	13,154,200	13,995,200
Imports (ton)	5,519,744	5,890,448	6,261,153	6,631,857	7,002,562
Beef (equivalent carcass)	9,298,000	10,456,000	11,615,000	12,773,000	13,932,000

Production (ton)	7,275,000	8,101,000	8,927,000	9,753,000	10,579,000
Consumption (ton)	1,902,000	2,205,000	2,518,000	2,831,000	3,144,000
Exports (ton)					

Source: estimated by study team.

(1) Refer to sugar cane used in the production of sugar, ethanol and other uses (e.g. production of fodder and brandy).

The outlook for harvested area suggests that the total area harvested with the selected crops should expand approximately 13 million hectares between 2010 and 2030, increasing from 62 million to 75 million hectares[11]. This expansion is associated with a significant boost in the harvested area with sugar cane, soybeans and sorghum, a moderate increase in the area of maize, and a fall in the area of rice and wheat. The harvested area with cotton, coffee, edible beans and cassava is expected to remain roughly unchanged, experiencing annual average growth rates between -0.3% and 0.2%, depending on the crop.

Given the outlooks for the production and harvested area of the selected crops, the yields obtained dividing the production and the harvested area estimates show that yield increase should play a major role in the future expansion of rice and coffee production. This is because the yield increase is estimated to more than compensate the expected change in the harvested areas of these crops.

The estimated yields also indicate that, unless the future yields of soybeans, sugar cane, sorghum and cassava increase more than is suggested by historical trend, the production growth of these crops will be determined mainly by area expansion in the next decades. Regarding wheat, cotton, edible beans and maize, the yield level implied by the outlooks for production and harvested area of these crops is estimated to increase at moderate annual average growth rates in 2010-30, i.e. 1.1% to 1.7% per year.

[11] As will be discussed later, in Brazil part of the area cultivated is utilised more than once during the same cropping year (multiple-cropping). Therefore, these estimates are measures of land use and not of the geographical area needed to cultivate the selected crops.

According to Table 2, the future domestic consumption of soybeans, maize, sugar, coffee and beef is expected to increase substantially in the next decades. Specifically, the annual average growth rate of consumption of these products is estimated to be between 1.7% and 2% per year depending on the product. The national consumption of rice, wheat, edible beans and cotton is also expected to expand in 2010-30. However, due in part to the low income elasticity of demand for these products, especially of the first three, their estimated increase should be lower than those of the previous group of products.

The Brazilian contribution to world markets of soybeans, sugar, coffee, cotton, maize and beef is expected to remain quite significant in the next decades. Between 2010 and 2030 the exports of soybeans and beef should increase approximately 70% and 65% respectively. The first would expand from 29.6 million tons to 50.5 million and the second from 1.9 million to 3.1 million tons. Cotton exports should almost double during this period and the foreign sales of maize should increase approximately 50%. The exports of sugar are estimated to expand at an annual average growth rate of 1.7% in 2010-30, reaching 33.5 million tons at the end of the period. In contrast to the above commodities, the outlook for coffee exports suggests a moderate expansion in the next 20 years. The exports of this product are estimated to increase from 1.6 million tons to 1.9 million during this period.

The long-term prospects for Brazil´s imports of rice, wheat and edible beans, as defined by the respective outlooks, are that the country should continue relying on the international market to meet part of the domestic requirements of these products, especially wheat. The imports of this product are estimated to increase 27% between 2010 and 2030, resulting in foreign purchases of 7 million tons in the last year of this period. Edible beans imports are expected to expand at an annual average growth rate higher than wheat (i.e. 2.2% vis-à-vis 1.2%), achieving an import level of 343,000 tons in 2030. The estimates for rice imports are that they should fall sustainably from 832,000 tons in 2010 to 707,000 in 2030.

4. Agricultural production by main classes of producers: historical trend and perspectives[12]

Agricultural production in Brazil comes from the activities of three main classes of producers: i.e. small, medium and large, defined according to specific levels of annual production (Table 3). The first of these classes comprises a very large number of producers with low levels of production per year. The group of large producers consists of a smaller number of producers with high levels of annual output. The class of medium producers, in turn, has number of farmers and level of production between those of the other two classes.

Table 3: Main classes of agricultural producers according to specific levels of annual production

Classes of producers	**Coffee ton/year**	**Edible beans ton/year**	**Maize ton/year**	**Milk litres/year**	**Rice ton/year**
Small	(0 to 5,000]	(0 to 5]	(0 to 20]	(0 to 18,000]	(5 to 10]
Medium	(5,000 to 15,000]	(5 to 30]	(20 to 200]	(18,000 to 72,000]	(10 to 200]
Large	> 15,000	> 30	> 200	> 72,000	> 200

Source: Defined by the study team

Given the above characteristic and looking towards the next 20 years, what is the perspective with regard to the contribution of these different classes of producers to agricultural production? Would there be major changes in their relative shares? What implications could this bring, if any? How could they be dealt with in order to overcome attendant challenges?

[12] The development of this Chapter is based largely on a substantial contribution made by Eliseu R. de Andrade Alves. The analysis carried out here does not cover all the selected products considered in the study. However, the results obtained provide a general picture regarding the changes that have been observed in the participation of the different groups of producers in the total number of farms and aggregate production of almost all major agricultural products in Brazil.

As discussed below, the total number of farms corresponding to the three classes of producers has been falling through time. Moreover, the share of the respective classes of producers in the total production of specific agricultural activities has been changing towards a greater participation of the class of large producers. Therefore, as a result of this process, agricultural production has been concentrating significantly in this class of producers[13].

According to the 2006 Agricultural Census, approximately 8% of the total number of reported farms with monthly value of production above ten minimum wages (i.e. R$ 3,500[14]) were responsible for 85% of the aggregated value of agricultural production in that year. A similar concentration trend to this one is also observed when examining the participation of the main classes of producers in both level of production and total number of farms producing rice, edible beans, maize, coffee and milk during the 1995-2006 period.

As presented in Table 4, the total number of rice-producing farms reported by the 1995-96 and 2006 Agricultural Census fell 57% during this period dropping from 928,000 to 397,000. This reduction resulted mainly from the decrease in the number of farms managed by small producers. The number of rice-cultivating farms run by medium and large producers increased respectively, by 12% and 20% between 1995-96 and 2006. Given these changes, the share of the class of small producers in the total production of rice fell from 17% in 1995-96 to 5% in 2006 while that of the large producers increased from 66% to 73%.

A similar picture to the one above has also been observed in the production of maize and edible beans. The total number of maize-producing farms fell from 2.5 million in 1995-96 to 2 million in 2006 and those cultivating edible beans dropped from 2.1 million to 1.5 million. As in the case of rice, the main factor behind this change was the reduction in the number of maize (538,000) and edible beans (625,000) producing farms operated by small producers.

[13] As highlighted earlier, the definition of the different classes of producers used here is based on level of production. Therefore, the output produced by these classes can come from different sizes of cultivated area.

[14] Considering an exchange rate of R$1.7 per US Dollar this value corresponds to US$2,059.

The number of farms managed by medium and large producers of these crops increased significantly especially the latter. This resulted in a boost in the participation of the large producers´ class in the total output of maize between 1995-96 and 2006, i.e. an expansion from 48% to 68%. Regarding edible beans, the observed increase in the share of this same class of producers was a rise from 24% in 1995-96 to 57% in 2006. The participation of the small producers´ class growing maize and edible beans in the total output of these crops fell substantially during this period dropping from 25% to 10% and from 57% to 19%, respectively.

Table 4: Participation of the different classes of producers in both total production of selected crops and number of farms reported in the 1995-96 and 2006 Agricultural Censuses

Class of Producers	1995-96 Agricultural Census			2006 Agricultural Census		
	Number of farms	Share in the total number of farms (%)	Share in total production (%)	Number of farms	Share in the total number of farms (%)	Share in total production (%)
Coffee						
Small	236,136	74.4	10	123,360	69.1	9.7
Medium	48,416	15.2	15	33,399	18.7	15.7
Large	33,016	10.4	75	21,700	12.2	74.6
Total	317,568	100	100	178,459	100	100
Edible beans						
Small	2,093,943	97.9	56.56	1,436,518	94.9	18.6
Medium	39,778	1.9	19.26	60,202	4.0	24.1
Large	4,053	0.2	24.18	16,555	1.1	57.3

Total	2,137,774	100	100	1,513,275	100	100
Maize						
Small	2,384,595	93.9	24.8	1,847,052	91.0	10.0
Medium	139,303	5.5	27.6	150,984	7.4	21.7
Large	15,994	0.6	47.6	31,858	1.6	68.3
Total	2,539,892	100	100	2,029,894	100	100
Milk						
Small	1,586,667	87.6	36.1	1,084,944	80.4	26.7
Medium	189,530	10.5	35.9	250,852	18.6	53.2
Large	33,844	1.9	28.0	13,530	1.0	20.1
Total	1,810,041	100	100	1,349,324	100	100
Rice						
Small	889,438	95.9	16.9	353,387	89.1	4.6
Medium	32,302	3.5	16.7	36,139	9.1	22.2
Large	5,878	0.6	66.4	7,034	1.8	73.2
Total	927,618	100	100	396,560	100	100

Source: Agricultural Census, IBGE

Coffee production also experienced a substantial reduction (44%) in the total number of farms engaged in the cultivation of this crop, as reported by the 1995-96 and 2006 Agricultural Censuses. Specifically, it dropped from 318,000 to 178,000 farms in that period. This reduction was due mainly to a fall in the number of coffee-producing farms managed by small producers. However, unlike what was observed with rice, maize and edible beans, the number of coffee-cultivating farms associated with the classes of medium and large producers suffered also major reductions during the period 1995-96 to 2006, i.e. 31% and 34%, respectively. However, despite the above changes, the share of the different classes of producers in the total output of coffee during this period remained more or less the same, maintaining the concentration trend towards the class of large producers.

The production of milk has shown a similar trend to that presented by the above crops in terms of reduction in the total number of farms involved in this activity. According to the 1995-96 and 2006 Agricultural Censuses, the total number of farms engaged in milk production decreased from 1.8 million to 1.3 million. In contrast to what was observed in the case of the previous products, this reduction resulted from a fall in the number of farms operated by small and large producers. Given these changes, the share of the classes of small and large producers in the total production of milk decreased during the period 1995-2006 while that of the medium producers´ class increased significantly, rising from 36% to 53%.

In summary, between the mid-1990s and 2006 there was a substantial reduction in the number of farms producing rice, maize, edible beans, coffee and milk. This trend was largely influenced by a fall in the number of farms managed by small producers of these products. In addition, the participation of the classes of medium and large producers in the total production of those products increased significantly. Therefore, the domestic production of agricultural products has been following a concentration path towards classes of producers with larger annual output. This trend, which is similar to that observed in several developed countries, is expected to continue in the next decades. This has several implications, including the need to identify policy alternatives capable of making the option of living in rural areas attractive to members of the small producers' class. This is particularly important to about 11 million people who in 2006 lived in 3.8 million farms with monthly income below two minimum wages (i.e. 73% of the total number of farms recorded by the 2006 Agricultural Census).

According to Alves and Rocha (2010), the solution to the above challenge involves adopting public policies of general nature as well as specific measures aimed at improving the income level of those families. These measures go beyond agricultural matters; they include also income transfer programmes, access to education, transport to urban areas, rural retirement schemes and simplification of labour legislation to enable part-time employment in agriculture. The national and local governments have some experience with these policy measures and several others. Nevertheless, additional efforts will be needed to overcome the challenge brought by a continued trend towards the concentration of agricultural production in the class of large producers.

5. Spatial dynamics of agricultural production and livestock raising in Brazil[15]

Chapter 3 provided an approximate view of Brazil´s production, harvested area, yield, domestic consumption and trade of the selected products for the period 2010-30. Given this outlook and considering the importance of maintaining the country´s biodiversity and addressing issues related to land use, it is relevant to examine where most of the estimated production should take place and how much area would be used in these locations.

This analysis is particularly important for a country like Brazil, since agricultural production has shown important trends in spatial dynamics changing land use among crops and between crops and livestock. Moreover, Brazil is one of the few nations that still have a large agricultural land to be developed. Given these aspects, the first step in carrying out this analysis is to examine the spatial dynamics of production of the selected crops and cattle raising in Brazil. This is what will be done in this chapter in relation to the 1978-2008 period. Following this assessment, its results will serve as a basis to develop Chapter 6, i.e. to obtain an approximate estimate of the area needed to produce the selected crops on specific geographic locations.

[15] This chapter was developed by Danielle A. P. Torres, Fernando Luis Garagorry and Homero Chaib Filho. Its content is based largely on analysis carried by these last two professionals as specific contribution to this study (see list of references).

5.1 Regional and state-level dynamics of crop production and livestock raising

The spatial dynamics of agricultural production can be analysed through several methods. One of these, which has been employed here, starts from the % distribution of the volume (in the case of this study, production of a specific crop and cattle stock) in each year, among the units of a given geographical level. Then, a distance measure is used in order to determine the change from one distribution to the other. For convenience, this distance has been named L1, since it is a variant of the L_1 distance used in mathematics (also called Manhattan or city-block distance).

The L1 distance used in this chapter is calculated as follows: if $(f_1^s, f_2^s, \ldots, f_K^s)$ and $(f_1^t, f_2^t, \ldots, f_K^t)$ are the percent distributions corresponding to years *s* and *t* of the volumes recorded in the K geographic units (regions or states) under consideration, then the distance L1 between them is determined as follows:

$$d(s,t) = (1/2)\sum_{k=1}^{K} |f_k^s - f_k^t|.$$

In this study, $K = 27$ when the analysis is carried out in terms of states[16].

Since the starting entities are percent distributions, the distance may take values between 0 and 100. A simple interpretation can be illustrated through an example, as follows: a distance of 40 means that the change in the distribution of the "initial year" to that of the "final year" was greater than or equal to 40 percent of the maximum (theoretically) possible change. Usually, this lower bound is very tight; besides, at the regional or state level, the maximum possible change is always difficult to imagine, since it would mean a complete substitution of the geographical units which were involved in the initial year.

Distances L1 were calculated for all pairs of the years 1978, 1988, 1998 and 2008. Table 5 shows the L1 distances between the distributions observed at the initial and the last year of the period 1978-2008. As it can be seen, except for edible beans and wheat, all the other commodities experienced significant

[16] Brazil has five geographic regions (North, Northeast, Centre West, South and Southeast), 27 states and a Federal District.

changes at the regional level, particularly sorghum, cotton and soybeans. Rice, cassava, maize and coffee also went through important dislocation at the regional level, although of a lower magnitude. The same was observed with cattle raising; specifically, in this case there was an increase in the participation of the North and Centre West regions and a decrease in the share of the Northeast, South and Southeast regions.

Table 5: L1 distances at regional and state level, from 1978 to 2008

Product	Regional Distance (%)	State Distance (%)
Rice	39.26	41.24
Cotton	66.71	80.82
Edible beans	7.47	15.06
Wheat	2.33	19.90
Cassava	22.52	31.03
Coffee	19.68	51.34
Maize	20.07	30.26
Soybeans	52.61	55.51
Sugar cane	24.70	31.80
Sorghum	70.81	82.54
Livestock	24.99	27.40

Source: Garagorry and Chaib 2010

The L1 distances between the percentage distributions of volume at state level corroborate the above results. In addition, since they are generally larger (because of the triangle inequality of the metric), they indicate that production location has changed more rapidly at state than at regional level. It is interesting to note that in addition to sorghum, cotton and soybeans, the L1 distance at state level is also quite large in the case of coffee. This highlights a major spatial change in the production of this crop at this level of analysis. Specifically, from 1978 to 2008 there were sharp increases in the shares of the states of Minas Gerais and Espírito Santo, and a substantial fall in that of São Paulo. These three states are in the same region, Southeast.

Another method to assess spatial production changes is based on the determination of the location of the gravity centre[17] of production at different points in time, and the calculation of the terrestrial distance (in km) between them. The gravity centre can be considered as the simplest weighted average related to the geographic distribution of an additive variable[18]. The trajectory of the estimated gravity centre summarises the dislocation of the variable in question. The distance between the centres of gravity can also be used to obtain an approximate measure of the intensity of the observed phenomenon, in terms of speed (in km/year). In this study, the variables considered in calculating the gravity centre are crop production and cattle stock.

Table 6 presents the distances between the gravity centres calculated for the different products in 1978 and 2008. The distance between the gravity centres in these two years for soybeans, sorghum, cotton, rice and sugar cane exceeded 500 km, which indicates a major spatial shift in the production of these crops.

Table 6: Terrestrial distances (in km) between gravity centres of selected products, 1978 and 2008

Product	Distance (Km)
Rice	605
Cotton	672

[17] In physics this term is known centre of mass; in statistics gravity centre is widely used.
[18] It is worth noting that being a weighted average a gravity centre may be located in an area with little or no presence of the product.

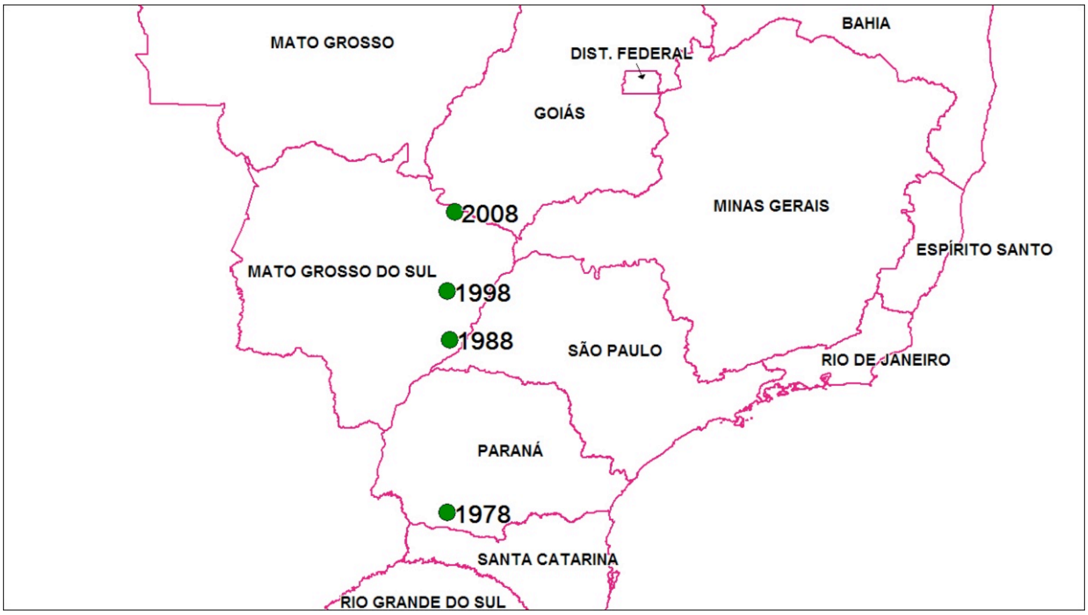
Beans	88
Wheat	160
Cassava	379
Coffee	353
Maize	246
Soybeans	792
Sugar cane	582
Sorghum	941
Livestock	401

Source: Garagorry and Chaib Filho, 2010

Soybean production followed a geodesic trajectory (that is, a terrestrial ‘straight line’) moving from the South region towards the Centre West of the country (Figure 1). The reasons behind this change include: high soybean prices, development of soybean varieties suitable to be grown in tropical regions, favorable credit policies and introduction of new technologies which improved soil fertility (e.g. nitrogen fixation). The know-how brought by experienced soybean producers who migrated from the South to the Centre West contributed also to this trajectory (EMBRAPA-CNPSO, 2004).

Sorghum production followed a similar trajectory as soybeans, moving from the South to the Centre West. At the beginning of the period, sorghum was mainly produced in Rio Grande do Sul during the summer. Through time, the production of this crop lost competitiveness in this state to other crops such as maize and soybeans. In addition, it started to be cultivated as a second crop in the Southeast and especially in the Centre West. The possibility of growing sorghum under no-tillage after soybean cultivation, and the fact that during the dry season, sorghum is more resistant than maize were important reasons behind the expansion of this crop into these regions (Tsunechiro *et al*., 2002).

