4. Vulnerabilities, impacts and adaptations to climate change in the agricultural sector and agricultural soils

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4.1. Introduction

According to the Intergovernmental Panel on Climate Change - IPCC (2001a), by the year 2100 the average global temperature will increase between 1.6°C and 5.8°C, representing warming rates from 0.1-0.4°C per decade. In Brazil, the highest warming rates will be seen in the Amazon rainforest and the lowest in the states of the Southeast region, on the Atlantic Rainforest coast (Morengo, 2006).

According to Morengo (2006), a warming trend has been observed in Brazil since the beginning of the 20th century, and it has been especially detected in winter, when the minimum temperature shows a tendency to rise greater than that of the maximum temperature. According to Morengo, an indicator of this warming would be a tendency to experiencing a greater frequency of warm days in winter and also, to a lesser extent, more frequent warmer days in summer and winter. In terms of rainfall, the trend is more uncertain due to the shortage of research in this area, although an increase in extremes of rainfall has been observed in the South and Southeast regions, as well as in Amazonia.

Agriculture is an activity that depends greatly on climatic factors, alterations in which may affect productivity and crop management, as well as social, economic and political factors, and therefore it will be influenced by global climate changes. This influence is specific to each crop and region. The adaptability of agricultural establishments to climate changes may vary, putting them in vulnerable positions according to different climate scenarios. The threat global climate changes represent to agriculture is mainly translated into a decrease in productivity and a reduction in the number of suitable areas for farming.

According to long-term predictions based on the global climatic models from the IPCC (IPCC, 2001a), tropical and subtropical regions, or regions at low latitudes, will be more affected by climate change than other regions (IPCC, 2001b; FAO, 2003; Ramankutty et al., 2002; Jones & Thornton, 2003; Mendelsohn et al., 2004c). The report also states that developing countries may be more vulnerable to climate alterations due to the predominance of agriculture in their economies, lack of financial resources for adaptation measures and their high exposure to extreme events (Parry et al., 2001; Fischer et al., 2005), as well as to inadequate provision of markets, among other factors. According to the IPCC (2001b, 2007), the ability of production systems in Latin America, Africa and Asia to adapt is low and their vulnerability is high, especially among low-income producers, who depend on more traditional agricultural systems or on land less suitable for agriculture.

The IPCC (2001b, 2007) points out a great probability of degradation of natural resources such as soil and water occurring as a result of temperature and rainfall changes, with negative consequences for agriculture. It also projects a reduction in the productivity of many crops, even when the direct effects of doubled concentration of CO_2 and of the implementation of moderate adaptation measures at farm level are considered. Despite the high variability in the projections of productivity, a certain pattern is consistent in indicating a reduction in rice production after 2010, and the increase of soybean production when the effects of CO_2 increases are considered (IPCC, 2007)

The increase in CO_2 may have positive effects on some plants, and may also provide a more efficient use of water. However, in scenarios of growing temperature increase, this effect may be neutralized by the impacts of climatic variability.

Some uncertainties remain as challenges to the composition of future scenarios, such as the size and the persistence of the effects of the increasing concentrations of CO_2 on agricultural production under realistic conditions of production; potential changes in loss of produce due to plant and animal diseases, spatial variability in responses to climate change, the effects of changes on climate variability and of extreme events on agriculture.

This paper discusses the impacts climate change may have on Brazilian agriculture and the subsequent risks to this area, as well as some adaptation strategies to face the problem.

4.2. Effects of different atmospheric concentrations of CO_2 on plants

Studies show that the concentration of atmospheric CO_2 increased from 280 ppm in the pre-industrial period to 379 ppm by 2005. Climate coupling and carbon cycle (C4MIP) models project increases in the concentration of CO_2 of between 730-1020 ppm, around the year 2100 (IPCC, 2007). The effect of this increase on plants has been the subject of studies, especially in terms of the impact on agriculture and food supply.

Recent research shows that the effects of CO_2 on plant growth and productivity will depend on the photosynthetic pathway of the species, the growth stage, and the system for managing water and applying fertilizer (Jablonski et al. 2002; Kimball et al., 2002; and other authors quoted in IPCC, 2007).

One of the characteristics of plant species which determines their productive potential is the photosynthetic pathway. Arboreal and bush species, the main plant components of important biomes on Earth, use the C3 photosynthetic pathway (see Box 1). In the same way, major agricultural crops, including some species from the gramineae family such as rice and wheat, also use this pathway, while several forage gramineae, including brachiaria, and those found on small plantations, such as com, sorghum and sugarcane, use the C4 pathway. The latter is characterized by a higher efficiency in CO_2 fixation, notably through morphological and physiological modifications of the photosynthetic system, which causes different performances of plants in different environmental conditions (Table 1). The higher the intensity of light the more efficiently C4 type plants perform photosynthesis, and therefore they do not show saturation in assimilating CO_2 in relatively low conditions of lighting, as happens with C3 type plants. If sunlight is not a limiting factor, the production of C4 plants may be 2 or 3 times greater than that of C3 plants.

Box 1 - C3 and C4 plants

There are three types of photosynthetic assimilation of CO_2 by chlorophyll plants. According to their type, plants may be classified as C3, C4 and CAM plants. C3 and C4 refer to the number of carbon atoms in the first product of CO_2 fixation. In C3 plants the first product of the biochemical chain is 3-phosphoglyceric acid (3-PGA), a 3 carbon molecule. The C3 photosynthetic pathway involves a carboxylation process, which consists in the addition of a CO_2 molecule to a ribulose-1.5-bisphosphate, by means of the Rubisco enzyme (ribulose-1.5-bisphosphate carboxylase-oxygenase), a simplification of the so-called Calvin cycle.

The photosynthetic system of C4 plants produces a 4 carbon molecule, oxalacetic acid. These plants have a differentiated structure characterized by a layer of cells which wrap around the sap-conducting vessels like a sheath (Kranz anatomy), in which we find the Rubisco enzyme. Carboxylation is carried out in the other cells of the leaf through the addition of the CO_2 molecule to a phosphoenolpyruvate molecule (PEP), by means of the phosphoenolpyruvate carboxylase enzyme (PEPCase), forming oxalacetic acid, which is immediately transformed into malate and aspartate. In the chloroplasts (organelles containing chlorophyll, the substance which transforms light energy into chemical energy) of the sheath, aspartate and malate are turned into CO_2 and pyruvate. CO_2 is captured by the Rubisco enzyme, following the Calvin cycle.

C3 plants are limited by CO_2, that is, even with an abundance of light, the rate of CO_2 supply to the chloroplast is very slow. C4 plants overcome this limitation because they use available CO_2 more efficiently, with consequently higher rates of liquid production at high levels of light. Levels of lighting and temperature are environmental factors that limit photosynthesis for C4 plants.

Considering an average of several species under stress conditions, studies show that there would be an increase of 10-20% in the productivity of C3 plants and of 0-10% in C4 plants with a CO_2 concentration of 500 ppm, in relation to the current atmospheric concentrations (Ainsworth et al., 2004; Gifford, 2004; Long et al., 2004, quoted in IPCC, 2007). Good photosynthetic response is generally obtained at higher levels of temperature and radiation in C4 plants rather than in C3 species (Table 1). Stress due to high temperatures causes a set of morphoanatomical, physiological and biochemical changes in C3 plants (Wahid et al., 2007) which affects their development and may in some cases result in drastic reductions in productivity.

