Potential Economic Impacts of Global Warming on Two Brazilian Commodities, According to IPCC Prognostics

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Abstract

The effects of global warming on soybeans and arabica coffee at the end of the 21st century were assessed based on the prognostics of IPCC and on the methodology of the agricultural zoning program. The potential economic impact on the production of soybeans and arabica coffee can be significant in the regions analyzed showing the immediate need for political and technical actions in order to minimize unfavorable effects that can affect the Brazilian economy in the next decades.

Introduction

The GDP (Gross Domestic Product) of Brazilian Agribusiness reached around 30% of total national GDP in 2003, corresponding to 165 billion dollars. The exportations associated with the sector represented 40% of the national total, bringing on the order of 30 billion dollars into the country, which is fundamental for the 26-billion-dollar trade surplus that was registered in the trade balance in 2003. Jobs linked to agribusiness represented 40% of total employment. Brazil is the world largest producer of sugar, alcohol and coffee, the second largest of soybeans, beef and chicken and the third largest of fruit and corn (maize). It is the largest exporter of sugar, alcohol, coffee and soybeans. It sells 82% of the orange juice, 29% of the sugar, 28% of the coffee beans, 44% of the instant coffee, 38% of the soybeans and 23% of the tobacco consumed on the planet (SAMPAIO, 2005). It is possible to affirm, according this data, that Brazilian agribusiness is fundamental for the country and for other regions in the World because of these export products.

Among the various important factors of Brazilian agricultural production, climate is one of the most important due to the diversity of regional conditions. According to ROSSETI (2001), about 90% of all losses in Brazilian agriculture registered until the middle of 90's were directly related to two main climate factors: dry spells during the reproductive stage (in 60% of cases) and excessive rainfall in the harvest (in 30% of cases). These losses were directly related to poor knowledge of rainfall distribution, which led farmers to grow crops with high risk of loss due to water stress or excess in some specific phenologic stages.

As an attempt to decrease climate risks for agriculture in Brazil (mainly excessive rain during harvest and dry spells during the reproductive stage), in 1996 the Ministry of Agriculture started an official program of agricultural zoning to define planting calendars based on meteorological parameters for the main crops in Brazil, such as rice, beans, corn, soybeans, wheat, sorghum, cotton, coffee and fruits. The calendars have been calculated in order to achieve less than 20% of risk of climate problems. The Agricultural Zoning is updated every year with new crops, cultivars, climate data and interpolation methods. Climate oscillations such as those attributed to El Niño and La Niña that can impact the agriculture production in some regions are usually considered during the development of Agricultural Zoning.

The importance of agriculture for the Brazilian economy requires impact assessment studies for seasonal climate variations and for climate change such as that presented by the "Intergovernmental Panel on Climate Change" (IPCC, 2001a and 2001b) report published by UNEP/WMO (Environmental Program of the United Nations - World Meteorological Organization). This report indicates a disturbing situation regarding global warming due to natural and anthropogenic effects. Global mean temperature could increase from 1.4°C to 5.8°C during this century considering the average of 1961/1990 as reference. These scenarios complement the studies presented previously by IPCC (1997), when an estimate of 0.05°C temperature increase per decade was made based on more reliable measurements started in recent years. It was also verified that precipitation had increased from 0.5% to 1.0% per decade, until the end of 20th century, mostly in northern Hemisphere. In tropical region (from 10°N to 10°S), precipitation increased from 0.2% to 0.3%.

This paper analyses the economic impacts of climate change at the end of the 21st century for two important Brazilian commodities, soybeans and arabica coffee, considering the current climate risk zoning as a basis for comparison. The economic impact on the production of soybeans and arabica coffee could be significant in the regions analyzed, showing the need for immediate political and technical actions in order to minimize unfavorable effects that can affect the national economy in the next decades.

Materials and Methods

The potential economic impact of the climate changes presented by IPCC (2001a, 2001b) were assessed considering a direct and linear relationship between the variations in the size of suitable areas for soybean production caused by new climate scenarios and the variations in soybean production. The suitable areas were defined using the same methodology as the agricultural zoning program. It was assumed that production is directly proportional to the dimension of suitable areas for planting, decreasing or increasing at the same rate as the decrease or increase of suitable areas. Some other assumptions were also considered:

a) The agricultural zoning that is used in Brazil as a public policy tool indicates correctly suitable areas for soybean production with risk of climate problems lower than 20%;
b) This agricultural zoning is being used by farmers;
c) The temperature will increase at the same rate throughout the year;
d) Production in suitable areas will not compensate for the loss of production in presently suitable areas that will become unsuitable in a new climate scenario;
e) Productivity in suitable areas will not increase in a new climate scenario compared to the current situation;
f) There will be no adaptation of current varieties nor use of varieties which are better adapted to more elevated temperatures;
g) The main planting time will be the same used today.

Four different climate scenarios were used: the current scenario and three others related to possible climate changes due to elevations of the average temperature of 1°C, 3°C and 5.8°C. This corresponded to development of four different zonings, one for each climate scenario. The simulations were performed for the States of Mato Grosso and Paraná, since they are the two main soybean producers and are representative of the conditions of soybean production in the Southern and Center-West Brazilian macro regions.