Figure 1: Soybean gravity centres



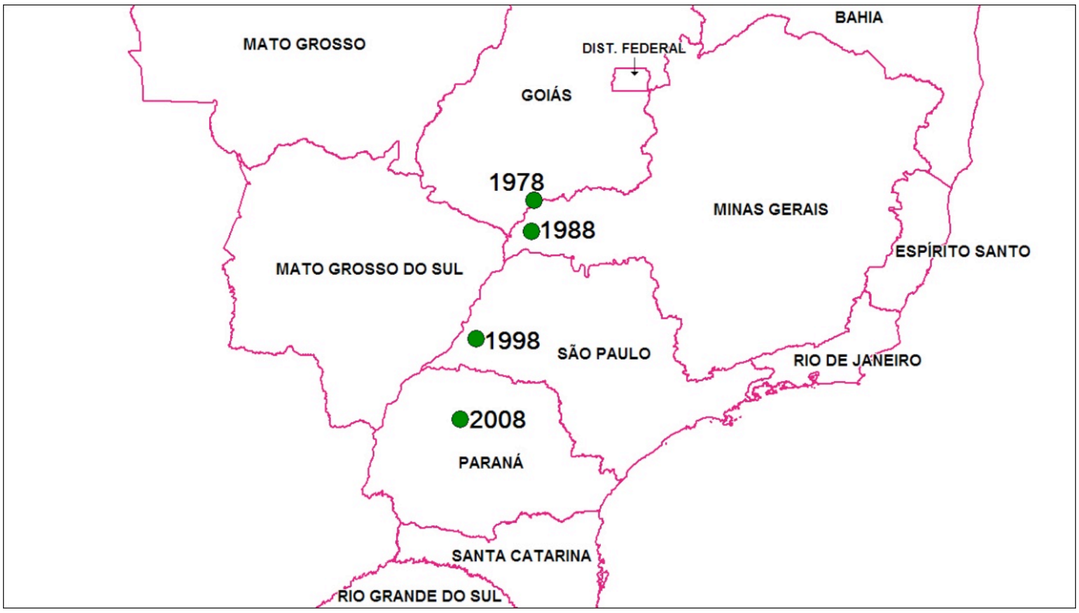
Source: Garagorry and Chaib, 2010

In 1978 and 1988, the gravity centre of cotton production was located in the Southeast region. In 1998, it moved to the south of the Centre West region, and in 2008 it was located in the north of that region, more specifically in the state of Mato Grosso. According to Melo Filho (2003), the Centre West has better climate and topography for that crop. Moreover, serious frost events in Paraná affected significantly its production in this state. Therefore, cotton producers were attracted to grow this crop in the Centre West, displacing production from the South and Southeast to this region.

Compared to cotton, rice production moved in the opposite direction. In 1978, the gravity centre was in the Centre West. After that year, rice production followed a path towards the South, resulting in a concentration of production in Rio Grande do Sul and Santa Catarina in 2008 (Figure 2). Rice produced in the South is irrigated, while that in the Centre West is mainly rain-fed. Also, upland rice was largely used in the Centre West as a first crop, after clearing the original savanna vegetation ('cerrado'), in order to prepare the soil for pastures or other crops. Besides, in the Centre West there is a strong competition among grains, particularly soybeans, cotton and maize. Depending on prices, producers change their production among these crops.

This has made rice production in the Centre West very volatile. On the other hand, the South, due to its humid climate, does not have many alternative crops (Miranda *et al.*, 2007). As a result, rice production in this region is fairly inelastic to price changes. These facts explain the return of rice production to the South.

Figure 2: Rice gravity centres



Source: Garagorry and Chaib 2010

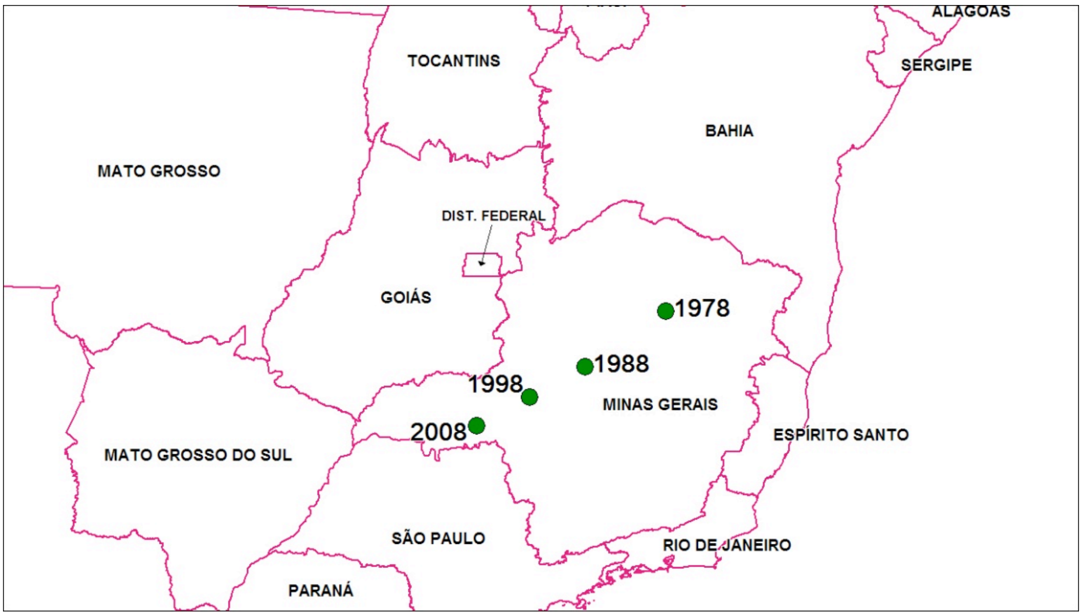
The gravity centres calculated for sugar cane production moved 582 km between 1978 and 2008. However, they remained inside the same state, i.e.

Minas Gerais. Specifically, the gravity centres moved from the northeast of Minas Gerais towards the southwest of the state, closer to São Paulo (Figure 3). According to Garagorry and Chaib Filho (2010), this trajectory captures the fact that the Northeast region is decreasing its share of sugar cane production while those of the Southeast and Centre West are increasing.

The main factors explaining the expansion of sugar cane production are: first, government incentives to increase its production in order to produce ethanol; secondly, in some areas, (i.e. the west of São Paulo, east of Mato Grosso do Sul and north of Paraná), land was largely used for pasture, but producers realised that they could make higher profits through sugar cane production. Therefore, they started to cultivate it. According to Palomino *et al.* (2007), sugar cane production should continue to expand in these regions because they have favorable climate conditions, better infrastructure, and are close to main consumer markets.

According to Table 6, between 1978 and 2008, cassava and coffee production, as well as cattle raising, experienced an important, but less intense change in the geographical location where these activities were carried out. The differences between the gravity centres for these activities, during this period, varied between 353 and 401 kilometres.

Figure 3: Sugar cane gravity centres



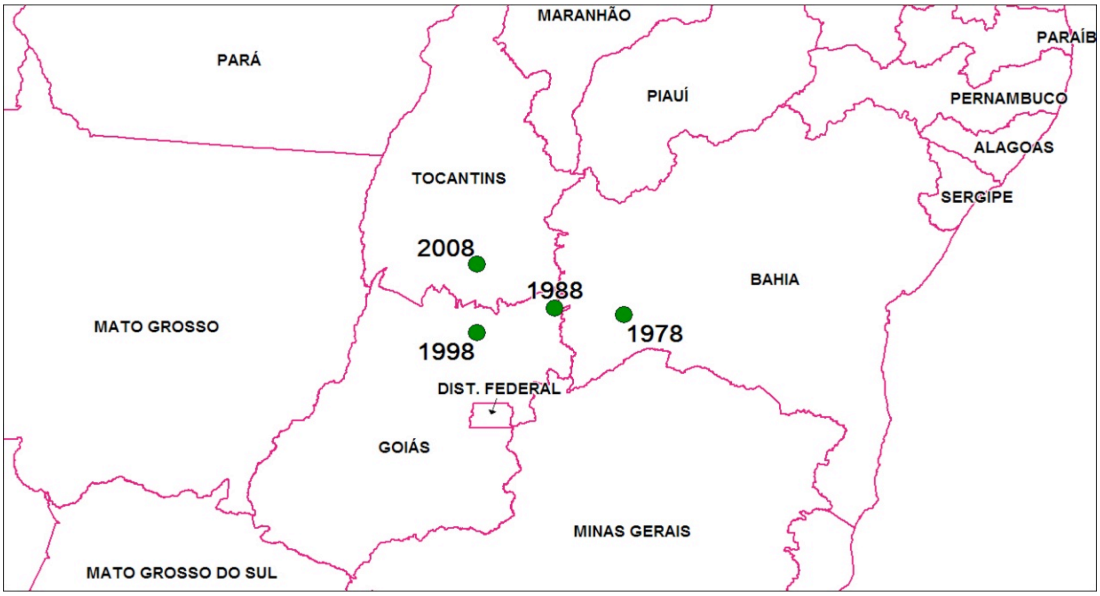
Source: Garagorry and Chaib Filho, 2010

Cassava production experienced a significant change in terms of geographical location, moving from Bahia in the Northeast in 1978 towards the Centre West in 1998 and after that, to Tocantins in the Northern region (Figure 4). The state of Pará, in the North, is the main producer of cassava. However, due to its efficient use of water resources and easy adaptation to soils with low fertility, cassava is produced in all regions of Brazil. Even though cassava does not contribute significantly to Brazilian exports, it is an important product for food security as a source of carbohydrate to millions of people in the country. Moreover, it is one of the nine major Brazilian agricultural products in terms of cultivated land area (Santini *et al.*, 2010).

Coffee production registered a major geographical shift, moving from São Paulo towards Minas Gerais, while remaining in the Southeast region. The distance between the 1978 and 2008 gravity centres (353 km) and the path followed by them corroborates the fact that São Paulo and Paraná are decreasing their share in coffee production while those of Minas Gerais, Espírito Santo and Bahia are increasing.

Changes in Brazil's coffee production started at the end of the eighties with market deregulation and the end of an international coffee agreement which maintained high prices through export quotas for member countries. As a consequence of market changes, there was a decrease in domestic production between 1991 and 1995; only in 1998, due to the 1997 higher prices, coffee production increased again. These events, plus some severe frosts in the state of Paraná, changed the geographical location of coffee production. There was a substantial drop in cultivated area in São Paulo and an increase in Minas Gerais. With the implementation of the sugar cane programme, sugar cane producers started to rent land from coffee producers, particularly in São Paulo.

Figure 4: Cassava gravity centres



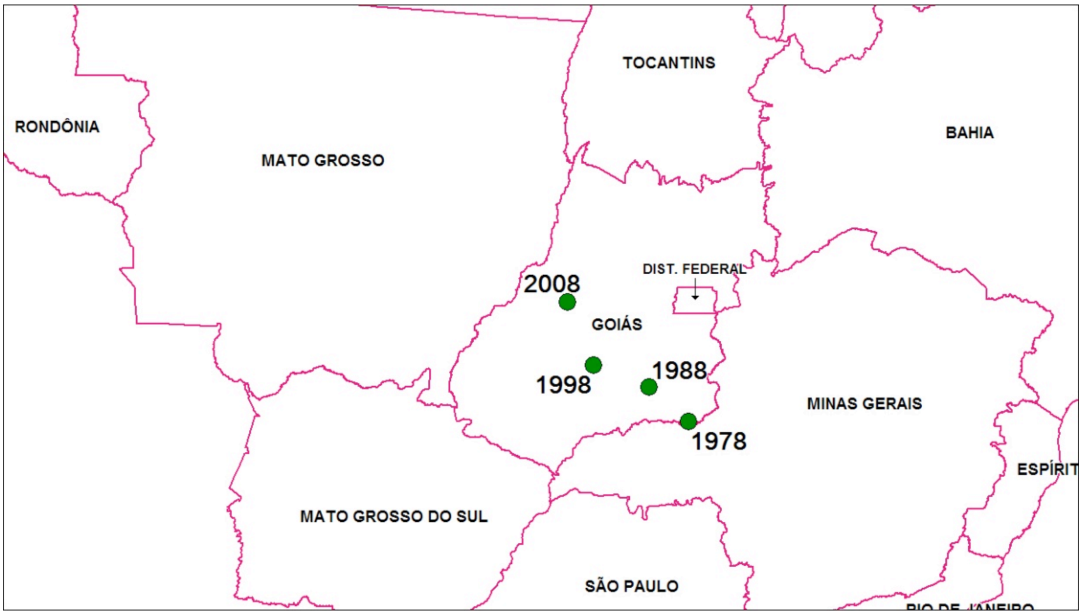
Source: Garagorry and Chaib 2010

According to Figure 5, the gravity centres calculated for cattle stock moved from the border of the Southeast region towards Mato Grosso following practically a straight line. Examining the cattle stock by region, it is found that, in 1978, about 20% of the total was located in the South, 33% in the Southeast, 23% in the Centre West and 5% in the North. In 2008, the situation was quite different: 14% was in the South, 19% in the Southeast, 34% in the Centre West, and 19% in the North. It highlights the increase in the share of the North and Centre West regions and the significant fall in the participation of the South and Southeast.

In contrast to other crops, maize, wheat and, particularly, edible beans production experienced relatively small spatial changes in 1978-2008. The gravity centres of maize production remained inside the state of São Paulo during the entire period. The only observed change was that they moved from the north to the northwestern part of the state, towards the Centre West region.

As in the case of other grains, product price is one of the main determinants of maize production. In this regard, soybeans are displacing maize production in the Centre West region, and in the states of Paraná and São Paulo. Recently, there has been an increase in the second crop of maize, which is grown after the harvest of soybeans. This form of land-use intensification compensated part of the land lost to soybeans in the above-mentioned region and states (Garcia *et al.*, 2006).

Figure 5: Livestock gravity centres



Source: Garagorry and Chaib Filho, 2010

Wheat production was concentrated in the South region during the entire period of analysis. The only observed change was a shift in the main producing state in the region. In 1978 the gravity centre was located in Santa Catarina. In the following years it moved towards the north of Paraná. Most of the wheat consumed domestically comes from abroad, and imports are generally greater than national production. The country does not have a comparative advantage in wheat production as a single crop. Brazilian production in the eighties was a result of government support through policies such as minimum prices, agricultural credit and public purchases of local production. According to Brum and Müller (2006), among the reasons why wheat is still produced is the need for crop rotation to cover the soil during the winter, and to share the fixed costs of summer crops.

5.2 Geographic concentration of selected crops and cattle stock

The analysis above showed that the Centre West is attracting the production of several commodities as well as livestock. It also indicated that some states in other regions, such as São Paulo, Minas Gerais and Paraná, are main producers of several commodities. These results reveal that there is an important degree of concentration of production in this geographical area, but the situation may be different for some products (e.g., rice and wheat, which are concentrated in the South). In order further to investigate this concentration, Gini coefficients were calculated for the regional distributions of volume in the years of 1978, 1988, 1998 and 2008.

According to Table 7, in 2008 seven products had Gini coefficients higher than 0.590, showing production concentration in certain regions. Through time, the coefficients calculated for rice and cotton showed the largest increase, highlighting the increasing concentration of rice production in Rio Grande do Sul and of cotton in the Centre West. On the other hand, soybeans presented a substantial decrease in the Gini coefficient, from 0.892 to 0.596, which highlights the behaviour of a crop that is expanding to new areas, but still persists in the old ones.

Table 7: Geographic concentration of production - selected crops and cattle raising Gini coefficients of regional distributions

Product	1978	1988	1998	2008
Rice	0.340	0.331	0.534	0.693

Cotton	0.519	0.501	0.637	0.797
Beans	0.460	0.444	0.386	0.357
Wheat	0.970	0.897	0.972	0.950
Cassava	0.533	0.492	0.350	0.408
Coffee	0.806	0.808	0.871	0.820
Maize	0.557	0.498	0.583	0.507
Soybeans	0.892	0.668	0.636	0.596
Sugar cane	0.752	0.743	0.707	0.704
Sorghum	0.731	0.419	0.733	0.751
Cattle stock	0.31	0.25	0.26	0.23

Source: Garagorry and Chaib Filho, 2010

Beans and cassava had the smallest Gini coefficient in 2008, corroborating the fact that they are produced in many states. The Gini coefficients calculated for livestock followed a downward trend, dropping from 0.306 in 1978 to 0.230 in 2008. Therefore, compared to commodities, livestock production is much less geographically concentrated. Even though the Centre West region is responsible for the largest livestock share, cattle-raising is spread throughout the country.

A large degree of geographic concentration of production is also observed when analysing the share of the different states in the total production of each of the selected crops and cattle stock. Specifically, in 2004-08, five or less states were responsible for 80% of the production of seven out of the ten selected crops (Table 8). In the case of the remaining three crops (i.e. cassava, edible beans and maize) and cattle-raising, between 7 and 12 states accounted for 80% of the national production and cattle stock.

The state of Mato Grosso, in the Centre West region, is the first producer of cotton and soybeans, the second of rice and sorghum, and the third of maize. Goiás, another state located in the Centre West, is the fourth producer of edible beans. The South is also an important agricultural producing region.

Paraná is the first producer of edible beans, maize and wheat, the second of sugar cane and the third of cassava. Rio Grande do Sul is the major producer of rice. States of the South are important in seven out of the ten crops studied. The Southeast region is a major producer of sugar cane, coffee, edible beans and maize. It also produces cassava and sorghum. The main producing states in this region are São Paulo and Minas Gerais.

Table 8: Share of major producing states in the national production of selected crops and cattle stock during – average for the 2004-08 period (percentage)

States	Livestock	Cassava	Edible beans	Maize	Rice	Soybeans	Sorghum	Sugar cane	Cotton	Coffee	Wheat
Rondônia	5										
Amazonas		3									
Rio Grande do Norte		2									
Alagoas								5			
Espírito Santo										23	
Maranhão		6			6						
Ceará		3	5								
Pernambuco		2	4								
Pará	8	19			4						
Mato Grosso do Sul	11					8	11				
Bahia	5	17	11						25		
Santa Catarina		2	5	7	9						

Mato Grosso	13			11	10	30	15		50		
Goiás	10		8	8		12	36	5	9		
Minas Gerais	11	3	16	13			12	7		49	
São Paulo	6	4	8	10			12	60		10	
Paraná	5	13	22	26		19		8			52
Rio Grande do Sul	7	5	4	9	54	12					35

Source: IBGE

The concentration of agricultural production in Brazil is observed not only in geographic terms, but also with respect to the number of rural properties that contribute to the total value of agricultural production. According to Alves and Rocha (2010), about 8% of the total number of rural properties recorded in the Agricultural Census of 2006 was responsible for 85% of the declared production. These authors also showed that this concentration is larger in the Centre West, South and Southeast regions. Specifically, the annual average production value by rural properties in the Northeast, in 2006, was US$6,362. The corresponding figures for the other regions are: North US$7,101; Centre West US$34,338; Southeast US$28,577; and South US$22,643.

Given the results presented above, the analysis carried out in the next chapter will focus on the groups of major producing states which account for 80% of the total production of the respective crops and livestock under consideration. Table 8 above shows the composition of these groups of states.

6. Land area needed by major producing states to produce at least 80% of the estimated national production of the selected crops, 2010-30

According to the previous chapter, crop production and livestock-raising in Brazil have at least two main characteristics: (a) in general, they are dynamic regarding the geographic location of the production processes; and (b) this dynamism has contributed to concentrate agricultural production in the Centre West, South and Southeast regions of the country over the 1978-2008 period.

Assuming the above-mentioned characteristics are going to continue in the near future, an approximate picture of the area needed by groups of major producing states to produce at least 80% of the estimated national production of the selected crops (Chapter 2) will be provided. This will be accomplished using harvested area as an approximation for planted area and considering two yield scenarios: (a) assuming a continuation of past trends (scenario one); and (b) reflecting the possibility of observing higher yields (scenario two). The method of analysis used to pursue this objective is as follows.

6.1 Method of analysis

Considering the spatial concentration of agricultural production highlighted in the previous chapter, the analysis will focus on the groups of states that were responsible for 80% of the domestic production of the selected crops and livestock raising in the 2004-08 period. As presented in Table 8, these groups comprise two states in the case of wheat, of three states when the products under analysis are coffee and cotton, and five states for rice, soybeans, sorghum and sugar cane. Groups ranging from 7 to 12 states were considered in the analysis of maize, edible beans, cassava and cattle raising.

