Climate change and future scenarios for palisade grass production in the state of São Paulo, Brazil

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Abstract – The objective of this work was to analyze future scenarios for palisade grass yield subjected to climate change for the state of São Paulo, Brazil. An empirical crop model was used to estimate yields, according to growing degree-days adjusted by one drought attenuation factor. Climate data from 1963 to 2009 of 23 meteorological stations were used for current climate conditions. Downscaled outputs of two general circulation models were used to project future climate for the 2013–2040 and 2043–2070 periods, considering two contrasting scenarios of temperature and atmospheric CO_2 concentration increase (high and low). Annual dry matter yield should be from 14 to 42% higher than the current one, depending on the evaluated scenario. Yield variation between seasons (seasonality) and years is expected to increase. The increase of dry matter accumulation will be higher in the rainy season than in the dry season, and this result is more evident for soils with low-water storage capacity. The results varied significantly between regions (<10% to >60%). Despite their higher climate potential, warmer regions will probably have a lower increase in future forage production.

Index terms: *Brachiaria brizantha*, *Urochloa brizantha*, empirical model, ETA, Precis, tropical grass.

Mudanças climáticas e cenários futuros para a produção de capim-marandu no Estado de São Paulo

Resumo – O objetivo deste trabalho foi analisar cenários futuros da produção de forragem de capim-marandu, submetido às mudanças climáticas, no Estado de São Paulo. Utilizou-se um modelo de cultivo empírico para estimar a produção, de acordo com os graus-dia de desenvolvimento ajustados pelo fator de penalização hídrica. Dados climáticos de 23 estações meteorológicas, observados de 1963 a 2009, foram utilizados para caracterizar as condições climáticas atuais. Projeções regionalizadas de dois modelos de circulação global foram utilizadas para projetar o clima futuro, para os períodos de 2013–2040 e 2043–2070, considerando-se dois níveis contrastantes de aumento de temperatura e concentração atmosférica de CO_2 (alto e baixo). A produção anual de matéria seca poderá ser de 14 a 42% superior ao acúmulo atual, a depender do cenário avaliado. A variação do acúmulo deverá aumentar entre estações (sazonalidade) e entre anos. O aumento da taxa de acúmulo de forragem será maior na estação chuvosa do que na seca, e este resultado é mais evidente para solos com baixa capacidade de armazenamento de água. Os resultados variaram significativamente entre as regiões (<10% a >60%). Apesar de seu maior potencial climático, as regiões mais quentes provavelmente terão menor incremento na futura produção de forragem.

Termos para indexação: *Brachiaria brizantha*, *Urochloa brizantha*, modelo empírico, ETA, Precis, gramínea tropical.

Introduction

Changes observed in recent years, associated with more pronounced climate change projections in the future, worry scientists, particularly with regards to the impacts on various sectors of the economy, especially agriculture (Core Writing Team et al., 2007; Smith et al., 2007). The global agricultural production is expected to decrease by 0.5% in the medium term, and 2.3% in the long term, and the distribution of harvested land is supposed to change, which implies on modifications on production and international trade patterns (Calzadilla et al., 2013). In Southeastern Brazil, studies have been performed to evaluate the tendency of past climate time-series variations (Dantas et al., 2007; Horikoshi & Fisch, 2007; Blain, 2010) and of future climate projections, as well as to quantify their impacts on agriculture (Assad et al., 2004; Marin et al., 2013).

Future impacts on the productivity of meat and milk in response to increasing temperatures were forecasted for Latin America by Magrin et al., 2007. In Brazil, climate change will particularly affect livestock productivity. From 1996 to 2006, the total grassland area decreased from 177.7 million to 158.6 million hectares, while in the same period cattle herds increased (Instituto Brasileiro de Geografia e Estatística, 2006). These data confirm the importance of pastures, indicate improvements in their use, and point out to a general area reduction trend, mainly due to environmental pressure and to the advancement of agriculture. The maintenance of many pasture areas will probably depend on the use of technology and increased productivity, seeking a competitive advantage with regards to other activities; or else, it will depend on its relocation to marginal areas, where there are greater edaphoclimatic conditions, which limits forage production. In São Paulo, this trend is pronounced, due to the expansion of sugarcane cultivation which enhances the vulnerability of grasslands to climate change. Cattle in São Paulo state is estimated to represent 11.2 million heads, located in about 8.1 million hectares of pasture, which is about 32.6% of the total state area (Governo do Estado de São Paulo, 2008).

