Estimating cassava yield in future IPCC climate scenarios for the Rio Grande do Sul State, Brazil

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ABSTRACT: *The objective of this study was to simulate the yield of two cassava cultivars in two IPCC future climate scenarios, the SRES-A1B (Cmip3) and the RCP4.5 (Cmip5), for the state of Rio Grande do Sul, Brazil. The Simanihot model, with the Thornthwaite and Mather water balance sub-model, and the SRES-A1B (Cmip3 – Third Coupled Model Intercomparison Project) and RCP4.5 (Cmip5 - Fifth Coupled Model Intercomparison Project) scenarios of the Fourth and Fifth IPCC Assessment Report, respectively, was used. Cassava cultivars used in this study were 'Fepagro – RS13' (forrage) and 'Estrangeira' (human consumption). In both cultivars, there was an increase in tuberous roots yield in future climate scenarios. The cultivar for human consumption benefits more roots yield in the scenario with higher CO_2 (Cmip3 scenario); whereas, the forage cultivar benefits more the Cmip5 scenario. Among the three future periods (2010-2039, 2040-2069 e 2070-2099), changes in tuberous roots yield are more evident in the end of the century period (2070-2099) and for early planting dates (01 September and 01 October). The northeastern region of the state has the greatest changes in tuberous roots yield in future climates, because this is the coldest region, with winter minimum temperature during between 6 and 8ºC.*
Key words: *Simanihot, agricultural modeling, elevated temperature, elevated CO_2.*

Produtividade simulada de mandioca em cenários climáticos futuros do IPCC para o Rio Grande do Sul, Brasil

RESUMO: *O objetivo deste trabalho foi simular a produtividade de duas cultivares de mandioca em dois cenários climáticos futuros do IPCC, o SRES-A1B (Cmip3) e o RCP4.5 (Cmip5), para o Rio Grande do Sul. Foi utilizado o modelo Simanihot, com o submodelo de balanço hídrico do solo diário sequencial de Thornthwaite e Mather, e os cenários SRES- A1B (Cmip3 - 3ª Projeto de Intercomparação de modelos globais) e o RCP4.5 (Cmip5 - 5ª Projeto de Intercomparação de modelos globais) do 4ª e 5ª relatório do IPCC, respectivamente, regionalizados por downscaling dinâmico com modelo RegCM3 e RegCM4 (Modelo Climático Regional), respectivamente. As cultivares utilizadas no estudo foram a 'Fepagro – RS13' (uso forrageira) e 'Estrangeira' (uso para mesa). Em ambas há aumento na produtividade de raízes em cenários climáticos futuros. A cultivar de mesa se beneficia mais na produtividade de raízes no cenário com maior concentração de CO_2 (cenário Cmip3), enquanto a cultivar forrageira, se beneficia mais no cenário Cmip5. Nos três períodos futuros (2010-2039, 2040-2069 e 2070-2099), as mudanças na produtividade são sempre mais expressivas no último período (2070-2099) e nas primeiras datas de plantio (01/09 e 01/10). A região do Rio Grande do Sul com maiores mudanças na produtividade é a nordeste, a qual, no clima atual é a mais fria do Estado, com temperatura mínima do ar no inverno entre 6 e 8°C.*
Palavras-chave: *Simanihot, modelagem agrícola, aumento de temperatura, aumento de CO_2.*

INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC, 2007, 2013) has reported impacts of the greenhouse effect on meteorological variables such as air temperature, solar radiation and precipitation, which in turn directly influence the growth and developmental processes of agricultural crops. One of the most significant crops for food security and the main food source of several countries in Africa and Asia is cassava (***Manihot esculenta*** Crantz L.). In the Rio Grande do Sul state, cassava plays a key role in family farming.

As a result of its social significance in the developing nations, field and greenhouse experimental research is gaining momentum (IMAI et al., 1984; ROSENTHAL et al., 2012) and increasing in number (CHINVANNO, 2004; LIU et al., 2008; LOBELL et al., 2008; SCHLENKER & LOBELL, 2010). However, studies focused on assessing the impact of climate scenarios in the future on cassava productivity in Rio Grande do Sul are not available.

Future climate scenarios of the IPCC include the SRES-A1B scenario (Cmip3 - 3rd Intercomparison Project global models), an intermediate scenario between the least advantageous scenarios (A1, A2) and the most beneficial ones (B1, B2) of the 4th IPCC Assessment Report, and the RCP4.5 scenario (Cmip5 - 5th Intercomparison Project global models), which is also an intermediate scenario of the 5th IPCC Assessment Report. These two scenarios showed variations in the trends of the meteorological variables. In the SRES-A1B (Cmip3), the CO_2 concentration begins with 300ppm in 1960 and reaches 710ppm by 2100 (IPCC, 2007), while in the RCP4.5 scenario (Cmip5) the CO_2 concentration is around 300ppm in 1960 and goes up to 538ppm by 2100 (IPCC, 2013). The surface temperature is projected to increase during the 21st century in both scenarios and rainfall changes will vary depending upon location on the planet (IPCC, 2007, 2013). To study the response of the cassava cultivation in these future scenarios, dynamic process-based models, such as the Simanihot (TIRONI, 2016), are suitable tools as they describe the processes that affect the root growth and take into account the effect of CO_2 fertilization and soil water balance.

