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Impacts of climate projections on water balance and implications on olive crop in Minas Gerais

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ABSTRACT
Minas Gerais is vulnerable to climate change, with negative impacts on water balance and changes in the cultivation of several crops. Currently, the olive crop has been an alternative source for farmers, especially those in the South of the state. However, there is no information on areas with climatic conditions suitable for olive cultivation, as well as the possible impacts of climate change. The aim of this study was to verify the impact of climate projections on water balance and agroclimatic zoning for olive cultivation in the Minas Gerais, based on current climate conditions (1980-2011), and different climate change projections for three future periods (2011-2040, 2041-2070 and 2071-2100). For the current climate, Minas Gerais showed 37% of suitable area, 15% of marginal area and 48% of unsuitable area for olive cultivation. For the period 2071-2100, only 4% was classified as suitable area, 6% as marginal area and 90% as unsuitable. Projections of climate change, of both temperature and rainfall, will affect the olive cultivation, substantially reducing the suitable area in the entire state.

Palavras-chave:
aquecimento global
Olea europaea L.
Thornthwaite

Impacto das projeções climáticas no balanço hídrico e implicações na oliveira em Minas Gerais

RESUMO
Minas Gerais apresenta-se vulnerável às mudanças climáticas com impactos no balanço hídrico e alterações nas áreas destinadas ao cultivo de diversas culturas. Atualmente, a oliveira se mostra como uma alternativa de renda para os agricultores mineiros especialmente os do sul do estado. No entanto, não se tem informações sobre as áreas com maior aptidão ao seu plantio, assim como as possíveis implicações das mudanças climáticas. O objetivo deste estudo foi verificar o impacto das projeções climáticas no balanço hídrico e no zoneamento agroclimático para a cultura da oliveira em Minas Gerais baseado nas condições de clima atual (1980-2011) e futuro considerando-se diferentes projeções de mudanças climáticas, para três períodos (2011-2040, 2041-2070 e 2071-2100). Para o clima atual, Minas Gerais apresentou 37% de área apta, 15% de área marginal e 48% de área inapta ao cultivo de oliveira. Para o período de 2071-2100 apenas 4% foram classificadas como aptas, 6% como marginal e 90% como inapta. As projeções de mudanças climáticas, tanto em temperatura quanto em precipitação, irão afetar o cultivo de oliveira reduzindo substancialmente a área apta ao seu cultivo, no estado.

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Introduction

To make viable the expansion of olive cultivation in Brazil, it is necessary first to know the areas that are promising and adapted to this crop, especially in regions with climatic conditions different from those of its center of origin (Martins et al., 2014). Unfavorable climatic conditions can cause physiological disorders in the plants and thus affect their development, growth and yield (Tanasijevic et al., 2014), and water stress and irregular temperature are the main limiting factors to olive cultivation (Moriondo et al., 2015).

Recent climate studies point to alterations in the mean seasonal fields and of variability in various meteorological elements, particularly in rainfall and air temperature for Minas Gerais and large part of Brazil (Torres & Marengo, 2014). In general, the models project, for the end of the century, a warmer climate, of up to 5 °C in Northern Minas Gerais, and heterogeneous tendencies in rainfall with projections of reduction in the Northern regions of the state and a slight increase in Central and South regions (IPCC, 2013). Alterations in the climatic patterns can impact and even make unviable the cultivation of olive, especially due to the modifications in the patterns of evapotranspiration and water balance, such as alterations in physiological and phenological responses and duration of development stages (García-Mozo et al., 2010; Moriondo et al., 2015).

Studies on climate changes and on their impact on olive cultivation have been conducted in various countries (García-Mozo et al., 2010; Tanasivejic et al., 2014). However, in Brazil, especially in Minas Gerais, which has had strong investment in olive cultivation, there is no such type of information. In this context, this study aimed to evaluate the impact of climate changes on water balance and climatic zoning for the olive crop in Minas Gerais, based on the conditions of current and future climate, through different projections of climate changes.

Material and Methods

The study used daily data of cumulative rainfall (mm) and minimum and maximum air temperature (°C) of the 49 conventional weather stations of the National Institute of Meteorology (INMET) in Minas Gerais. The climatic means of rainfall and mean air temperature were calculated using the period of 1980 to 2011 (referred to as PR0) and the recommendations of the WMO (1989).