Table 7-1: Average photosynthetic response to radiation and temperature for four groups of crops

Characteristics	Crop adaptability group			
	I	II	III	IV
Photosynthetic pathway	C_3	C_3	C_4	C_4
Photosynthetic rate in saturation conditions of optimum lighting and temperature, in mg CO_2 dm^{-2} h^{-1}	20-30	40-50	70-100	70-100
Optimum temperature for maximum photosynthesis in °C	15-20	25-30	30-35	20-30
Radiation intensity in maximum photosynthesis	0.2-0.6	0.3-0.8	>1.0	>1.0
Crops	Wheat Potato Beans (temperate and high -altitude tropical cultivation)	Beans (tropical cultivation) Soybean Rice Cotton Sweet potato Cassava	Millet Sorghum (tropical cultivation) Corn (tropical cultivation) Sugarcane	Sorghum (temperate and tropical high -altitude cultivation) Corn (temperate and tropical high -altitude cultivation)

With current atmospheric CO_2 concentrations, C3 and C4 plants do not achieve saturation of the photosynthetic system, and this is the most common factor for the limitation of photosynthetic rates (Larcher, 2000). Considering the less efficient use of CO_2 made by C3 plants, in which photosynthetic system saturation would only occur with CO_2 concentrations of around 1000 ppmv, one would expect a significant increase in primary production of these plants as a response to the increase of CO_2 in the atmosphere. The primary production of tropical forests would be a direct effect, since other factors do not show a negative effect on plants (Karnosky, 2003). Studies under controlled conditions, including temperature and humidity, show an average increase of 30% in productivity of several C3 crops submitted to an atmosphere with doubled concentration of CO_2. Under less controlled conditions in the field, there were minor gains in productivity (10 to 28%). C4 plants show practically no advantage coming from the higher concentration of CO_2 (Fuhrer, 2003).

The larger accumulation of biomass by plants which benefit from higher concentrations of CO_2 in the atmosphere is followed by more efficient use of nitrogen, without necessarily producing crops richer in protein (Fuhrer, 2003). In the long term, productivity is expected to diminish due to the decrease of N stocks in the soil, which could be compensated for by soil fertilization. This could be a negative factor for agriculture in developing countries due to the lower than required doses of nitrogen fertilizers used on crops. In this respect, crop rotation, with the cultivation of leguminous plants that can fix atmospheric N_2 may contribute to a greater presence of N in the soil. Soybean crops, which occupy wide areas of Brazil as a summer crop, besides their relevance as a source of oil and protein, may decrease the risk of damage in future scenarios of N shortage as a component of crop rotation which is capable of fixing enough nitrogen from the air for high productivity and leaving a nitrogen surplus for the next crop in the form of stubble.

It is obvious that a rise in CO_2 levels may result in higher photosynthetic rates in C3 species, with direct consequences for productivity. However in scenarios of increasing global temperatures, this positive effect of CO_2 enrichment would be counteracted by negative effects resulting from high temperatures. Figure 4-1, which shows data compiled by Fuhrer (2003), indicates clearly the effects of temperature changes on wheat productivity, neutralizing the positive effects of a CO_2-enriched atmosphere.

In terms of adaptability to temperature and day length, there are marked differences between crops which use the C4 pathway for carbon assimilation (photosynthetic pathway) and those which use the C3 pathway. Good photosynthetic response is normally obtained with higher levels of temperature and radiation for C4 plants than those of C3 species (Table 1). Stress due to high temperatures causes a set of morphoanatomic, physiological and biochemical changes in C3 plants (Wahid et al., 2007), which affects their development and may in some cases result in drastic reductions in productivity.

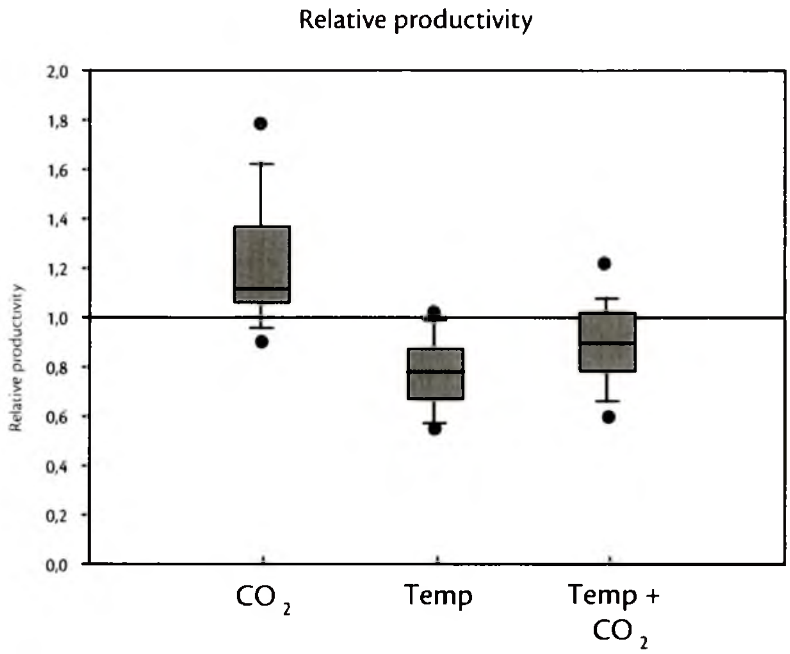


Figure 4-1: Effects of high concentration of CO2 and high temperatures, and effects of the combination of both factors on relative productivity of wheat; productivity in altered conditions in relation to normal environmental conditions of the studies.

Source: Fuhrer (2003).

According to climate scenario data generated by general circulation models, in 2050 soybean crops in Brazil will benefit from the higher concentration of CO_2 in the atmosphere, with an increase of productivity of about 20%. Wheat and corn productivity will be reduced as a consequence of temperature effects on crop cycles (Siqueira et al., 2001). However it is important to point out that effects of plague and diseases and climate risks were not considered in the model, which could drastically modify productivity predictions for crops.

Nowak et al. (2004) and Ainsworth and Long (2005) observed an increase of 10% in the production of air biomass in pastures composed of C3 plants. In tropical pastures there is a predominance of C4 plants which, according to studies revised by Porter (1993) (quoted in Howden et al., 1999), present a smaller increase in the production of dry matter (28%) compared to C3 plants (71%) under doubled concentrations of CO_2 in the atmosphere. Gains would be associated rather with more efficient use of water than to necessarily higher rates of CO_2 assimilation. More efficient use of water is due to smaller stomatal conductance which reduces humidity loss, while increased levels of atmospheric CO_2 maintain internal concentrations of CO_2, and thus also maintain the process of photosynthesis. We must also consider the combined effect of increasing concentrations of CO_2 and temperature oscillations, which may have a much more adverse effect in tropical areas than in temperate areas, as a consequence of larger evaporation and evapotranspiration, added to direct (temperature, precipitation) and indirect (plagues and diseases) effects on plants.