The species of *Urochloa* (Syn. *Brachiaria*), popularly known as palisade grass, is present in about 7.19 million hectares of pasture (about 89% of pasture lands) (São Paulo, 2008). Among the palisade grass species, 'Marandu' [*Urochloa brizantha* (Hochst. ex A. Rich.) Stapf. 'Marandu'] is the most widely cultivated genotype (Miles et al., 2004). Despite the economic importance and the large areas occupied by pastures in the São Paulo state, there are few studies that evaluated forage-related climate risks, and virtually no studies on the potential future effects of climate change over pasture growth and development. In Brazil, the existing zoning works address the implantation phase of pasture (Santos et al., 2012), or focus on aspects of the species climate requirements for growth (Pezzopane et al., 2012). Moreover, methods of climate zoning used for annual crops focus on reproductive development and are not suitable for grazing pastures, where vegetative growth is mainly explored. Grassland-based livestock systems vulnerability to global climate changes was defined as the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes, according to Sautier et al. (2013). The projected forage production, under a range of climate scenarios, is important for the evaluation of the impacts of global climate changes upon pasture-based livestock production systems in Brazil.

The objective of this work was to analyze future scenarios for palisade grass yield subjected to climate change for the state of São Paulo, Brazil.

Materials and Methods

Projections for future climate were created from downscaled outputs of two general circulation models: Providing Regional Climates for Impacts Studies – Precis model –, and ETA-Centro de Previsão do Tempo e Estudos Climáticos - ETA-CPTEC model (Marengo et al., 2009; Pisnichenko & Tarasova, 2010; Chou et al., 2012). Details about the Precis modeling system and the ETA-CPTEC regional model are described in Marengo et al. (2009), Chou et al. (2012), and Marengo et al. (2012). Briefly, Precis modeling system runs the Hardley Centre regional model (HadRM3). The regional climate model (HadRM3P) has 19 vertical levels and was run considering the lateral boundary conditions from the global climate model HadAM3P and a 50 km resolution. The ETA-CPTEC regional model was adapted from the ETA model and allows the integration of any-time periods. Four combinations of boundary conditions from the HadCM3 global model were used. The HadCM3 was run considering a 2.5° latitude x 3.75° longitude resolution provided at a 6-hour frequency. The ETA-CPTEC model nested to the HadCM3 global model had 38 vertical layers and was configured with a 40 km horizontal resolution.

Observed climate data and projections were associated with an empirical model of dry matter accumulation of palisade grass, and the simulation of the current and future yield were obtained. Daily observed data on temperature and rainfall from 23 meteorological stations (12 in the state and 11 in surrounding areas) were used. Just meteorological stations with temperature and rainfall time series longer than 45 years were used in this study.

For each climate model, projections were made for one present (1963 to 2009) and two future scenarios (2013 to 2040, and 2043 to 2070). Pessimist and optimistic scenarios were evaluated for each model and period. For Precis modeling system, future scenarios were based on A2 (pessimist scenario, high) and B2 (optimist scenario, low) scenarios described on the Special Report on Emissions Scenarios (Marengo et al., 2009). For the ETA-CPTEC model, future scenarios were based on A1B scenario described on the Special Report on Emissions Scenarios and were selected to represent results which displayed high (pessimist scenario, high) and low (optimist scenario, low) sensitivity in global mean temperature response (Chou et al., 2012; Marengo et al., 2012).

Mean temperatures and rainfall for three intervals of 30 years were projected as follows: reference, Precis and ETA references (1961–1990); and two future projections, Precis and ETA 2025 (2011–2040), and Precis and ETA 2050 (2041–2070). From the projected means, the temperature differences between the reference and future periods were calculated as: $\Delta T2025 = ETA_{2025} - ETA_{reference}$, and $Precis_{2025} - Precis_{reference}$; $\Delta T2050 = ETA_{2050} - ETA_{reference}$, and $Precis_{2050} - Precis_{reference}$. Variation fractions were also calculated for mean precipitation in the future and reference projections as: $\Delta P2025 = ETA_{2025}/ETA_{reference}$, and $Precis_{2025}/Precis_{reference}$; $\Delta P2050 = ETA_{2050}/ETA_{reference}$, and $Precis_{2050}/PrecisS_{reference}$. The ΔT values were added to the observed temperature series (data from meteorological stations) to calculate future temperatures, and the ΔP values were multiplied by the observed precipitations to calculate future precipitations. To eliminate operational errors, the initial years of the future series (2011, 2012, 2041, and 2042) were disregarded. For current yield calculations, the observed data from 1963 to 2009 were used.