The potential evapotranspiration (ETP) was calculated using the method proposed by Thornthwaite (1948), mainly because of the low national availability of meteorological data of hard measurement and for having good results for the studied area, besides being the ETP estimation method most used in studies of climatological water balances (Sentelhas et al., 2008).

The climatological water balance was calculated using the methodology proposed by Thornthwaite & Mather (1955), which provides the amount of water stored in the soil, actual evapotranspiration, deficiency (DEF) and water surplus (EXC) at a regional level, being an important tool for planning and agroclimatic zoning (Sentelhas et al., 2008). This method requires, as input data, the availability of climatic means of monthly rainfall, monthly ETP and Available Water Capacity (AWC). Because of the types of soils in the state, olive root length (1.2 to 1.7 m) and AWC value recommended for the olive crop (150 to 200 mm) (Pastor & Orgaz, 1994), the AWC value of 175 mm was used.

Future climates were projected using simulations and climatic projections of 24 General Circulation Models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al., 2012), which were used in the 5th Report of the Intergovernmental Panel on Climate Changes (IPCC, 2013). Monthly climatic means of rainfall and air temperature close to the surface were simulated for 1971-2000 and projected for three different periods: PR1 = 2011 - 2040, PR2 = 2041 - 2070 and PR3 = 2071 - 2100. The GCMs were selected due to the unavailability of updated results of regional models, which are highly computationally expensive, and the new generation of GCMs represents the state of the art in the modeling of the climatic system.

The simulations of the current climate, referring to the XX century, are characterized as control experiments for which the climate forcings that could impact the climate are identified and historic series observed in the forcings are included in the integrations of the GCMs. In addition, the projections of the CMIP5 use the new generation of forcing scenarios: Representative Concentration Pathways - RCPs - 2.6, 4.5, 6.0, and 8.5, which correspond to the approximate radiative forcings at the end of the XXI century of 2.6, 4.5, 6.0 and 8.5 W m^{-2}, respectively, relative to the pre-industrial conditions (Moss et al., 2010). As to the CO_2-equivalent concentrations, the RCPs correspond to 490, 650, 850 and 1370 ppm at the end of the XXI century, respectively (Moss et al., 2010).

The horizontal resolutions of the GCMs from the CMIP5 vary around 1 to 3 degrees of latitude/longitude. With the objective of intercomparison, all variables were interpolated for a common regular grid of 1° x 1° of latitude/longitude using the bilinear interpolation, which is the interpolation method most used in Geosciences for data distributed on a regular horizontal grid (Jones, 1999; Chen & Knutson, 2008). In this study, the term "climate changes" refers to the difference between the mean values of the projected climatic variables and the respective mean value of the period 1971-2000. The water balance and current zoning of the olive crop used data of the climatic means of the PR0, while future projections used the sum of the climatic means of the PR0 with the changes for each period (PR1, PR2 and PR3).

The impact of climate changes on the water balance was verified through the analysis of projections of mean temperature and rainfall changes and the variables of the excerpt of the annual water balance (ETP, DEF, EXC) in each RCP. The agroclimatic zoning, according to Pastor & Orgaz (1994), considers as suitable the regions with $DEF_{annual} \leq$ AWC (175 mm); marginal the regions with AWC $< DEF_{annual} \leq$ AWC + 25 (200 mm) and unsuitable the regions with $DEF_{annual} > 200$ mm. The surplus values of 25 mm were used, according to the recommendations of Sediyama et al. (2001) and Assad et al. (2013) for coffee and cotton, respectively.

Once the classes of climatic aptitude were obtained, the data were spatialized for a regular grid covering the state of Minas