Nowadays it is agreed that the effects of high concentration of CO_2 observed in experimental sites may be overestimating the real situation at farm level, because limiting factors such as plagues and diseases, weeds, competition for water and nutrients, among other factors, are not well understood on a large-scale, and are not sufficiently used in the most sophisticated models available (IPCC, 2007).

4.3. Vulnerabilities of pasture areas and animal production systems

There is still great uncertainty about the effects of global changes on animal production systems. The prediction is that animal production in Latin America, predominantly characterized by the pasture system, will be negatively affected by greater variability in precipitation. Seasonal patterns of water availability and low nutrient availability in the soil are factors limiting the pasture areas of most of the region, and the nutritional value of tropical pastures, which is low already, may decrease even more as a consequence of the increase in the C:N (carbon:nitrogen) relationship (Zhao et al., 2005).

Among the most important factors for animal production systems is temperature increase and the CO_2 fertilizing effect. According to an FAO study (2003), agricultural livestock in temperate regions, especially in developed countries, will be favored, while in developing countries it will suffer losses due to heat stress on stock.

In terms of a direct effect on animals, temperature is the main factor. Variation in the rainfall regime may affect animals by drying water tanks and restricting water supply for consumption. Heat stress has a negative effect on the production of milk by cows, as well as on the fertility of pigs (Berman, 1991; Hahn & Mader, 1997; Hahn, 1999, quoted in Zhao et al. 2005).

Brazil, the greatest meat exporter in the world, has a beef stock mainly composed of zebu breeds, which is an advantage in relation to thermotolerance, given a future scenario of higher temperature. Zebu or Indian cattle (Bos indicus) have some advantages over the European (Bos taurus) in terms of thermotolerance, since zebu animals have greater capacity for regulating body temperature in thermal stress conditions, and high temperatures have less effect on their body cells in comparison to European cattle. In addition, zebu cattle's hide has special properties which increase heat loss and reduce the absorption of solar radiation (Hansen, 2004). Chicken breeding, in which Brazil is the second-largest producer, may also be affected by climate changes. Adult animals develop best when exposed to temperatures ranging from 18°C to 20°C, and are susceptible to high temperatures, with high mortality rates when the ambient temperature exceeds 38°C. Heat stress is responsible for great losses in chicken yield; a decrease in body weight is observed, followed by an increase in mortality rates (Fabrício, 1994). Thermotolerance is being investigated, but no great advance has yet been made. Acclimatization by exposing newborn chicks (up to 5 days old) to the stress of non-lethal heat (Arjona et al., 1988), or breeding birds with genes that result in fewer feathers, and therefore higher heat loss (Cahaner et al., 1993), are attempts at achieving better results from these birds in heat stress conditions. A plausible solution may be investments in facilities which ameliorate the effects of high temperatures.

Besides direct climate factors, other factors which affect agricultural livestock are the impact of changes on food availability and crop prices, impacts on pasture areas and forage crops, and the occurrence of plant and animal disease (Zhao et al., 2005).

4.4. Vulnerability of agricultural soil

Potential effects of climate changes on organic soil matter are still not well understood. It is however agreed that a significant alteration in carbon stocks in this sector will have an important effect on the composition of atmospheric gases, and will consequently affect the planet's weather. Climate change may induce losses of organic soil matter, interfering in the input and output of nutrients, and influencing the productivity of agricultural systems.

The amount of carbon present in the soil is the net outcome of the deposition and decomposition of organic residues when the former is part of the primary production of the surrounding vegetation. It is estimated that, in the first 30cm of depth, original stocks of carbon under native vegetation were around 37 Pg of C, and the largest stocks were found in Brazil's Southern region (Figure 4-2).

The inevitable removal of part of the native vegetation to obtain agricultural land has meant a reduction of carbon stocks in the soil, the level of which depended on the intensity of this agricultural use, as shown in Table 2, which illustrates the effects of soil use on important biomes around the country. Carbon loss in the soil is partly explained by a smaller production of residues in cultivated areas in comparison to areas with remaining native vegetation, and partly due to soil management, which has long been carried out on a conventional basis, with plows and harrows.

The increased adoption of production systems based on direct planting, and minimal cultivation, with crop rotation using plant species to promote soil overage and high residue production, with the emphasis here on integrating plantation and stock breeding, has not only reduced loss but created carbon accumulation in the soil, contributing to mitigating the greenhouse effect on the planet (Boddey et al., 2006; Cerri et al., 2007).

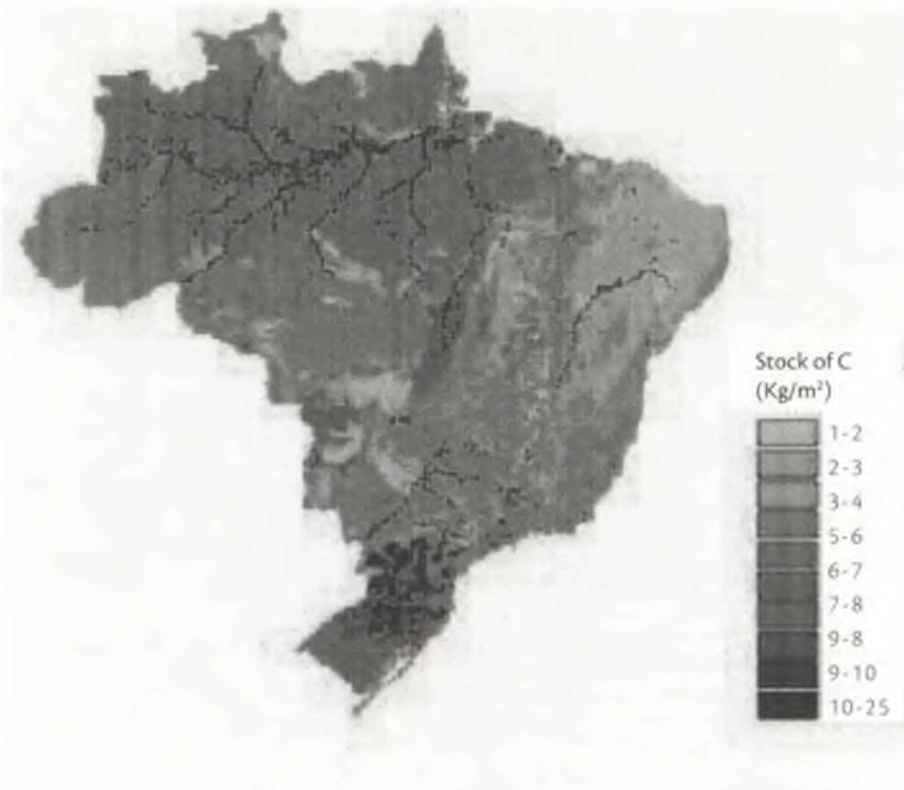


Figure 4-2: Carbon stocks (kg m⁻²) in Brazilian territory (www.mct.gov.br)

Table 7-2: Effect of soil use on carbon stocks down to 1m deep, in subtropical forest and Cerrado regions

Soil use	C stocks (kg/m³) for different soil layers (cm)	
	0-30	0-100
(subtropical) Forests	13.04	28.99
Cultivated (e.g. Forests)	6.56	13.58
Cerrado	9.35	19.46
Pasture (e.g. Cerrado)	7.52	13.61
Cultivated (e.g. Cerrado)	6.33	16.11

Changes in rainfall and temperature regimes will directly affect plant production, with consequent alterations in the balance between the deposition and decomposition of residues (Greenland et al., 1992). Increase of average soil temperature as a result of increased air temperature will have direct effects on the metabolism of organisms responsible for the decomposition of organic soil matter. As discussed by Davidson & Janssens (2006), organic matter decomposition is accelerated by an increase in temperature but this effect varies according to the organic matter component, thus the fraction which is protected by soil aggregates would not suffer from temperature effects. However if soil partitioning occurs due to direct impact of raindrops or to soil mechanization, organic matter will be unprotected and susceptible to mineralization, which will be more intense in a high-temperature scenario. In this case, a direct plantation system, which presupposes continual soil protection by preserving stubble, would play an important role in alleviating the effects of climate change on carbon loss from the soil.