The method used to calculate the dimension of suitable areas for soybean production was based on cumulative water balances carried out for dekads (periods of 10 days) during the cropping season (from planting to maturity). This required a preliminary collection of some input parameters, such as the length of four growth stages (15 days for the initial stage, 40 days for the vegetative stage, 40 days for the reproductive stage and 30 for maturity) and total growing period (125 days), crop coefficient for each growth stage, soil water load capacity

(50mm for Mato Grosso and 65mm for Paraná) and rainfall. A cumulative water balance proposed by FOREST (1984) which was tested by ASSAD (1986) and modified by VAKSMANN (1990) was used to calculate the values of the "Water Requirement Satisfaction Index (WRSI)" (ratio between actual and maximum evapotranspiration, where actual evapotranspiration was given by Eagleman's equation (EAGLEMAN, 1971) in the four growth stages) that summarizes the degree to which cumulative crop water requirements have been met. WRSI values during the reproductive stage (flowering and grain-filling stage) for a minimum frequency of 80% were spatialized through a Geographical Information System based on a Kriging method and used to assess the suitability of a place: suitable or favorable (when the WRSI value was greater than or equal to 0.6) or unsuitable (when the WRSI value was lower than 0.6).

The planting date from 1 to 11 November was chosen for Mato Grosso and from 1 to 10 December for Paraná. Crops were assumed to be rainfed, that is, rainfall is considered their only water supply. Potential evapotranspiration (PET) was calculated using the method proposed by THORNTHWAITE & MATTER (1955) and adapted by CAMARGO & CAMARGO (1983). Figure 1 shows a simplified flowchart of the methodology that was used for soybeans.

The other crop analysed in this paper was arabica coffee (***Coffea arábica*** *L.*), with the suitable areas defined according to the following climate requirements proposed by CAMARGO et al. (1977), PINTO et al. (2001), SEÇÃO DE CLIMATOLOGIA AGRÍCOLA (1972) and INSTITUTO BRASILEIRO DO CAFÉ (1977, 1986): i) annual water deficit from 0mm to 100mm per year; ii) average annual temperature from 18ºC to 22ºC; and iii) frost risk less than or equal to 25%. Areas where the average annual temperature is between 22°C and 23°C are suitable with thermal excess restriction. Areas where the annual water deficit is from 100mm to 150mm and the average annual temperature is from 22°C to 23°C are suitable with supplementary irrigation. Frost risk was computed using a model presented by CAMARGO et al. (1993), considering 1°C as the reference temperature for frost occurrence (PINTO et al., 1977, 1983). Figure 2 shows a simplified flowchart of the methodology used in the climate risk zoning of arabica coffee. Economic impact was assessed with the same methodology and assumptions used for soybeans. The simulations were performed for the States of São Paulo and Minas Gerais. Results for the States of Paraná and Goiás were presented by ASSAD et al. (2004).

Results

Figure 3 shows the spatial distribution of soybean production (in tons) of Mato Grosso's municipal districts in 2003 according to IBGE (2005).

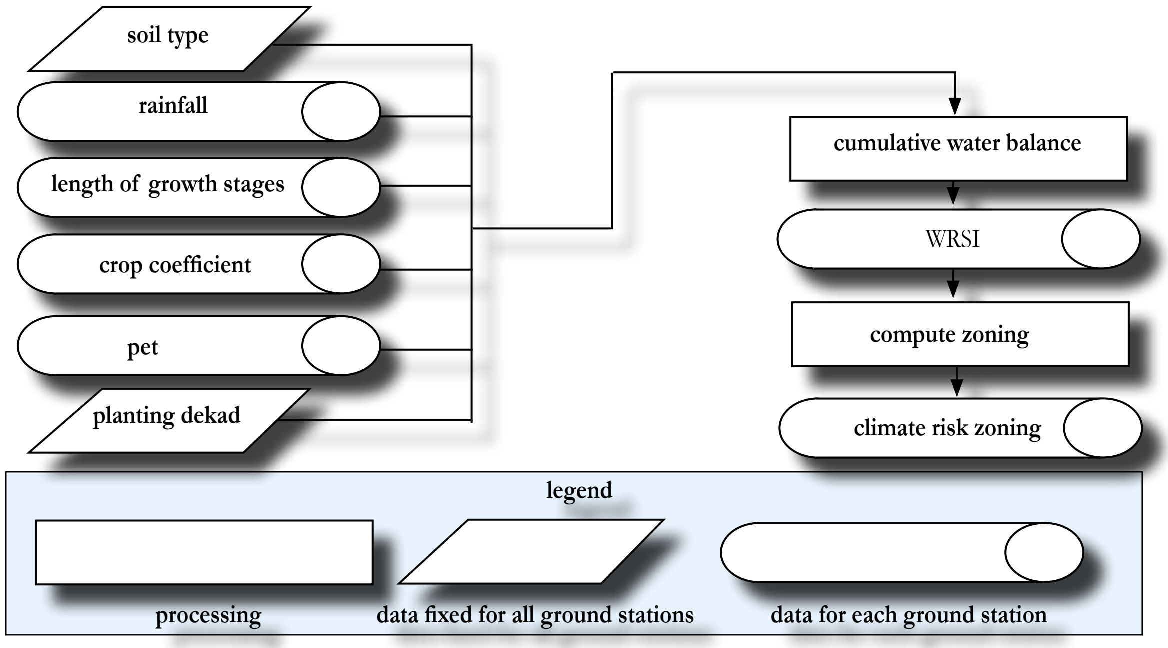


Figure 1 – Simplified methodology flowchart used in climate risk zoning of soybeans.