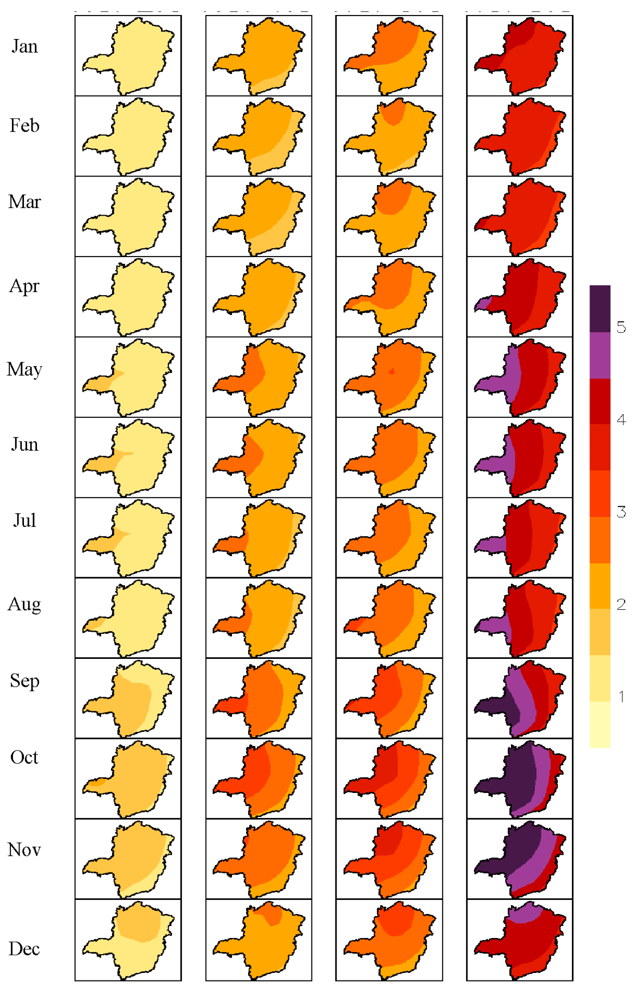
Gerais through the Ordinary Kriging method implemented in the R software version 3.0.2. The interpolation through the Kriging method was selected for being more adequate in the transformation of dispersedly located data to a regular grid (Jones, 1999; Chen & Knutson, 2008). The thematic maps of the agroclimatic zoning were constructed using the software open GrADS (Grid Analysisand Display System) version 2.0.

Results and Discussion

Figures 1 and 2 present the spatial distributions of the projections of air temperature and rainfall, respectively, for the end of the XXI century (PR3). For brevity, the periods PR1 and PR2 were omitted, which showed analogous spatial patterns, but with lower intensity in comparison to the end of the century.

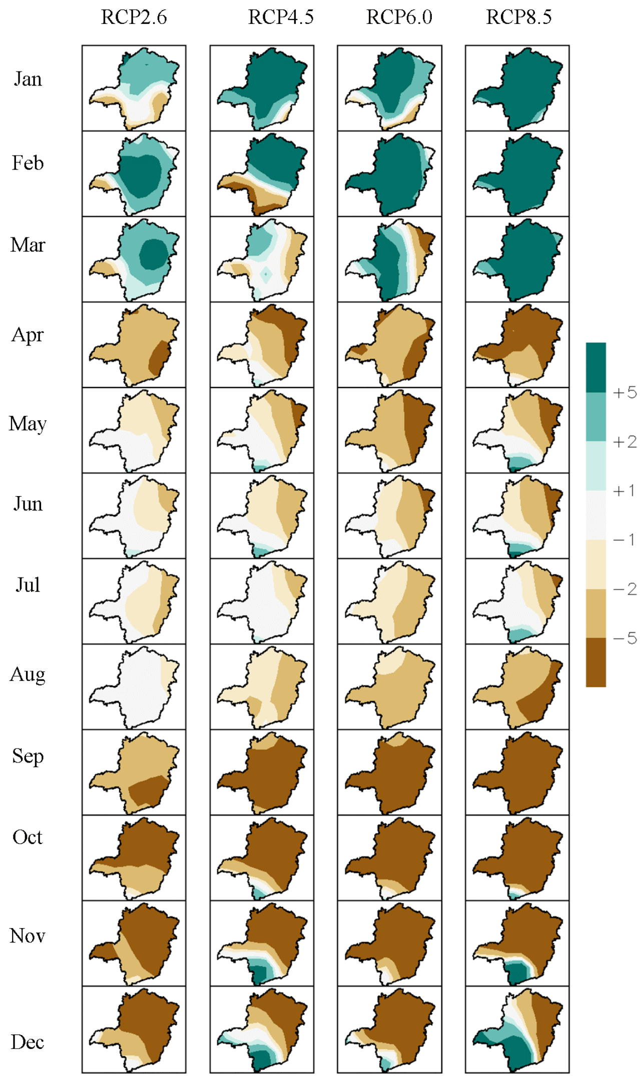
In the entire state, an increase in air temperature is expected (Figure 1), especially in the spring (September, October and November), which may reach 5 °C in some localities in the scenario RCP 8.5, with increment in the thermal contrast between the North and South of the state.