A possible change in increase rainfall along with temperature rise, leads to uncertainties concerning the consequences of climate change for soil carbon stocks. More intense rains may break down aggregates and expose organic soil matter, where humid soil favors micro-organisms and their access to organic matter. On the other hand, in drier conditions, decomposition is reduced. In addition, it is more difficult to achieve soil humidity after long periods of drought by reason of an effect that repels water. This effect also occurs in areas which undergo frequent fires (Davidson & Janssens, 2006), which may happen in a scenario of higher temperatures, especially in forest regions.

These possibilities add to the uncertainties about the impact climate change may have on carbon stocks in the soil.

In relation to the growing concentrations of CO_2 in the atmosphere, recent research shows carbon stocks in the organic matter of the soil may rise and there may even be a saturation of this stock in conditions of high atmospheric concentrations of CO_2 (IPCC, 2007).

There are still many uncertainties about how extreme events (e.g. high temperatures, floods, etc.) and other atmospheric pollutants (e.g. tropospheric ozone) may affect soil carbon, especially in tropical soils, which reinforces the need for more research in this area in Brazil.

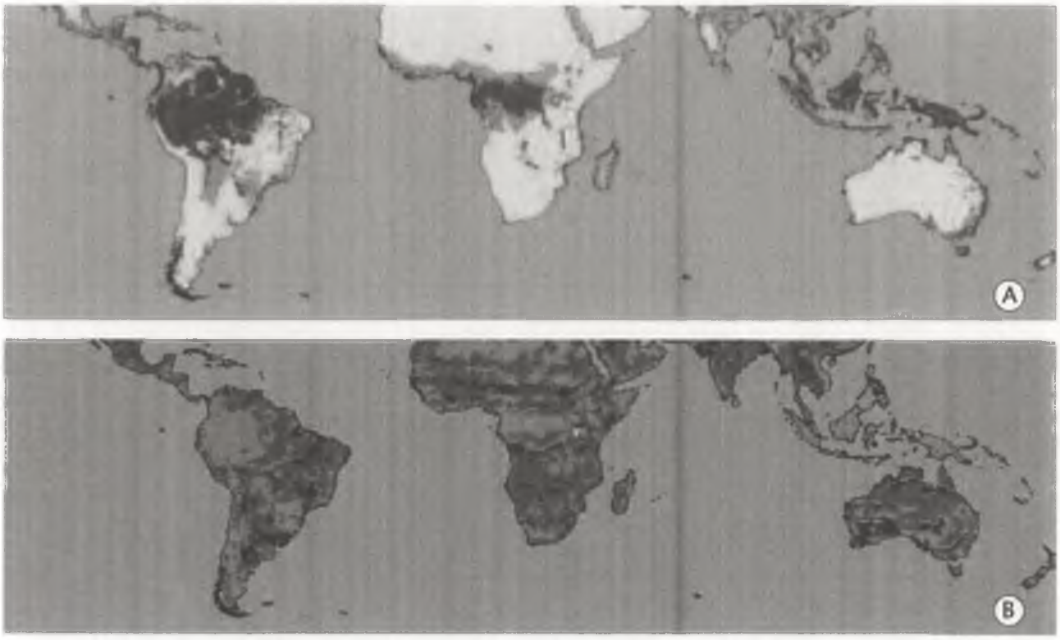
In an attempt at finding possible ways of reducing agricultural soil vulnerability to climate change, the IPCC (2007) draws attention the importance of identifying synergies between strategies of adaptation and mitigation in agricultural systems, bringing together questions about carbon capture, emission of greenhouse gases, change in land use and sustainable development of production systems within coherent networks of climate policy.

4.5. Effects of climate change on forests

Burning of forests and the intense use of their soil for agriculture largely contribute to the rise of the greenhouse-effect gases in the atmosphere, with Brazil responsible for more than 80% of total emissions caused by human agencies (Teixeira et al., 2006).

Forest ecosystems may be deeply affected by changes in concentration of CO_2 in the atmosphere and by alterations in climate variables. Global circulation models point to significant temperature rises in areas under natural vegetation, including the Amazon rainforest (Figure 4-3). In this case, biomass production and diversity may be influenced in a negative or positive way.

The great increase in concentration of CO_2 in the atmosphere projected for the coming decades must have a positive effect on tree growth, the extent of which will be influenced by plant species, soil fertility and the effect of other pollutants in the air (Karnosky et al., 2003). Oren et al. (2001) proved the fertilizing effect of CO_2-enriched atmospheres on *Pinus taeda* species, but experiments have shown that in low-fertility soils, no fertilizing effect has been observed. Since most forests occupy low fertility-soils, where nitrogen is an important limiting factor for tree growth (Vitousek & Howarth, 1991), we may not expect a significant compensatory effect from the excess of CO_2 in the atmosphere due to carbon capture in the forest biomass. An increase of 500ppm in the concentration of CO_2 in the air biomass has been observed for trees, within a range of 0-30%, where young trees have shown the highest values, and natural adult forests have shown few or no values at all (Nowak et al., 2004; Ainsworth and Long, 2005, quoted in IPCC, 2007).



Key		
Crimson - High	**Red** - Medium	Orange - Low

Figure 4-3: (A) Areas under tropical forests throughout the world, in green; (B) vulnerability according to climate changes.

Source: WWF - www.panda.gov.br

Temperature increase has a direct effect on the photosynthetic mechanism and in extreme conditions it may lead to a system collapse (Larcher, 2000). Water availability is a key factor in this process, and some regions such as the Amazon rainforest may suffer from water stress, becoming very vulnerable, although there are still great uncertainties concerning this.

The availability of nitrogen and other nutrients in the soil may rise due to accelerated decomposition of organic matter because of temperature increase (Melillo et al., 2002), and become more available for plant development, a situation which would allow an increase of carbon stocks in the system in the form of biomass. The presence of pollutants such as O_3 in the troposphere, combined with higher concentrations of CO_2, may decrease plants' defenses and increase their susceptibility to diseases, and the result would be a reduction in plant production (Percy et al., 2002). However some plagues and diseases themselves may be negatively affected, enabling better development of the forest (Zhao et al., 2005).