The objective of this study was to simulate the yield of two cassava cultivars in two future climate scenarios of the IPCC, the SRES-A1B (Cmip3) and RCP4.5 (Cmip5) in the Rio Grande do Sul state, Brazil.

MATERIALS AND METHODS

The Simanihot, version 1.2 <www.ufsm.br/simanihot>, was the cassava model used in this study. It is a dynamic process-based model which calculates the crop growth and development in a daily step, taking into account the effects of water stress and the fertilizing effect of CO_2 on several growth and developmental processes, including tuberous roots (TIRONI, 2016). The Simanihot model was forced by the SRES-A1B scenario (Cmip3) of the 4th IPCC Assessment Report (IPCC, 2007) and the RCP4.5 scenario (Cmip5) of the 5th IPCC Assessment Report (IPCC, 2013). The boundary conditions and CO_2 were from the ECHAM5 global model (ROECKNER, 2005) for the Cmip3 and HadGEM2-ES global model (JONES et al., 2011) for Cmip5. The scenarios were regionalized by dynamic downscaling (HOSTETLER et al., 2011) with the RegCM3 model (Regional Climate Model version 3) for the Cmip3, and with the RegCM4 model (Regional Climate Model version 4) for the Cmip5. The downscaling was for a total of 37 points across the state.

In addition to a previous validation of the Simanihot model by GABRIEL et al. (2014), we also compared observed tuberous roots yield data from field experiments at four locations in the RS State (Santa Maria, Vera Cruz, Rio Pardo and Glorinha) during 12 growing seasons (Figure 1), for two cultivars ('Fepagro-RS13' and 'Estrangeira') in different planting dates, harvesting dates, and plant densities. Yield was calculated with the Simanihot in terms of tons/ha of fresh weight using as the input data the actual meteorological variables recorded at the weather stations of the Instituto Nacional de Meteorologia (INMET) and the meteorological variables of the future scenarios.

