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Impact assessment study of climate change on agricultural zoning

Jurandir Zullo Junior[1], Hilton Silveira Pinto[1] & Eduardo Delgado Assad[2]
[1]*Cepagri/Unicamp, Cidade Universitária Zeferino Vaz, 13083970 Campinas, Sao Paulo, Brazil*
[2]*Embrapa/Cnptia, R. André Tosello, 209-13083886 Campinas, Sao Paulo, Brazil*
Email: jurandir@cpa.unicamp.br

*If mean temperature increases, in accordance with Intergovernmental Panel on Climate Change (IPCC) projections and adaptations and/or genetic modifications are not considered, suitable areas for farming corn (*Zea mays*) and coffee (*Coffea arabica*) will decrease in the state of Sao Paulo (Brazil). Further, increases in precipitation will not be enough to ameliorate the impacts associated with increases in mean temperatures. Suitability for grain production will decrease more rapidly in regions with sandy soils than in regions with clay or medium soils, as the temperature increases. The projected increase in mean temperature of up to 5.8 °C would decrease the suitability for grain production drastically in spite of soil texture. Besides the reduction of suitable areas for coffee production, the projections suggest that changes will be more enhanced in the southeast of the state, especially in higher elevation regions, where farming practice, soils, and infrastructure are unsuitable for the economic production of coffee. In both cases, no compensatory increase in suitable areas for production is likely under current IPCC scenarios.*

Keywords: climate change, corn, coffee, IPCC, agricultural zoning

1. Introduction

Agricultural losses in the middle of 1990s were limiting the development of Brazilian agriculture. These losses were caused by two main factors: (1) excessive rain during the harvest period (30% of all cases) and (2) dry spells during the reproductive (flowering and grain-filling) stage (60% of all cases) (Rosseti 1997). These losses were related to a poor knowledge of rainfall distribution that led the farmers to plant after the first rainfalls of spring. To decrease these two main climatic risks, Embrapa (the National Institute for Agricultural Research) and the Brazilian Department of Agriculture started an official program of agricultural zoning in 1996 to define planting calendars for rice, beans, corn, soybean, wheat, sorghum, cotton, coffee, and fruits, based on simulation of cumulative water balance. These calendars were calculated to provide plants with adequate water supply during the reproductive stage and no excess during the harvest period in 80% of all simulated cases. A cumulative water balance model, BIPZON (Forest 1984), was used to calculate the Water Requirement Satisfaction Index (WRSI) based on historical rainfall data, potential evapotranspiration, length of growth stages, and soil waterholding capacity. The agricultural zoning is based on the integration of crop growth models, climate and soil databases, decision analysis techniques, and geoprocessing tools (Cunha & Assad 2001).

The planting calendars are available for all regions except the Amazon, corresponding to areas which produce more than 95% of Brazilian agribusiness Gross Domestic Product (GDP) that is about U.S.$165 billion/year, while national GDP is about U.S.$449 billion/year (IBGE 2005). The federal government has been providing subsidiary support for agriculture since 1965. The funds provided were about U.S.$8 billion for the 2004/2005 cropping season, with U.S.$2.5 billion available for small farmers (Banco do Brasil 2004). Agricultural zoning has been used as a federal farm credit policy since the rural lenders, mainly the Bank of Brazil, have had to use the planting calendars when supplying federal credit to farmers. This program has helped farmers to use proper technologies, protect the soil and the environment, plan their activities, decrease the production costs and risks, and increase the national production and productivity (Rosseti 2001).

The agricultural zoning has been updated every year with new crops, cultivars, climate data, and interpolation methods, improving it year after year. The importance of agriculture for the Brazilian economy requires impact assessment studies not only for seasonal climate variations (such as that attributed to El Niño and La Niña) but also for climate change, such as that presented by the report of “Intergovernmental Panel on Climate Change” (IPCC 2001a and 2001b). These reports suggest a disturbing situation regarding potential global temperature increase. When considering both natural and anthropogenic effects in the fitting of observed and simulated data, it is suggested that global mean temperature may increase by 1.4–5.8 °C, with precipitation increase of 15% in this century, based on the 1961–1990 reference period. This scenario complements the studies presented previously by IPCC (1997), which suggested an increment of 0.05 °C per decade for mean global temperature based on more reliable measurement systems. It has also been verified that, during the period 1961–2000, precipitation increased by 0.2–0.3% per decade in the tropics (from 10 °N to 10 °S).

The present paper assesses the specific impacts of potential climate change, as indicated by IPCC scenarios in 2001, in the agricultural zoning of coffee and corn, applying the methodology used by the Brazilian Department of Agriculture.

2. Material and methods

The state of Sao Paulo was chosen for this study as this is an important agricultural region, with high levels of climate variability and the largest amount of data available. Coffee and corn were chosen since they are two of most important crops in Brazil and they also have different agronomic characteristics. The impacts of climate changes presented by IPCC (2001a, 2001b) were assessed using the same methodology of climate risk zoning described below, assuming increases of mean monthly temperature of 1, 3, and 5.8 °C, calculated by the equations proposed by Pinto et al. (1972). Precipitation data from 390 ground stations from 1961 to 1990 were raised by 15%. Three new agricultural zonings were then prepared based on three different climate scenarios from the current situation: (1) increase of 1 °C in temperature and 15% in precipitation, (2) increase of 3 °C in temperature and 15% in precipitation, and (3) increase of 5.8 °C in temperature and 15% in precipitation.

2.1. Climate risk zoning for corn production in the state of Sao Paulo

The methodology applied was based on cumulative water balances carried out for each dekad during the cropping season (i.e., from planting to maturity). This required a preliminary collection of parameters such as cultivar types, duration of four growth stages (initial stage, vegetative stage, reproductive stage, and maturity) and total growing period, crop coefficients (to allow estimates of crop water requirements for each growth stage), soil water holding capacity, rainfall, and soil erosion. A cumulative water balance program, BIPZON (proposed by Forest (1984), tested by Assad (1986), and modified by Vaksmann (1990)), was used to calculate the values of WRSI (Doorenbos & Pruitt, 1977), the ratio between actual and maximum evapotranspiration, where actual evapotranspiration was given by Eagleman's equation (Eagleman 1971) at the four growth stages. The WRSI summarizes the degree to which cumulative crop water requirements have been met. The WRSI values during the reproductive stage (flowering and grain-filling stages) for a minimum frequency of 80% were spatialised through a Geographical Information System (GIS) and used to assess the suitability of a planting dekad: suitable or favorable (when the WRSI value was greater than or equal to a chosen threshold value) and unsuitable (when WRSI value was lower than a chosen threshold value). Rainfall was assumed to be the only supply of water to the crops. The number and length of different cultivars (early and normal), mainly the length of each growth stage, and crop coefficients (K_c) were defined according to the details provided by specialists in each crop. Three values for the "soil holding water capacity" were used according to the soil texture: 30 mm for sandy soils, 70 mm for clay soils, and 50 mm for medium soils.