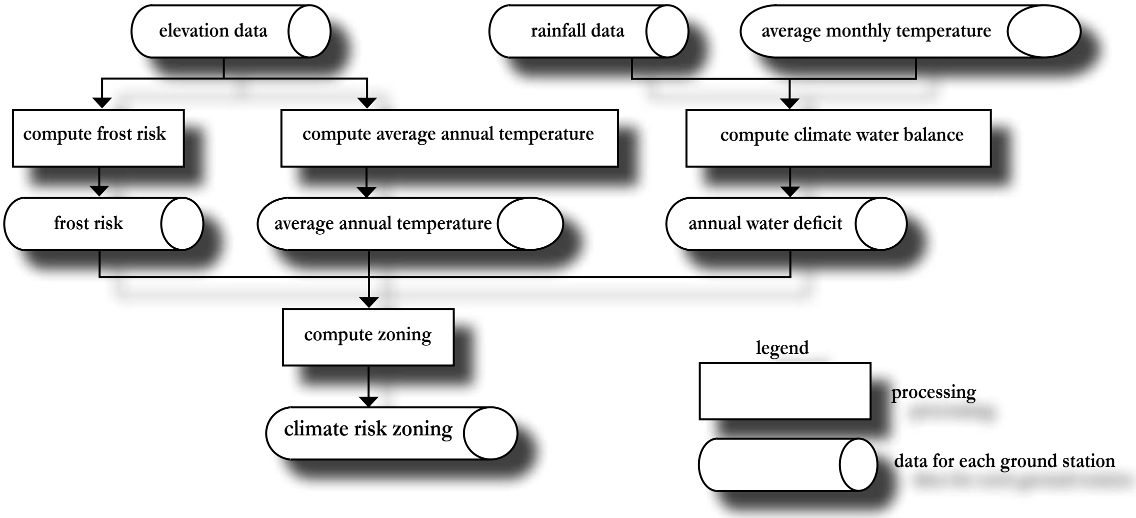
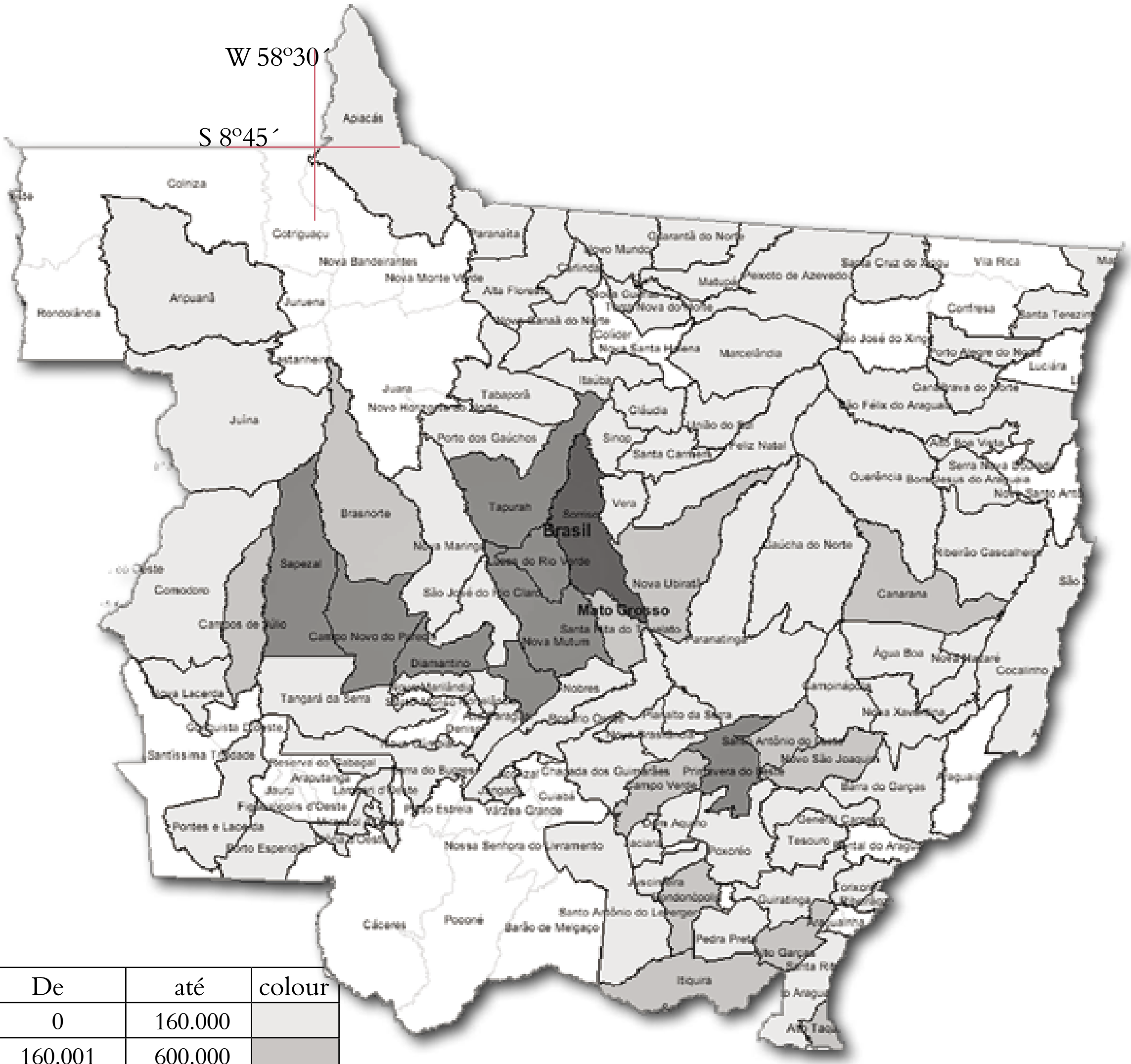


