# IMPACT OF CLIMATE CHANGE ON THE PHOMA LEAF SPOT OF COFFEE IN BRAZIL

*Wanderson Bucker Moraes, Waldir Cintra de Jesus Junior, Leonardo de Azevedo Peixoto, William Bucker Moraes, Sara Morra Coser and Roberto Avelino Cecílio*

*SUMMARY*

*The potential impact of global climate change on the spatial-temporal distribution of phoma leaf spot of coffee in Brazil was evaluated. Maps were prepared with the favorability of the climate to the occurrence of the disease in the current period and future. The future scenarios used were centered for the decades of 2010-2030, 2040-2060, and 2070-2090 (scenarios A2 and B2). These scenarios were obtained from six global climate models (GCM's) provided by the Intergovernmental Panel on Climate Change (IPCC). Assuming the future scenarios outlined by the IPCC, a reduction will occur in the occurrence of climatic favorability of phoma leaf spot in Brazil in both future scenarios (A2 and B2). As with the temporal distribution, the period of greatest risk of phoma leaf spot will tend to diminish in future decades. These planned changes will be larger in the A2 scenario compared to the predicted scenario B2. Despite the decrease in the favorability of phoma leaf spot in the country, some regions still present a potential risk of this disease. Furthermore, the increased frequency of extreme weather was not taken in to account. These will certainly influence the magnitude of potential impacts of climate change on the phoma leaf spot in Brazil.*

## Introduction

Global climate change is one of the largest current scientific paradigms and has been attracting attention from various segments of society, especially regarding its causes and consequences. The increased concentration of greenhouse gases in the atmosphere has been considered a major cause of the climate change. The atmospheric concentration of $CO_2$ is significantly higher when compared to that in the last 650000 years (Siegenthaler *et al*., 2005). The growth rate of atmospheric $CO_2$ has increased considerably since 2000 compared to previous decades (Canadell *et al*., 2007). Similar trends have been observed for methane ($CH_4$), nitrogen oxide ($N_2O$) and other greenhouse gases (Spahni *et al*., 2005).

Agriculture is highly vulnerable to the action of climatic factors. It is estimated that any change in climate may affect the agricultural zoning, productivity and the progress of epidemics of plant diseases (Smith and Tirpak, 1989). For disease occurrence it is required that a susceptible host, a virulent pathogen and favorable environmental factors interact (Agrios, 2005). The environment is an important component in this interaction and may even prevent the occurrence of a disease even in the presence of virulent pathogen and susceptible host (Jesus Junior *et al*., 2003). Thus, the spatial distribution of plant diseases is largely influenced by climatic conditions. Important diseases can become secondary if environmental conditions are not favorable. In contrast, secondary diseases may become important if the environment is extremely favorable (Jesus Junior *et al*., 2003).

Therefore, climate change can be a serious threat to the Brazilian phytosanitary scenario and may promote significant changes in the occurrence and severity of plant diseases. It might have direct and indirect effects both on pathogens and host plants, as well as on the interaction between them (Chakraborty, 2005). In the near future, there will certainly occur changes in the relative importance of each plant disease (Chakraborty, 2000). In addition, there may be greater potential for establishment of quarantine pathogens depending on climatic conditions. New diseases may appear in certain regions and others can lose or increase their economic importance, especially if there is displacement of crop fields (Coakley, 1995). Additionally, the temporal distribution of diseases can also be affected by climate change (Chakraborty, 2005). However, despite the threats of climate change for crop protection in the near future, there are few reports on this subject (Garrett *et al*., 2006).

Brazil is currently the largest producer and exporter of coffee

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## IMPACTO DE LOS CAMBIOS CLIMÁTICOS SOBRE LA MANCHA DE PHOMA EN LOS CAFETALES EN BRASIL