In addition to the geographic concentration of production, the method applied here takes into account the changes in cropland use observed in the country. Therefore, an outlook for the expected share of the groups of main producing states in Brazil´s total production and harvested area of the selected products was obtained for the 2010-30 period. This was accomplished based on univariate time series models (Statespace, Box and Jenkins, and Exponential

Smoothness), which were estimated through SAS procedures and using annual data published by IBGE. In the case of soybeans, wheat, maize, cassava and edible beans, the time series considered in the estimation of the models covered the 1975-2008 period. Due to great changes observed in the share of the major producing states of rice and coffee over the 1975-2008 period, both in relation to production and harvested area, the time series analysed was from 2000 to 2008[19].

Given the above-mentioned outlook, an approximation for the production of the selected crops by the groups of major producing states was obtained for 2010-30. This was accomplished multiplying the estimated production for Brazil (Chapter 3) by the expected share of these groups in the national production. A similar procedure was used to generate a projection for the harvested area for the group of major producing states. The ratio of the estimated production and harvested area obtained through these procedures for the groups of major producing states approximates the yields resulting from the continuation of past trends. They comprise the first yield scenario.

Considering the levels of production estimated for the groups of major producing states through the above-mentioned procedure, the harvested area needed by them to produce the same levels under a scenario of higher yield (scenario two) was determined. In this regard, the first step was constructing this scenario. This was produced through the estimation of univariate time series models and consultations with Embrapa´s researchers.

Following the above, the harvested area needed under a scenario of higher yield to produce the estimated levels of production in the major producing states was obtained, dividing the estimated levels of production by the yields of scenario two. The next sections present the estimates resulting from the application of this method.

[19] In the case of these crops, the use of a long data series such as 1975-2008 results in estimated shares above 100%. The reason for this is that the share of production and harvested area of the major producing states of these crops in the respective total production and harvested area experienced large increases along that period. Therefore, a shorter series which reflects the more recent situation was considered.

6.2 Future share of major producing states in Brazil´s production and harvested area of selected products

According to Table 9, the share of the five major producing states of rice[20] in Brazil´s production and harvested area should vary at an average rate of +0.5% and +0.6% per year between 2010 and 2030 resulting in a participation of 93% and 83% respectively at the end of this period. This expected increase in the participation of this group of states in the national production of this crop reflects to a great extent, a continuation of a substantial expansion of rice production in Rio Grande do Sul and Santa Catarina vis-à-vis other states.

The share of the major producing states of soybeans, maize and wheat in their respective national production levels, followed a downward trend during the 1975-2008 period. Assuming that this trend will continue in the next two decades, the participation of those states in the domestic production of these crops should experience a small fall in 2010-30. Nevertheless, the resulting shares in 2030 should be above 77% in the case of production and 66% of harvested area.

Table 9: Groups of major producing states: expected participation in Brazil´s estimated production and harvested area, selected crops, 2010-30.

Products	2010	2015	2020	2025	2030
Cassava					
Share of Group G12	79.9	79.6	79.3	79.0	78.7
In total production (%)	81.0	81.2	81.3	81.4	81.6
In total harvested (%)					
Coffee					
Share of Group G3	82.6	83.1	83.5	83.9	84.4

[20] This group of states consists of Pará, Maranhão, Santa Catarina, Rio Grande do Sul and Mato Grosso.

In total production (%)	79.2	80.7	82.2	83.7	85.2
In total harvested (%)					
Cotton					
Share of Group G3	82.4	82.4	82.4	82.4	82.4
In total production (%)	75.4	75.4	75.4	75.4	75.4
In total harvested (%)					
Edible beans					
Share of Group G9	83.0	83.0	82.7	82.5	82.2
In total production (%)	73.6	72.9	72.2	71.5	70.8
In total harvested (%)					
Maize					
Share of Group G7	84.2	83.4	82.9	82.4	81.9
In total production (%)	68.6	68.0	67.3	66.6	65.9
In total harvested (%)					
Rice					
Share of Group G5	84.4	86.5	88.7	90.9	93.2
In total production (%)	74.0	76.2	78.4	80.7	82.9
In total harvested (%)					
Sorghum					
Share of Group G5	85.2	85.2	85.2	85.2	85.2
In total production (%)	80.9	80.9	80.9	80.9	80.9
In total harvested (%)					
Soybeans					
Share of Group G5	80.8	80.0	79.0	78.0	77,0
In total production (%)	81.2	80.6	79.9	79.3	78.6

In total harvested (%)					
Sugar cane					
Share of Group G5	82,1	82.1	82.1	82.1	82.1
In total production (%)	77.0	77.0	77.0	77.0	77.0
In total harvested (%)					
Wheat					
Share of Group G2	87.3	86.3	85.3	84.4	83.4
In total production (%)	87.6	87.0	86.3	85.7	85.0
In total harvested (%)					

Source: Estimated by the study team

Cassava G12 = Amazonas, Pará, Maranhão, Ceará, Rio Grande do Norte, Pernambuco, Bahia, Minas Gerais, São Paulo, Paraná, Santa Catarina, Rio Grande do Sul.
Coffee G3 = Minas Gerais, Espírito Santo, São Paulo.
Cotton G3 = Bahia, Mato Grosso, Goiás.
Edible beans G9 = Ceará, Pernambuco, Bahia, Minas Gerais, São Paulo, Paraná, Santa Catarina, Rio Grande do Sul, Goiás.
Maize G7 = Minas Gerais, São Paulo, Paraná, Santa Catarina, Rio Grande do Sul, Mato Grosso, Goiás.
Rice G5 = Pará, Maranhão, Santa Catarina, Rio Grande do Sul, Mato Grosso.
Sorghum G5 = Minas Gerais, São Paulo, Mato Grosso do Sul, Mato Grosso, Goiás.
Soybeans G5 = Paraná, Rio Grande do Sul, Mato Grosso do Sul, Mato Grosso, Goiás.
Sugar cane G5 = Alagoas, Minas Gerais, São Paulo, Paraná, Goiás.
Wheat G2 = Paraná, Rio Grande do Sul.

The underlying factors behind the above trends are: a larger reduction in the production of soybeans in Rio Grande do Sul and Santa Catarina than an expansion in Mato Grosso, Goiás and Mato Grosso do Sul; a drop in the production of maize in Minas Gerais, São Paulo, Santa Catarina and Rio Grande do Sul which outweighs the increase in Paraná, Mato Grosso and Goiás; and a fall in wheat production in Rio Grande do Sul and Paraná vis-à-vis an increase in Santa Catarina, São Paulo and Minas Gerais.

In contrast to the above, the participation of the major producing states of cassava and edible beans in the national production of these crops is expected to reduce very little during the 2010-30 period. In the last 20 years the changes observed in the production of the states that comprise the groups of major producers of these crops have almost been compensated in aggregated terms. This situation is assumed to continue in the next decades.

The participation of the major producing states of sugar cane, cotton and sorghum in Brazil´s production and harvested area of these products followed a steep trajectory in 1975-2008. Therefore, projected shares of these crops obtained through time series models with data covering this period result in estimates above 100%. It is unlikely that the future production of those crops will take place exclusively in the groups of states under consideration. In this context, the expected share of these groups of states in 2010-30 is approximated by the average participation observed in 2006-08.

6.3 Production, harvested area and yields of selected crops in major producing states under a scenario of continued past trends

The outlook of Brazil´s production and harvested area of the selected crops together with the above estimates of the expected share of major producing states indicate that soybean production in the G5 group of states should expand 42% in 2010-30, reaching 78 million tons at the end of the period (Table 10). This production would result from a harvested area of 26.4 million hectares.

Sugar cane, sorghum, coffee and rice production should also expand substantially in the respective groups of major producing states. The production of sugar cane and sorghum are expected to reach 879 million tons and 2.9 million tons in 2030, respectively. This production should come from a harvested area of 9.9 million hectares in the case of sugar cane and 1.2 million of sorghum.

Regarding coffee and rice, the estimated levels of production at the end of the 2010-30 period are respectively, 3.6 million and 16.5 million tons. Compared to the estimates of harvested area for 2010, less area would be needed to achieve this level of rice production. The opposite would happen in the case of coffee. The first of these results reflects the downward trend that has been observed in the harvested area of rice, and the second the growing share of the major producing states of coffee in the total harvested area of this product, which, as seen earlier, is estimated to change very little in 2010-30 (-0.08% per year).

Table 10: Production and harvested area of major producing states – scenario of continued past yield trends, 2010-30

Products	2010	2015	2020	2025	2030
Cassava					
Production (ton)	21.695,810	22,480,414	23,256,122	24,024,906	24,786,763
Harvested area ha)	1,535,719	1,550,566	1,565,385	1,580,243	1,595,139
Yield (kg/ha)	14,127	14,498	14,856	15,203	15,539
Coffee					
Production (ton)	2,279,541	2,383,064	2,818,010	3,136,684	3,590,696
Harvested area (ha)	1,757,431	1,784,165	1,810,649	1,836,883	1,862,868
Yield (kg/ha)	1,297	1,336	1,556	1,708	1,928
Cotton					
Production (ton)	3,321,318	3,184,340	3,868,094	3,848,181	4,274,478
Harvested area (ha)	858,542	764,083	861,565	795,639	820,377
Yield (kg/ha)	3,869	4,168	4,490	4,837	5,210
Edible beans					
Production (ton)	2,806,772	3,051,755	3,201,945	3,346,204	3,499,256
Harvested area (ha)	2,765,625	2,702,137	2,638,308	2,575,207	2,512,839
Yield (kg/ha)	1,015	1,129	1,214	1,299	1,393
Maize					
Production (ton)	46,799,671	50,244,799	54,492,233	58,690,585	62,832,484
Harvested area (ha)	9,556,993	9,649,385	9,832,060	10,002,175	10,168,055
Yield (kg/ha)	4,897	5,207	5,542	5,868	6,179

Rice					
Production (ton)	10,609,382	11,999,809	13,446,583	14,949,704	16,509,172
Harvested area (ha)	2,019,355	1,847,814	1,662,775	1,464,238	1,252,202
Yield (kg/ha)	5,254	6,494	8,087	10,210	13,184
Sorghum					
Production (ton)	1,818,855	2,095,458	2,372,060	2,648,663	2,925,265
Harvested area ha)	726,726	834,579	942,432	1,050,284	1,158,137
Yield (kg/ha)	2,503	2,511	2,517	2,522	2,526
Soybeans					
Production (ton)	54,798,752	60,851,369	66,624,031	72,236,769	77,684,660
Harvested area (ha)	19,784,993	21,124,070	22,868,003	24,665,901	26,445,688
Yield (kg/ha)	2,770	2,881	2,913	2,929	2,938
Sugar cane (1)					
Production (ton)	595,038,255	668,220,668	738,391,834	808,553,557	878,715,251
Harvested area (ha)	7,001,268	7,779,883	8,513,336	9,246,548	9,979,759
Yield (ton/ha)	89,99	85,89	86,73	87,44	88,05
Wheat					
Production (ton)	5,261,445	5,447,087	5,671,083	5,844,116	5,974,177
Harvested area (ha)	2,040,396	1,950,720	1,862,144	1,774,669	1,688,293
Yield (kg/ha)	2,579	2,792	3,045	3,293	3,539

Source: estimated by study team
(1) Refer to sugar cane used in the production of sugar, ethanol and other uses.

In contrast to the above, wheat and cassava production should expand relatively less in the respective groups of major producing states. Wheat output is estimated to reach approximately 6 million tons in 2030 and cassava

25 million tons. The underlying reasons for this are a strong competition faced by wheat with respect to other crops, and the lack of a world market for cassava. Concerning harvested area, it is estimated that in the case of wheat it will continue to follow a downward trend, i.e. fall from 2 million hectares in 2010 to 1.7 million in 2030. In turn, the harvested area with cassava is expected to change very little, increasing from 1.5 million to 1.6 million hectares in the same period.

Regarding cotton, maize and edible beans, the estimates obtained indicate that the level of production in the respective groups of major producing states of these crops should grow respectively, 29%, 34% and 25% in 2010-30. In terms of harvested area, the main producing states of edible beans and cotton should experience small reductions, while those growing maize are expected to increase at an annual average growth rate of 0.3%.

In aggregated terms, the estimates obtained for the groups of major producing states indicate that together the 18 states which participate in these groups should produce a total of 198 million tons of grains[21], 3.6 million tons of coffee and 879 million tons of sugar cane in 2030. This production should come from 57.5 million hectares of harvested area, i.e. an additional 9.4 million hectares vis-à-vis the 2010 estimate.

This difference reflects the net effect of an estimated fall in the harvested area of rice, cotton, wheat and edible beans, and an expansion in that of maize, sorghum, coffee, cassava and especially, of soybeans and sugar cane. The harvested areas with these two crops in 2030 should exceed the respective 2010 levels by 6.7 million and 3 million hectares respectively. The fact that the sum of these estimates exceeds the total additional harvested area calculated with respect to 2010, i.e. 9.4 million hectares, is explained by the estimated reduction for rice, cotton, wheat and edible beans mentioned above.

The ratio between the estimated production and harvested area obtained for the different groups of major producing states provides an approximation of

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[21] The term grains here comprises maize, rice, sorghum, soybeans, wheat, cassava and edible beans. This terminology coincides largely with that used by CONAB, which includes also other grains of less relevance, i.e. peanuts, oats, rye, barley, sunflower, castor bean and 'triticale'.

the future yield levels in these locations under a scenario of continued past trends. In this regard, according to Table 10, the yield of the major producing states of rice and coffee shows a trajectory which implies a greater annual average growth rate than that of the main states that produce the other selected crops. Therefore, under this scenario, the yield level of the group G5 of rice should reach 13.184 kg/ha in 2030 and that of the G3 of coffee 1.928 kg/ha.

Under this scenario, the yields of the major producing states of wheat, cotton, edible beans and maize are expected to increase at moderate levels in the next decades, i.e. between 1.2% and 1.6% per year. On the other hand, under this scenario, relatively smaller annual average growth rates are estimated for the yield of the major producing states of soybeans, sugar cane, sorghum and cassava. This however, should not be interpreted as a sign of a levelling off in the yield curve of these products. As shown in the next section, there are several facts that suggest the possibility for a higher yield scenario to take place.

6.4 Prospects for a higher yield scenario

The soybeans research programme currently carried out by agricultural research institutions in Brazil focus, among other aspects, on the development of technologies which contribute to reducing crop loss due to climate change, infestation of major diseases such as soybean rust, and attacks from nematodes. The research agenda also includes the generation of new cultivars adapted to different seedling periods, as well as the development of techniques and methods which maximise soil quality, improve crop rotation and enhance the efficiency of integrated crop-livestock systems.

The results of these researches should further increase soybean yields in the next years. As a matter of fact, the economic, social and environmental impact evaluation of technologies generated by Embrapa identified several top soybean producers in the country which achieved yields of about 4 tons/ha in 2009 (Embrapa, 2009). This yield level is close to the ones resulting from field experiments carried out by research institutions in the country, i.e. 5 tons/ha.

Therefore, it seems reasonable to expect average yields of about 4 tons/ha in the major producing states of this crop in 2030.

According to Embrapa Agroenergy, in the last 34 years sugar cane yield grew at an annual average rate of approximately 2%. This performance was largely due to genetic improvements, since little was done to improve production systems. It is believed however, that in the next decades relatively higher sugar cane yields can be achieved through improvements in several areas, including controlled irrigation, which permits the application of other technologies such as foliar fertilization.

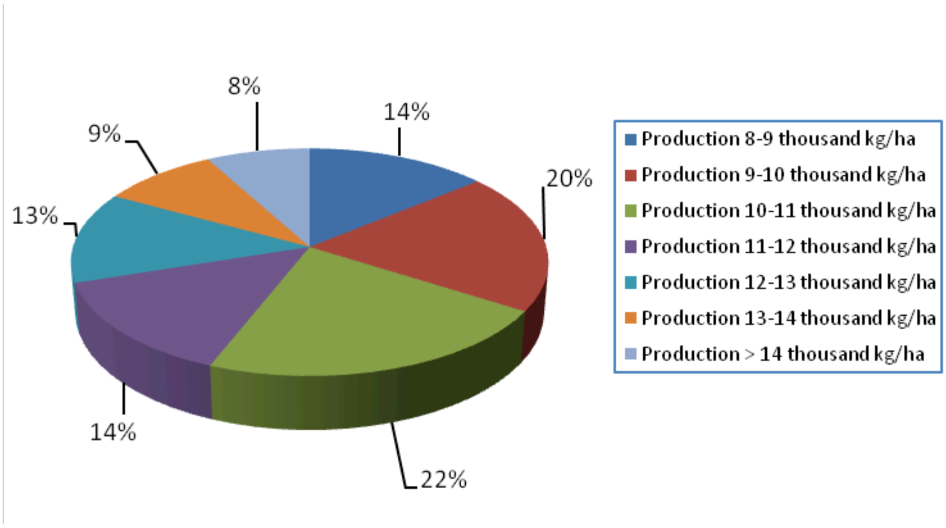
A wider use of the Plene System should also contribute to obtaining higher yields of this crop. The use of this system is expected to reduce the costs of sugar cane implantation by 15%. Under normal conditions sugar cane producers currently make five cuts after the sugar field is established. The yield level which is higher in the first cuts drops substantially in the next ones. Therefore, the use of technologies such as the Plene System, which reduces the cost of sugar cane implantation, enables the renovation of sugar cane fields every three cuts, which by itself contributes to higher yields.

Currently, there are some national producers who, applying effectively the best technology available, achieve an average sugar cane yield of 110 ton/ha in five cuts. The yield obtained in the first cut in these properties is about 200 ton/ha. Thus, the yield level suffers indeed a major reduction along the various cuts. This fact also suggests that it is quite feasible to achieve annual average yields of about 118 tons/ha in 2030 in the major sugar cane producing states in Brazil.

As part of its activities, Embrapa Maize and Sorghum carried out a maize yield survey in selected farms which agreed to test new technologies available in the market in the 2008-09 crop year. It covered 1,095 farms located in all major producing states of the Centre West and South regions plus some other states from the North and Northeast, i.e. Tocantins, Pará, Maranhão, Bahia and Piauí. The results of this exercise showed yield levels between 8 and 14 tons/ha (Figure 6). This illustrates the potential of the producing systems used, which included simple hybrids, seed treatment, weed and disease control, fungicide application and plant population of about 65,000 per hectare. Moreover, it suggests the possibility of observing yields similar to the ones above at the end of the next two decades.

In contrast to maize, the possibility for observing relatively higher sorghum yields in 2010-30 is less probable. This crop is mostly grown in February and March after the harvest of soybeans. The weather conditions in these months are more restricted and unstable than at the end of the year. Therefore, given the available technologies and those being generated, the possibility for substantial growth in sorghum yield in 2010-30 is limited. However, it seems feasible to observe yield levels of approximately 3 ton/ha in the group of major producing states of this crop at the end of this period.

Figure 6: Maize yield obtained by selected Brazilian producers through recent technologies available in the market, 2008-09 cropping year



Source: Embrapa Maize and Sorghum

The genetic progress of cotton in the Northeast of Brazil during 1976-94 was 1% per year (Carvalho *et al.*, 1997). More recent studies of this nature, such as the one of Moresco (2003) carried out for the Brazilian savannas, arrived at estimates of 3% per year. Currently, top cotton producers in the country obtain yields of 6 tons per hectare. Assuming that the estimated 3% growth will prevail in the next years, the yield level achieved by these producers in 2030 would be 9.6 tons/ha. According to Embrapa Cotton, supposing that the current genetic progress is maintained, it seems reasonable to expect an average yield around 7.2 tons/ha at the end of the next two decades in the major producing states of cotton.

Given the past trend of the yield of wheat in Brazil, the level of this variable could be estimated at approximately 3 tons/ha in 2020 and 4 tons/ha in 2030. However, in the view of Embrapa Wheat, even though the current genetic materials have the potential to result in higher yields than these, it is very unlikely that they will be observed. The reasons for this include the concentration of wheat production in the south of the country where there is a high risk for climatic adversities, and a limited perspective for the expansion of irrigated wheat in the 'cerrado' area. In this context, the expected yield of wheat for 2030 under a higher yield scenario should not be significantly different from what may be observed under a continuation of past yield trend.