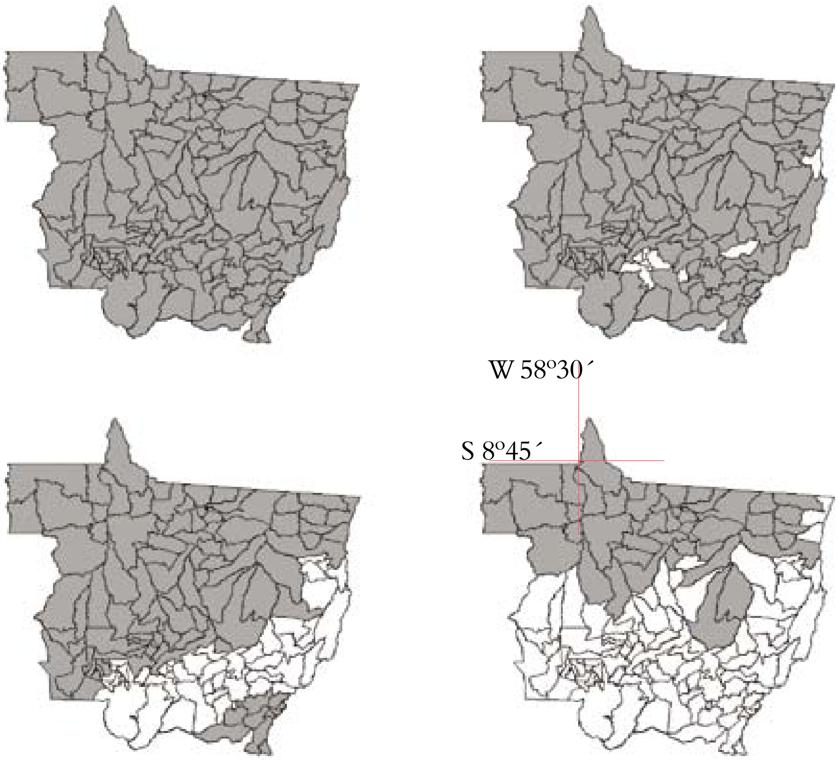
Figure 2 – Simplified flowchart of the methodology used in the climate risk zoning of coffee.



De	até	colour
0	160.000	
160.001	600.000	
600.001	1.100.000	
1.100.001	1.610.000	

Figure 3 – Soybean production (in tons) of Mato Grosso's Municipal districts in 2003.

Figure 4 – Climate risk zoning scenarios for soybeans in the State of Mato Grosso: current situation (upper left side), 1°C increase (upper right side), 3°C increase (lower left side) and 5.8°C increase (lower right side). Suitable areas are shaded.



The central region, especially the municipal districts of Sorriso, Lucas do Rio Verde, Nova Mutum and Tapurah, is the main producer.

Figure 4 shows the climate risk zoning of soybeans for the State of Mato Grosso in four different climate scenarios: the current situation (upper left side), 1°C increase (upper right side), 3°C increase (lower left side) and 5.8°C increase (lower right side). Suitable areas are shaded.

Soybeans are produced throughout the state of Mato Grosso, showing an overlap of the agricultural zoning (Figure 4 – upper left side) and the real situation (Figure 3). The 1°C increase does not significantly decrease the suitable area, while the Southern and East regions become unsuitable with the 3°C increase. The central region, however, which was the main producer in 2003, will still be suitable. The 5.8°C increase will change the suitability of the main producing regions. Table 1 shows an estimate of suitable area, production and financial return for each climate scenario compared with the values for 2003: suitable area of 893,243km^2, production of 12,965,983 tons and a return of US$200 per ton.

Figure 5 shows the spatial distribution of soybean production (in tons) of Paraná's municipal districts in 2003 according to IBGE (2005). Soybeans production is centered on two regions: from the west to the north (especially in Cascavel, Toledo and Assis Chateaubriand) and in the east (Castro,

Table 1 – Estimate of suitable area, production and financial return in different climate scenarios compared with values for 2003 for soybeans in Mato Grosso

Temperature Increase	Suitable Area (km^2)	Variation (%)	Production (tons)	Difference according to reference values	
				Production (ton)	Financial Return (US$)
+1°C	847,560	-5.11	12,302,866	-663,117	-132,623,400
+3°C	633,776	-29.0	9,199,657	-3,766,326	-753,265,200
+5.8°C	326,666	-63.4	4,741,762	-8,224,221	-1,648,844,200

De	até	colour
0	30.000	
30.001	100.000	
100.001	200.000	
200.001	300.000	

Figure 5 – Soybean production (in tons) of Parana's Municipal districts in 2003.