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*RESUMEN*

*Se evaluó el potencial del impacto de los cambios climáticos globales sobre la distribución espacio-temporal de la mancha de phoma (derrite o requemo) en los cafetales en Brasil. Se elaboraron mapas de favorabilidad climática a la ocurrencia de la enfermedad en el período actual y futuro. Los escenarios futuros utilizados fueron centrados en las décadas de 2010-2030, 2040-2060, and 2070-2090 (escenarios A2 e B2). Estos escenarios fueron obtenidos a partir de seis modelos climáticos globales (MCG's) que están disponibles en el Panel Intergubernamental de Cambio Climático (IPCC). Admitiendo los escenarios futuros trazados por el IPCC, habrá una reducción de la favorabilidad climática a la ocurrencia de la mancha de phoma en Brasil en ambos escenarios futuros (A2 e B2). En cuanto a la distribución temporal, el período de mayor riesgo de ocurrencia de la mancha de phoma tenderá a reducirse en las décadas futuras. Tales alteraciones previstas serán más acentuadas en el escenario A2 en comparación a las previstas en el escenario B2. Aunque haya una reducción de la favorabilidad a la mancha de phoma en el país, algunas regiones aún presentarán potencial riesgo de ocurrencia de esta enfermedad. Además, el aumento de la frecuencia de extremos climáticos no ha sido considerado. Estos ciertamente influenciarán en la magnitud de los potenciales impactos de los cambios climáticos sobre la mancha de phoma en Brasil.*

## IMPACTO DAS MUDANÇAS CLIMÁTICAS SOBRE A MANCHA DE PHOMA DO CAFEEIRO NO BRASIL

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*RESUMO*

*Avaliou-se o potencial impacto das mudanças climáticas globais sobre a distribuição espaço-temporal da mancha de phoma do cafeeiro no Brasil. Elaboraram-se mapas de favorabilidade climática à ocorrência da doença no período atual e futuro. Os cenários futuros empregados foram centrados nas décadas de 2010-2030, 2040-2060, e 2070-2090 (cenários A2 e B2). Estes cenários formam obtidos a partir de seis modelos climáticos globais (MCG's) disponibilizados pelo Painel Intergovernamental de Mudanças Climáticas (IPCC). Admitindo os cenários futuros traçados pelo IPCC, haverá a redução da favorabilidade climática a ocorrência da mancha de phoma no Brasil em ambos cenários futuros (A2 e B2). Quanto à distribuição temporal, o período de maior risco de ocorrência da mancha de phoma tenderá reduzir nas décadas futuras. Tais alterações previstas serão mais acentuadas no cenário A2 quando comparada as preditas no cenário B2. Apesar da redução da favorabilidade a mancha de phoma no país, algumas regiões ainda apresentarão potencial risco de ocorrência desta doença. Além disso, o aumento da frequência de extremos climáticos não foi levado em consideração. Estes certamente influenciarão a magnitude dos potenciais impactos das mudanças climáticas sobre a mancha de phoma no Brasil.*

(FAO, 2010). Coffee plays a relevant role for the social and economic development of this country, ensuring the creation of jobs and revenue. However, the cultivation of coffee is a challenge to producers because of the large number of diseases and pests that attack this crop. The phoma leaf spot (*Phoma* spp.) is one of the major coffee diseases. This disease reduces the photosynthetic leaf area, and while colonizing the branches of the coffee it can cause loss of flowers and fruits (Salgado, 2009). Such losses are severe in temperatures ~20°C, high relative humidity and winds, especially in areas with altitude >900m (Zambolim and Vale, 1999).

Therefore, given the importance of climatic factors for the development of phoma leaf spot, the hypothesis that climate change will probably alter the current phytosanitary scenario of the coffee plant has to be considered. In this sense, knowledge of these effects is essential for future management recommendations and elaboration of public policies for the Brazilian coffee industry. The analyses will serve as support for companies and research bodies in the development of mitigation measures to avoid future losses.

This study evaluated the impacts of climate change on the phoma leaf spot of coffee in Brazil, through the analysis of the spatial-temporal distribution of the classes of favorable climate to the disease in the current period (1961-1990) and future (2010-2030, 2040-2060, and 2070-2090), using scenarios A2 and B2.

## Material and Methods

The study area defined in this study was Brazil, a country located between 5°16'20''N and 33°45'03''S and between 34°47'30'' and 73°59'32''W.