Unlike air temperature, the rainfall (Figure 2) does not have evident tendencies of increase. In a large portion of the state, there will be the increase of extremes, with rainfalls above the mean in the summer months, especially in January, and decrease at the end of the winter and in the spring. In the North and East regions of the state, the rainfall tends to decrease, aggravating the DEF and aridity (Figure 3), while in the Central and South regions of the state the rainfall tends to increase.



RCP - Representative Concentration Path ways corresponding to approximate radiative forcing at the end of XXI century of 2.6, 4.5, 6.0 and 8.5 W m^{-2}

Figure 1. Projection of change for air temperature (°C) for the period PR3 (2071-2100), along the year, in the four forcings: RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5

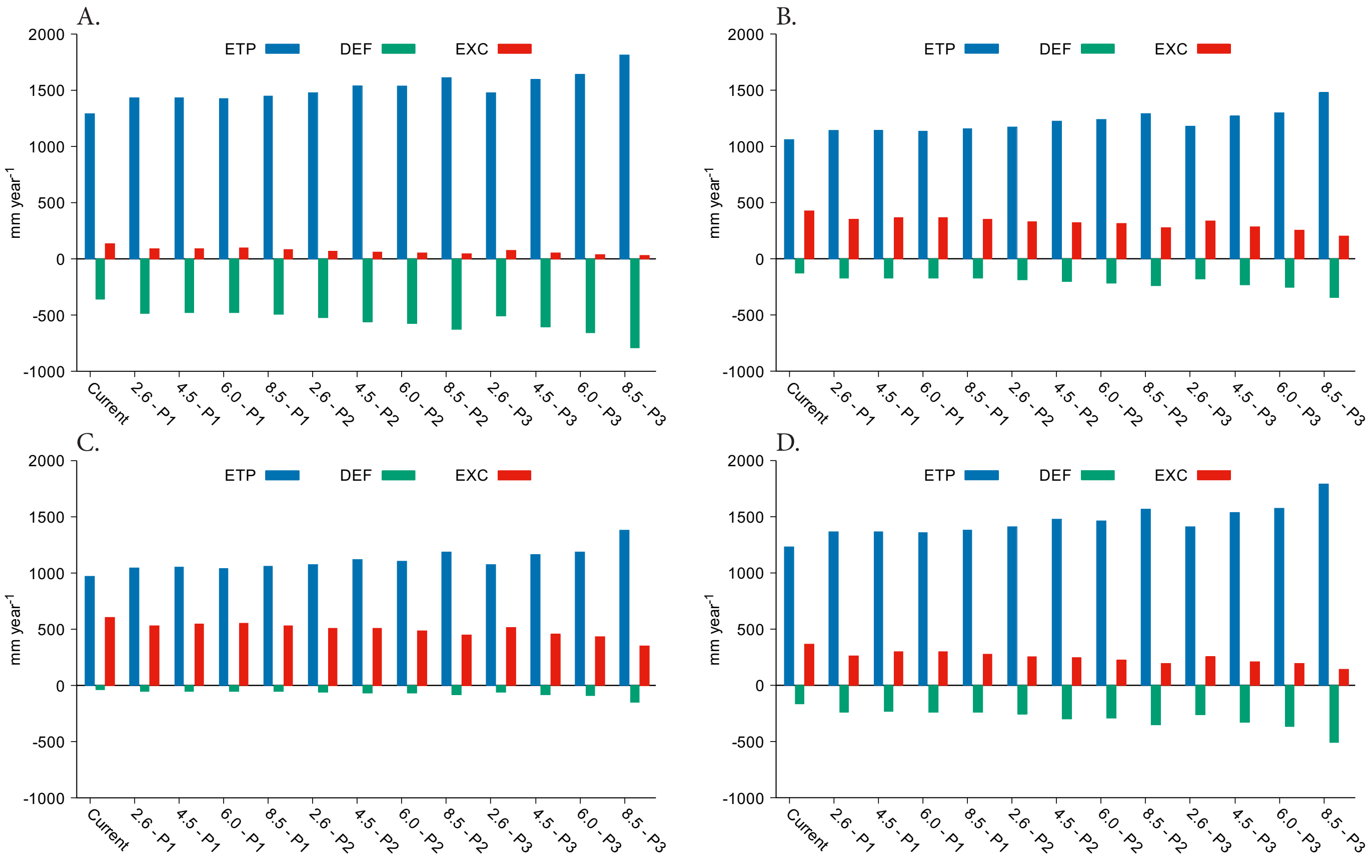


RCP - Representative Concentration Path ways corresponding to approximate radiative forcing at the end of XXI century of 2.6, 4.5, 6.0 and 8.5 W m^{-2}