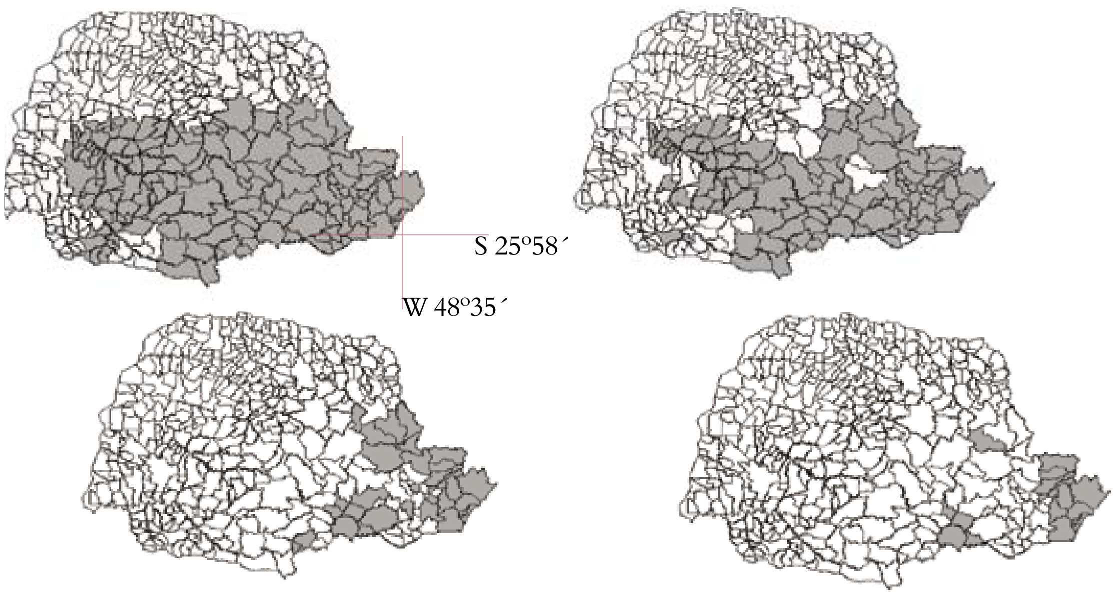
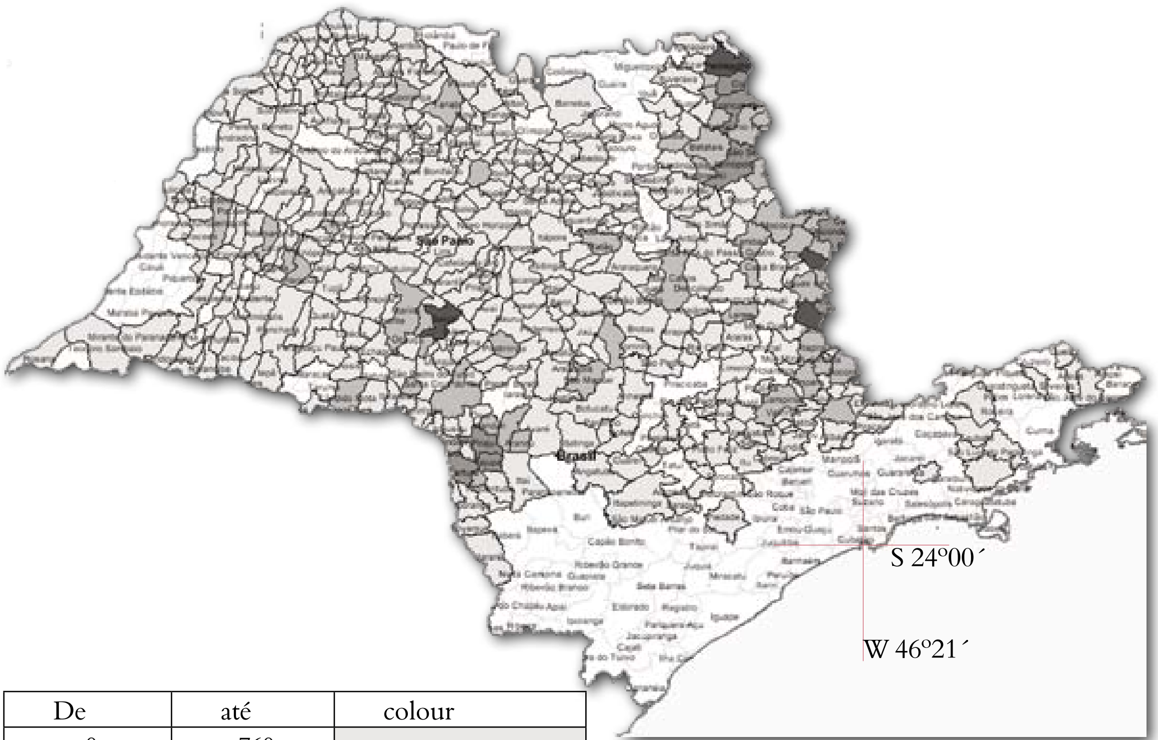


Figure 6 – Climate risk zoning scenarios for soybeans in the State of Paraná: current situation (upper left side), 1°C increase (upper right side), 3°C increase (lower left side) and 5.8°C increase (lower right side). Suitable areas are shaded.

Table 2 – Estimate of suitable area, production and financial return in different climate scenarios compared with values for 2003 for soybeans in Paraná.

Temperature Increase	Suitable Area (km^2)	Variation (%)	Production (ton)	Difference according to reference values	
				Production (ton)	Financial Return (US$)
+1°C	70,698	-27.2	8,012,653	-2,997,293	-600,458,600
+3°C	21,654	-77.7	2,454,185	-8,555,761	-1,711,152,200
+5.8°C	6,728	-93.1	762,527	-10,247,419	-2,049,483,800



De	até	colour
0	760	
761	2.500	
2.501	5.000	
5.001	7.600	

Figure 7 – Coffe production (in tons) of São Paulo's Municipal districts in 2003.