### *Classes of favorable conditions*

Climatic favorability classes were used to make monthly maps of the spatial distribution of the disease., The classes of favorable climate for the germination and infection of phoma leaf spot were established on the basis of published reports. The species *Phoma tarda* and *Phoma costarricensis* were used to establish the limits of mean air temperature (Tm, °C) and relative humidity (RH, %) for the development of phoma leaf spot. These limits were defined on the basis of epidemiological data on the effect of temperature and relative humidity on development of phoma leaf spot of coffee. The established classes (Zambolim and Vale, 1999, Salgado *et al*. 2002; Pozza *et al*., 2003) were

TABLE I
BRAZILIAN REGION (%) OCCUPIED BY THE CLASSES OF FAVORABILITY FOR PHOMA LEAF SPOT OF COFFEE FOR EACH STATIONS AT CURRENT PERIOD (AVERAGE 1961-1990) AND FUTURE (2010-2030, 2040-2060 AND 2070-2090) IN A2 AND B2 SCENARIOS

| Regions | Stations | Class[1] | Current | 2020 | | 2050 | | 2080 | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | A2 | B2 | A2 | B2 | A2 | B2 |
| Midwest | Summer | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2 | 18.17 | 4.24 | 5.45 | 0.00 | 1.53 | 0.00 | 0.00 |
| | | 3 | 7.32 | 4.96 | 4.88 | 2.38 | 3.87 | 1.27 | 0.00 |
| | | 4 | 74.51 | 90.81 | 89.67 | 97.62 | 94.60 | 98.73 | 100.00 |
| | Fall | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2 | 1.89 | 1.89 | 2.24 | 0.01 | 0.46 | 0.00 | 0.00 |
| | | 3 | 13.10 | 13.10 | 13.00 | 0.91 | 1.62 | 0.19 | 0.00 |
| | | 4 | 85.01 | 85.01 | 84.76 | 98.08 | 97.92 | 98.81 | 100.00 |
| | Winter | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 3 | 32.49 | 1.47 | 2.20 | 0.00 | 1.21 | 0.00 | 0.00 |
| | | 4 | 67.51 | 98.53 | 97.80 | 100.00 | 98.79 | 100.00 | 100.00 |
| | Spring | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 3 | 6.28 | 2.34 | 1.48 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 4 | 93.72 | 97.66 | 98.52 | 100.00 | 100.00 | 100.00 | 100.00 |
| Northeast | Summer | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2 | 2.77 | 0.40 | 0.11 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 3 | 14.33 | 5.50 | 6.33 | 0.48 | 1.83 | 0.00 | 0.14 |
| | | 4 | 82.90 | 94.10 | 93.56 | 99.52 | 98.17 | 100.00 | 98.86 |
| | Fall | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2 | 6.73 | 1.17 | 0.30 | 0.00 | 0.23 | 0.00 | 0.00 |
| | | 3 | 22.84 | 9.42 | 5.73 | 1.89 | 3.23 | 0.00 | 0.50 |
| | | 4 | 70.43 | 89.41 | 93.98 | 86.55 | 96.55 | 100.00 | 98.50 |
| | Winter | 1 | 1.38 | 0.38 | 0.41 | 0.00 | 0.02 | 0.00 | 0.00 |
| | | 2 | 13.94 | 13.44 | 14.08 | 10.24 | 12.78 | 3.13 | 8.83 |
| | | 3 | 13.36 | 13.18 | 12.78 | 14.63 | 13.21 | 6.58 | 12.67 |
| | | 4 | 71.32 | 73.00 | 72.72 | 75.12 | 74.00 | 90.30 | 78.50 |
| | Spring | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2 | 3.26 | 0.00 | 0.69 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 3 | 10.14 | 4.40 | 4.32 | 1.25 | 1.21 | 0.00 | 0.22 |
| | | 4 | 86.61 | 95.60 | 94.99 | 98.75 | 98.79 | 100.00 | 99.78 |
| North | Summer | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2 | 6.94 | 0.09 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 3 | 0.99 | 0.19 | 0.33 | 0.08 | 0.11 | 0.00 | 0.01 |
| | | 4 | 92.07 | 99.71 | 99.58 | 99.92 | 99.89 | 100.00 | 99.99 |
| | Fall | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2 | 2.12 | 0.03 | 0.02 | 0.01 | 0.01 | 0.00 | 0.01 |
| | | 3 | 0.85 | 0.37 | 0.38 | 0.15 | 0.21 | 0.00 | 0.04 |
| | | 4 | 97.02 | 99.61 | 99.60 | 99.84 | 99.78 | 100.00 | 99.95 |
| | Winter | 1 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2 | 11.76 | 0.85 | 0.85 | 0.01 | 0.00 | 0.00 | 0.01 |
| | | 3 | 9.52 | 0.70 | 0.77 | 0.27 | 0.00 | 0.00 | 0.13 |
| | | 4 | 78.72 | 98.45 | 98.38 | 99.72 | 100.00 | 100.00 | 99.87 |
| | Spring | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2 | 0.52 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 3 | 0.21 | 0.23 | 0.26 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 4 | 99.27 | 99.77 | 99.72 | 100.00 | 100.00 | 100.00 | 100.00 |

(*continue*)

highly favorable: Tm= 15-20°C and RH >80%; favorable: Tm= 12-15 or 20-25°C and RH >80%; relatively favorable: Tm= 12-25°C and RH= 70-80%; and unfavorable: Tm <12°C or >25°C or RH <70%.