Figure 2. Projection of change for cumulative rainfall (mm month^{-1}) for the period PR3 (2071-2100), along the year, in the four forcings: RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5

This heterogeneity is directly reflected in changes of evapotranspiration, which, associated with increases in temperature, generate higher atmospheric demand (Lemos Filho et al., 2010) impacting the water balance and agroclimatic zoning. Regarding the water balance, there were increments in DEF values and reduction in EXC values, with greater intensity in the Northwest, North and Jequitinhonha and Mucuri Valleys at the end of the XXI century in RCP 8.5 (Figure 3A), and also for the other regions of Minas Gerais, corroborating the results of Cardoso & Justino (2014).

Based on the climatic zoning for the olive crop and considering the PR0 (Figure 4), the suitable areas (37%) are concentrated especially in the South-Central region, regions of higher altitude and lower air temperature, which ultimately cause lower evapotranspiration. The areas considered as



Panel 'A' refers to the junction of the mesoregions Northwestern Minas, Northern Minas, Jequitinhonha and Mucuri Valleys; panel 'B' refers to the junction of the mesoregions *Zona da Mata*, *Campos das Vertentes*, Rio Doce Valley, Metropolitan and a small part of the South; panel 'C' refers to the junction of the mesoregions Western and Southern Minas; panel 'D' refers to the junction of the mesoregions *Triângulo Mineiro* and Central.

Figure 3. Excerpt of the climatological water balance for Minas Gerais considering the current period (1981-2010), future periods (PR1- 2011-2040; PR2 - 2041-2070; PR3 - 2071-2100) and forcing scenarios (RCP 2.6, 4.5, 6.0 and 8.5)

marginal to cultivation (15%) were concentrated in the transition region, while unsuitable areas (48%) prevailed particularly in the North and West of Minas Gerais.

Considering the projections of changes in air temperature and rainfall (Figures 1 and 2), there was a reduction in the suitable area and a displacement of the marginal and unsuitable areas towards the South of the state at the end of the XXI century (Figure 5 and Table 1), agreeing with some results for the Mediterranean, which indicates displacement of suitable areas towards the opposite direction in relation to the Equator line (Tanasijevic et al., 2014).

Modifications of temperature, as indicated in the projections of climate changes (Figures 1 and 2), will negatively affect olive

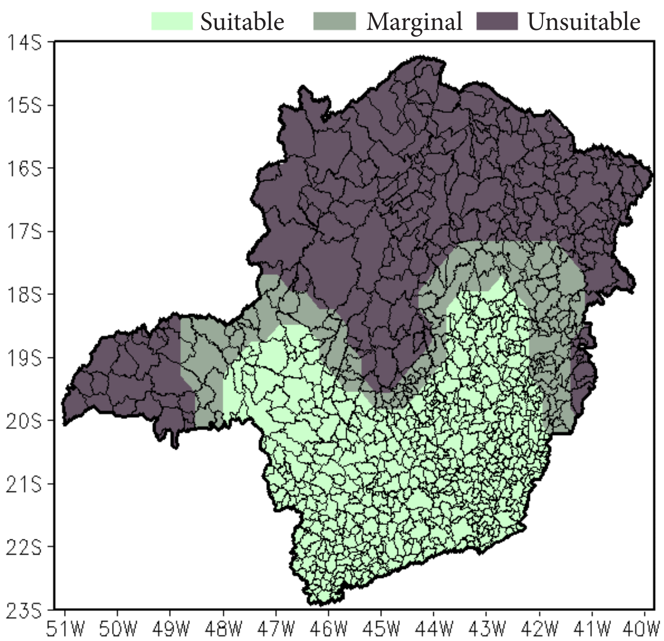
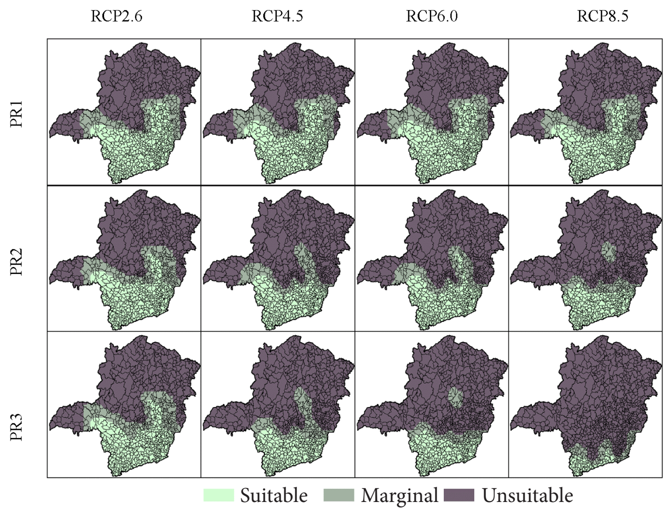