Ponta Grossa, Tibagi and Palmeira).

Figure 6 shows climate risk zoning for soybeans in the State of Paraná in four different climate scenarios: current situation (upper left side), 1°C increase (upper right side), 3°C increase (lower left side) and 5.8°C increase (lower right side). The suitable areas are shaded.

There is also a strong correlation between the suitable areas (in Figure 6 - upper left side) and the principal production regions (Figure 5) and likewise between the unsuitable areas and the low production regions. The current suitable areas in Paraná are much more sensitive to the increase of average temperature than in

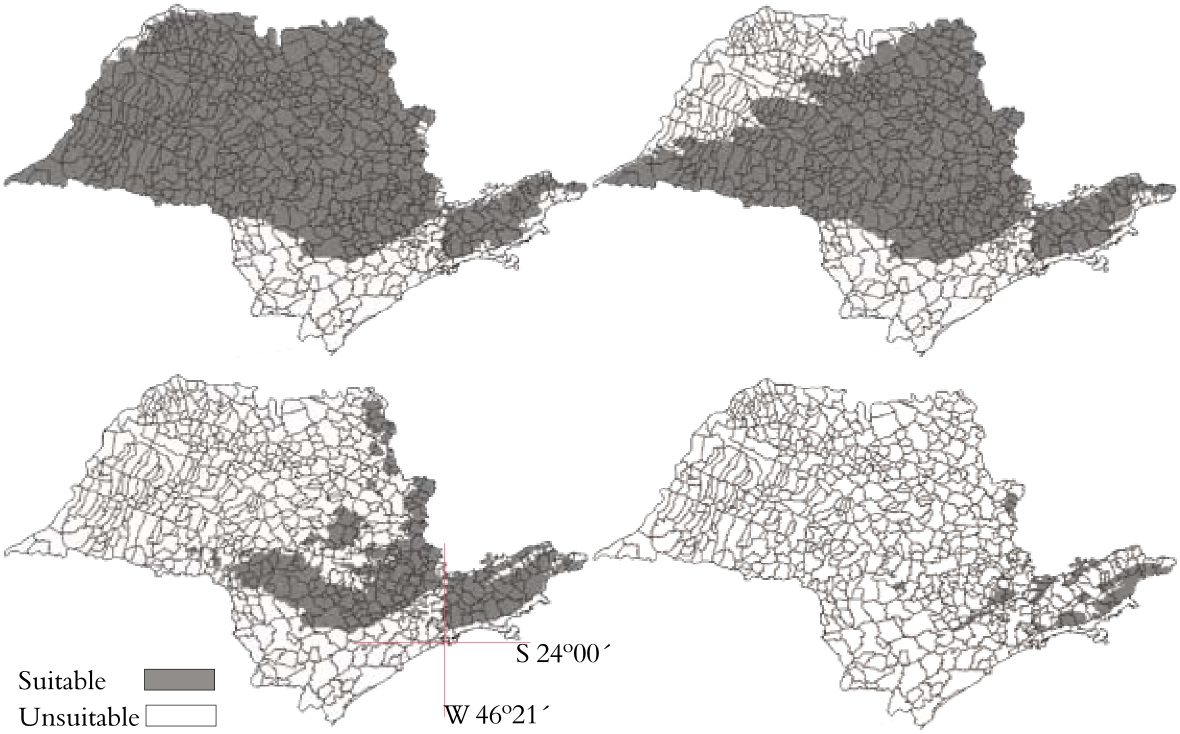


Figura 8 – Climate risk zoning of arabica coffee in the State of São Paulo for the current situation (upper left side) and the three climate change scenarios, corresponding to increases of 15% in precipitation and 1°C (upper right side), 3°C (lower left side) and 5.8°C (lower right side), respectively, in average annual and monthly temperatures.

Mato Grosso since Paraná has some important areas defined as unsuitable for soybean production even in the current climate situation. Table 2 shows an estimate of suitable area, production and financial return for each climate scenario related to the values for 2003: suitable area of 97,144km^2, production of 11,009,946 tons and a return of US$200 per ton.