### *Climate Data*

Current climatic data, average air temperature and relative humidity are the historical averages of these variables in the period between 1961 and 1990 (New *et al.*, 2002). These data are available in matrix or grid format with cells of 10'lat × 10'long.

Data regarding future predictions of the deviations of the temperature and relative humidity variables forf each month were obtained from the Intergovernmental Panel on Climate Change website (IPCC, 2007). Future averages of air temperature were calculated using the deviations of this variable provided by six different global climate models (GCM's): HadCM3 (Hadley Centre Coupled Model ver. 3), CSIROMk2 (Commonwealth Scientific and Industrial Research Organisation GCMmark 2), CCSR/NIES (Centre for Climate Research Studies Model), ECHAM4 (European Centre Hamburg Model ver. 4), CGCM2 (Canadian Global Coupled Model ver. 2)-R30, and GFDL (Geophysical Fluid Dynamics Laboratory model resolution R-30), all available at IPCC (2007). Among the models, only HadCM3 considered future deviations of relative humidity. The other models assume that this variable will remain constant or undergo little change in the future. Therefore, future data of relative humidity used were derived from the HadCM3 model.

The future scenarios selected were A2 and B2 (IPCC, 2001), with focus on the decades of decades of 2010-30 (periods between 2010 to 2039), 2040-2060 (2040 to 2069) and 2070-2090 (2070 to 2099). The A2 scenario represents a future where more heterogeneous regionalization is dominant. The B2 scenario represents a future in which the emphasis is on local solutions to economic, social and environmental. Therefore, the A2 scenario can be considered a more 'pessimistic' one, providing greater emission of greenhouse gases. Conversely, the B2 scenario is 'optimistic' concerning climate change, because the adoption of mitigation measures is taken into account. The other existing future scenarios (A1 and B1) were not used because they are global and there is no future data of the variable temperature in some models.

### *Preparation of maps of the climatic favorability*

The deviation predictions presented in each model have different spatial resolutions (HadCM3: 3.75°×2.5°, CSIROMk2b: 5.625°×3.214°, CCSR/NIES: 5.625°×5.625°, ECHAM4: 2.8125°×2.8125°, CGCM2: 3.75°×3.75° and GFDL-R30: 3.7°×2.2°). Therefore, the deviations of future climate data were resampled using the Idrisi32 GIS to produce maps with a spatial resolution of 10'lat×10'long.

In order to reduce variability in the simulation, the average values of the estimated data by the six models were calculated for the generation of monthly maps of future deviations from the mean air temperature. To this end, the spatial analysis (arithmetic) tool of the Idrisi32 GIS was used. This technique is called 'multimodel ensemble', because it uses the average values provided by each of the GCM's. Recent studies have found that the use of the technique 'multimodel ensemble' has reduced the variation in impact predictions of climate change on plant diseases and agricultural zoning. Among these studies, Jesus Junior *et al.* (2008) reported that future predictions of the geo-