Figure 4. Agroclimatic zoning for the olive crop in Minas Gerais considering the current period (1981-2010) based on the climatological water balance



PR0 = Atual, PR1 = 2011-2040, PR2 = 2041-2070 and PR3 = 2071-2100. RCP - Representative Concentration Path ways corresponding to approximate radiative forcing at the end of XXI century of 2.6, 4.5, 6.0 and 8.5 W m^{-2}

Figure 5. Zoning of climatic aptitude of olive in the state of Minas Gerais for the periods PR1, PR2 and PR3 in the forcings RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5

Table 1. Proportion of suitable, marginal and unsuitable areas for olive cultivation for the current period and the periods of climatic projections in the four scenarios

Projections	RCPs	Suitable		Unsuitable		Marginal	
		%	km²	%	km²	%	km²
PR0	-	37	217015	48	281533	15	87979
PR1	RCP 2.6	32	187689	54	316725	14	87979
	RCP4.5	32	187689	52	304995	16	82114
	RCP 6.0	33	193554	52	304995	15	93844
	RCP 8.5	29	170093	55	322590	16	87979
PR2	RCP 2.6	27	158362	57	334321	16	93844
	RCP4.5	21	123171	67	392974	12	93844
	RCP 6.0	22	129036	66	387109	12	70383
	RCP 8.5	17	99710	75	439896	8	70383
PR3	RCP 2.6	26	152497	58	340186	16	46922
	RCP4.5	18	105575	71	416435	11	93844
	RCP 6.0	16	93844	76	445761	8	64518
	RCP 8.5	4	23461	90	527875	6	46922

PR0 = Atual, PR1 = 2011-2040, PR2 = 2041-2070 and PR3 = 2071-2100. RCP - Representative Concentration Path ways corresponding to approximate radiative forcing at the end of XXI century of 2.6, 4.5, 6.0 and 8.5 W m^{-2}

cultivation, especially for altering the evapotranspiration (Figure 3). The increment in temperature tends to increase evapotranspiration, causing the plants to lose water to the atmosphere at high rates. With the reduction of rainfall, the supply of water to the plants is lower than the evaporation rate, resulting in a situation of water deficit, and the reduction of leaf area and the stomatal closure are the main strategies of defense of the plant (Taiz & Zeiger, 2009). As a consequence, there is a reduction in the gas exchanges (transpiration and CO_2 assimilation for photosynthesis).

Additionally, high temperatures, above 35 °C (Wrege et al., 2015), in the flowering period, more precisely in the beginning of the flowering, from early August to late September (Oliveira et al., 2012), are harmful to the olive crop, because they cause flower abortion (García-Mozo et al., 2010). García-Mozo et al. (2010) evaluated phenological tendencies in Southern Spain in response to climate changes and observed that the increase in mean annual temperature also damages pollination, shortens the duration of the flowering and fruiting stages (Tanasijevic et al., 2014) and increases the respiration of the cell tissue (Taiz & Zeiger, 2009), particularly in plants with C_3 metabolism like olive, leading to lower yield. High air temperatures (above the optimal temperature, e.g. 14.7 and 16.1 °C) (Martins et al., 2014) also reduce the photosynthetic rate, mainly due to the reduction in the efficiency of the photosystem II (photosynthetic apparatus), increase in maintenance respiration and reduction of leaf area. In addition, alterations in the olive development stages will impact the management of the crop, accelerating flowering, maturation and harvest, and probable occurrence of adverse meteorological events during these stages.