The Amazon rainforest has received special attention concerning the effects of climate change. The region holds the largest amount of tropical forest remaining in the world, the importance of which is in its role in the hydrological and climatic regulation of wide areas of South America, besides holding a large carbon stock and great biodiversity (Fearnside, 1999). Due to its importance, there is great concern about the global impact that the gradual disappearance of the Amazon rainforest would cause. This concern rises from the high deforestation rates observed over the years, which are the result of new roads that facilitate access to natural resources, and the creation of pastures, usually accompanied by fires (Figure 4-4).

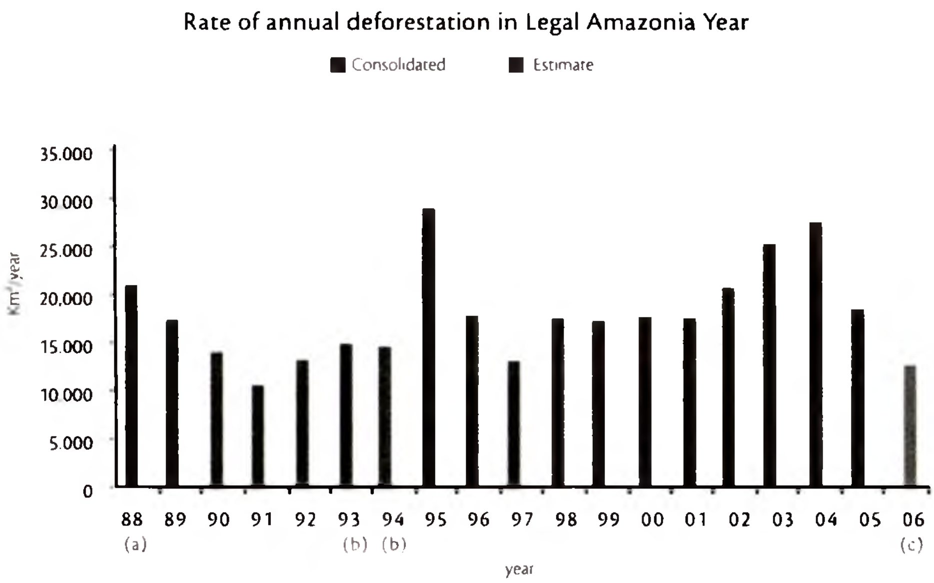


Figure 4-4: Deforestation next to roads opened within the Amazon Rainforest (A). The expectation of natural resources in the forest and the use of the land for agricultural activities are responsible for higher deforestation rates (B).

Source: www.inpe.br, INPE announces estimates of deforestation in Legal Amazon from August 2005 – August 2006, on 26/10/2006).

Deforestation leads to disastrous impacts on the environment, and fragments of forest remaining become even more vulnerable to climatic events. Laurance & Williamson (2001) show that forest fragments are more susceptible than intact forests to damage caused by long periods of drought caused by the El Niño phenomenon, which leads to physiological damage and even to the death of trees on the edges of the forest. These areas are drier, the risk of fire is higher and they are probably going to play a more important role in the permanence of plant covering than climate change (Zhao et al., 2005). The transformation of forest areas into pasture has immediate effect on temperature, evapotranspiration and precipitation. A study based on global circulation models confirms these effects, with increased drought periods, which would limit the development of humid tropical forests that are adapted to short periods of drought or even no drought at all (Nobre et al., 1991).

The predominance of drier environments has a negative effect on big forest trees, which cannot live under dry circumstances, and are then replaced by resistant species, which may give rise to the savannization of the Amazon rainforest.

Results presented by research studies are still filled with uncertainties about the impact of climate change on the survival and productivity of forests, especially tropical forests. However it seems reasonable to assume that the Amazon region may suffer from higher temperatures, and from periodic El Niño events, increasing the risk of fires. Forest areas in Brazil are certainly becoming more and more vulnerable due to deforestation and fires.

Finally, forests play an important role in regulating humidity and air temperature, on local, regional and global scales. Amazon forest evapotranspiration, for instance, is responsible for rains that pass over the Andes and arrive in the Mid-South region of Brazil (Fearnside, 2006), and this region is responsible for most of the nation's agricultural production. Thus changes in forest areas may result in great impacts on the country's agriculture.

4.6. Significant extreme events for agriculture

The frequency and magnitude of many climatic events increase as a result of even small temperature rises, and they will be higher given higher temperatures. Extreme events are floods, lack of soil humidity, tropical cyclones, storms, high temperatures and fires. Extreme events often have large-scale impacts locally and may significantly affect whole regions and specific sectors. Agriculture tends to be more vulnerable when exposed to extreme events related to water and temperature since this sector largely depends on natural resources. The growing of crops and quality of harvests may be relatively more susceptible to brief extreme events such as higher temperatures, severe frosts, hailstorms, and persistent droughts, situations which farmers fear the most.

The amount of damage caused by an extreme event depends on the development stage the crop has reached at the time of the incident. Cereals are a good example: if they are exposed to high temperatures before flowering, there will be a reduction in the number of grains that grow, leading to reduced grain production.

In order to measure the risk of extreme events and their consequences for crops, studies must consider crop-modeling activities. Large-scale models often mask local extreme events. Hence the importance of developing specific extreme event models for each crop.

According to Marengo (2006), global climate models have not shown a satisfactory simulation of current extreme events related to rainfall and statements declaring that extreme occurrences may be more intense and more frequent are based on observations made in the last 50 years and not necessarily on the projections of the models.

Observations made in Rio Grande do Sul, for instance, show that flood events and long droughts are respectively related to the El Niño phenomenon (warming of Pacific ocean waters) and to La Niña (cooling of Pacific waters). Harvest losses are observed during these events. According to the statistics available for the last two decades, four out of each ten harvests have been affected by drought events. Even though a forecasting system operates based on monitoring Pacific waters, much damage is still observed in production areas. Rainfall in the three summer months in 2004/2005 was less than 200mm in most of the state, the lowest in 53 years (Berlato and Cordeiro, 2005). According to these authors, this heavy drought led to a shortfall of about 20 million tons in the harvest in Brazil.

In Rio Grande do Sul alone, losses were more than 3.5 billion *reais* (US $1.7 billion). Harvest shortfall affects mostly poorer populations, which lose scarce resources invested in supporting their families and suffer food shortages, as is observed during the dry season in the Northeast region.

4.7. Projected impacts and risks for agriculture in Brazil

We do not yet have a reasonable idea of climate change consequences for Brazilian agriculture in general, although they are extremely important by reason of this sector's economic contribution to the country, with a GDP of approximately 6.4% (average GDP from 2000 to 2005, taking into account Gross Added Value of Agriculture and Stockbreeding to Basic Prices, according to the IBGE). Brazil is an important exporter of agricultural products, such as sugar, chicken, beef, pork, coffee, tobacco, soybean flour, soybeans, soybean oil and cotton, as well as cellulose and fruit. This agricultural situation may suffer changes due to climatic conditions in the areas recommended for each crop.

Based on observed evidence and tendencies in Brazil, as well as on studies which have considered climatic projections derived from climatic models from the IPCC, Marengo points out the fact that perennial crops, such as oranges, tend to seek out regions with gentler maximum temperatures, and hence they shift to the South. High temperatures in the summer will force this movement towards areas with favorable weather, which may lead to a reduction in the cultivated area, as is the case with rice, beans and soybeans.