The 120-year period for each climate scenario was divided into the baseline period (1980-2009) and three future periods: 2010-2039, 2040-2069 and 2070-2099. Tuberous roots yield (ton/ha of fresh weight) for each period was simulated by running the Simanihot model in both scenarios (Cmip3 and Cmip5) for two cultivars, 'Fepagro-RS13' (grown for forage in the RS) and 'Estrangeira' (one of the most cultivated in the RS and well accepted for consumption) (CARDOSO et al., 2004), in four planting dates (dd/mm): 01/09, 01/10, 01/11 and 01/12. Harvest date was set on 15 June. The Simanihot model was run without water limitation (potential condition) and with the soil water-balance model activated (rain fed condition) using the daily water balance according to THORTHWAITE & MATHER (1955). The potential evapotranspiration (ETo) was calculated using the Penman-Monteith method. The Simanihot software contains a database of soils of the Rio Grande do Sul and the physical properties such as the water content of the soils were calculated for different water tensions, essential for calculating the soil water balance, through a pedotransfer function used in the Hydrus model (SIMUNEK et al., 2013).
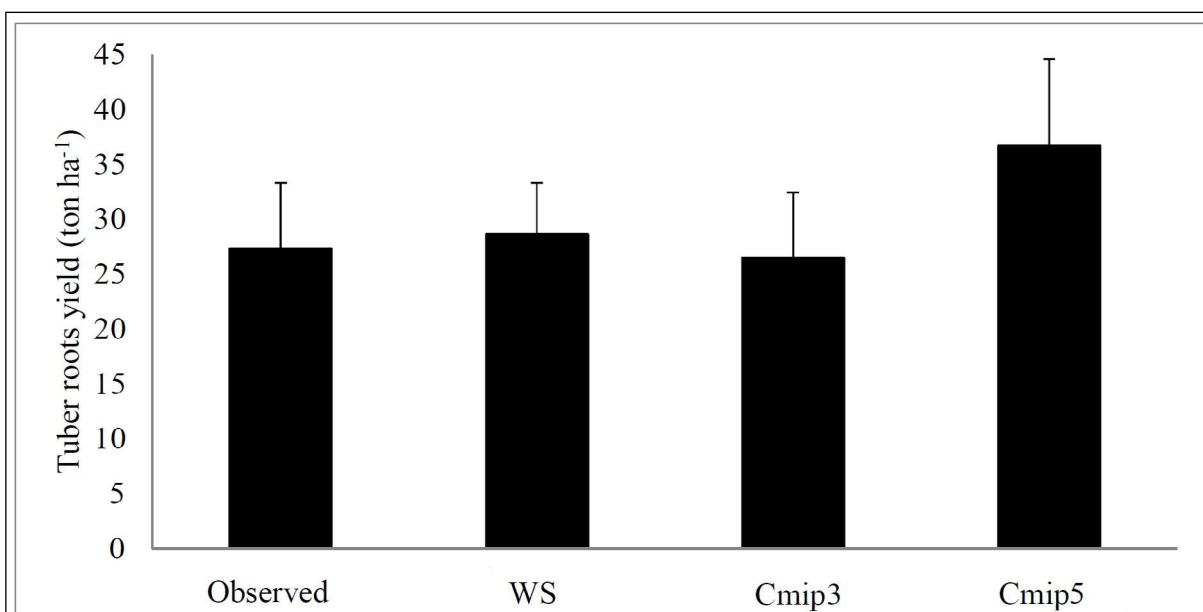
Figure 1 - Tuberous roots yield (in fresh matter) of cassava, cultivars 'Fepagro-RS13' and 'Estrangeira', as observed (Observed) and simulated with the Simanihot model using measured meteorological data from weather stations (WS) and using meteorological data from the Cmip3-A1B and Cmip5-RCP4.5 scenarios as inputs of the cassava model. Each bar is the average of 28 experiments in four locations in Rio Grande do Sul (Santa Maria, Vera Cruz, Rio Pardo and Glorinha) during twelve growing seasons (1999/2000, 2002/2003, 2004/2005, 2005/2006, 2006/2007, 2007/2008, 2008/2009, 2009/2010, 2010/2011, 2011/2012, 2012/2013 e 2013/2014).
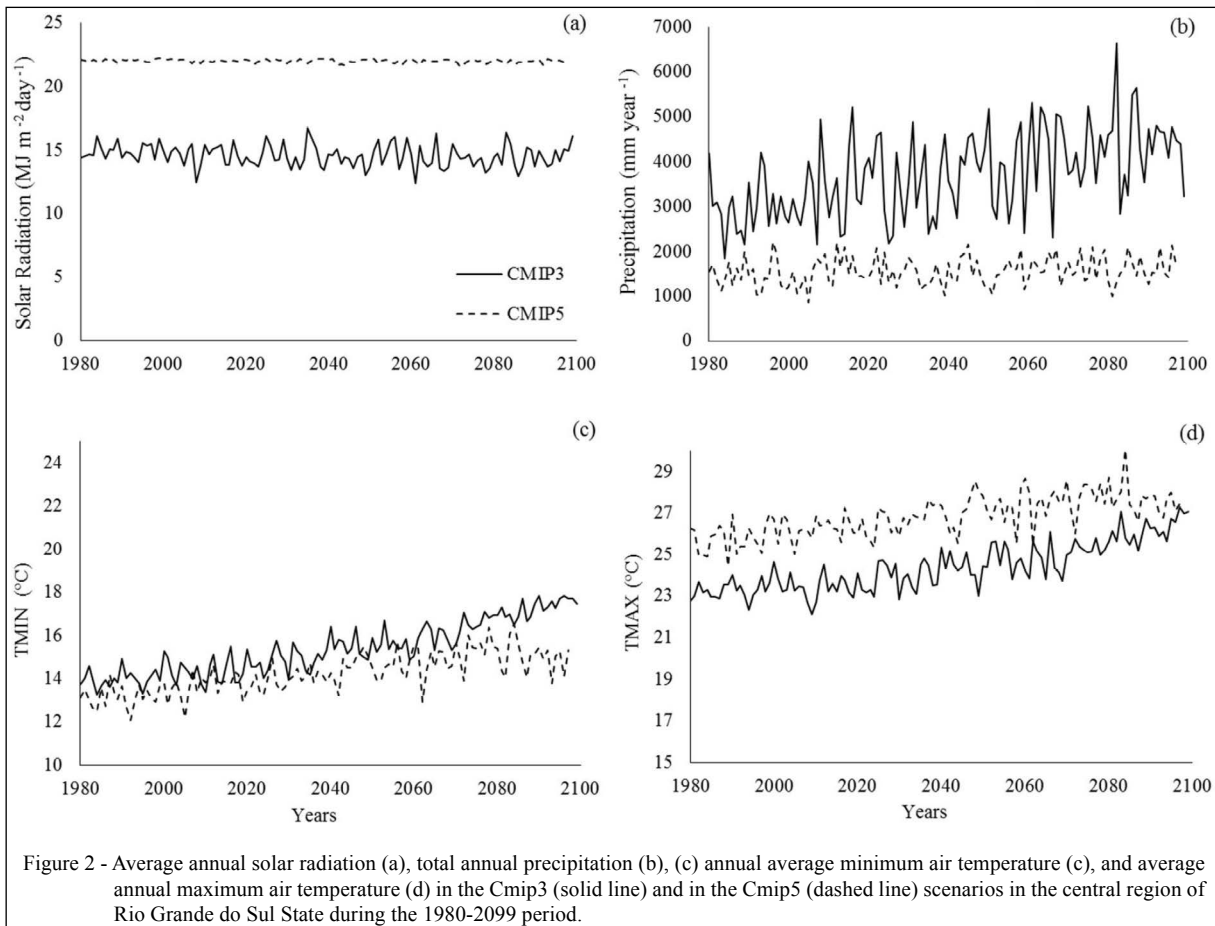
RESULTS AND DISCUSSION