TABLE I

| Regions | Stations | Class[1] | Current | 2020 A2 | 2020 B2 | 2050 A2 | 2050 B2 | 2080 A2 | 2080 B2 |
|---|---|---|---|---|---|---|---|---|---|
| Southeast | Summer | 1 | 0.86 | 0.44 | 0.53 | 0.11 | 0.26 | 0.00 | 0.06 |
| | | 2 | 29.35 | 13.89 | 17.66 | 1.68 | 3.66 | 0.01 | 2.53 |
| | | 3 | 45.48 | 33.42 | 34.14 | 25.94 | 36.68 | 6.46 | 16.39 |
| | | 4 | 24.31 | 52.26 | 47.68 | 72.27 | 59.41 | 93.53 | 81.02 |
| | Fall | 1 | 5.25 | 2.34 | 1.77 | 0.05 | 0.37 | 0.00 | 0.11 |
| | | 2 | 17.02 | 10.79 | 7.61 | 1.50 | 1.53 | 0.39 | 1.13 |
| | | 3 | 73.61 | 62.90 | 60.16 | 35.80 | 51.90 | 17.87 | 26.90 |
| | | 4 | 4.11 | 23.96 | 30.46 | 62.65 | 46.20 | 81.73 | 71.86 |
| | Winter | 1 | 4.75 | 1.36 | 0.38 | 0.01 | 0.21 | 0.00 | 0.01 |
| | | 2 | 4.93 | 4.27 | 1.84 | 0.43 | 1.36 | 0.00 | 0.11 |
| | | 3 | 43.21 | 35.39 | 33.13 | 24.04 | 25.27 | 7.65 | 15.89 |
| | | 4 | 47.10 | 58.98 | 64.65 | 75.52 | 73.16 | 92.35 | 83.99 |
| | Spring | 1 | 2.70 | 1.02 | 0.25 | 0.00 | 0.00 | 0.00 | 0.01 |
| | | 2 | 5.95 | 3.92 | 4.16 | 0.37 | 0.33 | 0.40 | 0.93 |
| | | 3 | 50.23 | 40.77 | 43.99 | 32.22 | 18.50 | 9.97 | 20.41 |
| | | 4 | 41.13 | 54.29 | 51.60 | 67.41 | 81.17 | 89.64 | 78.65 |
| South | Summer | 1 | 1.59 | 0.42 | 0.42 | 0.00 | 0.11 | 0.00 | 0.00 |
| | | 2 | 8.56 | 2.26 | 2.84 | 0.00 | 1.34 | 0.00 | 0.00 |
| | | 3 | 60.05 | 45.38 | 47.38 | 27.51 | 36.14 | 10.63 | 25.46 |
| | | 4 | 29.79 | 51.93 | 49.37 | 72.49 | 62.41 | 89.37 | 74.54 |
| | Fall | 1 | 30.94 | 11.93 | 20.01 | 0.04 | 4.06 | 1.92 | 2.83 |
| | | 2 | 4.17 | 3.58 | 8.92 | 1.87 | 6.19 | 1.03 | 6.01 |
| | | 3 | 60.91 | 77.99 | 64.94 | 77.54 | 79.16 | 58.50 | 77.34 |
| | | 4 | 3.98 | 6.51 | 6.13 | 20.55 | 10.59 | 38.55 | 13.81 |
| | Winter | 1 | 3.95 | 3.02 | 4.41 | 3.79 | 5.48 | 0.33 | 0.79 |
| | | 2 | 12.40 | 3.24 | 5.65 | 2.60 | 3.82 | 0.04 | 1.32 |
| | | 3 | 53.90 | 84.20 | 80.32 | 80.02 | 79.90 | 58.77 | 73.02 |
| | | 4 | 12.40 | 9.54 | 9.62 | 13.60 | 10.80 | 40.87 | 24.88 |
| | Spring | 1 | 11.81 | 13.00 | 3.46 | 2.73 | 2.82 | 1.56 | 6.55 |
| | | 2 | 0.77 | 1.92 | 1.61 | 3.40 | 2.59 | 7.72 | 5.93 |
| | | 3 | 79.56 | 70.69 | 61.17 | 50.14 | 52.98 | 57.97 | 58.60 |
| | | 4 | 7.86 | 14.39 | 33.76 | 43.73 | 41.61 | 32.75 | 28.92 |

[1] Favorability classes for phoma leaf spot of coffee are 1: highly favorable, 2: favorable, 3: relatively favorable, 4: unfavorable.

graphic distribution of black sigatoka made using the averaged data obtained for the GCM's led to a reduced variability of the simulation, compared with those generated by each model.

World maps of average temperature and relative humidity for the present and future (2020, 2050 and 2080) for both scenarios (A2 and B2) were classified according to the classes of climate favorability for moniliasis. Based on the overlapping of selected maps of temperature and relative humidity, new monthly maps of moniliasis distribution in Brazil were devised. The area corresponding to Brazil was selected from georeferenced data, and a mask delineating the individual states was applied to these maps.