In Brazil, most of the cassava has traditionally been cultivated by small farmers in marginal soils and with limited access to modern agricultural inputs. After a period of little change, the average yield of this crop experienced a small increase in the major producing states, reaching approximately 14 tons/ha in 2009. Currently, the top producers in the regions where cassava production is carried out under entrepreneurial schemes (i.e. in parts of São Paulo, Paraná, Santa Catarina and Mato Grosso do Sul) are obtaining 22 tons per hectare. Embrapa Cassava and Tropical Fruits has also observed exceptionally high yields obtained in yield competition activities, i.e. 65 tons/ha. These facts, together with the recent increases in the yield of the major producing states, suggest that is feasible to expect an annual average growth rate of cassava yield of about 0.8% in the next decades.

Despite the difficulties faced by the Brazilian coffee sector[22], the yield of this crop increased significantly in the major producing states in the last 35 years. During the 1975-89 period it fluctuated between 332 and 841 kg/ha with an annual average growth rate of about 0.5%. In the 1990s the average yield experienced a major growth (4.7% per year), increasing almost steadily from

[22] For instance frosts, closing of the Brazilian Coffee Institute (IBC), and the international crisis of coffee characterised by a long period of low prices.

522 to 751 kg/ha. In the last decade, coffee yield continued to grow; however, at a somewhat lower average annual rate (4.5%).

Several factors contributed to the above-mentioned performance, including a large increase in the population of coffee plants per hectare[23], adoption of new cultivars with higher yield and greater resistance to weeds and diseases, migration of coffee production from regions with high climatic risk to areas of low risk, increase in irrigated production, and greater emphasis of state governments in production increase through higher yields (Leite, 2005; Mourão *et al.,* 2008).

According to Embrapa Coffee, the observed past trend should continue in the next years. The goal of the Brazilian Coffee Research and Development Consortium[24], which is coordinated by Embrapa, is to achieve a national average yield of coffee of about 2,100 kg/ha in the next decades. Therefore, it is reasonable to expect an annual average growth rate of coffee yield around 2.5% in 2010-30.

Brazil is one of the few countries where rice from irrigated and upland areas is important and complementary to each other in the domestic supply of this grain. Until the 1970s, upland rice played a preponderant role in the national production of this crop, accounting for 70%-77% of the total production (Figure 7). However, as a result of strong work by both agricultural research and farmers, a valorisation program of the irrigated rice produced in Rio Grande do Sul[25], and an unfavourable reaction of domestic consumers to the quality of the rice produced at the agricultural frontier, a major change has taken place in the structure of rice production since the end of the 1970s and the beginning of the 80s. The yield of irrigated rice increased gradually and the

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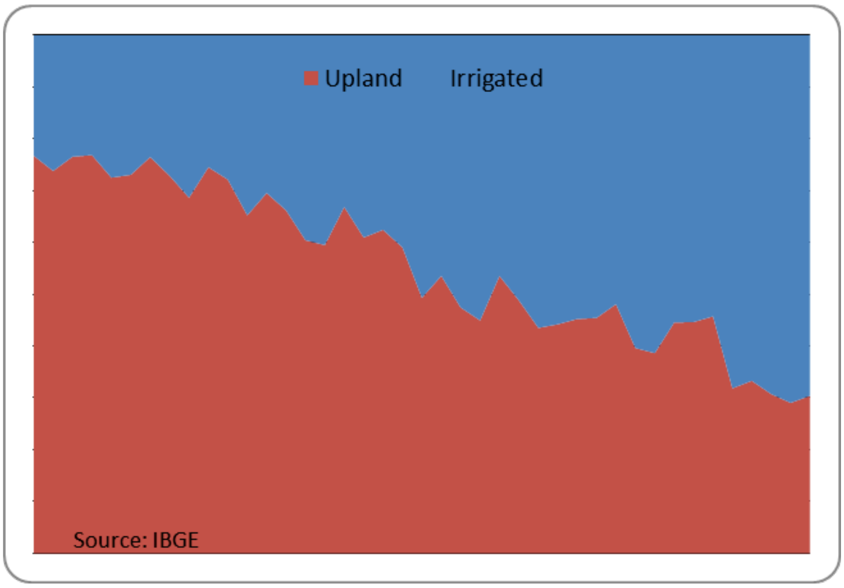
[23] Since the initial implementation of the "Plano de Renovação e Revigoramento dos Cafezais" (Renovation and Strengthening Plan of Coffee Fields) in the 1970s, the population of coffee plants increased from 3.3 billion in the 1960s to 5.7 billion in 2001.

[24] It comprises 39 institutions of higher learning, research and extension, production and industrialisation of coffee. It maintains a close relationship with government organs such as the Deliberative Council of Coffee Policies, where actions and policies for the coffee sector are defined.

[25] Among other aspects, this programme involved a rapid dissemination of new cultivars, such as BR IRGA 409 and BR IRGA 410, with high productive potential and wide acceptance by consumers.

cultivated area of upland rice dropped, resulting in a larger share of irrigated rice in the national production.

Figure 7: Brazil – production of irrigated and upland rice, 1970-2010



As pointed out by Pinheiro *et al.* (2008), with the introduction of the new cultivars with long grains known as ‘agulhinha de sequeiro’, the perspective for continued reduction in the cultivated area with upland rice changed. The adoption of these cultivars in areas with low risk of hydro-deficiency has increased rice yields, especially in Mato Grosso, where average yields of 3 tons/ha have currently been observed.

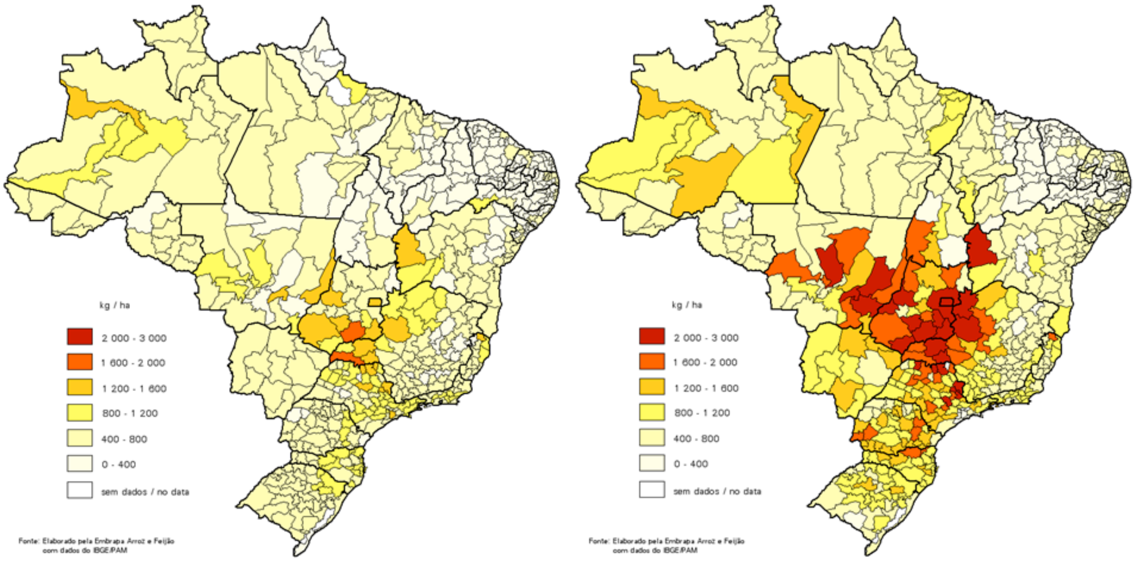
The average yield level in Rio Grande do Sul and Santa Catarina, where irrigated rice is cultivated, exceeded 7 tons/ha in 2009. Moreover, participating farmers in IRGA´s ‘Projeto 10-RS’ have been achieving yields of 12 tons/ha in the last years. This project is the main technology transfer instrument used by Rio Grande do Sul Rice Institute (IRGA) to improve the competitiveness and sustainability of rice production in this state, which is responsible for more than 60% of the national production of this crop. According to Amilibia et al (2008), the results achieved by this project during the 2004-07 period showed that it is possible to produce 10 tons/ha or more in all regions of the state.

Given the present structure of rice production, the observed trend of yield growth in irrigated and upland areas, and the availability of new technologies, the average yield of this crop in the group of main producing states in 2010-30 may grow approximately 5.5% per year.

Similar to rice, the production of edible beans in Brazil comes from two main sources, in this case species, i.e. *Phaseolus vulgaris* L. and *Vigna unguiculata* L. Walp also known as 'feijão-comum' (comum edible) and 'feijão-caupi' (caupi beans), respectively. The first accounted for an average share of 84% of the total domestic production of edible beans in 2006-08. It is produced everywhere in the country by small, medium and large producers, in three cropping periods, summer (37% of the production), dry season (33%), and winter (30%).

During the 1986-2006 period, the cultivated area with 'feijão comum' dropped 38%; however, its production expanded 12%, thanks to an 80% increase in yield. In 2003-05, the most productive micro-regions of 'feijão comum' in the states of Goiás, Bahia, Minas Gerais, São Paulo and Mato Grosso registered average yields between 2 and 3 tons/ha (Figure 8). However, since the productive systems used by farmers vary from low to high technology levels, the national average yield of 'feijão comum' in the three growing seasons during the 2006-08 period was 1.2 tons/ha.

Figure 8: Average yield of edible beans in geographic micro-regions of Brazil, 1990-92 and 2003-05 (kg/ha)



Source: Embrapa Rice and Beans based on IBGE/PAM

Caupi beans, in turn, were responsible on average, for 16% of the national production of edible beans in 2006-08. Their production is concentrated in areas with high incidence of dry spells, i.e. North and Northeast regions. Therefore, the yields in general are relatively low (annual average of 381 kg/ha in 2006-08). According to Freire Filho *et al.* (2008), between 1988 and 2007 31 new cultivars of caupi beans were introduced in Brazil: 25 in the Northeast, 5 in the North and 1 in the Southeast. The yields obtained from these cultivars under non irrigated systems varied between 1 and 1.2 ton/ha, while those cultivated under irrigation achieved 1.5 to 2 tons per hectare. This illustrates the potential of increasing caupi yields in the next years.

In view of the above, it is expected that the yields of 'feijão comum' should increase in the most productive areas and vicinities. In addition, it is very likely that the adoption of new technologies developed for caupi beans will intensify in the next years. Therefore, it is reasonable to expect a yield of edible beans around 1.4 tons in 2030 in the major producing states of this crop.

6.5 Higher yield scenario and attendant harvested area needed to produce the level of production estimated in section 6.3

Considering the above prospects, a higher yield scenario for the selected crops was established for the 2010-30 period (Table 11). For ease of discussion this scenario is referred to as scenario two, while that presented in section 6.3 (reflecting a continuation of past trends) was called scenario one.

Table 11: Harvested area needed to obtain the estimated production under a higher yield scenario – groups of major producing states – 2010-30

Products	2010	2015	2020	2025	2030
Cassava					
Production (ton)	21,965,810	22,480,414	23,256,122	24,024,906	24,786,763
Harvested area (ha), scenario 2	1,528,099	1,522,791	1,515,509	1,506,142	1,494,882
Yield (kg/ha), scenario 2	14,198	14,763	15,345	15,951	16,581
Coffee					
Production (ton)	2,279,541	2,383,064	2,818,010	3,136,684	3,590,696
Harvested area (ha), scenario 2	1,741,704	1,754,647	1,726,275	1,732,916	1,715,945
Yield (kg/ha), scenario 2	1,309	1,358	1,632	1,810	2,093
Cotton					
Production (ton)	3,321,318	3,184,340	3,868,094	3,848,181	4,274,478
Harvested area (ha), scenario 2	815,489	674,436	706,695	606,463	581,093
Yield (kg/ha), scenario 2	4,073	4,721	5,473	6,345	7,356

Edible beans Production (ton) Harvested area (ha), scenario 2 Yield (kg/ha), scenario 2	 2,806,772 2,732,793 1,027	 3,051,755 2,688,853 1,135	 3,201,945 2,588,041 1,237	 3,346,204 2,478,716 1,350	 3,499,256 2,375,729 1,473
Maize Production (ton) Harvested area (ha), scenario 2 Yield (kg/ha), scenario 2	 46,799,671 9,035,378 5,180	 50,244,799 8,357,544 6,012	 54,492,233 7,804,786 6,982	 58,690,585 7,238,288 8,108	 62,832,484 6,672,562 9,417
Rice Production (ton) Harvested area (ha), scenario 2 Yield (kg/ha), scenario 2	 10,609,382 2,052,639 5,169	 11,999,809 1,833,518 6,545	 13,446,583 1,591,087 8,451	 14,949,704 1,343,287 11,129	 16,509,172 1,104,583 14,946
Sorghum Production (ton) Harvested area (ha), scenario 2 Yield (kg/ha). scenario 2	 1,818,855 702,747 2,588	 2,095,458 809,826 2,588	 2,372,060 860,615 2,756	 2,648,663 917,407 2,887	 2,925,265 975,913 2,997
Soybeans Production (ton) Harvested area (ha), scenario 2 Yield (kg/ha), scenario 2	 54,798,752 18,974,407 2,888	 60,851,369 19,334,123 3,147	 66,624,031 19,746,675 3,374	 72,236,769 19,862,578 3,637	 77,684,660 19,853,112 3,913
Sugar cane (1) Production (ton)	 595,038,255	 668,220,66	 738,391,83	 808,553,55	 878,715,25

Harvested area (ha), scenario 2 Yield (ton/ha), scenario 2	6,914,303 86,1	8 7,169,603 93,2	4 7,315,327 100,9	7 7,396,518 109,3	1 7,422,298 118,4
Wheat					
Production (ton)	5,261,445	5,447,087	5,671,083	5,844,116	5,974,177
Harvested area (ha), scenario 2	2,047,203	1,948,666	1,851,408	1,756,009	1,662,630
Yield (kg/ha), scenario 2	2,570	2,795	3,063	3,328	3,593

Source: estimated by study team
(1) Refers to sugar cane used in the production of sugar, ethanol and other uses.

Before proceeding, it should be highlighted that the objective here is to develop an analysis concerning the harvested area needed under the higher yield scenario to achieve the same level of production estimated in section 6.3 for each of the selected crops. In order to avoid repeating this aspect, the text will simply say 'harvested area required to produce the estimated level of production' meaning the harvested area required to produce the level of production estimated earlier in section 6.3.

According to Table 11, the yields of scenario two for soybeans, sugar cane, maize and cotton are substantially higher than those of scenario one. On the other hand, the yields of wheat in both scenarios are almost the same. In the case of coffee, cassava, rice and edible beans, the yields are moderately higher in scenario two. The reasons for these differences and similarity are as highlighted above in the prospects for the higher yield scenario.

Table 11 also shows that, as expected, the total harvested area required to produce the same level of production estimated earlier is smaller under the higher yield scenario. Specifically, while under scenario one the total harvested area required to produce the estimated volume of production for 2030 is 57.5 million hectares, in the case of scenario two it is 43.8 million. Thus, with respect to the year 2030, the aggregated impact of higher yields vis-à-vis scenario one is to reduce the harvested area needed by 13.6 million hectares.

In disaggregated terms, the estimates obtained under the higher yield scenario show that, in 2030, the harvested area needed to achieve the estimated production for soybeans would be 19.8 million hectares and 7.4 million in the case of sugar cane. Maize and cotton are also envisaged to need substantially less harvested area in 2030 under scenario two vis-à-vis scenario one, i.e. 6.7 million and 581,000 hectares, respectively. The harvested areas estimated to be used by the remaining selected crops under the higher yield scenario are also relatively smaller than those associated with scenario one. As shown in Table 11, they vary between 1.7 million (coffee) and 976,000 hectares (sorghum) in 2030.

Another aspect showed by the analysis is that, in addition to being smaller than the total harvested area required under scenario one, the aggregated harvested area needed resulting from the higher yield scenario follows a downward trend during the 2010-30 period. More specifically, while under scenario one the total harvested area required to produce the estimated levels of production increases from 48 million hectares in 2010 to 57.5 million in 2030, in the case of scenario two it falls from 46.5 million hectares to 43.8 million.

This downward trend, however, is not observed in the estimates of all the selected crops. Comparing the data presented in Tables 10 and 11 it can be seen that, under both scenarios, the harvested area needed by the major producing states of rice, cotton, wheat and edible beans to produce the estimated levels of production is expected to follow a downward trend.

In contrast to the above, under scenarios one and two, the harvested area needed to produce the estimated levels of production of soybeans, sugar cane and sorghum follows an upward trajectory in 2010-30. Regarding maize, coffee and cassava, the harvested area required changes from an upward trend under scenario one to a downward trend in scenario two.

These results indicate that, unlike what is estimated for the other selected crops, soybeans, sugar cane and sorghum are envisaged to require growing amounts of harvested area under both yield scenarios to produce the estimated levels of production. Moreover, in the case of the higher yield scenario, the reduction in the harvested area of rice, cotton, coffee, edible beans, cassava, maize and wheat would more than compensate for the expansion in the harvested area of those three products in 2010-30. Therefore, under this scenario the harvested area which exceeds the amounts required by soybeans, sugar cane and sorghum could be devoted to the utilisation of other agricultural activities such as cattle raising, forest development and/or cultivation of crops not included in the study.

6.6 'Net area' required to produce the estimated level of production in the major producing states

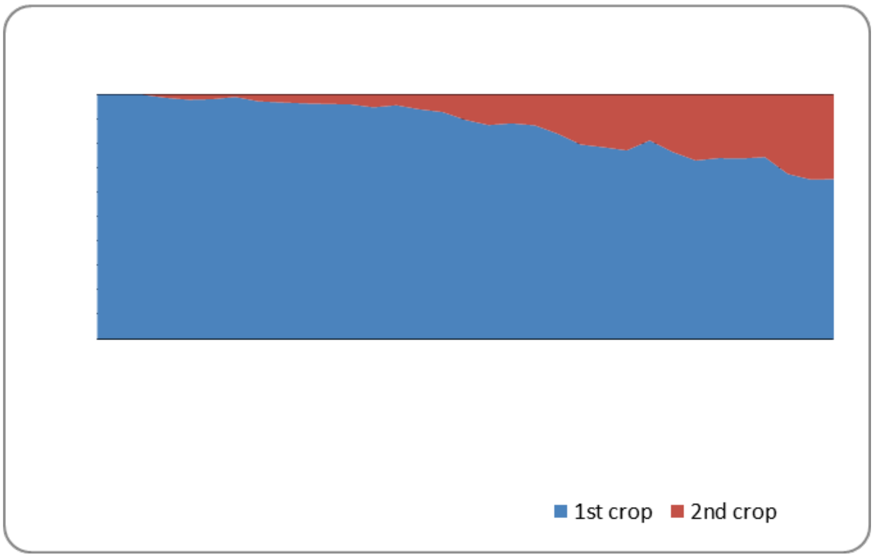
Until this point of the study, the analysis has been developed in terms of harvested area, which as indicated earlier can be considered a proxy for planted area. However, one of the characteristics of Brazilian agriculture is that part of the area used during the cropping year is utilised more than once to grow different crops in successive months of the same period. For instance, it is common to see farmers using the same area to grow soybeans from October to February/March and maize afterwards. Therefore, due to this intensification component, there is an important difference between harvested/cultivated land and the physical area used for agricultural production in this country.

Given this fact, this section provides an approximated measure of the 'net area' (i.e. excluding the intensification part) required under the two yield scenarios to produce the volume of production of the selected crops estimated earlier in section 6.3. for the groups of major producing states.

According to IBGE´s planting and harvesting calendar, most of the wheat currently produced in the country is planted in May/July, i.e. after the summer crops are grown. Likewise, the planted area with sorghum is largely concentrated in the months after the harvesting of the first crop of other products is concluded, in general soybeans (Bahia Filho et al., 2008). Maize and edible beans are grown respectively in two and three crops within the same cropping year.