The methodology used to define the farming planting calendars in the state of Sao Paulo were the same as those adopted in the Central, South, and Southeast macroregions of Brazil. The planting dekads suitable for corn production in the state of Sao Paulo, according to Brunini et al. (2001), were those in which the:

(1) WRSI was greater than or equal to 0.55 during the reproductive stage in 80% of all simulated cases (30 years)
(2) average minimum temperature during the cropping season was greater than or equal to 10 °C
(3) maximum length of total growing period was 150 days for early cycles and 165 for normal cycles.

There are more than 2200 rainfall ground stations in Brazil with at least 15 years of data. In the state of Sao Paulo, a historical series of 390 rainfall ground stations having 30 years (from 1961 to 1990) of data (Figure 1) were used. The potential evapotranspiration (PET) was calculated using the method proposed by Thornthwaite & Matter (1955) and adapted by Camargo & Camargo (1983) based on average monthly temperature. These values were estimated by models presented by Pinto et al. (1972) using the geographical coordinates of the rainfall stations (altitude, latitude, and longitude).

The length of each stage for corn was defined, based on values of degree-days, from germination to flowering and from germination to maturity. The difference between the two values was equal to the length of stage III (Reproductive Stage—Flowering and Grain-filling). The length of stage II (Vegetative Stage) was defined as 80% of the days from germination to flowering while the length of stage I (Initial Stage) was equal to 20% of the days from germination to flowering plus 6 days. The length of stage IV (Maturity) was equal to that of the stage I. Table 1 contains the values of degree-days and basal temperature used to define the growth stages for

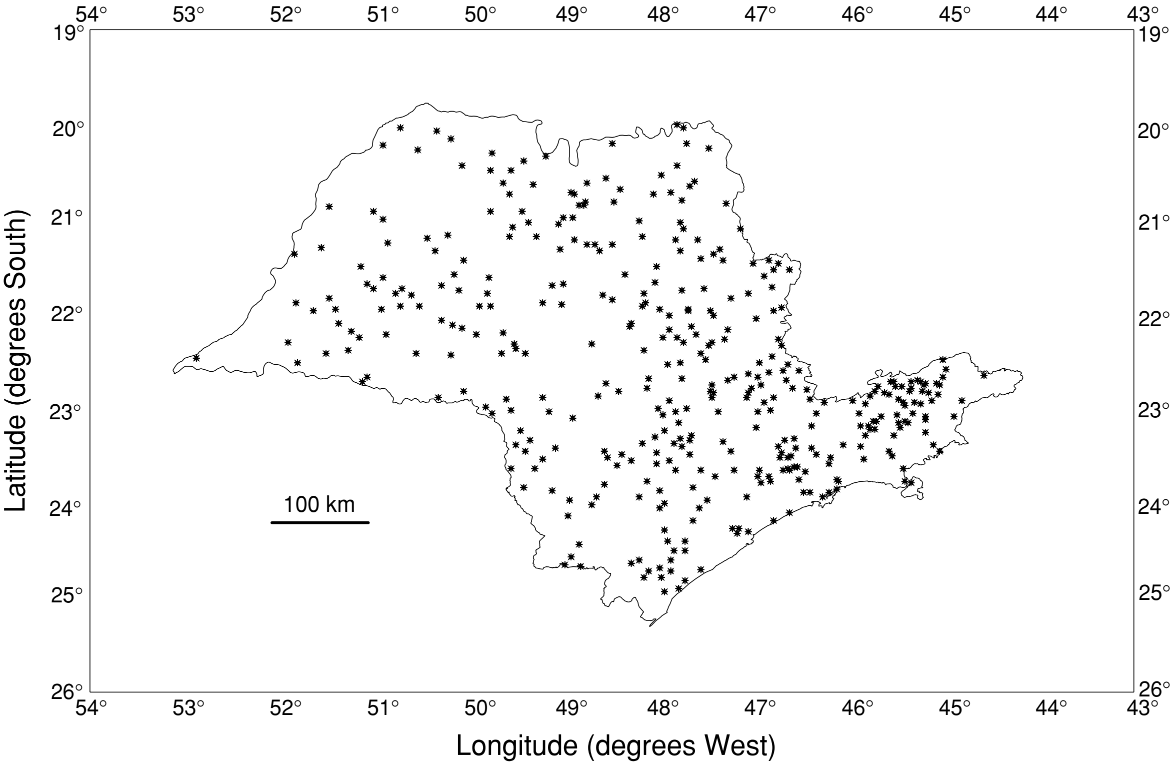

Figure 1. *Rainfall network with 390 ground stations located in the state of Sao Paulo (Brazil) having data from 1961 to 1990, used in agricultural zoning.*

Table 1. *Parameters used to define the length of growth stages for corn.*

	Degree-days from germination	
Cultivar	To flowering ($T_{BASAL} = 8\,°C$)	To maturity ($T_{BASAL} = 10\,°C$)
I	862	1237
II	780	1190
III	780	1075

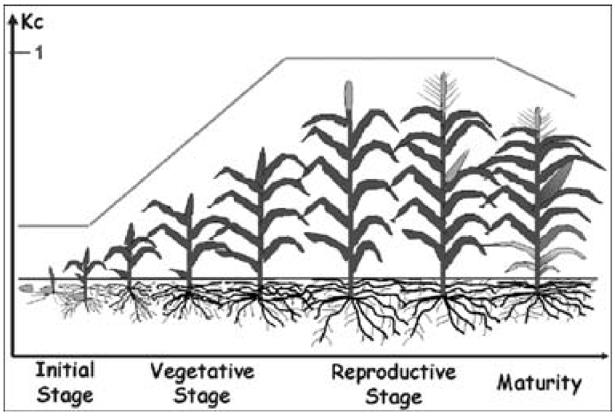

Figure 2. *Typical profile for crop coefficient (Kc).*

three possible cultivars of corn. The average temperature data were estimated, based on the models presented by Pinto et al. (1972). Crop coefficients (K_c) were defined according to the typical profile shown in Figure 2.