## Results and Discussion

In the current scenario (1961-1990), there is a predominance of areas with potential risk of phoma leaf spot (highly favorable, favorable and relatively favorable) in Southern Bahia and in Southeastern and Southern Brazil. In the Midwest, there is a predominance of areas classified as unfavorable for the disease almost all the months of the year. In the Northern region, due to the predominance of high temperatures throughout the year, there is a concentration of areas classified as unfavorable disease (Figure 1; Table I). It is noteworthy that coffee production in these regions is not significant when compared with the national production. The states of Minas Gerais, São Paulo, Espírito Santo, Paraná and Bahia are the main coffee-producing states of Brazil (Conab, 2010). Thus, emphasis should be given to these regions in the analysis of potential impacts of climate change on coffee plantations in the country.

In future decades, areas classified as negative for phoma leaf spot will predominate in the North, Midwest, and parts of Southeast and Northeastern of Brazil (Figure 1; Table I). Areas classified as relatively favorable for phoma disease will be concentrated in the South and in some places in the Southeast. Areas classified as highly favorable will be in the South and coastal areas. In general, spatial distribution of favorable climatic areas for phoma disease will be reduced drastically throughout the decades, concentrating in the South and in some areas in the states of Sao Paulo, Minas Gerais, and Espírito Santos.

Regarding the temporal distribution of phoma leaf spot in Brazil, the most favorable period for the disease in the current scenario is between March and July. However, in the decades ahead there will be a significant area of negative phoma leaf spot during this period (Figure 1). In the A2 scenario, the percentage of Brazilian territory occupied by class 4 (unfavorable) during the months from March to July will be 80, 88 and 94% in the decades of 2010-2030, 2040-2060, and 2070-2090, respectively. In contrast, the B2 scenario the area occupied by this class will be respectively 81, 85 and 90% in the decades 2010-2030, 2040-2060, and 2070-2090. In these future scenarios the period of the most favorable climate for the occurrence of disease in the country will be reduced. In 2070-2090, the most favorable period for the disease will be between April and July (Figure 1).

Looking at future scenarios, it appears that the reduction of climatic (spatio-temporal) favorability for phoma leaf spot does occur in both scenarios A2 and B2. However, this reduction is more pronounced in the A2 scenario, compared with forecasts predicted in B2. This fact is due to the higher increase in temperature and low relative humidity predicted by the A2 scenario in the coming decades.

The increase in unfavorable areas for phoma leaf spot in future decades is associated with areas where temperature will rise to >25°C and relative humidity will fall to <70%. These climate conditions have been shown by several authors to be adverse for phoma leaf spot development. Salgado *et al.* (2002) found that the maximum in vitro development of *P. tarda* occurs at 15-22°C, and stops at 25°C. Pozza *et al.* (2003) found better progress of the disease in coffee plants kept in a growth room between 15 and 20°C; these authors point out that temperatures >25°C inhibit the progress of this disease. Furthermore, the infection by phoma leaf spot is favored by increasing the duration of leaf wetness, and maximum growth occurred after 68h (Pozza *et al.*, 2003). Zambolim and Vale (1999) reported that the temperature range favorable for the development of *P. costarricensis* is 15-22°C and that a relative humidity >90% and low intensity rainfall favor the progress of the pathogen.

However, other environmental factors than those studied also influence the impacts of climatic changes on the phoma leaf spot. The models used in preparing the maps do not take into account the effect of wind, which affects the susceptibility of the phoma leaf spot stain (Carvalho, 1998). An increased frequency of heavy rains and strong winds are expected in future climate extremes (Rosenzweig *et al*., 2001). The effect of strong wind is highly favorable to the occurrence of phoma leaf spot, as it causes injuries in the leaves that can facilitate the entry of the pathogen (Carvalho, 1998). Thus, increased occurrence of strong winds could enhance injuries in coffee leaves, thereby promoting the development of the disease. An increased frequency of extreme weather conditions will certainly influence the magnitude of the impacts of climate change on this disease.