As Figure 9 shows, the share of the planted area with the first crop of maize fell from 100% of the total planted area with this product in the 1978-79 cropping year to 65% in 2007-08. In the case of edible beans, the participation of the first crop in the total area planted with this product remained more or less constant in the 1985-2008 period, i.e. around 34%.

Figure 9: Brazil – planted area with maize. First and second crop within same cropping year 1976-77 – 2008-09



Source: CONAB

The above facts suggest that the 'net area' utilized to grow the selected crops in the groups of major producing states can be approximated by deducting from the total harvested area with these crops, the area used by wheat and sorghum, plus the harvested area corresponding to the second crop of maize and to the second and third of edible beans. Regarding these last two products, it is assumed that the 2006-08 average participation of the harvested area with these crops in the first cropping season will continue in 2010-30[26].

[26] According to Figure 9, the area planted with the first crop of maize has been following a downward trend. In this context, if this trajectory continues in the future, the estimates obtained here will be gradually overestimated over the years.

6.6.1 'Net area' required under scenario one

According to Table 12, the utilisation of the above procedure shows that under scenario one the 'net area' necessary to get the total volume of production of the selected crops in the groups of major producing states should be about 50 million hectares in 2030, i.e. an increase of 13.5 million hectares above the 2006 level[27]. This increase is mainly associated with an estimated expansion in the area of soybeans and sugar cane of 8.4 million and 5.2 million hectares, respectively, in the same period. Part of this expansion should be compensated for by a fall in the area of rice and edible beans. However, despite experiencing a reduction in used area, the production of these crops is expected to increase substantially in the group of major producing states in the next decades. Therefore, an expansion in the area of soybeans and sugar cane during this period should not negatively affect the output of these two major food crops. The same applies to the production of the other selected crops (Table 10). Thus, contrary to what has been argued by some authors and institutions, the threat of a food-fuel competition to food security should continue not being an issue in Brazil.

Table 12: 'Net area' needed to obtain the total level of production of the selected crops in the major producing states under yield scenario one, 2006-30

Year	Net area needed	Change in net area with respect	Grasslands area	Total cattle stock	Cattle stock in the 18 major crop-	Stocki ng rate Heads/

[27] The selection of this year as a base for comparison is justified by the fact that the only official data source available for recent information on pasture land in Brazil is the Agricultural Census of 2006. As will be seen shortly, this data is necessary for developing an analysis concerning the implications of the expansion in the 'net area' used by the selected crops to pasture area.

	(ha)	to 2006 (ha)	(ha)	(heads)	producing states (heads)	ha
2006	36,336,767		141,994,171(*)	205,886,244(**)	188,861,974	1.33
2010	40,452,821	4,116,054	137,878,117	198,896,036	182,487,113	1.32
2015	42,388,783	6,052,016	135,942,155	214,483,835	196,788,919	1.45
2020	44,924,678	8,857,911	133,406,260	228,999,762	210,107,282	1.57
2025	47,328,769	10,992,002	131,002,169	242,091,022	222,118,513	1.70
2030	49,789,025	13,452,258	128,541,913	248,894,207	228,360,435	1.78

Sources: (*) – 2006 Agricultural Census, IBGE; (**) – Produção Pecuária Municipal, IBGE; Rest of the data: estimated by the study team

The fact that under scenario one the 'net area' necessary to produce the estimated volume of production of the selected crops in 2010-30 exceeds the area currently used implies a need for additional land. The question then is: from where within the major producing states considered in the analysis would this area come from? There are several possibilities, for instance, incorporation of new land into production and utilisation of pastures, especially degraded ones.

There are various studies which assess the future expansion of soybeans and sugar cane, with analysts having several contrasting positions with respect to the area which would be used. Some groups advocate that the future expansion of these crops will imply further land clearing; others are of the opinion that it will produce major dislocation of food crops; and there are those who argue that it will take place through some dislocation of crops and significant utilisation of degraded pasture. This study agrees with the last position.

According to Santana and Cismondi (2007), soybean production in Brazil has expanded, replacing other crops and pasture land and, to a lesser degree, by absorbing ‘virgin’ areas. Although the soybean-deforestation correlation is a controversial issue, in Brazil most studies agree that soybean cultivation has mainly expanded over grassland areas, some of which itself came into existence from the conversion of forest to pasture for extensive ranching. There is therefore a wide understanding that cattle farming, especially medium- and large-scale ranching, has contributed most to deforestation but that soybeans have had an indirect impact on the clearance of forest and savannah.

This perception is based on the following: it is very difficult to clear virgin areas, especially in the Amazon, and convert them to soybeans in the same year or even in a longer period; on the contrary, it takes years for such new areas to be suitable for soybean production[28]; the virgin areas of savannah and Amazon forest that are available do not generally have the minimum infrastructure needed to gain effective returns from an agricultural activity such as soybean cultivation that requires intensive capital input[29]; and it has been estimated that during 2001-03 the conversion of pasture to cropland amounted to 5 million hectares, and to more than 3 million in 2004 (Torres Jr. *et al.*, 2004). The sum of these figures is very close to the 7 million hectares increase in Brazil´s total soybean area in the 2001-03 period.

Regarding sugar cane, the estimates obtained by the recent agro-ecological zoning for sugar cane production show that Brazil has 64.7 million hectares of suitable land for the expansion of this crop in the next years (Ministerio da Agricultura, Pecuária e Abastecimento, 2009). In 2002, there were 37.2 million hectares of pasture suitable for sugar cane expansion. These data indicate that the country does not need to incorporate new area with native cover to the productive process, nor reduce the area used for food production in order to accommodate sugar cane expansion.

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[28] However, according to Morton *et al.* (2006), a new dynamic of direct conversion of forest into cropland began to emerge between 2002 and 2003, when forest cleared for pasture dropped from 78% to 66%, while cleared forest directly converted to cropland rose from 13% to 23%.

[29] This does not generally occur in regions already occupied by cattle ranching, which tend to be well endowed logistically.

Moreover, according to Mueller and Martha (2008), sugar cane production has specificities which distinctively limit both the speed and reach of its expansion. Like other commercial crops, it requires minimal transport infrastructure to expand into new areas. Thus, it is difficult to imagine growing sugar cane in the Amazon and shipping it to processing plants in the Centre South. It is not only transportation costs that prevent this from happening, but also the fact that, after being harvested, sugar cane quickly loses much of the required qualities as a feedstock for sugar or alcohol (Sparovek *et al.*, 2008).

In addition, in settled areas such as the southwest of the state of Goiás and the 'triangulo mineiro' (triangle region of the state of Minas Gerais bordering the states of São Paulo and Goiás, having Uberaba and Uberlândia as main municipalities) structural ties linking grain and oilseed crops (especially soybeans and cotton) to industrial operations (poultry and pork enterprises grains, and oilseed processing plants) are creating difficulties for the substitution of sugar cane for these crops. As a matter of fact, in order to preserve the local value-added chains of soybeans, poultry and pork against the risk of negative externalities of sugar cane expansion in Rio Verde[30] , the mayor of this municipality approved a decree limiting the area which could be used by this crop.

As pointed out by Martha Jr. (2008), since these industries do not as a rule, directly control the production of their agricultural inputs, in a situation of persisting high prices of sugar and ethanol relative to those of soybeans, maize and beef, the pressure for the replacement of these crops by sugar cane can increase even in these regions. In this context, the first area to be displaced will probably be degraded pastures, which are quite abundant in the country. Martha Jr. and Vilela (2002) estimated that only in the 'cerrado' region 60% of the 54 million hectares of cultivated pasture show some degree of degradation.

This figure, together with the above-mentioned facts, supports the widely prevalent view that there is no reason to worry about the impact of future

[30] A major grain, cotton, poultry, pork, soybean seed, meal and oil production municipality in the state of Goias.

expansion of soybeans and sugar cane regarding land clearing pressures. The recent commitment made by the Brazilian Government at the Copenhagen climate meeting to reduce deforestation by 80% in 2020, together with the growing conscience of soybean farmers to ensure that their production is coming from settled land, reinforces further this view.

As it will be seen later, some of the measures which will be promoted by the Government to achieve the above target of reduced deforestation include the intensification of cattle-producing processes through agricultural technologies such as integrated livestock-crop systems. Among other aspects, the utilisation of those systems should contribute to employing relatively less land, thus leaving more area to be used by other agricultural productive activities.

In this regard, Martha Jr. and Vilela (2010) examined the potential sparing-land effect arising from integrated crop-livestock system adoption in the Brazilian Cerrado. Considering the technical coefficients provided by research, and field observations concerning crop/pasture ratio during the rainy season, and stocking rates commonly practised in mixed farms, they found that the sparing-land effect would vary from 1.9 to 8.4 hectares spared per hectare of improved pasture. Assuming that approximately 10% of the existing pastures in the 'cerrado' (the estimate considered in general is 54 million hectares) show low stocking rates (0.4 head/ha), their improvement through the use of integrated crop-livestock systems under a stocking rate of 2 animals/ha and 50% of the area with pastures in the summer, would result in a land-sparing effect of about 3.9 million hectares. This effect corresponds to approximately 75% of the estimated area needed by sugar cane expansion during the 2010-30 period.

Besides sharing the above arguments, it is expected that the conversion of low productivity pastures to soybeans and sugar cane at the expected rates would not necessarily displace beef and dairy herds from the current main producing groups of states. Several technologies are available and being developed, which can contribute to recovering pasture productive capacity, improve soil fertility and increase the stocking rates and animal productivity. Moreover, the policies that the Brazilian Government is designing to achieve the target of reducing deforestation by 80% by 2020, aim at contributing to avoid that process.

Considering the above expectation, an assessment was made about the implications that the additional ‘net area’ needed under the first yield scenario would have on the availability of pasture in the 18 major producing states of the selected crops during the next decades. As presented in Table 12, assuming that the additional ‘net area’ needed would come mainly from degraded pastures, the total area with planted and natural pasture in the 18 major producing states should follow a downward trend in 2006-30, reducing from 142 million hectares to 129 million. As highlighted earlier, this reduction is mainly attributed to an expected expansion in the area with soybeans and sugar cane.

The outlook of the Brazilian production of beef for the next two decades indicates that the national output of this product should increase from 9.2 million metric tons of carcass equivalent (MMTCE) in 2010 to 14 MMTCE in 2030. Given this outlook, the cattle stock needed to produce the estimated levels of beef production for this period was determined through a cattle population dynamics model[31]. The technical coefficients used in this model are as presented in Table 13[32].

The analysis also considered productive gains of the cattle stock in meat production through linear variation of the following production indices during the simulation period (2006-30): birthrate; carcass weight, proportion of slaughter of males, and mortality rate of cattle population[33].

There is a major difference between the data provided by IBGE and the Agricultural Census on Brazil´s cattle stock. According to the Agricultural

[31] Beef production was taken as the drive for cattle population because the number of animals for meeting that demand overtook by far the animals required to meet the dairy products demand. It was also assumed that the milking cows and calves supply the beef sector.

[32] The model also considered the following coefficients: cattle:bull relation of 25:1; proportion of heifers in gestation (1 to 2 years): 15%; and proportion of heifers in gestation (2 to 3 years): 60%.

[33] Birthrate: from 58% (2006) to 70% (2030). Carcass weight: from 100% (2006) to 112.7% of the values presented in Table 13. Proportion of slaughter of males 1 to 2 years old: from 10% (2006) to 40% (2030). Mortality: from 100% (2006) to 75% (2030) of the figures presented in Table 13.

Census of 2006, the total cattle stock of the country in that year was 171.6 million animals. In contrast, the figure provided by IBGE´s 'Produção da Pecuária Municipal - PPM' (Municipal Livestock Production) for that same year is a total of 205.9 million animals.

Table 13: Technical coefficients used in the cattle population dynamics model

Category	Mortality rate (% of animal population per year)	Carcass Weight (kg)	Slaughter rate (% of animal population per year)	Average Age of animals (months)
Steers and heifers up to 1 year old	4.0	15	2.0	6
Steers: 1 to 2 years old	2.0	220	10.0	18
Steers: 2 to 3 years old	2.0	230	84.0	30
Steers: 3 to 4 years old	1.0	240	95.0	42
Steers: more than 4 years old	1.0	240	98.5	-
Heifers: 1 to 2 years old	3.0	155	2.0	18
Heifers: 2 to 3 years old	3.0	180	35.0	30
Bulls	1.0	290	NA	-
Cows	1.5	195	Adjusted by the model[34]	-

Source: assumed by the study team

The model was run using both of these data and with the same technical coefficients. The results showed a perfectly adjusted model when the PPM data was used. The same did not happen when taking the Agricultural Census data[35]. A significant deficit in the volume of beef production was observed for

[34]The slaughter of cows was adjusted in order to obtain the minimum squared sum of the difference between supply and demand during the period under consideration.
[35] Model fitting with Census data would demand overestimated technical coefficients.

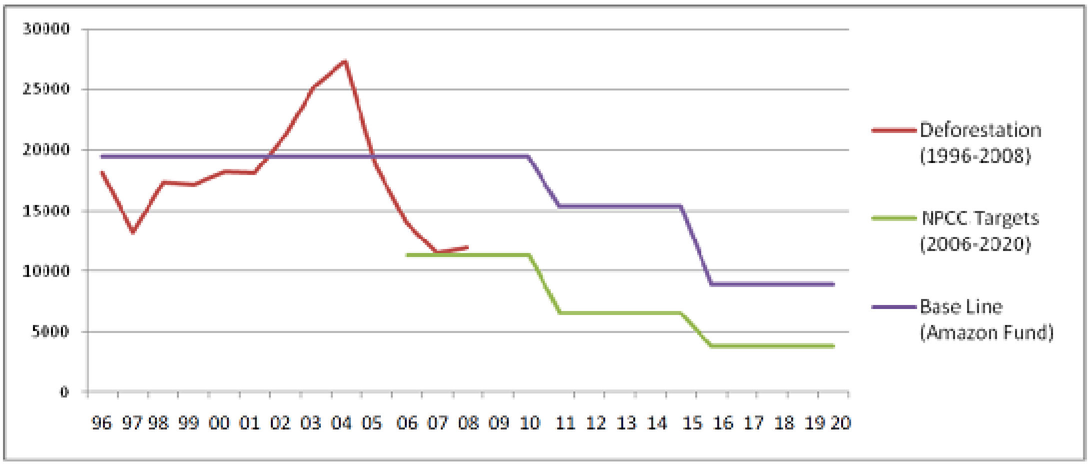
various years of the 2006-30 period vis-à-vis the estimated beef output estimated earlier (Table 2). In this context, the estimates resulting from the utilisation of PPM´s data were chosen to be used here.

According to Table 12, in 2030 the national beef production will be provided by a cattle stock of 249 million animals. In comparison to the existing situation in 2006, this stock represents an increase of 43 million animals. Table 12 also shows that, in 2006, the cattle stock located in the 18 major producing states considered in the previous analysis participated with approximately 92% of the total population of cattle in Brazil. Assuming that this share will remain approximately the same in the next decades, the 18 major producing states of the selected crops should contribute with 228 million animals to the domestic production of beef in 2030. The cattle stock estimated for these states, together with the pasture area that they should have after adjusting for the impact of the expected area expansion of the selected crops, results in stocking rates between 1.31 and 1.78 heads per hectare in 2010-30. The achievement of these rates during this period is feasible.

There are several facts which suggest that cattle raising in Brazil is in a continuous intensification process, hence moving towards higher stocking rates. As highlighted earlier, there is a major understanding among various institutions, analysts and civil society that cattle raising has been strongly correlated with the opening of new agricultural land. Given this understanding, the recent reductions in deforestation together with the substantial growth of the cattle population, and Government initiatives such as the National Plan on Climate Change which seeks to reduce substantially the average illegal deforestation in 2010-20 in relation to the average rate recorded in 1996-2005 (Figure 10), points out in the direction of increasing intensification of livestock activities.

Figure 10: National Plan on Climate Change: deforestation targets,

2006-20 (Values in square kilometres)

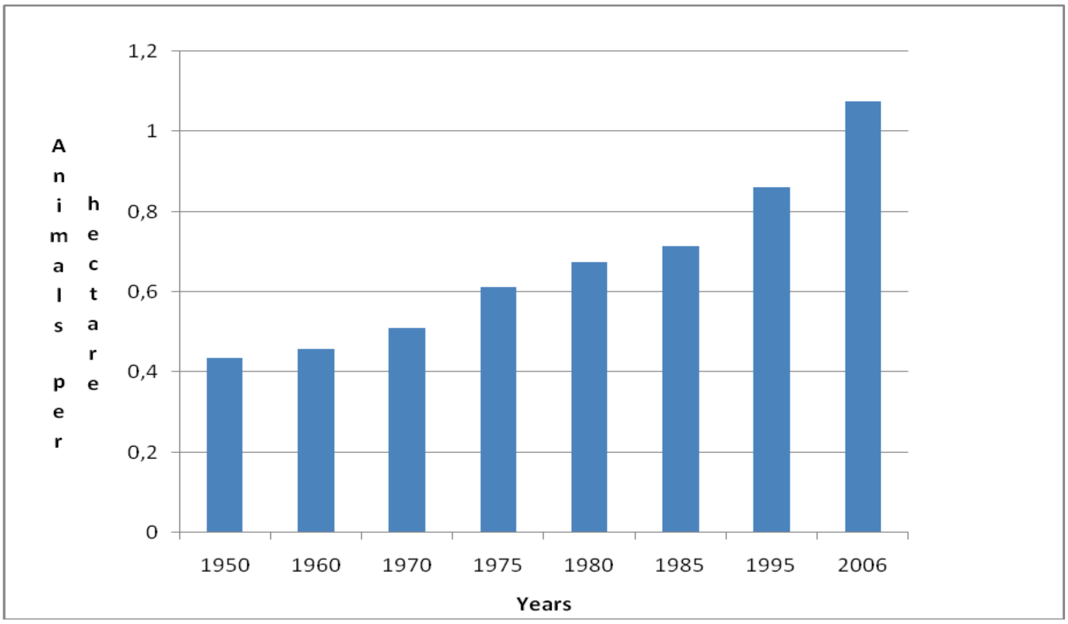


Source: Government of Brazil, Inter-ministerial Committee on Climate Change, National Plan on Climate Change, December 2008

This trend towards raising more cattle in relatively less area is also corroborated by the expansion in the production of fodder seeds as well as by the increase in the stocking rate during the 1960-2006 period. According to the Association of Seed Growers of the State of Goiás (AGROSEM-GO), a major cattle raising state, the production of fodder seeds by its members increased from 24,500 thousand tons in 2002-03 to 57,000 thousand in 2006-07. Regarding the increase experienced by the stocking rate, Figure 11 shows that the number of animals per hectare expanded from 0.46 in 1960 to 1.1 in 2006.

Various factors contributed to this increase including major technological developments in the areas of animal health, nutrition, breed improvement, generation of fodder and meadow grasses cultivars, pasture and livestock management, and cattle-raising systems. The adoption of the new technologies was and continues to be strongly motivated by the stabilisation of the economy. Specifically, in view of the monetary stabilisation, a large number of cattle farmers decided to leave behind the old practice of speculative production via buying and selling of cattle as a mean of making profits, and invest in production systems with greater productive efficiency.

Figure 11: Average stocking rate of pastures in Brazil, 1950-2006



Source: Agricultural Census, various years - IBGE

Further to the above, there are at least three other elements which suggest an upward trend towards greater intensification of cattle-raising in the country: (a) the Government decision to promote an increased use of integrated livestock-crop-forest systems, and the recuperation of degraded pasture as means to meeting its emission reduction targets; (b) the requirement imposed by several importers that the beef exported by Brazil should have a certificate of origin confirming that the product is not coming from a recently deforested area; and (c) a significant expansion in beef cattle feedlots. According to the 2000 and 2009 'Anuário da Pecuária Brasileira – Anualpec' (Yearly Book on Brazilian Livestock) the number of beef cattle in feedlots increased from 755,000 animals in 1990 to 2.8 million in 2008. A large part of this increase took place in the states of São Paulo and Goiás, where the agricultural frontier has nearly reached its limit.