The empirical crop model used was the univariate linear equation, adapted from Cruz et al. (2011), with the growing degree-days adjusted by one drought attenuation factor ($GDD_{adjusted}$) as forage accumulation estimator (equation 1). The drought attenuation factor was the current moisture/maximum storage capacity of the soil ($MOI_{current}/MOI_{max}$), based on the water balance calculated according to Thornthwaite & Mather (1955), considering three maximum storage capacities (“three soil types”): 40, 60, and 100 mm. The basal temperature of 17.2°C was used to calculate the GGD as $DMAR = 15.34 \times GDD_{adjusted}$, in which: DMAR is the dry matter accumulation rate (kg ha^{-1} dry matter per day); and $GDD_{adjusted}$ is the growing degree-days adjusted for drought attenuation factor (°C). The intercept was not significant at 5% ($p = 0.056$) and was considered = 0, therefore the equation and coefficient of determination were redefined (equation above is already adjusted, $p<0.0001$, $R^2=0.95$).

The crop model was obtained by Cruz et al. (2011), under the conditions of the experimental area of Embrapa Pecuária Sudeste (21°57'S, 47°51'W), São Carlos, SP, Brazil, in 2009 and 2010, which were: Cwa climate (Köppen classification), Xanthic Hapludox, range mean temperature between 16.8 and 27.1°C, mean solar radiation of 17.9 MJ m^{-2} (minimum of 12.7 MJ m^{-2} in June, and maximum of 21.8 MJ m^{-2} in November 2009), and annual fertilization with 300 kg ha^{-1} of N and K_2O. Cutting frequency was of 35 days with 25 cm residue.

Mean and third quartiles ($Q_{3/4}$) were used as location measures. Standard error of the mean was calculated as a measure of dispersion. Time series of annual forage accumulation were created using data from 1963 to 2070, excluding 2010, 2011, 2012, 2041, and 2042. Analyses of variance of the annual forage accumulation rate (dependent variable) were performed in accordance with the years (independent variable) and, when significant, the angular coefficient, intercept, and coefficient of determination were tested. These analyses were performed using the R software, version 12.15.0 (R Foundation for Statistical Computing, Vienna, Austria). Maps were obtained by the natural neighbor method, from the spatial interpolation of the average data with the ArcGIS Software version 10.1 (Esri Headquarters, Redlands, CA, USA), using the spatial analyst tools / interpolation / natural neighbor tool.

Results and Discussion

The projections indicate an increased accumulation of annual forage of palisade grass, in the future, for São Paulo state (Table 1). The estimated accumulation based on climate data projected by the Precis model is higher than that of the ETA-CPTEC model, mainly in the high-scenario. In both models, the increase is also more pronounced from 2043 to 2070 than from 2013 to 2040, and more pronounced still in the high-scenarios than in the low ones. The projected accumulation increase is a direct reflection of temperature increase. However, increased heat causes greater evapotranspiration potential and, thus, even without rainfalls, there is a future trend of reduced soil-water availability (Assad et al., 2004; Tubiello et al., 2007).

The mean annual temperature increase projected for the state was of 2 to 3°C, considering the high-scenario and the period from 2041 to 2070. Scenarios and intermediary periods result in proportionally smaller increases. The two used climate models have similar temperature projections results, although the ETA-CPTEC model simulates a slightly higher increase for spring-summer. Precipitation projections have lower confidence levels, and the models show diverging results, which are similar to those reported in studies using regional models (Marengo et al., 2010). The ETA-CPTEC model showed higher temporal and spatial variation.

Considering the high-emission scenario and the period from 2041 to 2070, the Precis model projects a positive precipitation change of about +15 to +25% from January to April and unchanged values in the rest of the year. However, the ETA-CPTEC model projects negative precipitation changes of about -15 to -25% from January to April, unchanged values from May to August, and pronounced negative changes from September to December (from -20 to -35%). This projected rainfall reduction in the ETA-CPTEC model explains the lower yields of palisade grass in comparison to the Precis model, considering the highest temperature simulated by ETA-CPTEC. Thus, the highest water deficit counteracts the effect of the sharp temperature rise on the ETA-CPTEC model.

The average forage accumulation based on simulated data by the Precis model were 17, 28, 26, and 42% higher than the simulated accumulation with the observed data (current), considering, respectively, the scenarios low/2013–2040, low/2043–2070, high/2013–2040, and high/2043–2070. In the same order of scenarios, simulations with the ETA-CPTEC model resulted in higher average accumulation of 14, 29, 19, and 36%. Data variations in the third quartiles were similar to the means.