The WRSI values of ground stations were interpolated by using a GIS to obtain WRSI values for the 645 counties of the state of Sao Paulo for a specific set of planting dekad, soil type, and growth cycle. The interpolation methods used were the inverse of the distance to square and krigging (Golden Software, 2002). A threshold value was used to define the minimum value of WRSI that could represent a satisfactory water supply during the reproductive stage in 80% of all simulated cases. Figure 3 shows a simplified flowchart of the methodology used in the climate risk zoning for corn production in the state of Sao Paulo.

The planting dekads suitable for planting, according to water requirements, were assessed before the final approval. The first test concerned the water excess during harvest, defined as a total rainfall of 50 mm in 3 days within a 5-day period. This was evaluated in three 5-day periods immediately after the ending of the cycle, considering a probability of 25%. The other tests used to filter the results were related to extreme temperatures according to physiological characteristics of each crop. The average monthly minimum and maximum temperatures were estimated, using the models presented by Pedro et al. (1991) based on the geographical coordinates of each county. The last test was the analysis by a specialist of each crop to assess the consistency of the planting periods according to their experience.

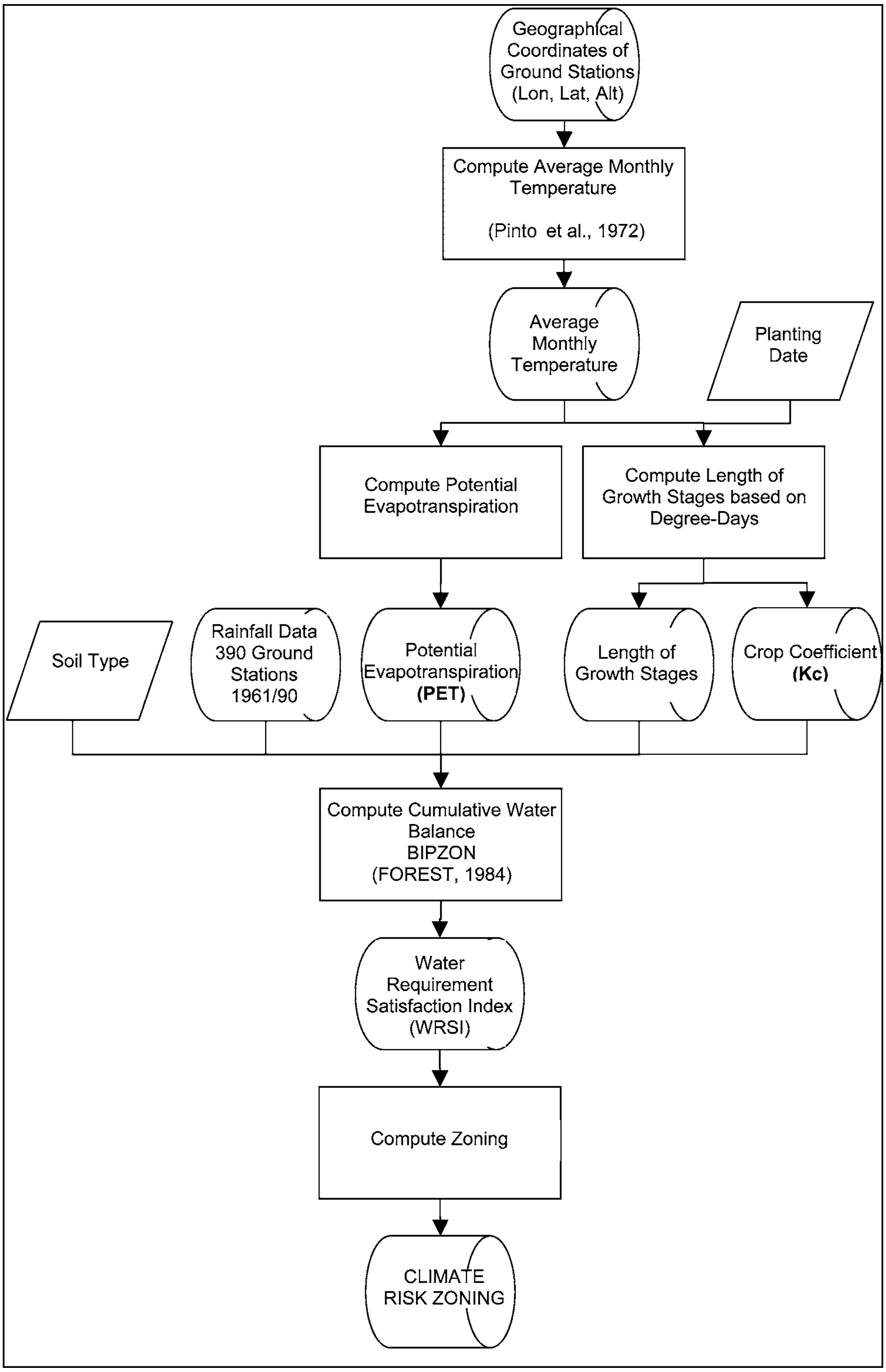

Figure 3. *Simplified flowchart of methodology used in the climate risk zoning for corn production in the state of Sao Paulo.*

2.2. Climate risk zoning for coffee in the state of São Paulo

The suitable areas for coffee (*Coffea arabica* L.) production, according to the climate requirements presented by Camargo et al. (1977), Seção de Climatologia Agrícola (1972), and Instituto Brasileiro do Café (1977, 1986), were those in which:

(1) average annual temperature was from 18 °C to 22 °C;
(2) annual water deficit was from 0 to 100 mm per year;
(3) frost risk was less than or equal to 25%.