In Brazil, the most important studies are those made by Siqueira et al. (1994, 2001), Alves & Evenson (1996), Assad et al. (2007), Pinto et al. (2004), Zullu Jr. et al. (2006), the main conclusions of which are shown below.

4.7.1. Simulation based on global circulation models and agricultural production models in Brazil

The projection of future agricultural productions under different scenarios of climate change, based on simulation models which include components of the soil-plant-climate system, has appeared as an important tool for evaluating technological strategies and environmental impacts.

Applying General Circulation Models (GCMs), such as GISS, GFDL and UKMO, and agricultural production models, Siqueira et al. (1994, 2001) have presented projections about the potential effects of global climate change on Brazilian agriculture, taking 13 different locations in the country as reference points and analyzing wheat, corn and soybean crops. The impact on crop production would be relatively large, with projected reductions in wheat and corn production. On the other hand, national production of soybeans would increase.

According to Siqueira et al. (1994, 2001), for the cultivation of wheat, the models projected a reduction in productivity of around 30%, accompanied by a shortening of plant growth cycles of between 14% and 15%, and the worst projected effects would take place in the Mid-South region (a transitional climatic zone between tropical and temperate climates). Projections for the cultivation of corn in the country were not favorable, according to these authors, with reductions in productivity estimated at 14% and 33% (an average of 16%), the most affected were Mid-South and Northern regions, with shortening of plant growth cycles of between 33% and 21% respectively.

Projections for soybean cultivation were positive, with a projected increase in productivity of between 5% and 34% (an average of 21%), where the effects on cycle length very from region to region, with the worst impacts on the Center-South and Southern regions, but not significant on a national scale (Siqueira et al., 2001).

The Northeast region would be especially vulnerable to a decrease in corn production and the Central and Mid-South regions would be vulnerable to reductions in wheat production. The Southern region would be vulnerable to wheat and corn reductions and the Northern region would be susceptible to reduced corn harvests

Applying the GISS transient atmospheric balance model, Siqueira et al. (1994, 2001) simulated scenarios with gradual alterations of CO_2 in plants to evaluate possible impacts on agricultural production. Projections pointed to a decline in wheat and corn production between 1990 and 2060. The most significant reductions in wheat and corn production appeared in the Mid-South region, while projections for soybean production were stable, and less marked for the Northeast region.

According to these authors, the main limitations of this study rest in the fact that the simulation devices applied were not enabled for all the regions analyzed and that technology and land use were taken as constant factors, even knowing that they might change in the future. They also pointed out the need for evaluating the real implications of physiological effects of CO_2 on the development of crop productivity.

4.7.2. Risks in climatic zoning of crops

Recent studies show that, according to scenarios of temperature increase, risks of production loss in several crops may occur, assuming they remain in the same areas where they are today, which are regarded as appropriate areas for agriculture. Risk scenarios in climatic zoning show a reduction in the favorable area for the cultivation of crops that are important for the country, with coffee growing the most harmed, followed by soybean production (Figure 4-5 and Table 4-3).There are uncertainties concerning these estimates, mainly because of the lack of information about all the variables involved, but they are useful for developing adaptation strategies for agriculture, and to serve as a basis for planning public policies for this sector.

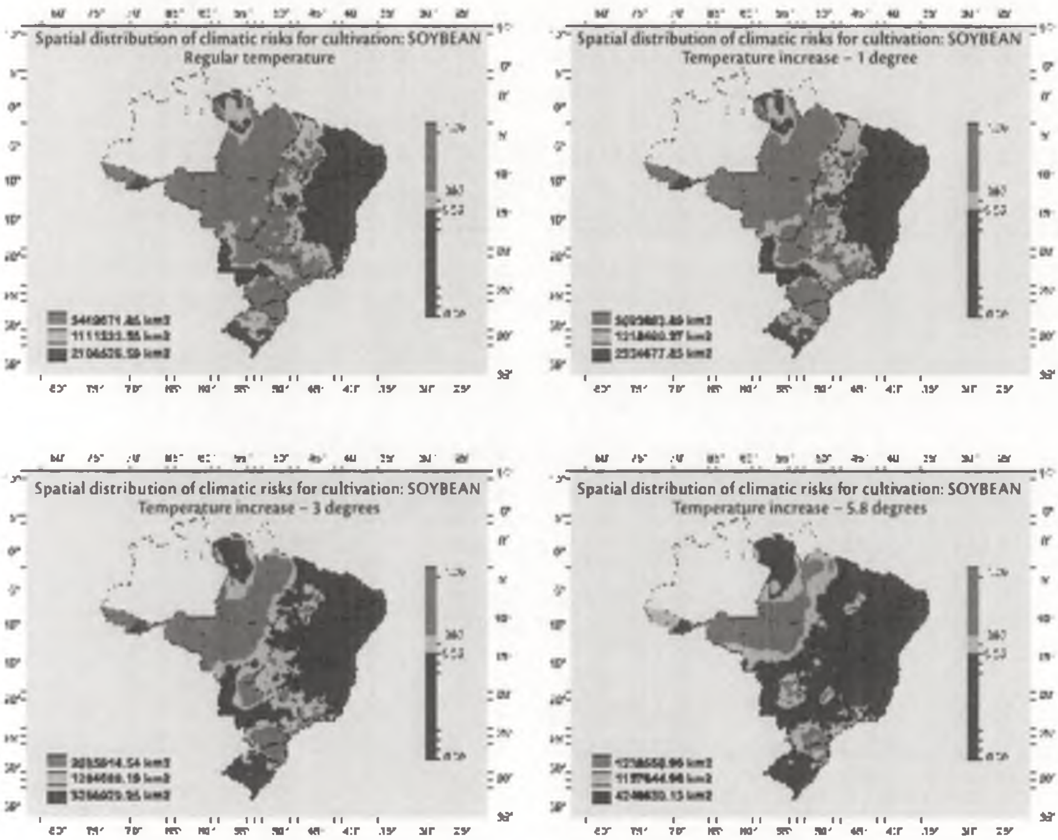


Figure 4-5: Impact of the variation of average air temperature on areas appropriate for soybean cultivation in Brazil. The maps show the distribution of favorable areas for the cultivation of soybeans, from green to red.

Table 4-3 – Future decrease of planted areas projected for an optimistic scenario of average global temperature rise of 1oC, and for a pessimistic scenario with a rise of 5.8oC, where current potential area is the reference.

Table 7-3: Future reduction in the planted area of certain crops expected in an optimistic scenario of +1°C in average global temperature, and for a pessimistic scenario of +5.8°C, taking as a reference current potentially usable area.