6.6.2 'Net area' required under scenario two

Following the same procedure employed on the above section, it is estimated that under the higher yield scenario, the total 'net area' needed at the major producing states for production estimates presented in section 6.3 is expected to increase from 36.3 million hectares in 2006 to 37.6 million in 2030 (Table 14). The difference between these estimates, i.e. an additional 1.2 million hectares, suggests that under this scenario, the ‘net area’ used by the selected crops in 2006 by the 18 states would be almost sufficient to generate the volume of production estimated for 2030. In other words, substantially less degraded pasture would be needed to accommodate the expansion of crop area.

Table 14: ‘Net area’ needed to obtain the total level of production of the selected crops in the major producing states under yield scenario two, 2006-30

Year	Net area needed (ha)	Change in net area with respect to 2006 (ha)	Grasslands area (hectare)	Total cattle stock (heads)	Cattle stock 18 major crop producing states (heads)	Stocking rate heads/ha
2006	36,336,767		141,994,171(*)	205,886,244(**)	188,861,974	1.33
2010	39,152,031	2,815,264	139,178,907	198,896,036	182,487,113	1.31
2015	38,933,116	2,596,349	139,397,822	214,483,835	196,788,919	1.41
2020	38,831,558	2,494,791	139,499,380	228,999,762	210,107,282	1.51
2025	38,251,613	1,914,846	140,079,325	242,091,022	222,118,513	1.59
2030	37,551,966	1,215,199	140,778,972	248,894,207	228,360,435	1.62

Sources: (*) – 2006 Agricultural Census, IBGE; (**) – Produção Pecuária Municipal, IBGE; Rest of data: estimated by study team

Assuming that the above would indeed be the case, the area with pasture in the 18 major producing states should fall from 142 million hectares in 2006 to 140.8 million in 2030 under scenario two compared with 128.5 million in the case of scenario one. This relatively larger pasture area under scenario two implies a lower intensification level with stocking rates of 1.62 heads per hectare in 2030 against 1.78 heads/ha in scenario one.

In summary, yields such as the ones expected under scenario two, contribute to achieving reasonably high levels of crop production (Table 2) in the set of major producing states in the next 20 years without affecting negatively their biodiversity resources. In addition, they lessen the competition for land among the selected crops and put less pressure on increasing the productivity of pastures to carry the estimated cattle stocks required to supply the production of beef envisaged for 2010-30.

6.7 Meeting additional 'net area' requirements with conversion of forest areas into cropland: relaxing the previous assumption

The previous two sub-sections were developed assuming that the additional 'net area' needed to produce the estimated level of crop production in the major producing states would come mainly from two sources: degraded pasture and land resulting from the dislocation of some crops. Despite the arguments presented earlier concerning the reasons for this assumption, it is legitimate to ask what would be the implications if it were relaxed. In other words, what could be the implications for society´s welfare if, in addition to dislocating crops and especially degraded pasture, the additional 'net area' needed comes also from the incorporation of areas with natural cover, particularly forests? The paragraphs below address this question.

There is no available information on what could be the contribution of degraded pasture, forest area and land from dislocated crops to meet the expected expansion of crop production in the next decades. However, regarding the areas with forest it is reasonable to assume that some part could come from forest vocation lands (FVL)[36] and another from agriculture vocation lands (AVL)[37].

According to Nascimento (2005) there are 16 different scenarios that may be observed when deforestation takes place in these types of lands. Twelve of them result in negative consequences for society, but for four scenarios the conversion of forest into cultivated area brings a positive impact on society's welfare (Table 15).

This author explains that, if the deforested area is not inside an effective protected area established to preserve genetic resources *in situ*, the real importance of deforestation depends on three factors: the use that the land will have afterwards, its vocation, and the greatest land rent[38] that the land can yield. Given these conditions he highlights that deforestation may be considered 'good' or 'bad'. 'Good' deforestation refers to the maximisation of land rent at same time that negative soil- and water-related externalities (S&WRE) are not present. 'Bad' deforestation, in turn, means that either land rent is not being maximised or that S&WRE are affecting adversely society, or both.

As shown in Table 15, most deforestation scenarios result in a net welfare loss for society. However, deforestation is 'good' in the cases where the new land use generates the greatest land rent and is sustainable, i.e., does not generate S&WRE. This happens for instance, when a natural forest covering a forest vocation land is deforested, and the land is used for forest use when it

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[36] According to Nascimento (2005), forest vocation lands (FVL) are those that, due to their physical site features such as soil, topography, and the rainfall it receives, *should* be kept under forest cover or other sustainable land use if soil- or water-related negative externalities are to be avoided. FVL classification does not depend on the type of cover the land actually has, nor does it depend on the requirements it may have for agriculture crop or forest production. Therefore, lands with no forest cover or use can still be classified as FVL if their physical features so indicate; while lands covered with forest may not be FVL.

[37] According to Nascimento (2005), agriculture vocation lands (AVL) are those that, due to their physical site features, such as soil, topography, and the rainfall it receives, do not require exceptional protective measures to avoid soil- and water-related negative externalities. AVL classification does not depend on the type of cover the land actually has, nor does it depend on the requirements it may have for agriculture crop or forest production. Therefore, lands with forest cover or use can still be classified as AVL if their physical features so indicate; while lands not covered with forest may not be AVL.

[38] Land rent is the economic rent of land as a factor of production.

is the one that generates the greatest land rent (scenario H1). The same can also happen when a natural forest covering an agriculture vocation land is deforested, and the land is used for sustainable agriculture when this land use generates the greatest land rent (scenario I3).

Table 15: Social desirability of deforestation according to land vocation, use, and land rent

	Forest vocation land		Agriculture vocation land	
Greatest land use rent got by	Forest use (H)	Ag. use (I)	Forest use (J)	Ag. use (K)
Forest use (1)	Good	Bad	Good	Bad
Forest cover (2)	Bad	Bad	Bad	Bad
Sustainable agricultural use (3)	Bad	Good	Bad	Good
Unsustainable agricultural use (4)	Bad	Bad	Bad	Bad

Source: Nascimento, 2005

Nascimento (2005) also reviewed the issue of biodiversity loss due to deforestation. He concluded that isolated patches of forests in individual landowners' properties have a very limited and questionable role in assuring the preservation of genetic resources. His findings corroborate the view that the most effective way to achieve the social goal of species preservation is to have in place a well-designed national system of protected areas where species are preserved as parts of larger ecosystems.

In summary, according to the above, the possibility that the additional 'net area' needed to produce the estimated level of crop production may also come from deforestation does not need to affect negatively society´s welfare. As highlighted above, the impact of deforestation on society´s welfare depends on several factors such as land vocation, the use that the land will have after being deforested, and the greatest land rent that it can yield. An appropriate policy framework can help the country to assure that only 'good' deforestation, if any, happens. In addition, genetic resources preservation is ecosystem specific and not site specific. Thus to ensure the preservation of these resources it is not feasible simply to preserve any piece of forest ecosystem regardless of the level of use it has had or its size.

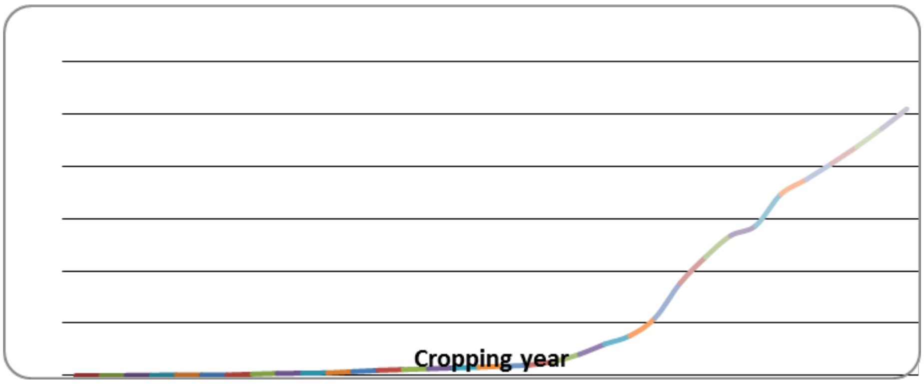
7. Future expansion of Brazilian agricultural production and sustained environment quality: what could be expected?

Agricultural production in Brazil has been experiencing a major growth since the late 1970s as a result of several factors, especially productivity increase brought by the use of high-level technologies. Area expansion has also contributed to this process; however, to a lesser extent. As argued by this and other studies, the perspective for the next 20 years is that the national output of this sector should continue to grow at high rates, placing the country in a more notable position in terms of world supply of food, fibres and biofuel feedstocks. This perspective poses several questions: among them, what implication would it bring to the trade-off between production expansion and environment quality?

The response to this complex question is not obvious. It involves the interaction of several elements including the environmental sustainability nature of agricultural technologies and the orientation of public policies and programmes. Nevertheless, as highlighted below, there is a growing trend towards the use of environmentally friendly technologies and the adoption of policies with positive contribution to environmental sustainability. The extension of this trend into the next decades, together with the growing requirements of Brazilian environmental legislation, should contribute to expand crop and livestock production with reduced pressure on environment quality loss.

Zero-tillage. Since the early 1970s Brazilian farmers have been using zero-tillage as part of their agricultural production systems. Among other characteristics, this technology prevents soil erosion, allows greater rainfall infiltration, boosts soil´s organic matter content and reduces the amount of carbon dioxide released into the air. Between 1972 and 1991, zero-tillage expanded slowly, reaching 1 million hectares at the end of this period. After this initial phase, however, the area cultivated with this technology expanded exponentially, totalling about 26 million hectares in 2006 (Figure 12), i.e. 46% of the total cultivated area with annual crops. This trend is expected to continue in the next years bringing major benefits to farmers and improving environmental quality. In this regard, the Low-Carbon Agriculture Programme recently announced by the Brazilian Government expects to expand the area cultivated with zero-tillage by 8 million hectares during the 2010-20 period. This should reduce the emission of carbon dioxide by 14,640 metric ton equivalent by 2020.

Figure 12: Brazil: cultivated area with zero-tillage, 1972-2006



Source: Zero-tillage Farmers´Association

Integrated crop-livestock systems. The set of environmentally friendly technologies with high productivity and competitive costs used in Brazil was further broadened in the mid 1990s with the introduction of the integrated crop-livestock system. It involves the use of zero-tillage together with a crop-and-pasture phase in rotation. The environmental advantages of this system, which enables a sustainable development of crop and livestock activities in the same area, includes the improvement of soil structure, reduction of the overall use of agrochemicals, retention of soil moisture and weed suppression by shading. The main land-use crops utilised in this system are corn and soybeans. The cultivation of this last product contributes also to improving environment quality through the biological fixation of nitrogen into the soil. The amount of nitrogen introduced by soybeans in the Brazilian production systems is twice the amount of all nitrogen contained in mineral fertilisers used in agriculture[39].

According to a recent World Bank study[40], in 2008 approximately 5.5 million hectares were cultivated with the integrated crop-livestock system. The Brazilian Government, through its Low-Carbon Agriculture Programme, is promoting the expansion of this system by 4 million hectares in the next ten years. This should contribute to reducing the emission of greenhouse gases by 27,117 metric ton equivalent between 2010 and 2020.

Genetically modified crops. In addition to the above farming practices, the cultivation of genetically modified crops in Brazil has been expanding significantly, reducing the environmental footprint of agriculture. In 2009, the area cultivated with the three main biotech crops grown in this country (soybeans, corn and cotton) increased 5.6 million hectares vis-à-vis the previous year totalling 21.4 million hectares[41] (i.e. 58% of the total cultivated area with these three crops). As a result of this expansion, Brazil became the second largest grower of biotech crops in the world after the United States. According to Agroconsult, in the 2009-10 cropping year, 58% of the total domestic production of soybeans was grown with transgenic seeds. The perspective for the next decades is that the utilisation of genetically modified crops should continue to grow, contributing to increased yield, reduction in pesticide usage and less CO_2 emissions due to fewer sprays of insecticide and herbicide.

Public policies and programmes. The development and use of technologies with positive outcomes for environmental sustainability has been accompanied by the implementation of policies and programmes with significant concern for improving environmental quality. Among others, these policies include the National Policy on Climate Change and the Agro-

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[39] Mello, I. and van Raij, B., No-till for Sustainable Agriculture in Brazil, Proceedings of World Association of Soil and Water Conservation, April 2006.

[40] Barioni, L. G.; Martha Jr.; G. B.; Sainz, R. D., Emissões do Setor da Pecuária, In: Gouvello, C., Estudo de baixo carbono para o Brasil. Banco Mundial , 2010. (Theme D, Technical Report, Compact Disk)

[41] International Service for the Acquisition of Agri-Biotech Applications, Global Status of Commercialized Biotech/GM Crops: 2009 – the first fourteen years, 1996 to 2009, Brief 41, 2009.

ecological Zoning for Sugar cane Production. The first aims at reducing illegal deforestation. The second supports the planting of sugar cane in suitable areas and prohibits its cultivation in several others, including environmental protected areas and the Amazon and Pantanal biomes.

Regarding agricultural public programmes with focus on environmental issues, at least three are notable: the Low-Carbon Agriculture Programme, which promotes the use of several environmentally friendly farming practices including recovery of degraded pastures, soil fertilisation and conservation practices; the Stimulus Programme for Sustainable Agricultural Production (PRODUSA) and 'Operação Arco Verde' (Green Arc Operation). PRODUSA[42] provides agricultural credit for both production of organic food and investment in sustainable agricultural practices. The Green Arc Operation in turn offers sustainable production alternatives to municipalities with large deforestation records. Embrapa participates in this multi-institutional effort, providing technologies that can be used in these localities.

In summary, the expected expansion of agricultural production in Brazil during the next 20 years draws special attention to the implications this process could bring to the environment. This challenge is quite apparent to the country, as is evidenced by the various measures that have been taken by different institutions and economic agents, some of which were highlighted above. This growing consciousness and actions should continue in the next years limiting negative impacts of production growth on the environment.

8. Climate change, harvested area and crop production in the major producing states[43]

[42] This programme has a budget of US$ 571 million to fund its loans in 2010.

[43] This chapter was developed by Rosana do Carmo N. Guiducci, Eduardo Assad Delgado and Giampaolo Q. Pellegrino.

Most discussions on climate change highlight that agricultural production and food security may be severely affected if nothing is done to change the trend towards a global warming. Assuming that despite this warning no actions are taken, this chapter estimates the impacts which temperature levels expected by scenario A2 of IPCC could have on the estimated harvested area and volume of production presented earlier (Chapter 6). Unlike a previous study undertaken by Assad et al. (2008), the analysis here is carried out with respect to the groups of major producing states of the selected crops.

The methodology employed to pursue this objective included the use of a Climatic Risk Zoning methodology developed by Embrapa and adopted by the Ministry of Agriculture, Livestock and Supply of Brazil since 1996 for the formulation and implementation of public policy. This methodology and software assess the climatic risk of growing about 30 crops in more than 5,000 Brazilian municipalities. In this context, it contributes to knowing which crop to grow, where and when.

Starting from the climatic risk zoning established for 2010 (base year), agricultural scenarios were developed for the selected crops based on climate change conditions defined by scenario A2 of IPCC´s fourth assessment report (AR4). Specifically, climate scenarios for 2020 and 2030 were simulated at state level for each of the selected crops, considering a rise on average world temperatures between 2ºC and 5.4ºC until 2100[44]. These simulations were carried out using the PRECIS System (Providing Regional Climates for Impacts Studies) from Hadley Center, and A2 scenarios as the input for the climate risk zoning model. It allows the verification of the impact that projected temperature rise may have on suitable areas for cultivation with a 50km x 50km downscale resolution.

The application of the above methodology shows that a climate change of the magnitude assumed by scenario A2 of IPCC could significantly affect the areas with low risk for growing some of the selected crops in the next two decades. This could take place because a rise in the temperature would

[44] States from the Amazon region were not included in this process due to the absence of agricultural climatic risk zoning and environmental restrictions.

increase the evapo-transpiration and consequently could lead to a more probable soil water deficit scenario, which in turn would promote a reduction in the areas with low climatic risk. In this context, the area with low risk for growing wheat and coffee in the main producing states may suffer a major reduction between the base year and 2030, i.e. 36% and 25% respectively (Table 16).

Table 16: Impact of climate change on low climatic risk areas for cultivating the selected crops % change with respect to base year (2010)

Crops	% change between 2010 and 2020	% change between 2010 and 2030
Cassava	2.82	7.08
Coffee	-19.10	-24.64
Cotton	-0.60	-1.98
Edible beans	-1.34	-3.09
Maize	-0.28	-0.75
Rice	-1.89	-2.70
Sorghum	-0.0005	-0.14
Soybeans	-3.03	-5.26
Sugar cane	0.08	1.21
Wheat	-17.48	-36.34

Source: Estimated by the study team

Wheat is mostly produced during the winter in the states of Rio Grande do Sul and Paraná. Thus, an increase in the average temperature may raise the water deficit and, consequently, reduce the area with low risk for growing this crop in these states.

Coffee production in turn is concentrated in three major producing states: Minas Gerais and São Paulo - from where most of the *Coffea arabica* comes from - and Espírito Santo, the main producer of *Coffea canephora* in the country. According to the simulated conditions for growing coffee in these states under a context of rising average temperatures, the area suitable for undertaking this activity is estimated to drop in Minas Gerais and São Paulo and expand in Espírito Santo. The net effect of these changes, however, would be a significant reduction in the low-risk area for cultivating this crop. Therefore, if no mitigation measures are taken, the low-risk area for growing *Coffea arabica* could register a significant loss in the next decades.

The area with low climatic risk for cultivating soybeans in the major producing states of this crop is also estimated to accumulate a significant reduction between 2010 and 2030, i.e. 5%. This reduction would take place in all five major producing states of this crop, but especially in Rio Grande do Sul, Paraná and Mato Grosso do Sul, where the impacts of a climate change on this product are expected to be greater[45].

Table 16 also shows that, under IPCC's A2 scenario, the low-risk areas for growing cassava and sugar cane in the respective groups of major producing states could increase progressively in the next two decades, reaching an accumulated expansion of 7% and 1% respectively by 2030.

The group of major producing states of cassava is comprised of 12 states situated in different regions of the country (Table 8). In a context of rising world average temperatures, the low-risk areas for growing this crop would expand especially in the states of Rio Grande do Sul, Paraná, Minas Gerais, Maranhão, Pará and Amazonas. This would more than outweigh the reductions which would take place in São Paulo, Santa Catarina and four major producing states located in the Northeast region[46].

[45] According to Assad *et al.,* the area with low climatic risk for growing soybeans in the cerrado region of Bahia, may also be substantially affected by a climate change in the next years. However, since Bahia is not part of the group of states that together accounted for 80% of soybean production in 2004-08 it was not considered in this analysis.

[46] These states are Bahia, Ceará, Pernambuco and Rio Grande do Norte.

The expansion in the area suitable for growing sugar cane could result from a substantial increase in Paraná and a small growth in São Paulo. The increase in the areas with low climatic risk to grow this crop in these states would more than compensate for reductions in the other major producing states, Alagoas and Minas Gerais.

Regarding rice, maize, edible beans, cotton and sorghum, Table 16 shows that the impact of a climate change on the areas with low risk for producing them in the respective major producing states would be minor.

The results presented above coincide with those obtained by Assad *et al.* (2008), in terms of the direction of the change which could take place in a situation of rising temperatures, i.e., expansion or reduction in the areas with low climatic risk. Nevertheless, there are some differences regarding the magnitude of the changes. The reasons for these differences are associated mainly with the following facts: utilisation of different climatic risk zoning base year - Assad *et al.* (2008) used 2006, while this study considered 2010; and the number of states covered by the analysis - Assad *et al.* (2008) took into account a relatively large number of states when here the assessment is limited to the group of major producing states.

Up to this point, the analysis has been focused on the impacts which IPCC´s scenario A2 could have on the areas with low climatic risk to grow the selected crops in the major producing states. The next section extends this assessment to the effects that a climate change of the magnitude assumed in this scenario could have on the estimated harvested area and production obtained earlier for the groups of major producing states (Chapter 6). Therefore, it may contribute to a better appreciation of the effects that a climate change could have in the future if no mitigation measures are taken.