If item (3) failed, then a suitable area for coffee production was restricted by the high possibility of

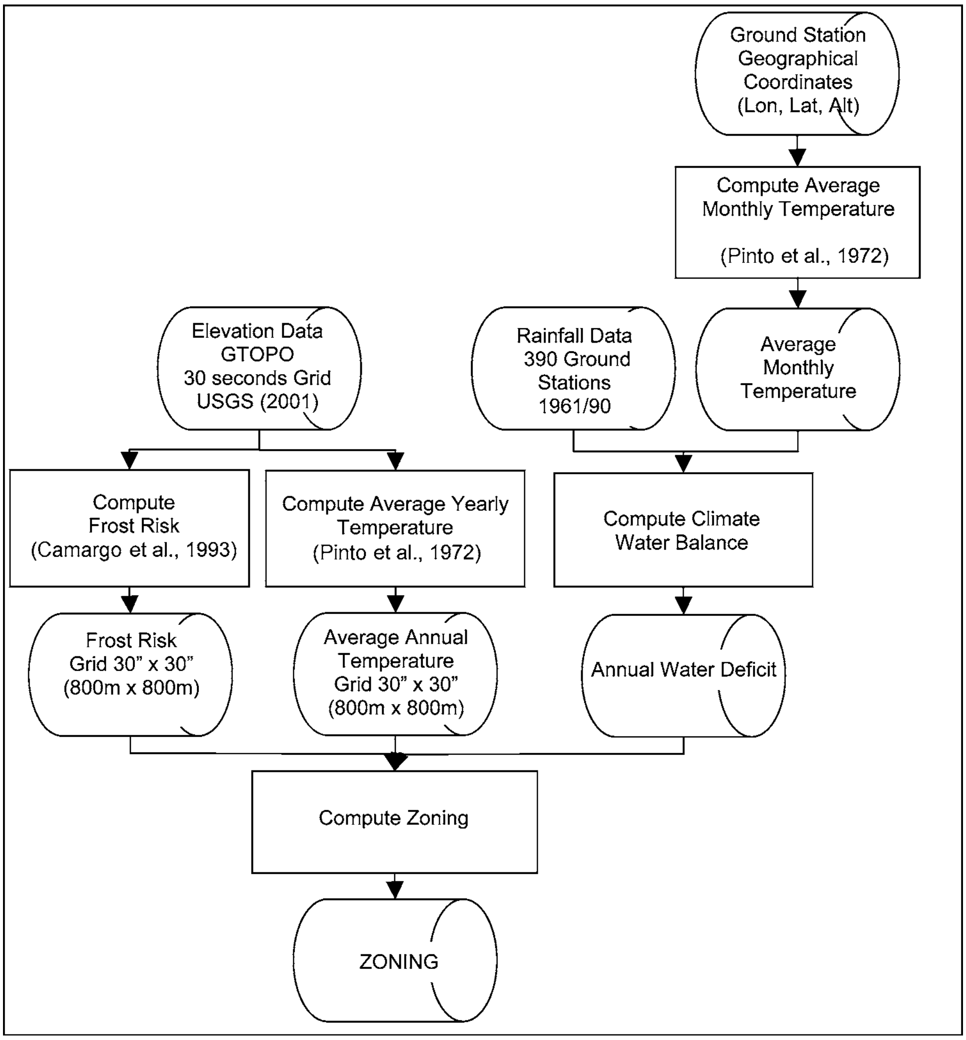

Figure 4. *Simplified flowchart of methodology used in the climate risk zoning for coffee in the state of Sao Paulo.*

frost occurrence. The areas where the average annual temperature was from 22 to 23 °C were restricted by thermal excess. Those areas where the annual water deficit was from 100 to 150 mm and the average annual temperature was from 22 to 23 °C were suitable with supplementary irrigation. Pinto et al. (2001) defined the suitable areas for coffee production in the state of Sao Paulo as shown in Figure 4. The average monthly and annual temperatures were calculated using the equations proposed by Pinto et al. (1972) and the elevation data with an horizontal grid spacing of 30 arc s calculated using GTOPO30 data, supplied by the United States Geological Survey (USGS, 2001). Frost risk was computed using the model presented by Camargo et al. (1993), considering the temperature of 1 °C as a reference for frost occurrence (Pinto et al. 1977; Pinto et al. 1983).

3. Results

The number of simulations (i.e., cumulative water balances) was 2,500,000 for corn. Planting dekads suitable for corn and coffee are available at Agritempo webpage (http://www.agritempo.gov.br). The rural lenders are using the planting calendars since 1996 as an official support to decide about agricultural financing. The following results are highlighted:

(1) reduction of agricultural losses due to adverse climate events;
(2) induction of technology;
(3) increasing of productivity that, in some cases, can guarantee the producer profits;
(4) availability of data useful to the official agricultural planning;
(5) reduction of federal budget used to cover the agricultural losses of about U.S.$150 million per year.

3.1. Coffee

Figure 5 presents a comparison between current climate zoning for coffee in the state of Sao Paulo and three simulated situations, corresponding to increases of 15% in precipitation, and 1, 3, and 5.8 °C in average annual and monthly temperatures, respectively, based on values from 1961 to 1990. Table 2 summarises the results presented in Figure 5.