The crop model used to estimate the yield only considers temperature and precipitation factors (Cruz et al., 2011). Similar studies for tropical forages are scarce, and other factors, especially the atmospheric CO_2 increase, should also be taken into consideration in this analysis. Xu et al. (2013) highlighted the strong evidence for enhanced water-stressed C_4 plants growth by an elevated CO_2 concentration [CO_2]. The vulnerability of tropical grassland-based animal production systems to climate changes would be better accessed by the use of mechanistic models. Although some mechanistic models have been parameterized for tropical forages (Pedreira et al., 2011; Lara et al., 2012; Araujo et al., 2013), parameters related to CO_2 effects on plant processes have not been adjusted yet. The refinement of the simulations, including more factors, especially the [CO_2], requires further experimentation.

Additionally, the variation in crop yields, estimated for the future by a mechanistic model, have a similar pattern to that estimated for sugarcane in São Paulo (Marin et al., 2013). Marin et al. (2013) predicted a mean increase 22% for the yield of fresh stem weight (Mg ha^{-1}) of sugarcane for the future (2010 to 2100), considering A2 and B2 scenarios described on the Special Report on Emissions Scenarios. Despite the use of the empirical model in the present work, the

Table 1. Mean±standard error and third quartile of the annual forage accumulation of palisade grass (*Urochloa brizantha* 'Marandu') simulated with observed data and future climate projections, using Precis and ETA-CPTEC models, in scenarios for the state of São Paulo, Brazil[(1)].

Simulation[(2)]	BL	Precis model				ETA-CPTEC model			
		Low/25	Low/55	High/25	High/55	Low/25	Low/55	High/25	High/55
				Mean (Mg ha^{-1} dry matter per year)					
Moi 40	18.4±0.18	21.6±0.27	23.7±0.29	23.2±0.28	26.3±0.30	21.1±0.26	23.8±0.28	21.8±0.26	25.0±0.29
Moi 60	19.6±0.18	22.9±0.28	25.1±0.30	24.6±(0.29	27.9±0.32	22.4±0.27	25.3±0.29	23.2±0.27	26.6±0.30
Moi 100	21.0±0.19	24.5±0.29	26.9±0.31	26.3±0.31	29.8±0.33	24.0±0.28	27.2±0.31	25.0±0.29	28.7±0.32
				Third quartile (Mg ha^{-1} dry matter per year)					
Moi 40	22.3	26.6	28.9	28.2	31.9	25.5	28.6	26.2	29.4
Moi 60	23.7	27.7	30.4	29.6	33.4	27.1	30.3	28.0	31.8
Moi 100	25.6	29.6	32.4	31.6	35.6	29.0	32.7	30.4	34.1

[(1)]Low and high, low- and high- greenhouse gas emission scenarios; 25, 2013-2040 period; 55, 2043-2070 period. [(2)]Moi 40, 60, and 100 correspond to soil-moisture storage capacity of 40, 60, and 100 mm, respectively (simulated "soil types").

results corroborate the work performed for sugarcane, since the mass yield increases ranged from 10 to over 50%, averaging between 30 to 40% depending on the performed simulation. Studies of sugarcane are useful in this comparison, as these plants have also C4 photosynthetic metabolism, and their vegetative shoots are economically explored.

It is believed that with increasing temperature and [CO_2], C4 plant metabolism, such as palisade grass, will have a similar response to that of sugarcane. Several direct and indirect effects of climate change are related to meteorological and physiological aspects of sugarcane by the DSSAT/Canegro mechanistic model (Marin et al., 2013). According to these authors, the increase of +3°C increased the potential evapotranspiration to 7.8 and 10.5% in the conditions of Piracicaba and Ilha Solteira, in São Paulo state, which have mean annual temperatures of 21.6 and 25.6°C, and annual rainfall of 1,230 and 1,156 mm, respectively. However, this increased potential does not necessarily translate into increased water consumption, given that the 750 ppm increase of [CO_2], for instance, reduced the transpiration by 11 and 10.5% and the actual crop evapotranspiration by 9.1 and 8.9%, and related the pronounced reduction of stomatal conductance of C4 plants.

Assessments of possible climate change impacts on temperate pastures have been performed for more than 20 years (Baars et al., 1990). Despite the comparative limitation due to difference on photosynthetic process of both tropical and temperate forage grasses, the results have a similar response pattern. Most studies point out predominantly to an yield increase (from 5 to more than 50%) (Baars et al., 1990; Zhang et al., 2007), but in scenarios with increased water deficit, yield can be reduced (Zhang et al., 2007).

The effect of fertilization should also be carefully considered in the interpretation of results from the present experiment, given it has a considerable impact on forage accumulation (Cecato et al., 2000). Thus, it is presupposed that forage accumulation estimated by the models for different scenarios will be obtained with similar fertilizer applications. Although a lower dose of fertilization is common, evaluations under these conditions cause responses to climate change to be limited by nutrients, which characterizes an interaction. Thus, fixing the fertilizer facilitates and allows focusing on the main analysis, which is the effect of climate change. Studies using mechanistic models refine the predictions considering these factors simultaneously.