Crop	Current potential area (km²)	Area reduction (%)	
		Optimistic scenario 33.8°F (1°C)	Pessimistic scenario 42.44°F (5.8°C)
Rice	4,755.204	4	41
Beans	5,141,047	3	23
Soybean	3,419,072	10	64
Corn	5,169,034	2	14
Coffee	904,971	23	92

Adapted from Assad et al. (2007)

Potential impacts of the increase in average air temperature of 1°C, 3°C and 5.8°C and of an increase of 15% in rainfall in the agroclimatic zoning of coffee (Coffea arabica L.) were simulated and evaluated by Assad et al. (2004) for Goiás, Minas Gerais, São Paulo and Paraná. Climatic risks for coffee growing in these states were defined based on annual water deficiency values, average annual temperature, and frost possibilities, resulting in a risk-zoning map. Evapotranspiration and water balance values in the simulation were re-calculated based on temperature maps (1°C, 3°C, 5.8°C). The authors showed a potential reduction of 95% in areas suitable for coffee cultivation in Goiás, Minas Gerais and São Paulo, and of 75% in Paraná, under a temperature increase scenario of 5.8°C. Zullu Jr. et al. (2006) also evaluated the impact on corn production, applying this methodology. According to their projections, crop production would decrease in sandy soil faster than in clay soil as temperatures increased. With a temperature increase of 5.8°C, there would be a severe reduction in the suitability for corn production, regardless of soil texture. They also argue that increased rainfall would not be enough to soften the impacts related to a rise in average temperatures.

4.7.3. The Ricardian model

Using another methodological approach, Alves & Evenson (1996) and Sanghi et al. (1997) apply the Ricardian model (Mendelsohn, Nordhaus and Shaw, 1994) to estimate the impact of global climate change on Brazilian agriculture. The Ricardian model consists in evaluating the influence of variables such as production, work, fertilizers, constructions, roads, scientific research, technology choice, rural extension, and climatic variables (temperature, rain, solar radiation, etc.) and soil variables (type of soil, declivity, texture, etc.) on land productivity, and consequently on its price. The Ricardian model analyzes land value according to different climatic values, combining these values with climatic variables (temperature and precipitation) and other factors. It is a cross-sectional approximation, based on the hypothesis formulated by David Ricardo, in which land value indicates the current value of expected productivity of the land in the future. The results are presented as the difference between the land value in a future climatic scenario, and the current land value. Based on this analysis, it would be possible to estimate the impacts of landowners' adaptations to climate change on the production and productivity of agricultural establishments. According to the authors, the net impact of climate change for Brazilian agriculture would be negative, especially for the Mid-West region, where the predominant vegetation is the *Cerrado*, while the Southern region would benefit moderately from global warming.

Following these research projects, a study has been recently carried out in seven South American countries (Argentina, Brazil, Chile, Colombia, Ecuador, Uruguay and Venezuela), with the aim of evaluating the impact of climate change on agriculture, as well as the vulnerabilities and possible directions for adaptation in each country. This study (Climate and Rural Poverty: Incorporating Climate into Rural Development Strategies) is part of a bigger project from the Yale School of Forestry and Environmental Studies, financed by the World Bank and applied to Southern Cone and Andean countries. In this study, impacts of climate variability and climate change on natural resources and on rural poverty in Brazilian regions were identified. The changes landowners are already applying to adapt to the weather and the new adaptations which might be applied in the future, were also evaluated. The results have shown that temperature and precipitation changes will negatively affect land values for 9-31% of small farmers and 47-80% of commercial producers (Mendelsohn et al., 2007).

4.7.4. Effects of climate change on pathogens

Climate changes are associated to the sensitivity of plants to humidity and their responses to pathogens. Climate change may lead to diseases emerging through gradual alterations in climate (through alterations of invertebrate vectors or increasing temperature and water stresses on plants) and a higher occurrence of unusual climate events (a tendency to dry weather favors insect vectors and viruses, while humid weather favors fungal and bacterial pathogens) (Anderson et al., 2004).

In a study on black sigatoka disease in banana trees using distribution maps of the disease and scenarios from the IPCC, Ghini et al. (2007) showed a reduction in the favorable area for the disease in Brazil, especially in A2 and B2[1] scenarios. The research considered the premise that the development of the disease is favored by temperatures between 20°C and 30°C, and relative humidity above 70%, so that regions where the average temperature is less than 20°C, or over 30°C, or where average relative humidity is less than 70%, were considered as unfavorable areas for the disease to flourish.

According to Fernandes et al. (2004), the risk of occurrence of *Fusarium* in wheat crops is very likely to rise as a consequence of climate change in southern Brazil and Uruguay.

Few measurement experiments have been conducted in the field in Brazil to evaluate the effects of climate change on agriculture, and these are very important to validate simulation models used to estimate impacts on agricultural soil, crops and livestock activities.

4.8. Adaptations of agriculture to climate change

Plant species have a wide range of physiological adaptability which provides a considerable capacity to create a buffer effect against the variability associated with climate change. On the other hand, it is necessary to increase our knowledge about the potentialities and limitations of production systems in relation to climate change, taking into account the determining factors of agro-climatic sustainability and flexibility in tolerating change. The main factors concerning plants would be the photosynthetic pathways, tolerance to high temperature stress and drought periods, as well as the photoperiod, which could be important if plantations need to migrate to different latitudes. Soil type, considering its characteristics of humidity storage, drainage and erosion risks, as well as management, must also be considered

The FAO (2003) has identified some actions for adaptation to climate change for the agricultural sector, for instance:

- formulation of support mechanisms for producers to help them adapt to climate change.

1 The A2 scenario presents high rates of greenhouse gas emissions, that is, it maintains the current standard of emissions. It describes a very heterogeneous world with a high growth of human population. Economic growth is regionally oriented. B2 is a scenario of lower emissions, with more optimistic characteristics than the A2 scenario. It describes a world which emphasizes local solutions to economic, social and environmental sustainability. It presents moderate population growth and medium levels of economic growth. It is oriented towards environmental protection and social equity, but focused on local and regional levels (IPCC, 2001c)

- maintenance of a wide genetic base for crops and development of varieties of crops and animal breeds more resistant to drought;
- improvement of resilience of agricultural ecosystems through the promotion of practices which create and maintain biological diversity;
- improvement of efficiency of water use and restocking underground water supplies through conservational agriculture;
- supporting pasture systems and other systems of animal production with activities concentrating on the production of food supplements, veterinary services, and water supply, among other measures.

We present below adaptation strategies for agricultural systems in Brazil, bearing in mind the current stage of knowledge.

4.8.1. Agroclimatic zoning

Agroclimatic zoning is achieved by data compilation concerning weather, which may be obtained from surveys on a regional scale, with information about the temperature and water needed for good development of a crop. The information originated allows the estimation of production risks for each crop, and helps to give guidance for better use of the land.

The use of this tool is very important for identifying better areas for each type of crop, allowing greater productivity, as has happened with the cultivation of rice on highlands in Mato Grosso, which is nowadays the second biggest producer of rice in Brazil. This work has been conducted in several *Cerrado* regions by Embrapa Arroz e Feijão (Rice and Beans - www.cnpaf.embrapa.br). Agroclimatic zoning will thus allow the identification of vulnerable areas, as well as areas which will be more suitable for each crop according to the rainfall and temperature systems.

4.8.2. Plant improvement

Temperature and rainfall regimes are the main climatic variables which will impact on global agriculture due to climate change. Accordingly, plant improvement is a key process for the adaptation of crops to stress conditions which might occur much more severely in future scenarios.

Stress caused by high temperatures, be it transitory or continuous, already affects some agricultural regions, Brazil included. It is believed that it will be possible to overcome thermal stress, by means of transference between individual thermotolerant species. High-temperature stress may occur in different phases of development of plants, from germination to the development of grains, which is encouraging research into ways of controlling this characteristic. In addition, some species, such as soy and other types of beans develop associations with soil bacteria which naturally feed the plant. These associations are also affected by high temperatures. Several studies are being conducted in order to select varieties with the potential for tolerating temperature effects but it is a slow process.