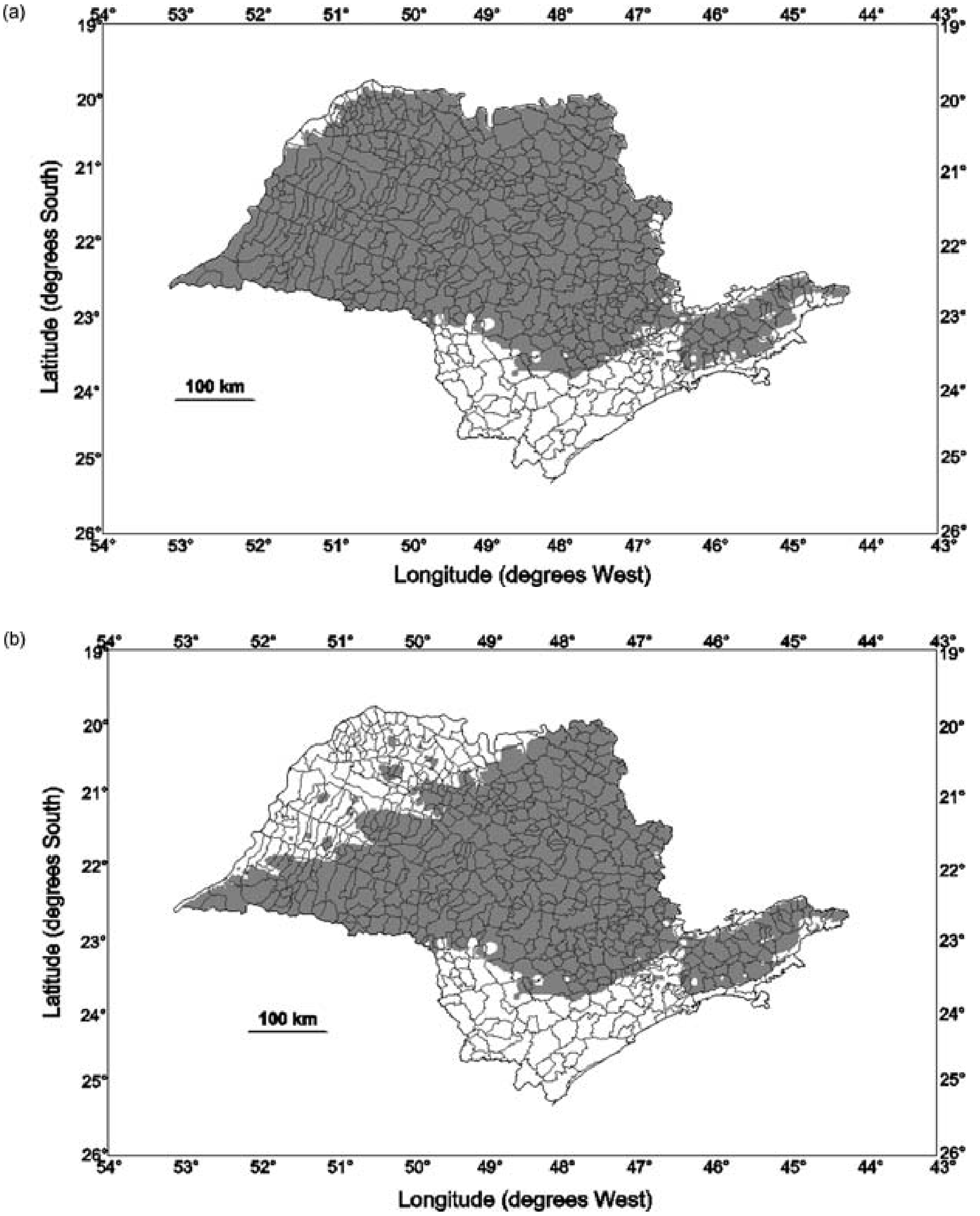

Figure 5. *Suitable (grey) and unsuitable (white) areas for planting coffee (*Coffea arabica*) considering: (a) the current climate, (b) an increase of 15% in precipitation and 1 °C in temperature, (c) an increase of 15% in precipitation and 3 °C in temperature, and (d) an increase of 15% in precipitation and 5.8 °C in temperature, above the current values of precipitation and temperature.*

Table 2. *Surface (in percentage) of Sao Paulo classified by level of suitability for coffee production in four different climate scenarios.*

	Levels of suitability	
Climate scenario	Suitable	Unsuitable
Current situation	78.7	21.3
Increase of 15% in precipitation and 1 °C in temperature	58.9	41.1
Increase of 15% in precipitation and 3 °C in temperature	30.3	69.7
Increase of 15% in precipitation and 5.8 °C in temperature	3.3	96.7

3.2. Corn

Figure 6 presents the suitable areas for early cultivars of corn, planted from November 11 to 20, in soils of medium water holding capacity (50 mm) and four climate scenarios: current situation (Figure 6a), increase of 15% in precipitation and 1 °C in temperature (Figure 6b), increase of 15% in precipitation and 3 °C in temperature (Figure 6c), and increase of 15% in precipitation and 5.8 °C in temperature (Figure 6d). Figures 7–9 present the percentage of surface suitable for early cultivars of corn, planted from October to December, in soils of medium (50 mm), low (30 mm), and high (70 mm) water holding capacity and the four