The tuberous roots yield averaged around 8 tons/ha more in the Cmip5 than in the Cmip3 scenario (Figure 1), because of greater solar radiation in the Cmip5 scenario (annual average around 23MJ m^{-2} day^{-1} in the Cmip5 compared to 15MJ m^{-2} day^{-1}, Figure 2A), lower precipitation (accumulated rainfall achieving nearly 5000mm per year in the central region of the state in the Cmip3 scenario compared to 1500mm in the Cmip5 scenario), and a higher inter annual variability of precipitation in the Cmip3 scenario (Figure 2B). Minimum air temperature is similar in both future scenarios up to around 2060, and from then on the increase in minimum air temperature is greater in Cmip3 (Figure 2C). The maximum temperature is higher in Cmip5 except in the eastern part of the state, and overall, the Cmip3 scenario experiences had lower thermal amplitude than does the Cmip5 (Figure 2D).

The tuberous roots yield for the baseline period was higher in the Cmip5 scenario for both cultivars, achieving values greater than 30 tons ha^{-1} for nearly the entire State in the 01/09 and 01/10 planting dates (data not shown). Yields in the baseline period was greater in the northwest part of the state, where air temperature and solar radiation are higher. This is in agreement with currently climatology, where temperature and solar radiation in this region is around 25°C and 26MJ m^{-2} day^{-1} during the summer compared with the northeast region, where they are around 19-20°C and 21-22MJ m^{-2} day^{-1} (MATZENAUER et al., 2011).