In relation to rainfall, its most pronounced reduction must occur precisely in the months of inflorescence and beginning of flowering and full flowering of the olive crop (Oliveira et al., 2012), in the months of September, October and November (Figure 2). As indicated by the projections (Figures 1, 2 and 3), the DEF will occur mainly in the stage of inflorescence and beginning of flowering, between August and September (Oliveira et al., 2012), which causes reduction in the number of inflorescences, increase in production of imperfect flowers and flower abortion (Orgaz & Fereres, 1999). However, in the West of the state, DEF may also occur in the maturation stage, from early January to March, which will lead to small-sized fruits, low pulp/weight ratio, reduction in yield and poor quality of flower for the production of the next year (Orgaz & Fereres, 1999). Still according to the projections (Figures 1, 2), there are also tendencies of increase in rainfall during the fruiting, which occurs from November to early January. However, precisely during this stage, it is not ideal that water surplus occur, because it may cause reduction in the oil content of the fruit.

Combined, these factors will cause reduction in yield and production quality of the olive crop, making its cultivation unviable in almost the entire state of Minas Gerais. For all of these reasons, the projections of the CMIP5 models, for both temperature and rainfall, will affect the water balance of the olive crop, substantially reducing the area suitable for its cultivation in Minas Gerais, and only the South region of the Minas Gerais state will be suitable for olive cultivation until 2100.

Conclusions

1. The probable increase of temperature and change in the rainfall regime will modify the water balance and harm the olive crop.

2. Large portion of the area suitable for olive cultivation will be reduced and there will be a displacement of marginal and unsuitable areas towards the South of the state.

3. For the end of the XXI century (2071-2100) in the scenario of more intense climatic alterations, olive cultivation will only be viable in the far South of the state.

4. The increase in temperature and the modification in the rainfall regime must affect mainly the flowering and fruiting stages of olive in the state.

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Literature Cited

Assad, E. D.; Martins, S. C.; Beltrão, N. E. M.; Pinto, H. S. Impacts of climate change on the agricultural zoning of climate risk for cotton cultivation in Brazil. Pesquisa Agropecuária Brasileira, v.48, p.1-8, 2013. http://dx.doi.org/10.1590/S0100-204X2013000100001

Cardoso, G. M.; Justino, F. Simulação dos componentes da evapotranspiração sob condições climáticas atuais e de cenários climáticos futuros de aquecimento global com o uso de modelos de clima-vegetação. Revista Brasileira de Meteorologia, v.29, p.85-95, 2014. http://dx.doi.org/10.1590/S0102-77862014000100009

Chen, C. T.; Knutson, T. On the verification and comparison of extreme rainfall indices from climate models. Journal of Climate, v. 21, p. 1605-1621, 2008. http://dx.doi.org/10.1175/2007JCLI1494.1

García-Mozo, H.; Mestre, A.; Galán, C. Phenologicaltrends in southern Spain: A response to climate change. Agricultural and Forest Meteorology, v.150, p.575-580, 2010. http://dx.doi.org/10.1016/j.agrformet.2010.01.023

IPCC - Intergovernamental Panel on Climate Change. Summary for policymaker. In: Stocker, T. F.; Qin, D.; Plattner, G. K.; Tignor, M.; Allen, S. K.; Boschung, J.; Nauels, A.; Xia, Y.; Bex, V.; Midgley, P. M. (ed.) Climate change 2013: The physical science basis. Cambridge: Cambridge University Press, 2013. 1535p. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

Jones, P. W. First and second-order conservative remapping schemes for grids in spherical coordinates. Monthly Weather Review, v.127, p.2204-2210, 1999. http://dx.doi.org/10.1175/1520-0493(1999)127%3C2204:FASOCR%3E2.0.CO;2

Lemos Filho, L. C. A.; Carvalho, L. G.; Evangelista, A. W. P.; Alves Júnior, J. Análise espacial da influência dos elementos meteorológicos sobre a evapotranspiração de referência em Minas Gerais. Revista Brasileira de Engenharia Agrícola e Ambiental, v.14, p.1294-1303, 2010. http://dx.doi.org/10.1590/S1415-43662010001200007

Martins, F. B.; Pereira, R. A. A.; Pinheiro, M. V. M.; Abreu, M. C. Desenvolvimento foliar em duas cultivares de oliveira estimado por duas categorias de modelos. Revista Brasileira de Meteorologia, v.29, p.505-514, 2014. http://dx.doi.org/10.1590/0102-778620140020

Moriondo, M.; Ferrise, R.; Trombi, G.; Brilli, L.; Dibari, C. Modelling olive trees and grape vines in a changing climate. Environmental Modelling & Software, v.63, p.1-15, 2015.