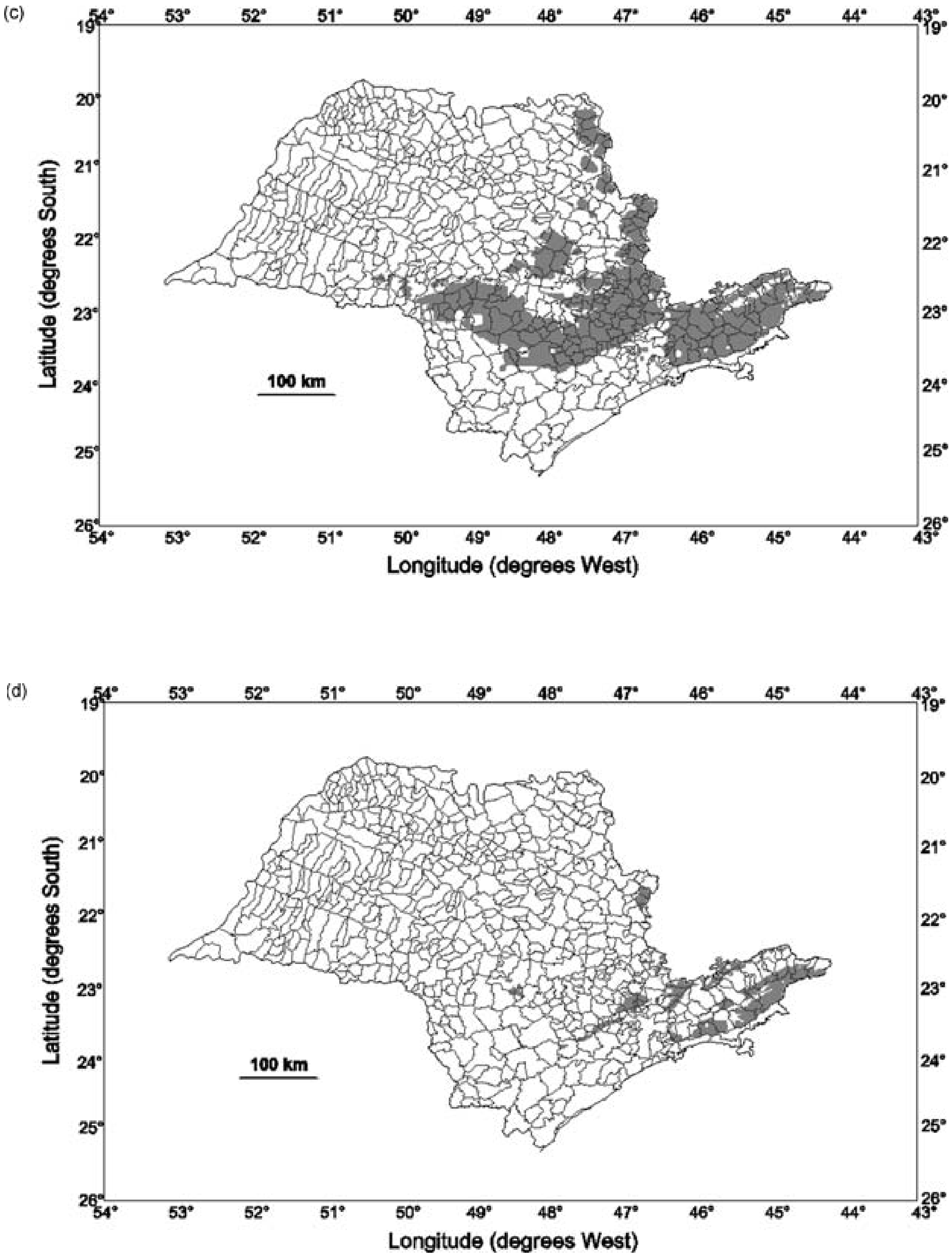

Figure 5. *Continued*

climate scenarios. Tables 3–5 summarize the results presented in Figures 7–9.

Tables 3–5 show a relationship between the decrease of suitable area, the soil water holding capacity, and the increase in average temperatures in the four climate scenarios. For clay soils, increase up to 3 °C in average temperature corresponded to maximum decrease of 5% in the suitable area. Increase of 5.8 °C reduced the suitable area drastically for the three soil waterholding capacities used in the simulations. An increase of 1 °C in average temperature reduced the suitable area for soils of medium waterholding capacity by less than 1%.

4. Conclusions

Increases in average temperature and precipitation, as presented by IPCC, will lead to decrease and changeover to other regions the current suitable areas for corn production from October to December, and coffee year-round without considering the adaptations and/or genetic modifications. Increases in precipitation

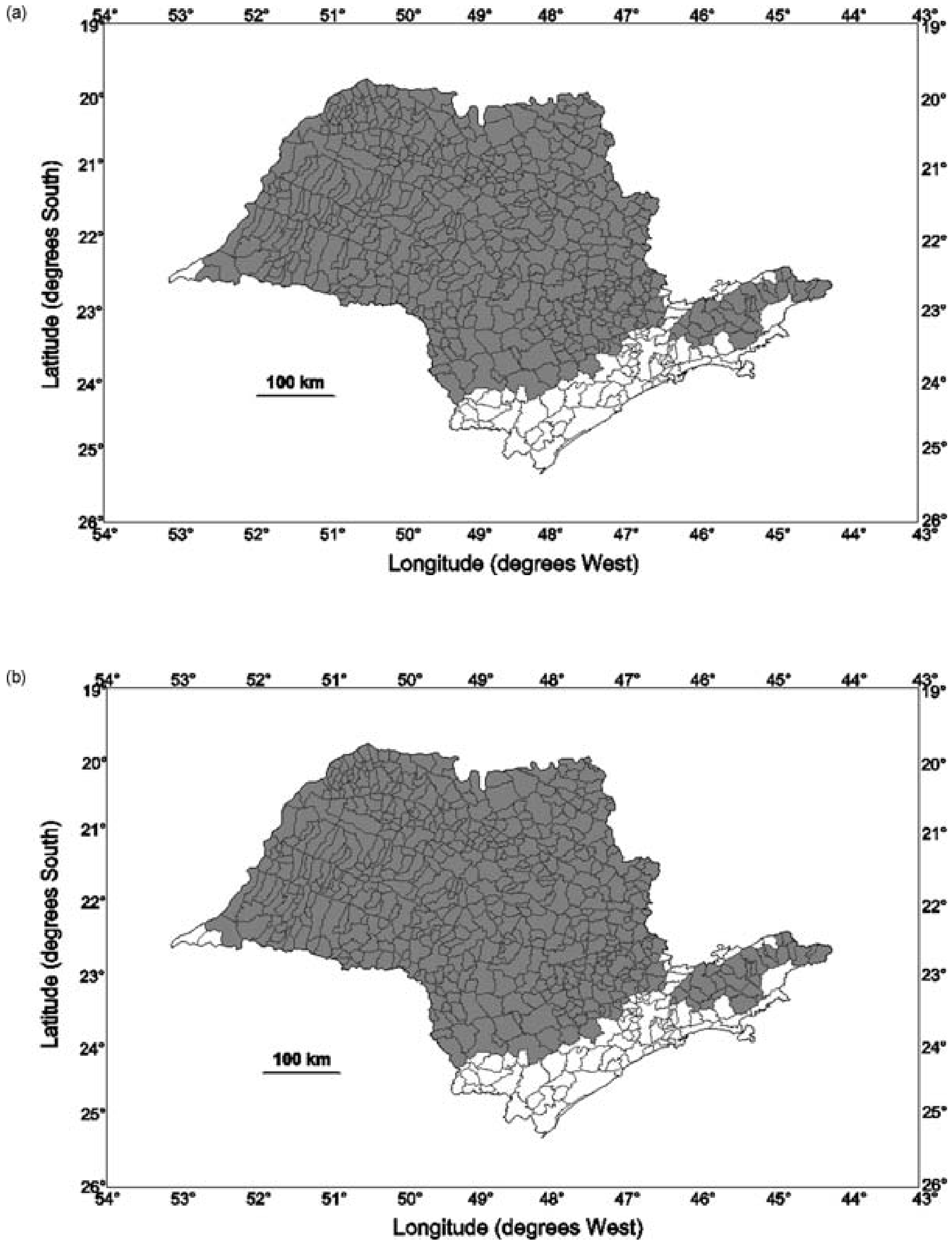

Figure 6. *Suitable (grey) and unsuitable (white) areas for early cultivars of corn, planted from November 11 to 20, in the state of Sao Paulo, Brazil, in soils of medium water holding capacity (50 mm) considering: (a) the current climate situation, (b) an increase of 15% in precipitation and 1 °C in temperature, (c) an increase of 15% in precipitation and 3 °C in temperature, and (d) an increase of 15% in precipitation and 5.8 °C in temperature, above the current values of precipitation and temperature.*

will not be enough to equalize the impacts due to increases in average temperatures. Regions having sandy soils will become unsuitable for corn production much more quickly than regions with medium and clay soils, as the temperatures and rainfall increase. A temperature increase of 5.8 °C will decrease the suitability for corn production drastically in spite of soil texture. Besides the reduction of suitable areas for coffee production, according to climate requirements, there will be a change in Southeast part of Sao Paulo mainly in the higher elevation regions, where farmers, soils, and infrastructure are not suitable for economic production of coffee. In both cases (coffee and corn in the state of Sao Paulo), no increase in suitable areas for production was observed when increasing the temperature and precipitation. Adaptive solutions, such as the development of cultivars adapted to higher temperatures, must be taken into account by policymakers in order to assist farmer decisions to plan for the effects of climate change. Importantly, impact assessment studies using different climate change models suitable for whole-farm strategic planning information for farmers are necessary and must be encouraged.