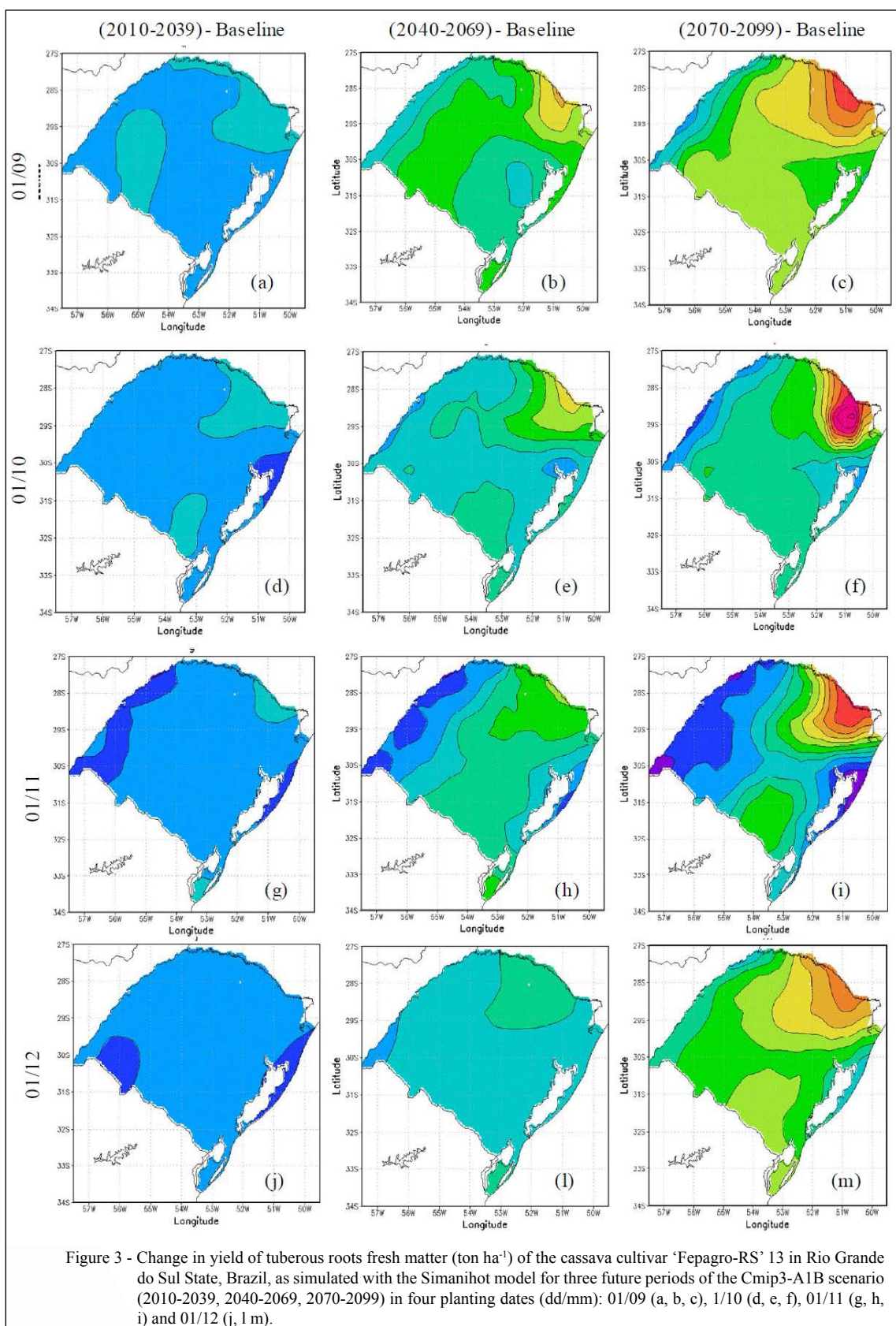
The 'Fepagro-RS13' cultivar in the Cmip3 scenario, for the three future periods (2010-2039, 2040-2069 and 2070-2099), showed higher tuberous roots yield changes in the earlier planting dates (01/09 and 01/10) and in the end of the century (2070-2099). The northeast part of the state, which is normally less productive due to low winter temperatures (6 to 8°C) (MATZENAUER et al., 2011), showed the highest increase in cassava yield (Figure 3) benefiting more from the rise in air temperature and CO_2 concentration. The northwest region of the state revealed the least changes in yield in all the planting dates and during all the three future periods (Figure 3). For the cultivar 'Estrangeira', in this scenario, yield increase was also during the last future period (2070-2099), with a rise of up to 30 tons/ha in the earlier planting dates (01/09 and 01/10) in almost every state (Figure 4).
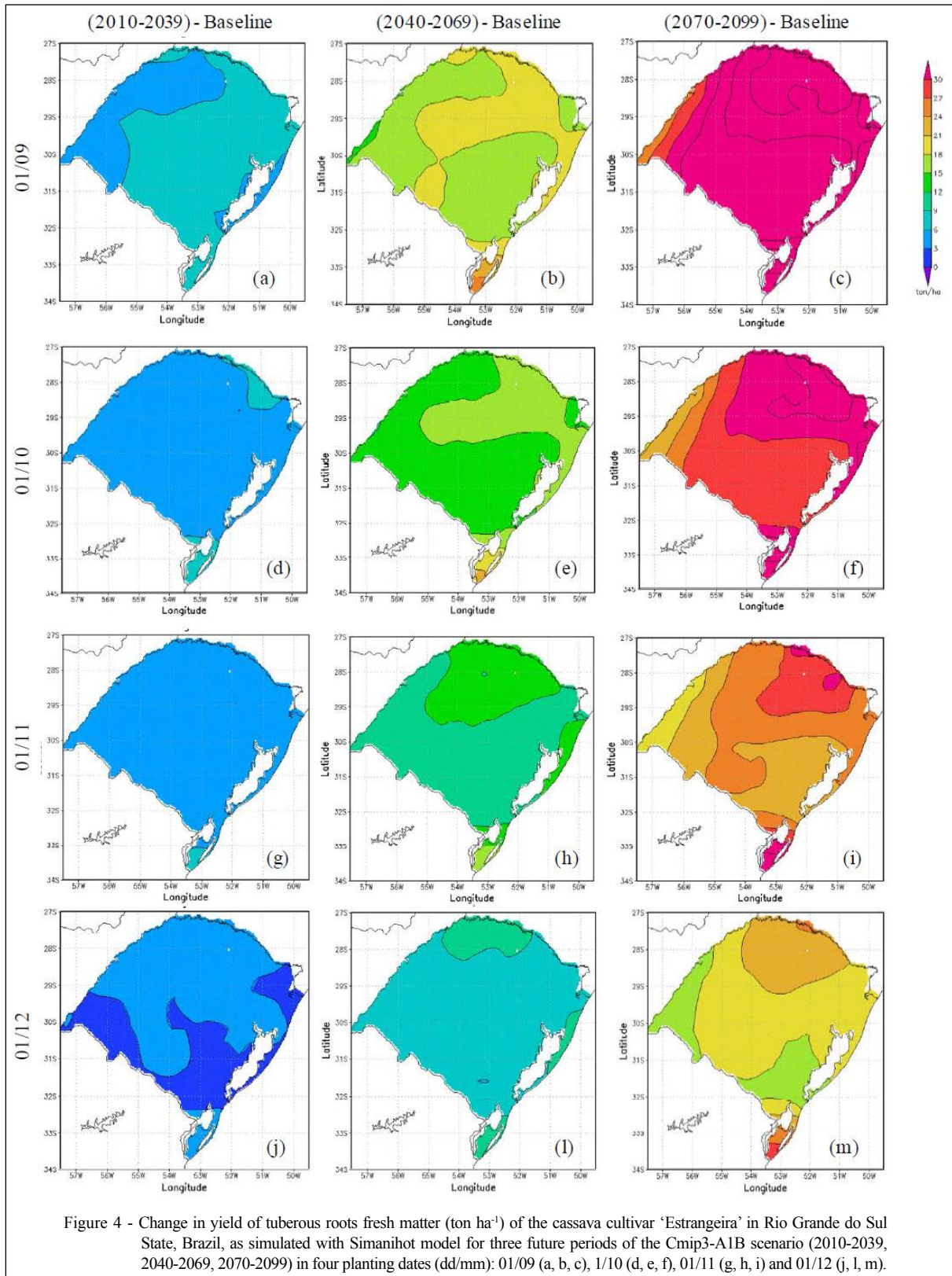
Figure 2 - Average annual solar radiation (a), total annual precipitation (b), (c) annual average minimum air temperature (c), and average annual maximum air temperature (d) in the Cmip3 (solid line) and in the Cmip5 (dashed line) scenarios in the central region of Rio Grande do Sul State during the 1980-2099 period.