8.1 Impacts of climate change on the estimated harvested area of the selected crops, 2010-30

Considering the information provided in Table 16, the annual average growth rate of the areas with low climatic risk for cultivating the selected crops was calculated based on the 2010 and 2030 estimates of suitable areas. The application of these growth rates to the estimated harvested area of the selected crops provides an approximation of the land which would be harvested with these crops under the context of IPCC´s A2 scenario.

The above procedure was applied to the estimates of harvested area associated with yield scenario one and two. It was also used to assess the impact which a climate change could have on the estimated volume of production of the selected crops. In both cases the analysis was carried out in relation to the groups of major producing states.

Before presenting the obtained results, it should be noted that the impact of a gradual rise in the temperature on harvested area and on crop production is viewed as a cumulative process. Specifically, as time goes by, the rise in temperature changes the amount of area suitable for growing a given crop in a cumulative way, i.e. by adding an additional reduction (assuming that the impact is negative) to the area lost in the previous periods. This process is reflected in the data presented in the next tables: in particular, in the line which shows the accumulated change of the variable under consideration between 2010 and the year indicated in the column of the table. Therefore, as can be seen, the estimates on this line increase along the period until 2030. The figure corresponding to this year shows the total change accumulated between the base year and 2030.

8.1.1 Impacts on the estimated harvested area of the selected crops under yield scenario one

According to Table 17, the impact of the climate change in this case would be to reduce substantially the harvested area with wheat and coffee in the respective groups of major producing states during the next two decades.

The first of these crops would experience an accumulated loss of 828,000 hectares of harvested area between 2010 and 2030; coffee, in turn, would lose a total of 509,000 hectares during the same period. Compared to the estimated harvested area in the base year, these reductions correspond to accumulated losses of 41% and 29%, respectively. Given these results, wheat and coffee are the crops which would be most affected by the climate change in terms of estimated harvested area.

Besides these crops, soybeans would also be significantly affected by the climate change under consideration. The estimated harvested area with this crop would reach an aggregated reduction of 1.2 million hectares in the major producing states by the end of 2010-30, i.e. an accumulated loss of 6.3% in relation to the estimated harvested area for 2010.

In contrast to the above, a rise in world temperatures as defined by IPCC's A2 scenario would result in an expansion in the harvested area with cassava and sugar cane in the groups of major producing states during the next decades. As Table 17 shows, by the end of the 2010-30 period, cassava would have accumulated an additional 107,000 hectares of harvested area in six of the twelve major producing states of this crop: Rio Grande do Sul, Paraná, Minas Gerais, Maranhão, Pará and Amazonas. The corresponding figure for the aggregated expansion of the harvested area with sugar cane in that same period is relatively small: 1.5% of the estimated harvested area for 2010.

The harvested area with rice, maize, edible beans, cotton and sorghum is estimated to suffer marginal reductions in the major producing states of these crops under a situation of higher temperatures.

In summary, under yield scenario one, the impact of a climate change would be to reduce the harvested area with grains[47] by a total of 2.3 million hectares between 2010 and 2030. Fifty four percent of this reduction would come from reductions in the harvested area with soybeans, 36% from wheat and the rest from the remaining grains considered. Coffee would register a total harvested area loss of 509,000 hectares during that same period, and sugar cane and cassava would experience accumulated increases of 103,000 and 107,000 hectares respectively. Therefore, while wheat and coffee would be the crops most affected by the climate change in terms of reductions in their respective harvested areas, soybeans would be the crop contributing most to the total reduction in the harvested area with grains.

[47] The set of grains considered here comprise soybeans, rice, maize, edible beans, cotton and sorghum.

Table 17: Impact of climate change on the estimated harvested area of selected crops under yield scenario one – Groups of major producing states, 2010 –30

Crop	2010	2015	2020	2025	2030
Cassava					
Harvested area under higher average temperatures (ha)	1,535,719	1,555,880	1,570,750	1,585,659	1,600,606
Accumulated expansion along the period in relation to base year (ha)		26,470	53,193	80,171	107,404
Coffee					
Harvested area under higher average temperatures (ha)	1,757,431	1,759,110	1,785,222	1,811,088	1,836,708
Accumulated reduction along the period in relation to base year (ha)		-124,526	-250,919	-379,161	-509,235
Cotton					
Harvested area under higher average temperatures (ha)	858,542	763,318	860,702	794,842	819,555
Accumulated reduction along the period in relation to base year (ha)		-4,112	-8,244	-12,319	-16,417
Edible beans					
Harvested area under higher average temperatures (ha)	2,765,625	2,697,898	2,634,170	2,571,167	2,508,897
Accumulated reduction along the period in relation to base year (ha)		-21,395	-42,288	-62,683	-82,586
Maize					
Harvested area under higher average temperatures (ha)	9,556,993	9,645,770	9,828,376	9,998,428	10,164,245
Accumulated reduction along the period in relation to base year (ha)		-17,942	-36,225	-54,833	-73,756

Rice					
Harvested area under higher average temperatures (ha)	2,019,355	1,845,283	1,660,498	1,462,232	1,250,486
Accumulated reduction along the period in relation to base year (ha)		-13,134	-25,037	-35,617	-44,782
Sorghum					
Harvested area under higher average temperatures (ha)	726,726	834,522	942,368	1,050,213	1,158,059
Accumulated reduction along the period in relation to base year (ha)		-268	-574	-915	-1,293
Soybeans					
Harvested area under higher average temperatures (ha)	19,784,993	21,067,070	22,806,297	24,599,344	26,374,328
Accumulated reduction along the period in relation to base year (ha)		-273,155	-571,571	-894,613	-1,241,848
Sugar cane (1)					
Harvested area under higher average temperatures (ha)	7,001,268	7,784,561	8,518,456	9,252,108	9,985,760
Accumulated expansion along the period in relation to base year (ha)		22,495	47,210	74,129	103,252
Wheat					
Harvested area under higher average temperatures (ha)	2,040,396	1,907,162	1,820,564	1,735,042	1,650,594
Accumulated reduction along the period in relation to base year (ha)		-221,785	-433,632	-635,663	-828,022

Source: Estimated by the study team

(1) *Refer to sugar cane used in the production of sugar, ethanol and other uses.*

8.1.2 Impacts on the estimated harvested area of the selected crops under yield scenario two

Regarding these impacts, Table 18 shows that as expected, they are relatively smaller than those obtained under yield scenario one. Nevertheless, the effects are still quite substantial in the case of wheat, coffee, soybeans and cassava.

As can be seen, under yield scenario two the impact of the climate change would be to reduce the harvested area with wheat by 40% during the 2010-30 period compared to 42% if yield scenario one is considered.

A similar result is observed in the case of coffee (i.e. an aggregated reduction of 27% and 29% by 2030 respectively, under yield scenario two and one) as well as with all other selected crops.

The closeness of these results suggests that the difference between the yields of scenario one and two does not matter much in terms of the impact produced by the rise in temperatures. Perhaps this could be a confirmation that a sustained rise on average temperatures would affect in the same way areas with different yield levels.

8.2 Impacts of climate change on the estimated production of the selected crops, 2010-30

Besides examining the impacts of climate change on harvested area, an analysis was also carried out to assess the effects which this phenomenon could have on the estimated production of the selected crops in the groups of major producing states. In this regard, the annual average growth rates of the areas with low climatic risk for production calculated in the previous section (Table 16), were applied to the respective levels of production estimated earlier for each year of the 2010-30 period (section 6.3).

The results of this procedure indicate that, mirroring the estimated impacts of the climate change on harvested area, a gradual rise in world average temperatures could reduce substantially the production of several selected crops in the next two decades (Table 19). Wheat and coffee could accumulate aggregated losses in production of 48% and 35% respectively, in the major producing states by 2030 in comparison to 2010. Soybeans in turn, could experience an accumulated loss of 3.6 million tons by the end of the 2010-30 period. Compared with the estimated production for 2010, this reduction corresponds to approximately 7%.

Table 18: Impact of climate change on the estimated harvested area of selected crops under yield scenario two - Groups of major producing

Crop	2010	2015	2020	2025	2030
Cassava					
Harvested area under higher average temperatures (ha)	1,528,099	1,528,010	1,520,703	1,511,304	1,500,006
Accumulated expansion along the period in relation to base year (ha)		26,132	52,156	78,032	103,729
Coffee					
Harvested area under higher average temperatures (ha)	1,846,352	1,718,378	1,858,953	1,653,202	1,765,167
Accumulated reduction along the period in relation to base year (ha)		-126,537	-254,662	-378,402	-501,135
Cotton					
Harvested area under higher average temperatures (ha)	815,489	673,761	705,987	605,856	580,511
Accumulated reduction along the period in relation to base year (ha)		-3,740	-7,231	-10,430	-13,420
Edible beans					
Harvested area under higher average temperatures (ha)	2,732,793	2,684,635	2,583,982	2,474,828	2,372,002
Accumulated reduction along the period in relation to base year (ha)		-21,401	-41,967	-61,742	-80,705
Maize					
Harvested area under higher average temperatures (ha)	9,035,378	8,354,413	7,801,862	7,235,576	6,670,062

Accumulated reduction along the period in relation to base year (ha)		-16,031	-31,069	-45,053	-57,975
Rice					
Harvested area under higher average temperatures (ha)	2,052,639	1,831,006	1,588,907	1,341,446	1,103,070
Accumulated reduction along the period in relation to base year (ha)		-13,177	-24,746	-34,624	-42,836
Sorghum					
Harvested area under higher average temperatures (ha)	702,747	809,771	860,557	917,345	975,847
Accumulated reduction along the period in relation to base year (ha)		-261	-541	-846	-1,170
Soybeans					
Harvested area under higher average temperatures (ha)	18,974,407	19,281,952	19,693,391	19,808,982	19,799,541
Accumulated reduction along the period in relation to base year (ha)		-258,654	-523,314	-790,773	-1,058,868
Sugar cane (1)					
Harvested area under higher average temperatures (ha)	6,914,303	7,173,914	7,319,726	7,400,966	7,426,761
Accumulated expansion along the period in relation to base year (ha)		21,301	43,137	65,292	87,590
Wheat					
Harvested area under higher average temperatures (ha)	2,047,203	1,905,154	1,810,067	1,716,799	1,625,504
Accumulated reduction along the period in relation to base year (ha)		-222,014	-433,048	-633,341	-823,120

Source: Estimated by the study team

(1) *Refer to sugar cane used in the production of sugar, ethanol and other uses.*

In contrast to the above, the impact of the climate change on the estimated production of rice and beans in the respective groups of major producing states would be relatively smaller – i.e. an accumulated reduction of about 3.5% by 2030 in both cases. The groups of the major producing states of cotton, maize and sorghum could have their respective levels of production reduced by an accumulated amount of less than 2% at the end of the next two decades in comparison to 2010.

In line with the expansion in the harvested area which could be observed under IPCC´s A2 scenario, the production of cassava and sugar cane could also increase during the next two decades in the respective groups of major producing states. The production of cassava could accumulate a total increase of 7.4% by 2030 vis-à-vis the 2010 level. Sugar cane production, in turn, is estimated to experience an aggregated increase of 1.5% during the same time period.

Further to the above assessment, the economic impact of the climate change on the production of the selected crops coming from the groups of major producing states was also quantified. The procedure employed for this purpose consisted in multiplying the estimated annual variations in the level of production due to the climate change by the average price received by farmers between November 2008 and October 2009[48]. The resulting values were converted from Real to US Dollar using an exchange rate of 1.8 Real per US Dollar. Table 20 shows the magnitude of the accumulated changes in the value of production between the base year and 2030.

Examining the estimates shown in this table it is observed that, in comparison to the respective base year figures, wheat and coffee are the crops which would suffer the most from a climate change in terms of value of production. As can be seen, in a context of climate change along the lines of IPCC's A2 scenario, wheat production in the two major producing states, Rio Grande do Sul and Paraná, could accumulate a total loss of US$ 334 million by the end of the 2010-30 period. This economic loss corresponds to 48% of the

[48] The source for the prices of sorghum and coffee is the Agricultural Economics Institute (IEA) and for the rest of the crops Getulio Vargas Foundation (FGV).

estimated value of production of this crop in 2010. Regarding coffee, the accumulated loss during that same period would be US$ 820 million, i.e. 35% of the estimated value of production in the base year.

Soybeans would be the third most affected crop in economic terms by the climate change. The value of production in the five major producing states of this crop would register a total accumulated loss of US$ 1.5 billion between 2010 and 2030.

Table 19: Impact of climate change on the estimated production of selected crops produced by the respective groups of major producing states, 2010-30

Crop	2010	2015	2020	2025	2030
Cassava					
Production under higher average temperatures (ton)	21,695,810	22,557,460	23,335,827	24,107,246	24,871,714
Accumulated expansion along the period in relation to base year (ton)		379,879	773,096	1,179,535	1,599,077
Coffee					
Production under higher average temperatures (ton)	2,279,541	2,349,598	2,778,436	3,092,636	3,540,271
Accumulated reduction along the period in relation to base year (ton)		-162,643	-349,137	-559,567	-798,947
Cotton					
Production under higher average temperatures (ton)	3,321,318	3,181,151	3,864,220	3,844,327	4,270,197
Accumulated reduction along the period in relation to base year (ton)		-16,632	-34,646	-53,781	-74,509
Edible beans					
Production under higher average temperatures (ton)	2,806,772	3,046,968	3,196,923	3,340,956	3,493,767
		-23,456	-48,031	-73,811	-100,786

Accumulated reduction along the period in relation to base year (ton)					
Maize Production under higher average temperatures (ton) Accumulated reduction along the period in relation to base year (ton)	46,799,671	50,225,976 -90,800	54,471,818 -189,703	58,668,597 -296,505	62,808,945 -411,105
Rice Production under higher average temperatures (ton) Accumulated reduction along the period in relation to base year (ton)	10,609,382	11,983,371 -78,350	13,428,163 -166,454	14,929,225 -264,699	16,486,557 -373,472
Sorghum Production under higher average temperatures (ton) Accumulated reduction along the period in relation to base year (ton)	1,818,855	2,095,315 -673	2,371,899 -1,440	2,648,483 -2,301	2,925,067 -3,256
Soybeans Production under higher average temperatures (ton) Accumulated reduction along the period in relation to base year (ton)	54,798,752	60,687,170 -789,149	66,444,256 -1,657,025	72,041,849 -2,601,517	77,475,039 -3,620,399
Sugar cane (1) Production under higher average temperatures (ton) Accumulated expansion along the period in relation to base year (ton)	595,038,255	668,622,484 1,923,890	738,835,846 4,059,565	809,039,758 6,406,191	879,243,642 8,963,767
Wheat Production under higher average	5,261,445	5,325,458	5,544,452	5,713,622	5,840,778

temperatures (ton) Accumulated reduction along the period in relation to base year (ton)		-596,706	-1,220,526	-1,865,646	-2,527,214

Source: Estimated by the study team

(1) Refer to sugar cane used in the production of sugar, ethanol and other uses.

Table 20: Impact of climate change on the estimated value of production of the selected crops produced by the respective groups of major producing states (Accumulated changes in the value of production during the period in relation to 2010.Values in US dollar)

Crops	2015	2020	2025	2030
Cassava	44,671,784	90,912,159	138,707,330	188,043,341
Coffee	-166,876,367	-358,224,582	-574,132,570	-819,743,774
Cotton	-9,393,808	-19,568,789	-30,376,383	-42,083,583
Edible beans	-23,140,676	-47,385,650	-72,820,184	-99,432,412
Maize	-16,268,347	-33,988,519	-53,123,788	-73,656,294
Rice	-30,469,261	-64,732,115	-102,938,646	-145,238,941
Sorghum	-160,540	-343,452	-548,737	-776,394
Soybeans	-321,870,695	-675,851,349	-1,061,081,563	-1,476,653,387
Sugar cane	38,362,910	80,948,857	127,741,235	178,739,994
Wheat	-78,943,886	-161,474,834	-246,823,784	-334,348,834

Source: Estimated by the study team.

Taking all the selected crops together, the economic impact of the climate change on the respective groups of major producing states during the 2010-30 period would be an accumulated reduction of about US$ 3 billion in the value of production of these crops. About half of this economic loss would come from a reduction in the value of soybean production, 27% from coffee, 11% from wheat and the remaining 13% from rice, maize, cotton, edible beans and sorghum.

The climate change could also produce a positive impact, expanding the harvested area with cassava and sugar cane as well as the value of production of these crops by US$ 367 million during that same period. Therefore, the net impact of a rise in the world average temperatures assumed in IPCC´s A2 scenario would be an aggregated loss of US$ 2.6 billion during the next two decades. This loss corresponds to approximately 5% of the total value of production of the selected crops in the base year.

In summary, a rise in world average temperatures between 2ºC and 5.4ºC until 2100 could affect significantly the production of the selected crops in the groups of major producing states. It could reduce the domestic production of wheat, coffee and soybeans: three important crops for local consumption as well as for the national foreign trade balance. It could also expand the areas with low climatic risk to growing sugar cane and cassava, bringing some economic gains in terms of additional value of production.

The possibility for the materialisation of these impacts, however, seems limited. The national research institutions have been developing technologies aimed at adapting these and other crops to a context of higher temperatures as well as enhancing their cultivation in non-traditional locations. Moreover, Brazil and other nations have been adopting a number of mitigating measures to reduce the level of greenhouse gas emissions.

Further to the pledge made at the United Nations Framework Convention on Climate Change held in Copenhagen (Denmark) last December, the Brazilian President signed on that same month a bill into law. This policy instrument requires that the country´s greenhouse gas emissions should be reduced between 36.1% and 38.9% below 2020 business-as-usual levels. With this bold action, the Government expects that the country stops emitting between 975 and 1,052 million tons of carbon dioxide (CO2) equivalent in the next decade.

The implementation of the above-mentioned Law includes the adoption of several mitigation actions in the areas of land use, agriculture, energy and iron and steel metallurgy. As Table 21 shows, more than half the target should be obtained through deforestation reduction. The mitigation actions associated with the agricultural sector should also contribute significantly towards achieving the target. The established actions for this sector includes pasture recovery, wider adoption of integrated crop-livestock systems, no-till farming and nitrogen biological fixation as a way of reducing greenhouse gases emissions.

The Government has just taken an additional step concerning the implementation of its National Policy on Climate Change. Specifically, the Ministry of Agriculture, Livestock and Supply included in its 2010-11 Agriculture and Livestock Plan (2010-11 Plano Agrícola e Pecuário) a Low-Carbon Agriculture Programme. This programme allocates US$1.1 billion to finance the adoption and wider use of the following agricultural practices, technologies and production systems during the 2010-11 cropping year: integrated crop-livestock systems; planting and maintenance of commercial forests; soil fertilisation and conservation practices; recovery of preservation areas and forestall reserves.

Table 21: Mitigation actions for Brazil’s emissions, 2020

Mitigation actions (NAMAs)	**2020 (trend million tCO2e)**	**Reduction amplitude 2020 (million tCO2e)**		**Reduction proportion (percentage)**	
Land use	1,084	669	669	24.7	24.7
Amazon deforestation reduction (80%)		564	564	20.9	20.9
’Cerrado’” deforestation reduction (40%)		104	104	3.9	3.9
Agriculture	627	133	166	4.9	6.1

Pastures recovery		83	104	3.1	3.8
Integrated crop-livestock systems (ILP)		18	22	0.7	0.8
No-till farming		16	20	0.6	0.7
Nitrogen biological fixation		16	20	0.6	0.7
Energy	901	166	207	6.1	7.7
Energy efficiency		12	15	0.4	0.6
Increase of biofuels use		48	60	1.8	2.2
Expansion of hydroelectric power supply		79	99	2.9	3.7
Alternative sources (small hydropower plants, bio and wind electricity)		26	33	1.0	1.2
Others	92	8	10	0.3	0.4
Iron and steel metallurgy – replace deforestation coal for planted coal		8	10	0.3	0.4
Total	2,703	975	1,052	36.1	38.9

Source: Brazilian Ministry of the Environment

9. Prospects for increased crop production through irrigation[49]

9.1 Brazil´s water resources and irrigated agriculture

Brazil is privileged regarding water resources. The annual average flow of its rivers is 179,000 m^3/s. This corresponds approximately to 12% of the world availability of water resources, i.e. 1.5 million m^3/s. Considering the flow originated in neighbouring countries and entering Brazil, the total water

[49] This chapter was developed by Maria Abadia da Silva Alves.

availability reaches about 267,000 m^3/s. This corresponds to 18% of the water available in the world (MMA/SRH, 2006).