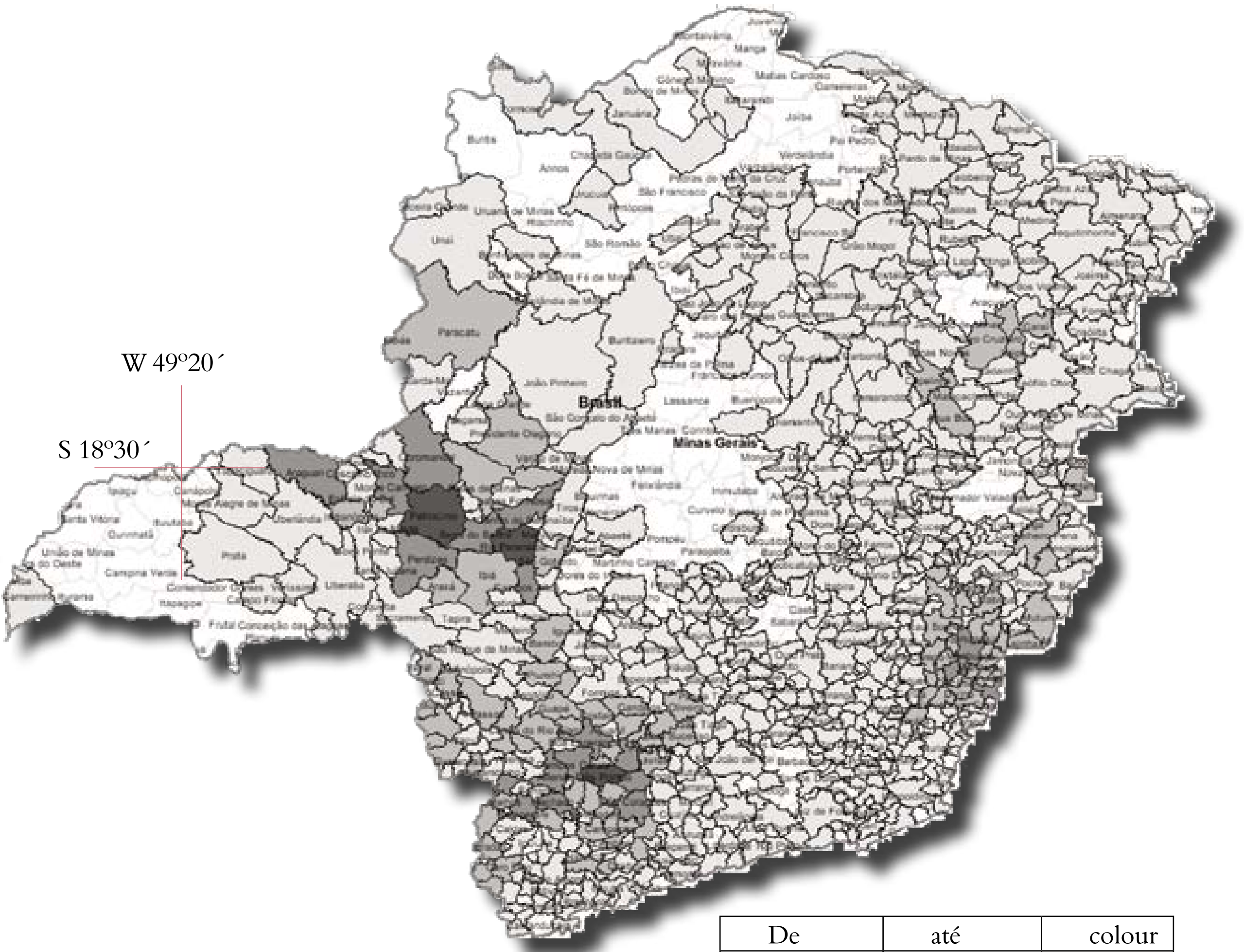
According to Tables 1 and 2, the economic impact caused by temperature elevation is greater in Paraná than in Mato Grosso despite a lower suitable area due to its greater sensitivity to climate conditions. This behavior can also be observed in the State of Rio Grande do Sul, the third largest producer of soybeans in 2003.

Figure 7 shows arabica coffee production (in tons) of São Paulo's municipal districts in 2003, according to IBGE (2005), corresponding to 9% of national production. Arabica coffee is produced throughout the state of São Paulo, mainly in the East region.

Figure 8 shows a comparison between current climate zoning for arabica coffee in the State of São Paulo (upper right side) and three simulated situations, corresponding to increases of 15% in precipitation, based on values from 1961 to 1990,

Table 3 – Estimate of suitable area, production and financial return in different climate scenarios compared with values for 2003 for arabica coffee in São Paulo

Temperature Increase	Suitable Area (km^2)	Variation (%)	Production (ton)	Difference according to Reference values	
				Production (ton)	Financial Return (US$)
+1°C	145,202	-23.1	269,082	-80,829	-113,160,600
+3°C	75,455	-60.1	139,614	-210,297	-294,415,800
+5.8°C	8,439	-95.5	15,746	-334,165	-467,831,000



De	até	colour
0	2.400	
2.401	8.000	
8.001	16.000	
16.001	25.000	

Figure 9 – Coffee production (in tons) of Minas Gerais's Municipal districts in 2003.

and 1°C (upper right side), 3°C (lower left side) and 5.8°C (lower right side), respectively, in average annual and monthly temperatures.

There is a strong agreement between the current climate risk zoning (Figure 7 – upper left side) and the main production regions (Figure 8) in São Paulo. Table 3 shows an estimate of suitable area, production and financial return for each climate scenario related to the following values: suitable area of 188,887km^2 (in 2003), average production from 1994 to 2003 (349,911 ton) and a return of US$1,400 per ton.

Figure 9 shows arabica coffee production (in tons) of Minas Gerais's municipal districts in 2003, according to IBGE (2005), contributing to 45% of national production. Arabica coffee is produced throughout the state of Minas Gerais, mainly in the southern region.

Figure 10 shows a comparison between current climate zoning for arabica coffee in the State of Minas Gerais (upper left side) and three climate change scenarios, corresponding to increases of