The tuberous roots yield changes for the cultivar 'Fepagro-RS13' was higher in the Cmip5 scenario (Figure 5) and lower for the cultivar 'Estrangeira' (Figure 6) during the three future periods (Figures 3 and 4). Elevated temperatures in both scenarios were advantageous to the crop because high temperatures are associated with higher rates of growth and photosynthesis in cassava (EL-SHARKAWY et al., 1992); however, differences in CO_2 concentration between these two scenarios was the main reason for the difference in the results among cultivars. The CO_2 enrichment (Cmip3 scenario) was more advantageous for the cultivar 'Estrangeira' than for the forage cultivar 'Fepagro - RS 13' because in this scenario the forage cultivar increased above ground growth, which resulted in the reduced growth of the tuberous roots. Precipitation did not appear to be a limiting factor for tuberous root growth because the yields simulated without (data not shown) and with the soil

water balance turned on was similar, implying that seasonal water supply was enough.

Previous numerical studies indicated decrease or almost no changes in the cassava yield in future climate scenarios (LOBELL et al., 2008; LIU et al., 2008; SCHLENKER & LOBELL, 2010), varying from -3.7 to 17.5% over the African continent (JARVIS et al., 2012), and increased productivity during the wet seasons in Thailand (CHINVANNO, 2004). Most of these studies were in the tropics, mainly Africa and Thailand, and only a few took into account the influence of CO_2 on cassava yield (CHINVANNO, 2004; LIU et al., 2008). Results of the present study agree with the results from CO_2 field enrichment experiments with cassava (IMAI et al., 1984; ROSENTHAL et al., 2012), that cassava can benefit from raising temperatures in the subtropics, which are currently marginal its growth, because in the future the risk for low air temperatures in these regions is lower (ASSAD & PINTO, 2008).
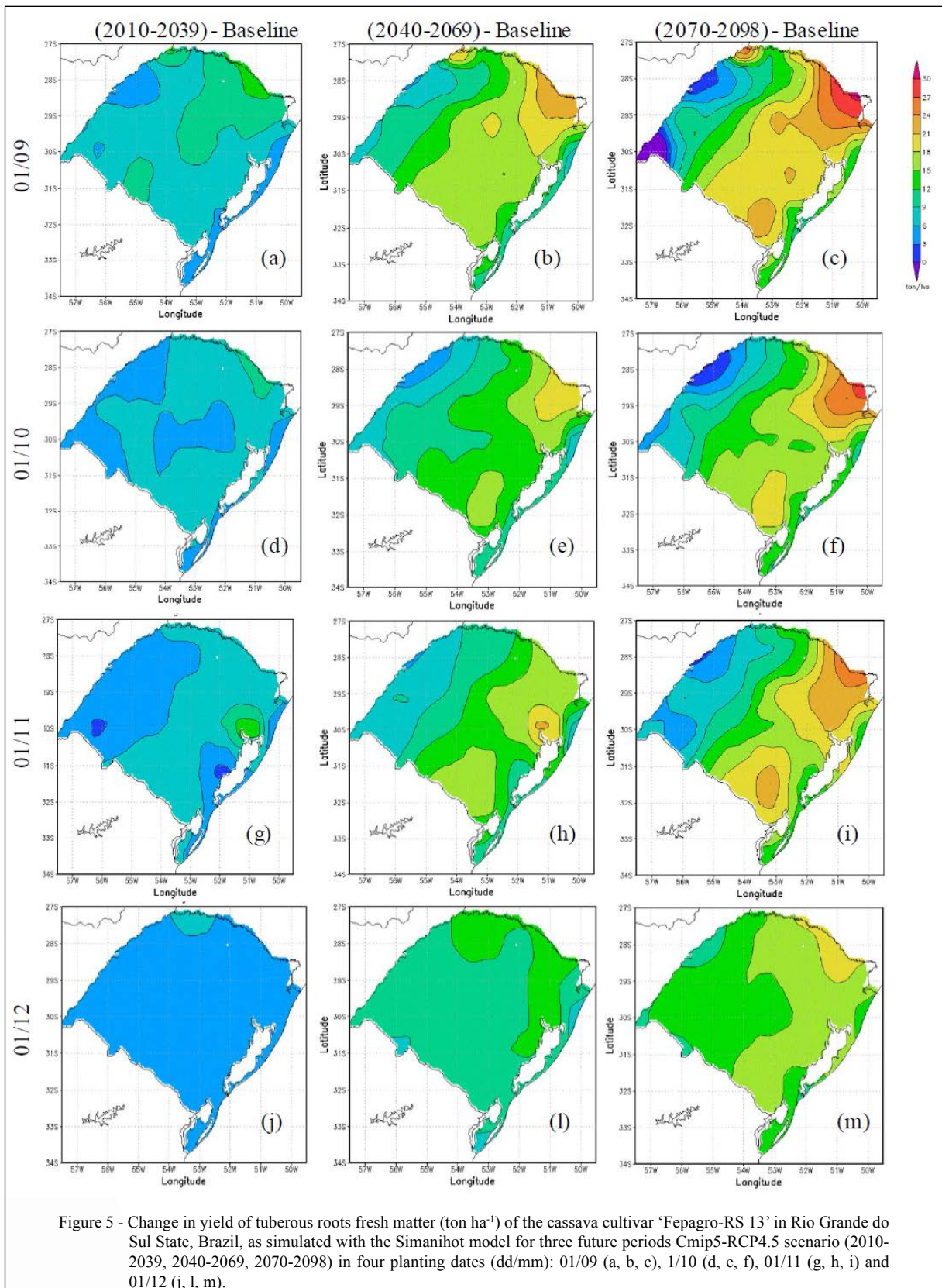
Figure 3 - Change in yield of tuberous roots fresh matter (ton ha^{-1}) of the cassava cultivar 'Fepagro-RS' 13 in Rio Grande do Sul State, Brazil, as simulated with the Simanihot model for three future periods of the Cmip3-A1B scenario (2010-2039, 2040-2069, 2070-2099) in four planting dates (dd/mm): 01/09 (a, b, c), 1/10 (d, e, f), 01/11 (g, h, i) and 01/12 (j, l m).

Figure 4 - Change in yield of tuberous roots fresh matter (ton ha⁻¹) of the cassava cultivar 'Estrangeira' in Rio Grande do Sul State, Brazil, as simulated with Simanihot model for three future periods of the Cmip3-A1B scenario (2010-2039, 2040-2069, 2070-2099) in four planting dates (dd/mm): 01/09 (a, b, c), 1/10 (d, e, f), 01/11 (g, h, i) and 01/12 (j, l, m).

Figure 5 - Change in yield of tuberous roots fresh matter (ton ha⁻¹) of the cassava cultivar 'Fepagro-RS 13' in Rio Grande do Sul State, Brazil, as simulated with the Simanihot model for three future periods Cmip5-RCP4.5 scenario (2010-2039, 2040-2069, 2070-2098) in four planting dates (dd/mm): 01/09 (a, b, c), 1/10 (d, e, f), 01/11 (g, h, i) and 01/12 (j, l, m).