Some varieties which show tolerance to long droughts may carry genes which guarantee thermotolerance, as must be the case for some varieties of beans, especially those planted in the Northeast region. Gene mapping and the development of transference techniques are primary objectives for future research (Wahid et al 2007).

Concerning micro-organisms, studies involving rhizobium selection capable of colonizing root nodules and fixing nitrogen in high temperature conditions have already enabled the isolation of efficient strains for bean plants (Hungria et al., 2000).

Besides the negative effect of high temperature, drought is one of the environmental stresses that most affects crop productivity around the world. However simply improving crops for high productivity in conditions without water stress already permits higher productivity when crops experience gentle or moderate stress situations (Cattivelli et al., 2008). Plants have several genetic characteristics related to water stress, and traditional improvement by crossing compatible individuals is a way to obtain stress-tolerant crops. The *robusta* coffee plant, for instance, has genetic characteristics which make it more tolerant to drought periods and is part of a research study being carried out by Embrapa Genetic Resources for transferring this characteristic to the *arabica* strain of coffee through traditional improvement techniques (Cenargen, Agricultural Report dated 14/04/2007). On the other hand, with the advance of molecular techniques which allow the genetic sequencing of many plant species, genes related to characteristics of drought tolerance have been identified. The cowpea (*Vigna unguiculata*) in the Northeast region produces great quantities of an amino-acid called proline which provides the plant with tolerance to drought and heat, the genes responsible for which have been isolated and are now used in studies on the genetic modification of crops submitted to water stress such as soybeans, corn, sugarcane, etc. (ACT, 2007), which will probably have a positive effect on these species' thermotolerance.

Embrapa, in cooperation with the Japanese government, is testing a new variety of soybean which has received, through biotechnology, a gene which makes it more tolerant of to drier periods (Figure 4-6) extracted from the first species of plant to have its gene sequenced, called *Arabidopsis thaliana*. It is a herbaceous plant of the Brassicaceae family, to which mustard also belongs. It plays an important role in botanic genetic studies, similar to that of drosophila, in other genetic fields. Research studies to evaluate performance in the field and possible environmental impacts are still being carried out before releasing the project for commercial use.

Figure 4-6: Soybean with drought-tolerant genes. The four pots on the left contain the gene for tolerance, the other four correspond to the common soybean. This photograph was kindly provided by Dr. Alexandre Nepomuceno, member of the research staff at Embrapa Soja, Londrina, PR.

4.8.3. Management of crops and soils

While efforts are made to improve of plants capable of resisting abnormally high temperatures and drought, the management of production systems may contribute in a more immediate way to reducing the problem. Coffee growing, for instance, is very sensitive to temperature changes, and according to Assad et al. (2004), more than 90% of the areas used for growing coffee would be compromised by a rise of 6°C in average air temperature. A possibility for mitigating this process is the use of shade systems, as practiced in Costa Rica. Under the shade of trees, temperatures are lower, contributing to a reduction in risks of productivity loss resulting from high temperatures. This possibility has already been the topic of discussions concerning the future of crops in Brazil ("Debate sobre arborização e mudanças climáticas traz alerta a cafeicultores" a paper published on 21/11/2006 on the Portal do Agronegócio - www.portaldoagronegocio.com.br), and it is already being used experimentally by Embrapa in growing organic coffee (Figure 4-7), which includes a greater variaty of species.

Figure 4-7: Shaded coffee plant in an organic system cultivated along with leguminosae species and banana plants. Embrapa Agrobiologia, Seropédica, RJ.

Afforestation is a strategy which may benefit crop production and pasture. Recently, Embrapa has invested in the development of silvopastoral and production systems which integrate crops-livestock-forest. The presence of trees in the production system creates favorable micro-climates for forage plants and animals which may be affected by heat waves caused by climate change.

Direct planting is a system which has great success in saving soil water (Figure 4-8). This system is applied in almost half the production area of crops in the country, and it is characterized by its lack of soil movement for planting, and therefore soil remains covered by harvest residue. Direct planting has replaced conventional soil preparation system as a way of interrupting water run-off, which took with it large quantities of soil, promoting erosion. According to data gathered by De Maria (1999), direct planting may decrease water run-off by 20% due to the slower run-off resulting from the presence of residues on the soil. Also, the presence of residues on the soil surface diminishes evaporation and leaves relatively more water for plants (Silva et al., 2005), raising the chances for the crops to survive through drought periods. In Brazil, it is estimated that this practice is applied in more than 20 million hectares, especially in the South and Central-Western regions (Cerri et al., 2007)

Figure 4-8: Direct planting on straw: reduces water loss by superficial run-off and preserves soil water due to less evaporation.

4.9. Preliminary recommendations for adaptation policies and strategies for the agricultural sector in terms of climate change

Due to the need to take decisions concerning possible climate changes by means of public policies, it is very important to improve prediction models at regional levels in order to deal with future climate events, taking into account uncertainties and associated probabilities of loss. Options for inaction, mitigation and adaptation derive from the expectations and magnitude of abnormal climate effects.

1) Elaborating and setting up sound R&D programs for evaluating impacts of climate change on agriculture and for proposing adaptation measures, bearing in mind the main agricultural and forage crops, and including predictions about extreme events with implications for agriculture. To achieve this objective, it is very important to promote and encourage technical training on the evaluation of risks caused by climate change, using different methodological approaches which can be applied to estimates of vulnerability.

   There is a shortage of studies in Brazil about the effects of increasing concentrations of CO_2 in the soil-plant system of agricultural ecosystems, combined with predicted temperature increase in water and nutrients. Field and laboratory research must be encouraged in order to generate knowledge about the real responses of each system to climate change, giving support to prediction models.

Other R&D actions include initiatives for implementing and improving socioeconomic, meteorological, environmental, agricultural and demographic databases to provide more consistent evaluation of climate change impacts on food security and rural properties in Brazil, seeking opportunities to reduce vulnerability to rural poverty which will lead to local actions concerning mitigation and adaptation measures in relation to climate change. Studies researching the synergy between mitigation and adaptation measures must be supported.

2) Rural extension courses to inform rural producers about the potential impacts of climate change, and to give them guidance about adaptation measures.
3) Development of services to give warning of extreme events and climatic variation.
4) Adopting incentives for preserving and expanding forest areas, forest corridors, integrated crop-forest systems, as well as stricter supervision of legal land use.
5) Development and application of management technologies for land use and plant improvement.
6) Incentive for mixed production systems (e.g. integrated crops-livestock-forest system)
7) Encouraging projects like the Clean Development Mechanism (CDM) with a view to instituting sustainable development and making a positive impact on local communities. According to Brazil's current emission profile, it is highly recommended that there should be discussion and application of new models of relationship between those interested in the CDM process: government agents, agricultural workers, landowners and private companies. The Federal government should stimulate projects concerning land use in a CDM context, defining clear policies which minimize risks and promote the engagement of every actor in the process. Wider implementation of an economic strategy, such as carbon credits or payment for environmental services, may be an interesting approach.

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