Despite there being an excellent water supply, it is unevenly distributed in the territory. Thus, there are regions with limited water availability and large population, resulting in water shortages. At the same time, there are regions like the Amazon Basin with 70% of Brazil´s water resources and 7% of the population (MMA/SRH, 2006).

Irrigated agriculture is the largest user of water resources in the country. It accounts for 69% of the total water consumed, while urban and animal use are responsible for 11% each (MMA/SRH, 2006). Despite this high level of consumption by irrigated agriculture, there is still a great potential for further irrigation development in Brazil. The total area suitable for a sustainable development of irrigation is approximately 29 million hectares, of which in 2006 only 4.45 million was being utilised for production under irrigation systems and techniques (Agricultural Census, 2006). Therefore, the country still has 85% of irrigable area to be explored. This low use of irrigation potential in Brazil becomes more evident when compared with other countries. Chile, for instance, uses 82% of its irrigable acreage, China 84%, and India 50% (FAO, 2010).

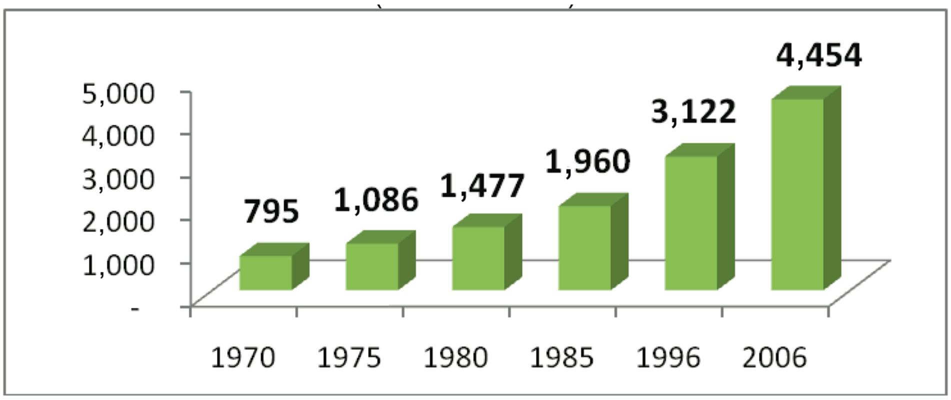
Although Brazil uses a small portion of its total area suitable for irrigation, this type of agriculture is very important for the Brazilian agriculture. In 1998, when the irrigated area corresponded to about 5% of the total cultivated land, irrigated agriculture contributed 16% of the total volume of production of the sector (Telles and Domingues, 2006). This activity was also responsible for at least 1.5 million direct jobs and 3 million indirect in 2006 (Telles and Domingues, 2006).

According to several Agricultural Censuses (1970, 1975, 1980, 1996 and 2006), the irrigated area in Brazil increased from 795,000 hectares in 1970 to 4.4 million in 2006 (Figure 13). During this 36-year period, there was an annual incorporation of approximately 102,000 hectares of land to irrigation. This expansion of irrigated agriculture increased in the last ten years, when its average growth rate rose to 180,000 hectares per year.

In 2006, three states accounted for more than 50% of the total irrigated area in the country. Rio Grande do Sul was responsible for 22%, São Paulo for 17%, and Minas Gerais 12%. In the first of these states, more than 80% of the irrigated area was used to grow rice under a flooding system in that same year. In contrast to what happens with other crops, the demand for water by irrigated rice is concentrated in few months during the cultivating period.

In the state of São Paulo, the irrigated area is utilised most with the cultivation of sugar cane, coffee, oranges and grains. The municipalities of Campinas, Ribeirão Preto and São Paulo are major producers of fruits and flowers under irrigation. The predominant method is sprinkler. In Minas Gerais the main irrigated crops are grains and coffee under centre-pivot irrigation.

Figure 13: Irrigated area in Brazil, 1970-2006 (million hectares)



Source: Agricultural Census, various years - IBGE

The ten major irrigated crops in the country are as indicated in Table 22. Among these crops, sugar cane, rice and *Canephora* coffee are distinguished for presenting the largest share of irrigated cultivation with respect to the total area used.

Table 22: Harvested area by major irrigated crops in Brazil, 2006

Crops	Harvested area (hectares)		
	Irrigated (a)	Not irrigated (b)	(a)/(a)+(b)
Sugar cane	1,705,200	3,872,432	30.57
Rice	1,128,860	1,280,705	46.85
Soybean	624,196	15,022,783	3.99
Maize	559,025	11,165,336	4.77
Edible beans	195,166	1,229,675	13.70
Orange	157,520	439,398	26.39
Canephora coffee	137,392	258,165	34.73
Arabica coffee	124,764	1,167,529	9.65
Caupi, Macáçar and Fradinho beans	120,739	2,017,662	5.65
Onion	85,727	50,236	63.05
Watermelon	66,088	100,888	39.58

Source: Christofidis e Goretti, 2009 from IBGE Agricultural Census, 2006

9.2 Perspectives for expanded irrigated agriculture

In 1999, the Brazilian Ministry of Environment - MMA - estimated the potential for the development of sustainable agriculture at 29 million hectares. In 2002, these estimates were reviewed by Christofidis and confirmed as still valid despite the time-lag (Christofidis, 2002). This review took into account the amount of land suitable for irrigation, the availability of water resources without the risk of conflicts with other priority uses, and the need to meet the requirements of environmental legislation. According to the results of this projection, the states with the highest potential for sustainable development of irrigation are Tocantins, Amazonas, Pará, Mato Grosso, Minas Gerais, Rio Grande do Sul, Roraima, São Paulo, Paraná and Goiás (Table 23).

Among these states, it is estimated that the growth of irrigated agriculture should be more significant in the Cerrado areas of the Centre West region (Telles and Domingues (2006). More specifically, the agricultural frontier of Mato Grosso and the states of Minas Gerais, Bahia, Tocantins, Roraima, and the South of Maranhão and Piauí, depending on road improvement and energy storage in these regions (Telles and Domingues, 2006).

Table 23: Potential for sustainable development of irrigated agriculture in Brazil

State	Potential area	State	Potential rea
Rondônia	995,000	Minas Gerais	2,344,900
Acre	61,500	Espírito Santo	165,000
Amazonas	2,852,000	Rio de Janeiro	207,000
Roraima	2,110,000	São Paulo	1,512,100
Pará	2,453,000	**Southeast**	**4,229,000**
Amapá	1,136,000	Paraná	1,348,200
Tocantins	4,437,000	Santa Catarina	993,800
North	**14,044,500**	Rio Grande do sul	2,165,000

Maranhão	243,500	**South**	**4,507,000**
Piauí	125,600	Mato Grosso do Sul	1,221,500
Ceará	136,300	Mato grosso	2,390,000
Rio grande do Norte	38,500	Goiás	1,297,000
Paraíba	36,400	Distrito Federal	17,500
Pernambuco	235,200	**Centre West**	**4,926,000**
Alagoas	20,100		
Sergipe	28,200		
Bahia	440,200	**Total**	**29,010,500**
Northeast	**1,304,000**		

Source: Christofidis e Goretti, 2009 – based on data from the 2006 Agricultural Census - IBGE

Regarding the future use of irrigation by specific crops, Domingues and Gisler (2009) estimated that the expansion of sugar cane cultivation in the next years should require substantial amounts of water for irrigation in the states of Goiás, Mato Grosso and Tocantins. These states, unlike the traditional areas of São Paulo and Paraná, face periods of well-defined intense drought.

According to those authors, the expansion of sugar cane in Goiás, Mato Grosso and Tocantins will require irrigation known as ‘salvation’ in July, August, September and sometimes in October. It is expected that, in addition to the water used at the beginning of planting, farmers should use 60 mm of water per hectare in each of those four months. In this context, Domingues and Gisler (2009) estimated that, in the next 10 years sugar cane will displace rice as the crop with the largest requirement of water resources in the country. Table 24 shows the water use by the Brazilian sugar cane agro-energy sector in the 1997-2020 period considering an average yield of 71.9 t/ha of sugar cane and the production of 50% of sugar and 50% of ethanol in 2020.

Table 24: Water use by the sugar cane agro-energy sector in Brazil, 1997-2020

Indicators	1997	2007	2020
Sugar cane production (million tons/year)	330	550	1,000
Planted area (million ha)	4.80	7.00	13.9
Water use by the industry (m^3 per 1t of sugar cane)	5.00	1.80	1.00
Water use by the industry (m^3/s)	53.70	32.00	34.20
Water use in sugar cane production ($m^{3/}$s)	-----------------	-----------------	388.90
Total water used – sugar cane production and industry (m^3/s)	53.70	32.00	423.10

Source: Domingues and Gisler, 2009

Further to the above, sugar cane production should also expand in the Northeast region of the country through irrigation. There are five irrigation projects administered by the federal government along the São Francisco River. The government intends to attract sugar cane and orange growers to these irrigated areas transforming the region into a new hub of citrus and sugar cane production (Valor Econômico, 12/02/2007). In contrast to this region, the conditions for irrigation expansion in the north of the country are less favourable due to a low rate of rural electrification (Telles and Domingues, 2006).

In the South and Southeast regions, the expansion of irrigation should arise from the establishment of irrigation systems devoted more to the production of high value crops such as coffee and fruits, and less for the cultivation of grains.

The areas with rice in Rio Grande do Sul should not expand at fast pace because a larger use of more productive cultivars is expected. Several years ago, the rice grown in this state was cultivated under water blades of 40-50 cm. Today these water blades have been reduced to 2.5 - 10 cm. Therefore the water consumption of this crop has decreased significantly over time.

In the right conditions of soil, topography and water management, water use efficiency in rice production reaches 60% to 65%. During the 1970-80 period, the average yield of rice in Rio Grande do Sul was 4 ton/ha. This level of production was achieved using more than 15,000 m^3 of water per hectare. Today the average yield in this state increased to 5.4 ton/ha and the water use fell to 8,000 m^3 per hectare; in other words, one thousand litres of water are used to produce 675 grams of rice. The goal in Rio Grande do Sul is to reach a relationship of one to one, i.e. $1m^3$ of water to produce one kilogram of rice. In this context, the levels of production presented in Chapter 6 would be achieved using relatively less water resources.

Projecting the growth of irrigated areas is a complex task, especially because, in Brazil, this activity is highly dependent on government programmes and special financing arrangements for the purchase of equipment, energy pricing, and infrastructure investment in water storage and establishment of public irrigated perimeters. Moreover, there is a declining trend in the coefficients of unit demand for water in irrigation, depending on the degree of effectiveness of programmes for rational use of water that are being established in the country. This fact complicates further the development of projections.

Despite these difficulties, Telles and Domingues (2006), using the average growth rates observed in the 1980-90 and 1960-2005 periods (i.e. 120 thousand ha/year and 70 thousand ha/year, respectively) estimated that the total irrigated area in Brazil should be between 4.4 million and 5.2 million hectares in 2020 (Table 25).

Table 25: Estimated area under irrigation in the different regions of Brazil, 2020

Regions	Lower limit (10³ ha)	Upper limit (10³ ha)	Average range (10³ ha)
North	285	470	344.5
Northeast	870	1,040	955
Southeast	1,130	1,300	1,215
South	1,610	1,780	1,695
Centre West	535	620	577.5
Brazil	*4,430*	*5,210*	*4,820*

Source: Telles and Domingues, 2009

In addition to the above, the Ministry of Environment estimated also the total irrigated area in the country in 2020. According to this institution, the irrigated area in Brazil should be around 5.6 million hectares in 2020.

As can be seen, according to these research efforts the irrigated area in the country should be situated between 4.4 million and 5.6 million hectares in 2020. However, if the growth rate registered between the 1996 and 2006 Agricultural Census (i.e. 1.8 million hectares per year) is observed in the next years, the irrigated area in Brazil could exceed 6 million hectares by 2020.

According to Machado (2006), in Brazil a unit of irrigated area is equivalent to three units of upland area in terms of volume of production. Moreover, it corresponds also to 8.4 units of upland area in economic value. Therefore, the expansion of irrigation in the next years in addition to enabling the growth in sugar cane and rice production should result in substantially higher productivity and economic indicators of the Brazilian agriculture.

10. Conclusions

The long-term perspective of Brazil´s agricultural productive capacity is quite positive. The production of the selected crops and beef cattle should increase substantially in the major producing states during the next 20 years without putting strong pressure on land expansion, threatening environmental sustainability and enhancing the loss of biodiversity resources.

The outlook of the domestic production of these products points in the direction of major increases throughout this period, reaching output levels of grains, sugar cane, coffee and beef substantially higher in 2030 than the 2007-09 average (i.e. between 47% and 68% depending on which of these products). Moreover, it signals that with the exception of wheat, the growing domestic consumption of these products should be more than met by the expected levels of production. The attendant excess production should enable the country to continue playing a major role in the international markets of soybeans, sugar, coffee, cotton and beef. The materialisation of this perspective, however, requires among other things, that substantial investment in storage facilities, transport infrastructure and port logistics is made in the short run in order to avoid major bottlenecks.

A noteworthy aspect behind this performance is that, under a scenario of continued past yield trends, the total 'net area' needed to produce the estimated volume of production of the selected crops in 2010-30 should grow at an annual average rate much lower than that observed in 2000-09, i.e. 1.1% vis-à-vis 3.3% respectively. In this context, the total additional 'net area' needed in 2030 would be about 36% above the 2009 level. As highlighted earlier however, since this additional area should come mainly from degraded pasture, its expansion is not expected to have a significant impact on the conversion of natural areas into agricultural production.

The perspective for growing production levels with lower pressure on land expansion, greater environmental sustainability and limited biodiversity loss is further reinforced by several aspects, including a good possibility for the materialisation of a higher crop yield scenario. As highlighted earlier, this would result not only in less total 'net area' required by the selected crops to achieve the estimated levels of production, but also a less demanding requirement to increase the average stocking rate in the next years.

The consultations carried out with Embrapa´s research units indicated that it is feasible to observe higher yields in the major producing states than those resulting from continued past yield trends. Besides existing new technologies which can increase significantly the yield level, there is evidence that some of them are currently being used by certain farmers. The challenge, then, includes further expanding the understanding of this technology adoption process, designing mechanisms to accelerate its spread over a larger number of producers and expanding investments on infrastructure development, especially transport.

The perspective of increased crop and livestock production with the above characteristics is also supported by the attendant results from the use of some technologies which the Government is promoting to mitigate the emissions of carbon dioxide, i.e. integrated-crop livestock system and restoration of grazing land. The wider use of these technologies in the next years should contribute significantly to reducing CO2 emissions. In addition, as highlighted earlier, they should produce a major sparing-land effect which will enable the reallocation of land use among food and agro-energy crops through the dislocation of degraded pasture.

Another aspect coming out of the analysis is that, while the cultivated area with rice and edible beans in the major producing states is expected to fall during the 2010-30 period under both yield scenarios, the opposite should happen with the area with soybeans and sugar cane. Nevertheless, as indicated above, the production of all selected crops is foreseen to increase substantially during the next 20 years. Therefore, the expansion of soybeans and sugar cane do not bring a threat to the domestic availability of those two major crops which are essential to the national food security.

Regarding the spatial dynamics of agricultural production during the 1978-2008 period, the conclusion is that soybeans, cotton and sorghum experienced major dislocations at both regional and state level. Wheat and edible beans registered movements of less magnitude, and the other selected crops showed significant spatial dislocations sometimes larger at regional level and others at state level.

The analysis concerning the movements of the gravity centres over that same period identified several products with well-defined trends. Rice, soybeans, sugar cane and sorghum practically followed a geodesic trajectory. In some cases the movements did not show a well-defined trend (e.g. wheat) and in others it displayed an erratic pattern (e.g. maize, edible beans).

Given the above spatial dynamics and the large concentration of agricultural production in a relatively small number of states, the estimated production of wheat and sugar cane for the 2010-30 period should come mainly from areas located in two groups of states, i.e. Paraná and Rio Grande do Sul in the case of wheat, and São Paulo, Paraná, Minas Gerais, Goiás and Alagoas of sugar cane.

The future production of soybeans, sorghum and rice is expected to originate mostly from areas in five states, while that of cotton and coffee should come from cropland in three states (see Table 8). In line with a lower geographic concentration, the 2010-30 production of maize, edible beans and cassava should derive from areas in seven, nine and twelve states respectively.

The total 'net area' needed to produce the estimated volume of production for the above-mentioned crops in this set of 18 states in 2030 should be 50 million hectares and 37.5 million hectares respectively, under yield scenarios one and two. The difference between these estimates highlights the sparing-land effect of higher yields.

Regarding the question, from where within the major producing states considered in the analysis this additional 'net area' would come from, two alternatives were considered: (a) degraded pasture and land resulting from the dislocation of some crops; and (b) degraded pasture, land originated from dislocated crops plus some areas with forest. With respect to the first of these alternatives the analysis showed that, after accounting the area coming from dislocated crops, degraded pastures would need to be reduced by 13.5 million or 1.2 million hectares in 2030 vis-à-vis the 2006 level, depending on the crop yield scenario considered. Thus, no additional pressure on land expansion should happen.

In the case of the second of those alternatives, it was concluded that the possibility that the additional 'net area' needed to produce the estimated level of crop production may also come from deforestation need not negatively affect society´s welfare. As highlighted earlier, an important factor which influences significantly this result is land vocation, especially forest vocation land. In this regard, a programme aimed at the identification of this type of land together with the design of an appropriate policy framework can help the country to assure that only 'good' deforestation happens, if any.

According to various institutions, researchers, governments and civil society, climate change poses a major threat to future agricultural production. In this respect, in line with the findings of a previous study carried out by Embrapa and Unicamp (Assad et al., 2008), the conclusion here is that, significant negative impacts on the estimated area for cultivating three major crops of great importance to Brazil's domestic consumption and agricultural foreign trade balance (i.e. wheat, coffee and soybeans) may already be felt in the major producing states of these products during the next decades.

In contrast to the above, the estimated area to be cultivated with the other selected crops during the next 20 years, is not envisaged to experience substantial changes in the major producing states under a context of relatively higher temperatures. It should be noted, however, that in the case of sugar cane and cassava, the increase in world temperatures may expand the area fit to grow these crops. Nevertheless, the increase in the estimated area to be cultivated with them in the major producing states is expected to be relatively small.

Given the above, the analysis carried out here turns on the yellow light concerning the negative impacts that an eventual increase in world temperatures of the magnitude foreseen in scenario A2 of IPCC may cause on three important crops to Brazil's domestic consumption and foreign trade. However, as indicated before, this alert is not a reason for alarm. There are a large number of mitigation measures which countries are taking in order to reduce global warming in the next years. In addition, Brazilian researchers have been developing technologies which enable the adaptation of crops to higher temperatures. These initiatives, together with the proven capacity of men to overcome major challenges, give us an optimistic view of the future, but without lowering the guard in relation to the need to continue strengthening the ongoing efforts.

The analysis carried out here showed also that irrigated agriculture can contribute significantly to expanding agricultural production in the next decades, especially of sugar cane and rice. This perspective highlights also the importance of avoiding greater conflicts over water use. Thus, it is necessary to develop a coordinated strategy of action with other sectors. Among other aspects, this strategy should involve the management of water resources and the implementation of programmes and research aimed at an efficient use of water in irrigation.

In summary, Brazil faces a positive perspective regarding the productive capacity of its agricultural sector. The transformation of this perspective into reality, however, depends on various factors, some of which can be influenced by public policies, others not. Thus, in addition to the measures highlighted above, it is essential that the Government ensures a continued economic stabilisation of the economy, adopts sound macroeconomic and agricultural policies, and succeeds in its efforts to reduce the domestic interest rates paid by producers and consumers. Moreover, it is indispensable to enhance further investment in agricultural research and infrastructure development, simplify export procedures, find a solution to the rural credit indebtedness faced by a large number of national farmers, and expand the domestic output of potassium and phosphate for fertiliser production. Above all these elements, it is fundamental that the Government maintains a strong political will to be timely in taking the measures required for a sustained growth of agriculture and the economy.

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