Figure 6 - Change in yield of tuberous roots fresh matter (ton ha^{-1}) of the cassava cultivar 'Estrangeira' in Rio Grande do Sul State, Brazil, as simulated with the Simanihot model for three future periods of the Cmip5-RCP4.5 scenario (2010-2039, 2040-2069, 2070-2098) and four planting dates (dd/mm): 01/09 (a, b, c), 1/10 (d, e, f), 01/11 (g, h, i) and 01/12 (j, l, m).
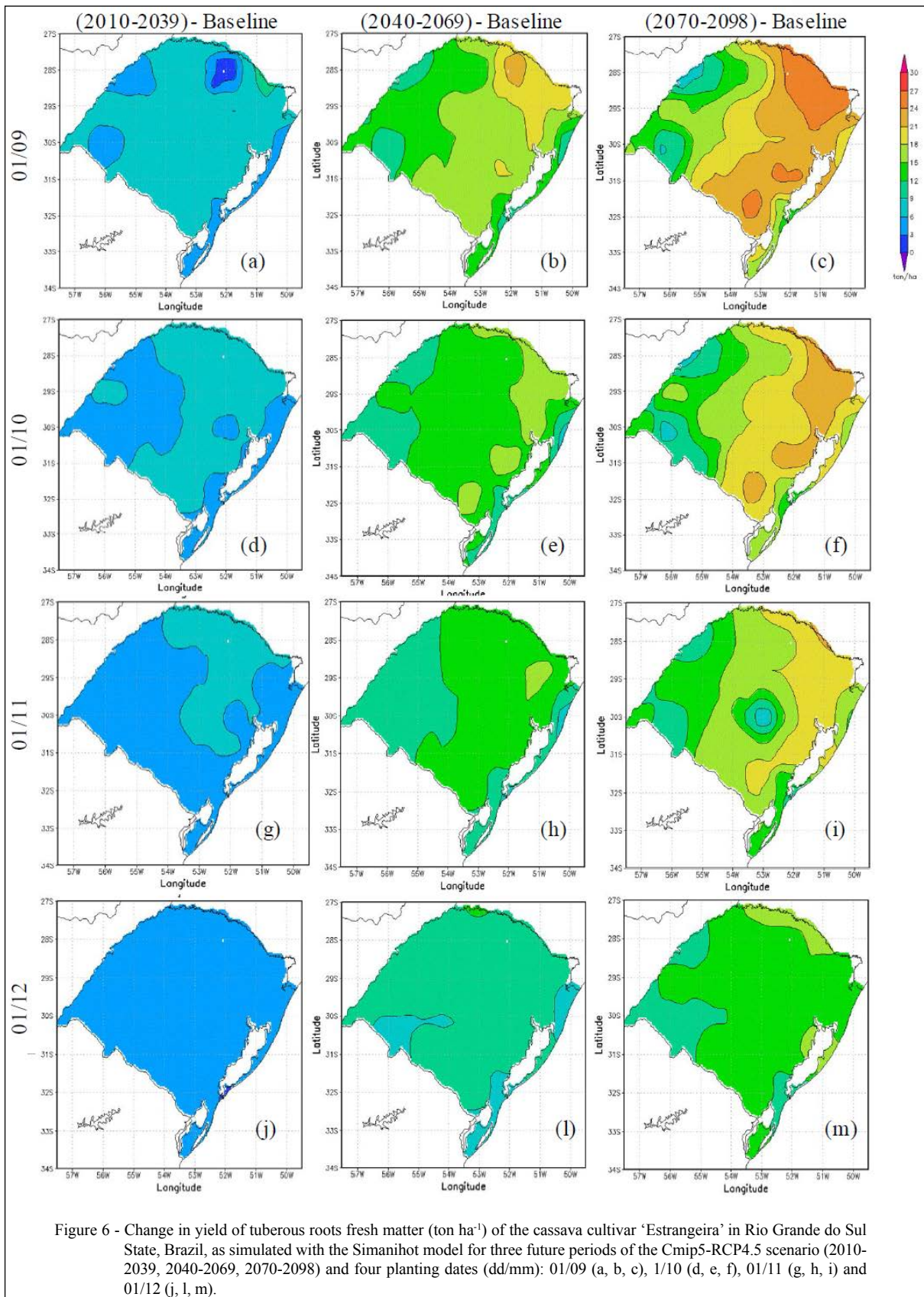
CONCLUSION

Both cassava cultivars (forage and for human consumption) reveal higher tuberous root yield in future climate scenarios. However, while the cultivar for human consumption benefits more in the scenario with the highest CO_2 concentration (Cmip3 scenario), the forage cultivar appears to benefit more in the Cmip5 scenario. The Cmip3 scenario, with its high CO_2 concentration, appears to support increased shoot growth in the forage cultivar. Among the three future periods analyzed, tuberous roots yield changes are higher during the end of the century period (2070-2099) and in the early planting dates (01/09 and 01/10). The Northeastern region of the state has the greatest changes in tuberous roots yield in future climates, because this is the current coldest region, with winter minimum temperature during between 6 and 8°C.

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