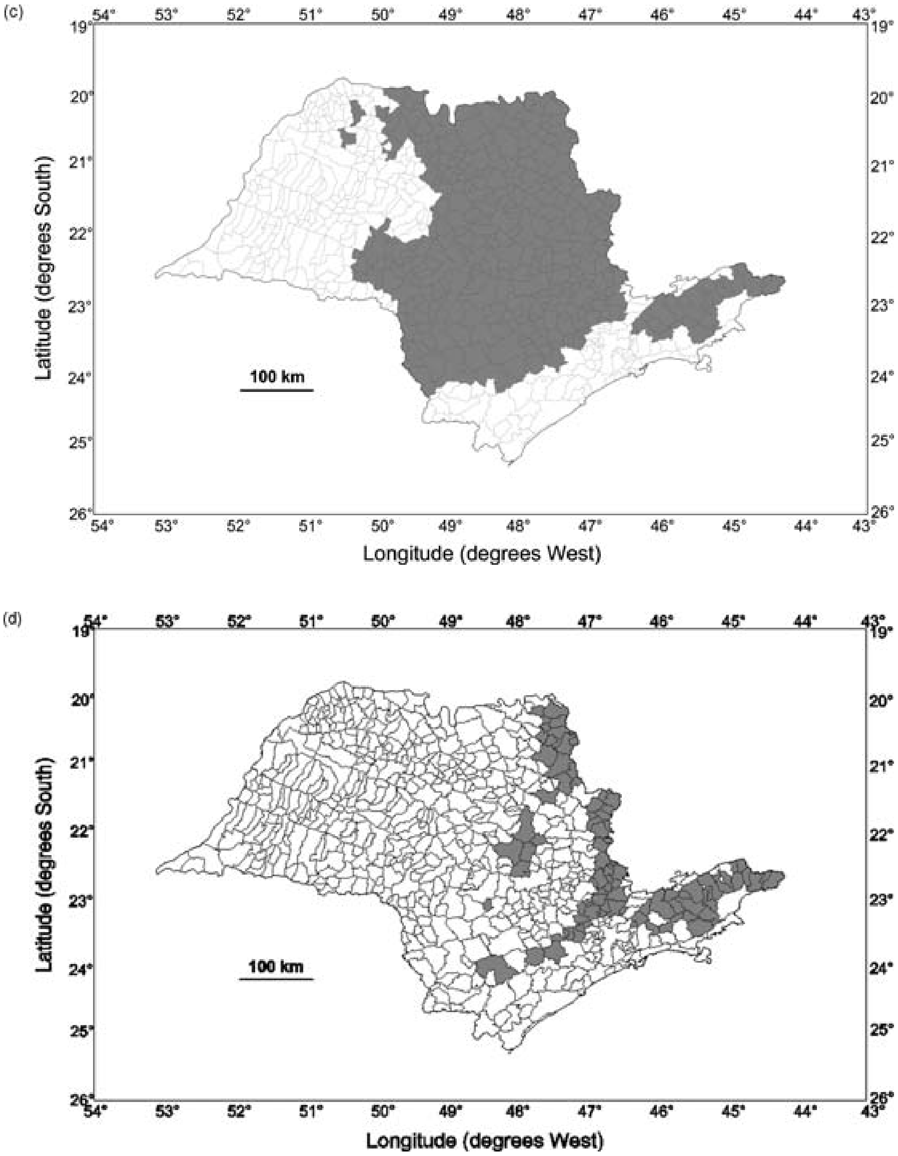

Figure 6. *Continued*

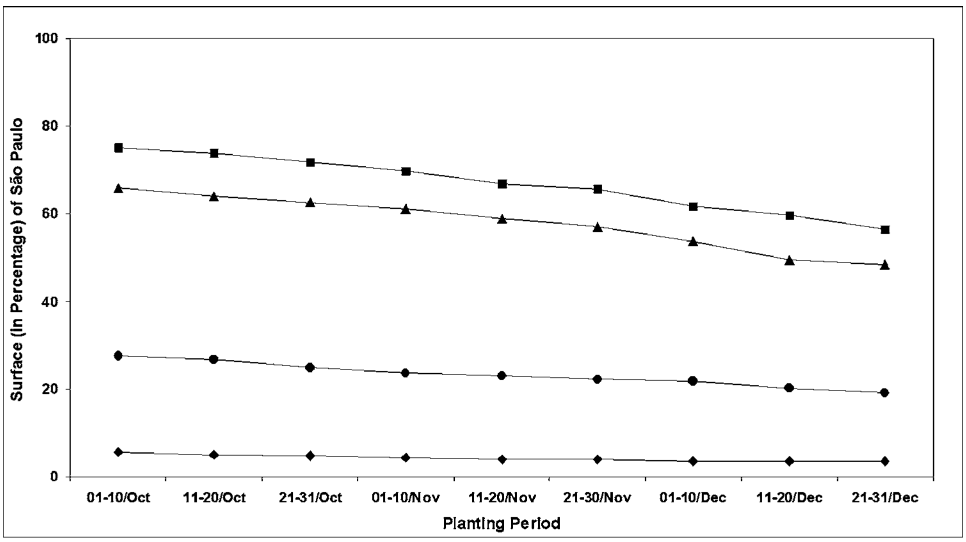

Figure 7. *Surface (in percentage) of Sao Paulo suitable for early cultivars of corn, in soils of low water holding capacity (30 mm), planted from October to December, in four climate scenarios. ◆, Increase of 5.8°C in Temperature and 15% in Precipitation; ●, Increase of 3°C in Temperature and 15% in Precipitation; ▲, Increase of 1°C in Temperature and 15% in Precipitation; ■, Current Situation.*