Reports in the literature have shown the potential impacts of climate change on major diseases and pests of coffee in Brazil. Chalfoun *et al.* (2001) examined changes in the progress curve of coffee rust in the light of climate change, and reported delays in the progress of the disease and the maintenance of higher levels of infection until the end of the cycle, in August. Moraes *et al.* (2009) reported a downward trend in the development of future climate favorability for *Cercospora coffeicola* in Brazil. According to these authors, these changes are more pronounced in the A2 scenario compared to those predicted by the B2 scenario. The same trend of reduction in favorable climate for the establishment of *Mycena citricolor,* a disease that has not been reported in Arabica coffee plantations in Brazil, was observed by Moraes *et al.* (2011). Conversely, Ghini *et al*. (2008) predict increased infestation by *Meloidogyne incognita* (races 1, 2 and 4) and *Leucoptera*

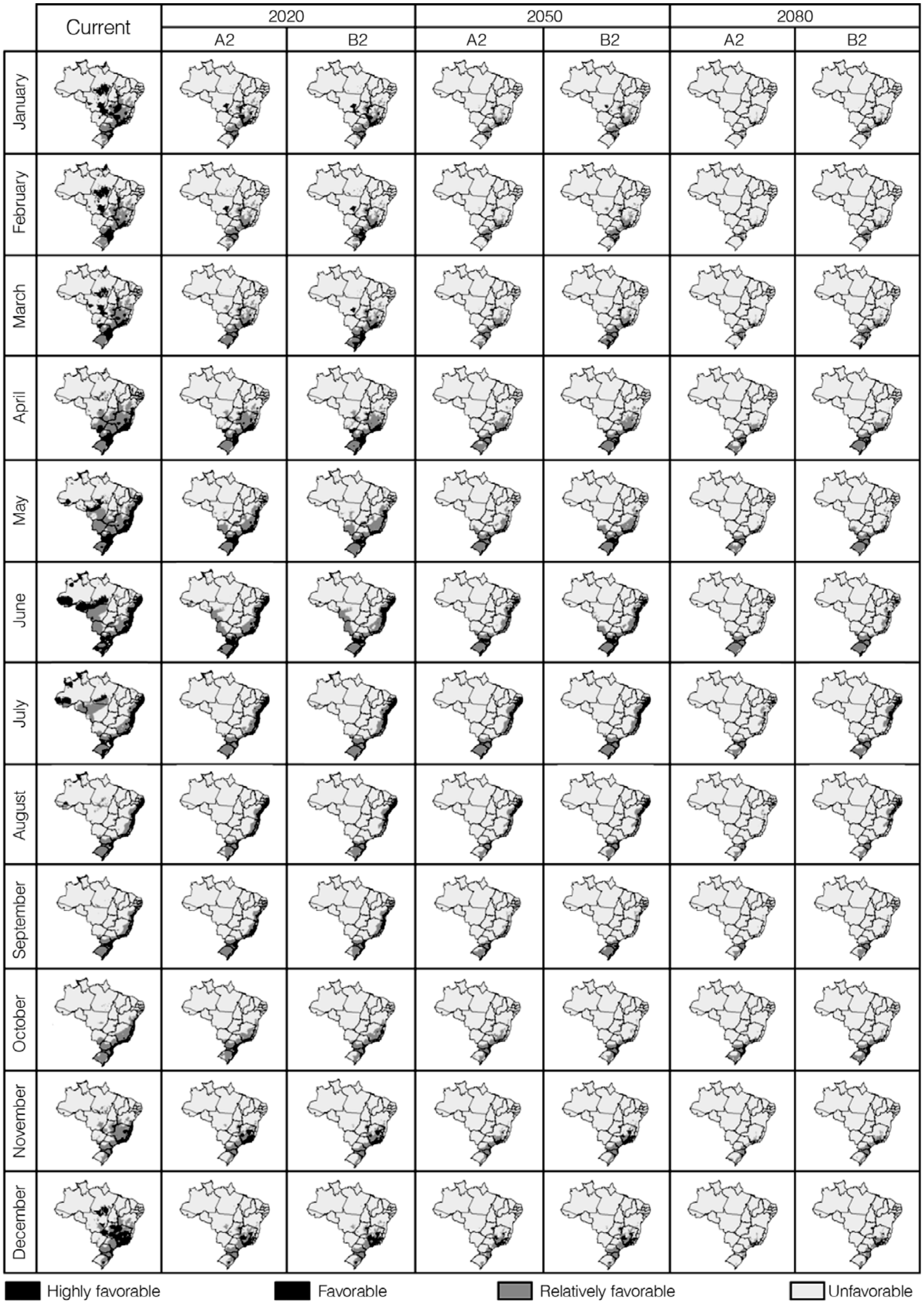


Figure 1. Maps of spatial distribution of climatic favorability classes of phoma leaf spot of coffee in Brazil, from January to December, for the current period (average 1961-1990) and future (2010-2030s, 2040-2060s, and 2070-2090s) in A2 and B2 scenario.

coffeella in future decades in Brazil. Additionally, these authors point out that the increase in the number of generations of nematodes and coffee leaf miner is more pronounced in the A2 scenario. Therefore, the results of the present study concur with those obtained by other authors in that climate change will likely alter the economic importance of major diseases and pests of coffee in Brazil.