Moss, R. H.; Edmonds, J. A.; Hibbard, K. A.; Manning, M. R.; Rose, S. K.; Vuuren, D. P. van; Carter, T. R.; Emori, S.; Kainuma, M.; Kram, T.; Meehl, G. A.; Mitchell, J. F. B.; Nakicenovic, N.; Riahi, K.; Smith, S. J.; Stouffer, R. J.; Thomson, A.; Weyant, J. P.; Willbanks, T. J. The next generation of scenarios for climate change research and assessment. Nature, v.463, p.747-756, 2010. http://dx.doi.org/10.1038/nature08823

Oliveira, M. C. de; Ramos, J. D.; Pio, R.; Cardoso, M. G. Características fenológicas e físicas e perfil de ácidos graxos em oliveiras no sul de Minas Gerais. Pesquisa Agropecuária Brasileira, v.47, p.30-35, 2012. http://dx.doi.org/10.1590/S0100-204X2012000100005

Orgaz, F.; Fereres, E. Riego. In: Barranco, D. Cultivo del olivo. Madri: Mundi-Prensa. 1999. p.267-288.

Pastor, M.; Orgaz, F. Riego deficitário del olivar. Agricultura, v.746, p.768-776, 1994.

Sediyama, G. C.; Melo Júnior, J. C. F.; Santos, A. R.; Ribeiro, A.; Costa, M. H.; Hamakawa, P. J.; Costa, J. M. N.; Costa, L. C. Zoneamento agroclimático do cafeeiro (*Coffea arabica* L.) para o estado de Minas Gerais. Revista Brasileira de Agrometeorologia, v.9, p.501-509, 2001.

Sentelhas, P. C.; Santos, D. L.; Machado, R. E. Water deficit and water surplus maps for Brazil, based on FAO Penman-Monteith potential evapotranspiration. Ambiente & Água, v.3, p.29-42, 2008. http://dx.doi.org/10.4136/ambi-agua.59

Taiz, L.; Zeiger, E. Fisiologia vegetal. 4.ed. Porto Alegre: Artmed, 2009. 848p.

Tanasijevic, L.; Todorovic, M.; Pereira, L. S.; Pizzigalli, C.; Lbionello, P. Impacts of climate change on olive crop evapotranspiration and irrigation requirements in the Mediterranean region. Agricultural Water Management, v.144, p.54-68, 2014. http://dx.doi.org/10.1016/j.agwat.2014.05.019

Taylor, K. E.; Stouffer, R. J.; Meehl, G. A. An overview of CMIP5 and the experiment design. Bulletin of the American Meteorological Society, v.93, p.485-498, 2012. http://dx.doi.org/10.1175/BAMS-D-11-00094.1

Thornthwaite, C. W. An approach toward a rational classification of climate. Geographical Review, v.38, p.55-94, 1948. http://dx.doi.org/10.2307/210739

Thornthwaite, C. W.; Mather, J. R. The water balance. Centerton: Drexel Institute of Technology - Laboratory of Climatology, 1955. 104p. Publications in Climatology, v.8, n.1.

Torres, R. R.; Marengo, J. A. Climate change hotspots over South America: From CMIP3 to CMIP5 multi-model datasets. Theoretical and Applied Climatology, v.117, p.579-587, 2014. http://dx.doi.org/10.1007/s00704-013-1030-x

WMO - World Meteorological Organization. Calculation of monthly and annual 30-year standard normals. Geneva: WMO, 1989. 13p. Technical Document, n.341; WCDP, n.10

Wrege, M. S.; Coutinho, E. F.; Pantano, A. P.; Jorge, R. O. Distribuição potencial de oliveiras no Brasil e no Mundo. Revista Brasileira de Fruticultura, v.37, p.656-666, 2015. http://dx.doi.org/10.1590/0100-2945-174/14