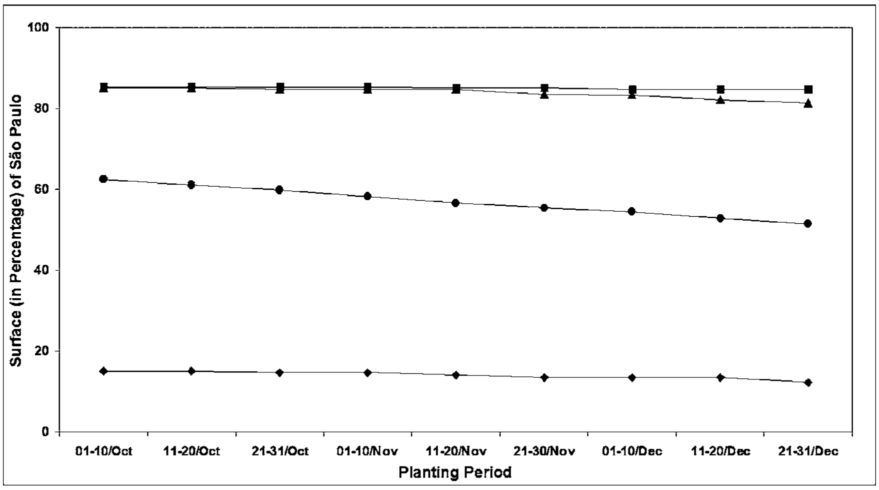

Figure 8. *Surface (in percentage) of Sao Paulo suitable for early cultivars of corn, in soils of medium water holding capacity (50 mm), planted from October to December, in four climate scenarios. ◆, Increase of 5.8°C in Temperature and 15% in Precipitation; ●, Increase of 3°C in Temperature and 15% in Precipitation; ▲, Increase of 1°C in Temperature and 15% in Precipitation; ■, Current Situation.*

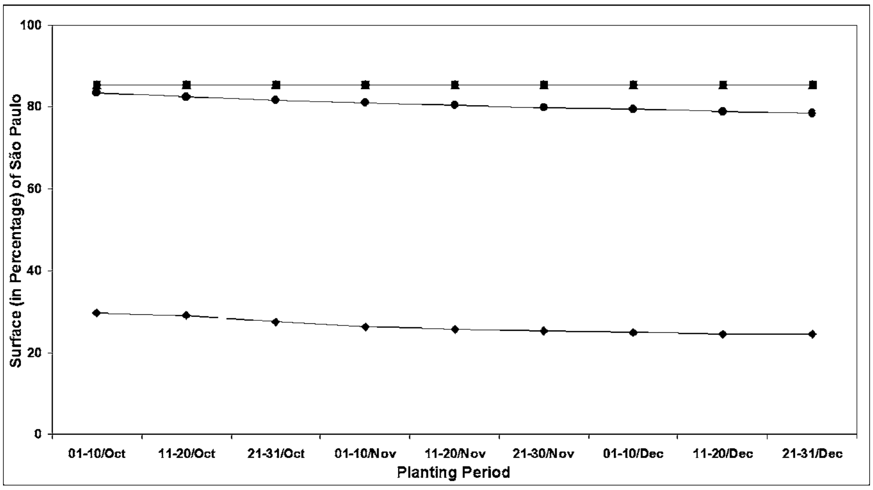

Figure 9. *Surface (in percentage) of Sao Paulo suitable for early cultivars of corn, in soils of high water holding capacity (70 mm), planted from October to December, in four climate scenarios. ◆, Increase of 5.8°C in Temperature and 15% in Precipitation; ▲, Increase of 1°C in Temperature and 15% in Precipitation; ■, Current Situation; ●, Increase of 3°C in Temperature and 15% in Precipitation.*

Table 3. *Surface (in percentage) of Sao Paulo suitable for early cultivars of corn, in soils of low water holding capacity (30 mm), planted from October to December, in four climate scenarios.*

	Climate scenario			
Planting dekad	Current situation	Increase of 15% in rainfall and 1 °C in temperature	Increase of 15% in rainfall and 3 °C in temperature	Increase of 15% in rainfall and 5.8 °C in temperature
Oct. 1st	75%	66%	28%	6%
Oct. 2nd	74%	64%	27%	5%
Oct. 3rd	72%	63%	25%	5%
Nov. 1st	70%	61%	24%	4%
Nov. 2nd	67%	59%	23%	4%
Nov. 3rd	66%	57%	22%	4%
Dec. 1st	62%	54%	22%	4%
Dec. 2nd	60%	49%	20%	4%
Dec. 3rd	56%	48%	19%	3%
Average decrease	—	13%	65%	94%

Table 4. *Surface (in percentage) of Sao Paulo suitable for early cultivars of corn, in soils of medium water holding capacity (50 mm), planted from October to December, in four climate scenarios.*

	Climate scenario			
Planting dekad	Current situation	Increase of 15% in rainfall and 1 °C in temperature	Increase of 15% in rainfall and 3 °C in temperature	Increase of 15% in rainfall and 5.8 °C in temperature
Oct. 1st	85%	85%	62%	15%
Oct. 2nd	85%	85%	61%	15%
Oct. 3rd	85%	85%	60%	15%
Nov. 1st	85%	85%	58%	15%
Nov. 2nd	85%	85%	57%	14%
Nov. 3rd	85%	84%	55%	13%
Dec. 1st	85%	83%	54%	13%
Dec. 2nd	85%	82%	53%	13%
Dec. 3rd	85%	81%	51%	12%
Average decrease	—	1%	33%	84%

Table 5. *Surface (in percentage) of Sao Paulo suitable for early cultivars of corn, in soils of high water holding capacity (70 mm), planted from October to December, in four climate scenarios.*

	Climate scenario			
Planting dekad	Current situation	Increase of 15% in rainfall and 1 °C in temperature	Increase of 15% in rainfall and 3 °C in temperature	Increase of 15% in rainfall and 5.8 °C in temperature
Oct. 1st	85%	85%	83%	30%
Oct. 2nd	85%	85%	82%	29%
Oct. 3rd	85%	85%	82%	27%
Nov. 1st	85%	85%	81%	26%
Nov. 2nd	85%	85%	80%	26%
Nov. 3rd	85%	85%	80%	25%
Dec. 1st	85%	85%	80%	25%
Dec. 2nd	85%	85%	79%	25%
Dec. 3rd	85%	85%	78%	24%
Average decrease	—	0%	5%	69%

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