It is noteworthy that this study only considered favorable climate conditions for the disease; however, the change in a particular climatic factor may have positive effects in one part of the disease triangle (relationship between pathogen/environment/ host) and negative ones in another (Chakraborty, 2005). Moreover, the effects can also oppose each pther at various stages of the life cycle of the pathogen (Coakley, 1995). Additionally, both the pathogen and the host may suffer alterations with climate change, modifying the results under discussion. Therefore, only the full system will determine the real impacts of climate change on the phoma leaf spot.

Concerning the pathogen, *Phoma* spp. may undergo selection pressure in favor of strains better adapted to new environmental conditions. Some genera have been associated with a teleomorph genus *Phoma* (Aveskamp, 2010). Salgado *et al.* (2007) reported the occurrence of a sexual stage in *P. tarda* (*Didymella* spp.) in *Coffea arabica* in Brazil. Therefore, with the finding of a sexual form of *P. tarda* and the possibility of the existence and/or introduction of other teleomorphs, sexual reproduction is possible as reproduction form for phoma leaf spot in the country. This increases the genetic variability of the pathogen (genetic mutations and recombination) and consequently the probability of the selection of strains adapted to future environmental conditions.

As the host, the development of coffee is likely to be affected by these changes in climate. Thus, new areas may become more suited for planting. Assad *et al.* (2004) concluded from the current genetic and physiological characteristics of *Coffea arabica* cultivars used in Brazil, that there will be a reduction of suitable areas greater than 95% in Goiás, Minas Gerais and São Paulo, and 75% in Paraná. These authors point out a possible displacement of the cultivation of coffee in the South of Brazil. Despite the reduction of the favorability of the phoma leaf spot in Brazil, areas in the South will still have a potential risk of phoma leaf spot. Additionally, in some regions of the country the coffee crop will be restricted to mountainous regions (Assad *et al.*, 2004). The increased upland planting of the crop may increase favorability for disease development, since at higher altitude the temperature is mild and there is a higher incidence of strong winds (Carvalho, 1998). Therefore, if these forecasts will materialize and displacement of culture takes place, changes can occur in the economic importance of this disease.

However, it is important to note that this situation can be avoided with the genetic improvement that will possibly develop new cultivars tolerant to future conditions (Fazuoli, 2007). Furthermore, mitigation practices such as farming under the agro forestry system, high density planting and irrigation have been implementedf (Fazuoli, 2007). However, despite genetic resistance of the new varieties to phoma leaf spot, the microclimate under the canopy in theses cropping systems affects the occurrence of the disease.

Moreover, it is important to note that the GCM's have a low spatial and temporal resolution. These factors have hampered analysis with biological models, as hourly or daily variations can influence the progress of epidemics of plant diseases. Additionally, microclimatic conditions are not considered in the analysis. Despite these limitations, the GCM's models have been useful tools in studying the impacts of climate change on plant diseases. The use of these models is more appropriate that some other methodologies that have been employed; some authors have simplified the analysis methodology adopting a constant variation of the climatic variable, independently of the age or geographic areas. Conversely, the GCM's provided by the IPCC predict temporal and spatial changes of climate variables, providing greater accuracy in the analysis of the impacts of climate change.

## Conclusions

Considering the global warming scenarios provided by the IPCC, there will be a reduction in favorable areas for phoma leaf spot of coffee in Brazil during the coming decades (2020, 2050 and 2080). Future climatic changes will also modify the temporal distribution of phoma leaf spot in Brazil. The length of the most favorable period for the disease tends to be reduced in future decades. Reducing climate favorability for the disease is anticipated in both future scenarios A2 andB2, and the reduction is more pronounced assuming the worst case scenario outlined by the IPCC (A2). Despite these reductions in some areas there will still exist potential risk of phoma leaf spot in future scenarios, especially in the Southern region of Brazil.

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