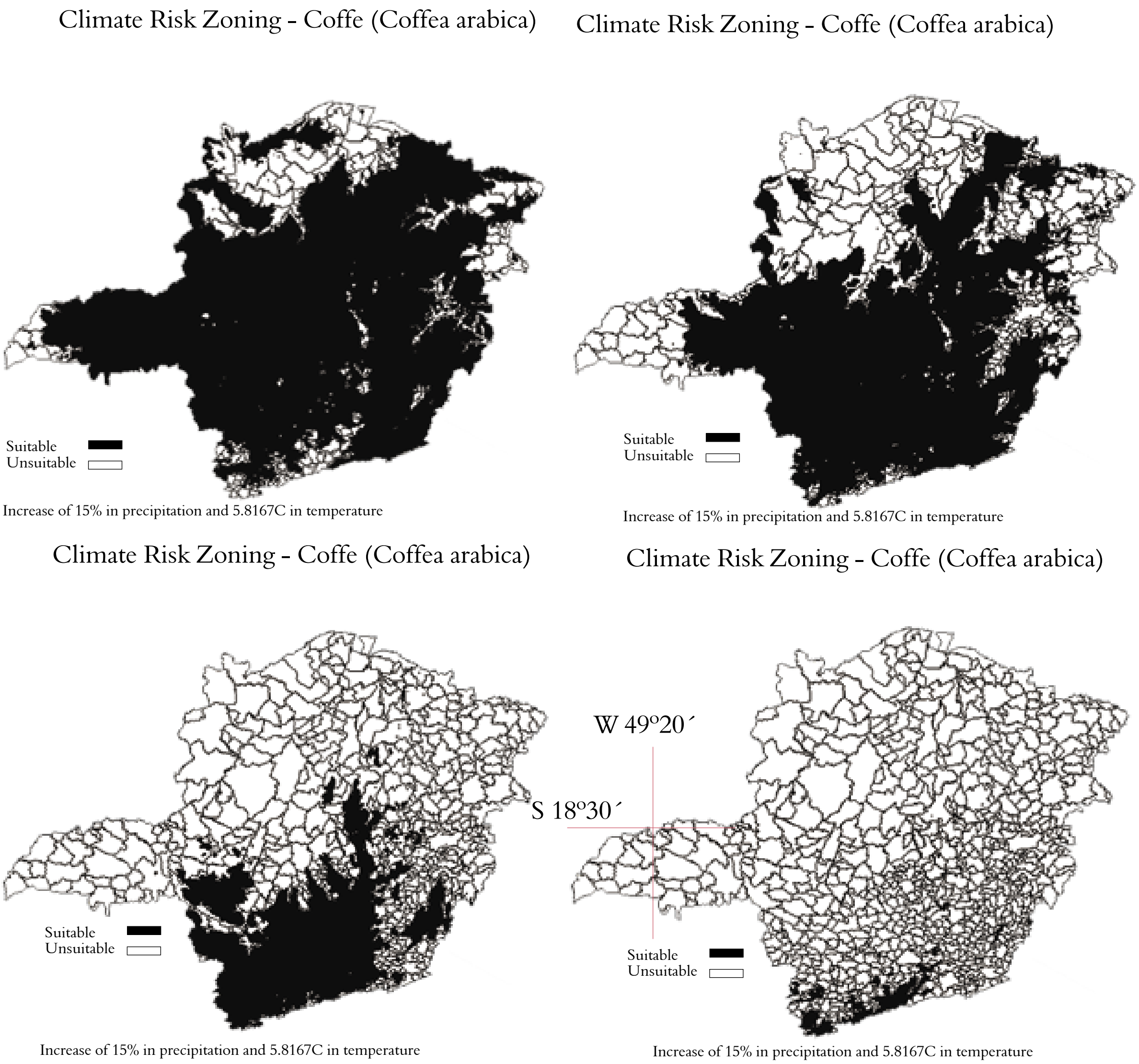


Figure 10 – Climate risk zoning of arabica coffee in Minas Gerais for current situation (upper left side) and three climate change scenarios, corresponding to increases of 15% in precipitation and 1°C (upper right side), 3°C (lower left side) and 5.8°C (lower right side), respectively, in average annual and monthly temperatures.

Table 4 – Estimate of suitable area, production and financial return in different climate scenarios compared with values for 2003 for arabica coffee in Minas Gerais

Temperature Increase	Suitable Area (km^2)	Variation (%)	Production (ton)	Difference according to Reference values	
				Production (ton)	Financial Return (US$)
+1°C	332,561	-25.3	1,174,631	-397,834	-556,967,103
+3°C	139,007	-68.8	490,609	-1,081,856	-1,514,598,288
+5.8°C	15,249	-96.6	53,464	-1,519,001	-2,126,601,666

15% in precipitation, based on values from 1961 to 1990, and 1°C (upper right side), 3°C (lower left side) and 5.8°C (lower right side), respectively, in average annual and monthly temperatures.

The dimensions of suitable areas are inversely proportional to the increase of temperature, chiefly for values of 3°C and 5.8°C. Table 4 shows an estimate of suitable area, production and financial return for each climate scenario related to the following values: suitable area of 445,174km^2 (in 2003), average production from 1994 to 2003 (1,572,465ton) and a price of US$1,400 per ton.

Conclusions

Global warming as presented by IPCC will cause a strong decrease in the production of commodities in Brazil in addition to moving crops to different regions. It appears that the extreme scenario of +5.8ºC will transform some states of the tropical area into "rainy deserts" since most crops will not develop due to excess of heat despite water availability. Independent of the increase in rainfall across the country due to elevation in temperature, it seems that the effect of excess of heat will be the cause of the strong decrease in production of commodities in Brazil. The principal cause can be considered the incidence of high temperature during the flowering phase of the plants, which kills the flowers. Another factor that must be considered is the possibility of a strong rise in soil salinity that can also cause a decrease in yield. On the other hand, there is a possibility that some areas in southern Brazil could be favored due to the diminishing possibility of frost. Adaptive solutions such as the development of cultivars adapted to higher temperatures must be considered by policymakers dealing with the effects of climate change. Impact assessment studies using different climate change models are necessary and must be encouraged.

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