Despite the overall forage accumulation increase, the yield variation will increase between years (Figure 1) and between seasons by the two climate

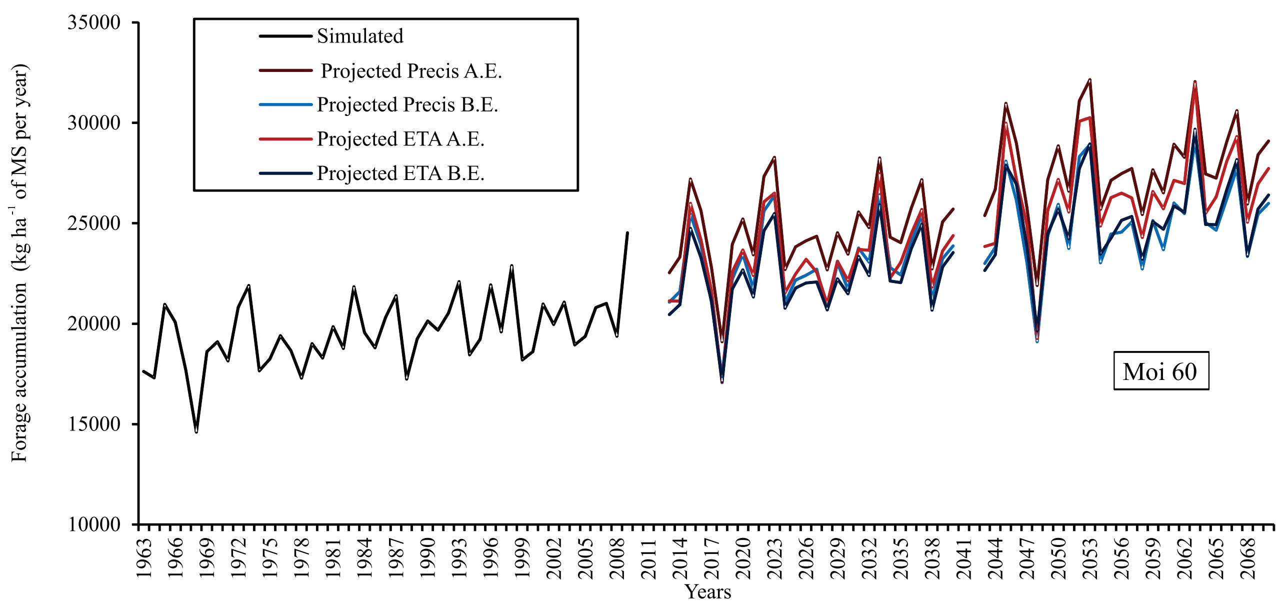

Figure 1. Mean annual forage accumulation of palisade grass (*Urochloa brizantha* 'Marandu') from 1963 to 2067 simulated for the state of São Paulo, Brazil, based on observed data (stations) and projected by the Precis and ETA-CPTEC models. High and low, high- and low-greenhouse gas emissions. Moi 60, soil-water storage capacity of 60 mm.

models (Figure 2). The base line means had a standard error from 0.18 to 0.19 Mg ha^{-1} dry matter per year, which were lower than the standard error of the mean projections, which ranged from 0.26 to 0.33 Mg ha^{-1} dry matter per year (Table 1), indicating higher forage yield variations between years and locations for São Paulo state, in the future, which is due to increased climatic oscillations.

The absolute increase in DMAR (kg DM ha^{-1} per day) will be higher in warm and humid periods (spring and summer seasons) than in cold and dry periods of year (autumn and winter seasons), enhancing an unequal annual yield pattern, which is well known by the productive system (seasonality). However, the increase in percentage will be higher in winter than in summer, in the simulations with data from the Precis model, whereas in the ETA-CPTEC model, the DMAR increase will be higher in the summer than in the winter. These differences between climate models are due to differences in rainfall, mainly in spring and summer (in ETA-CPTEC simulations, this seasons are drier than in Precis simulations).

Considering the Precis model, there will be an average increase in DMAR of 11.6 and 31.7 kg DM ha^{-1} per day compared to the base line, which represents a mean increase of 58.7 and 32.2% in the year's least and most productive month, respectively. However, considering the ETA-CPTEC in the same scenario, the mean increase in DMAR will be of 4.3 and 31.4 kg ha^{-1} DM per day, which represents an increase of 21.5 and 32.0% for the year's least and most productive month, respectively.

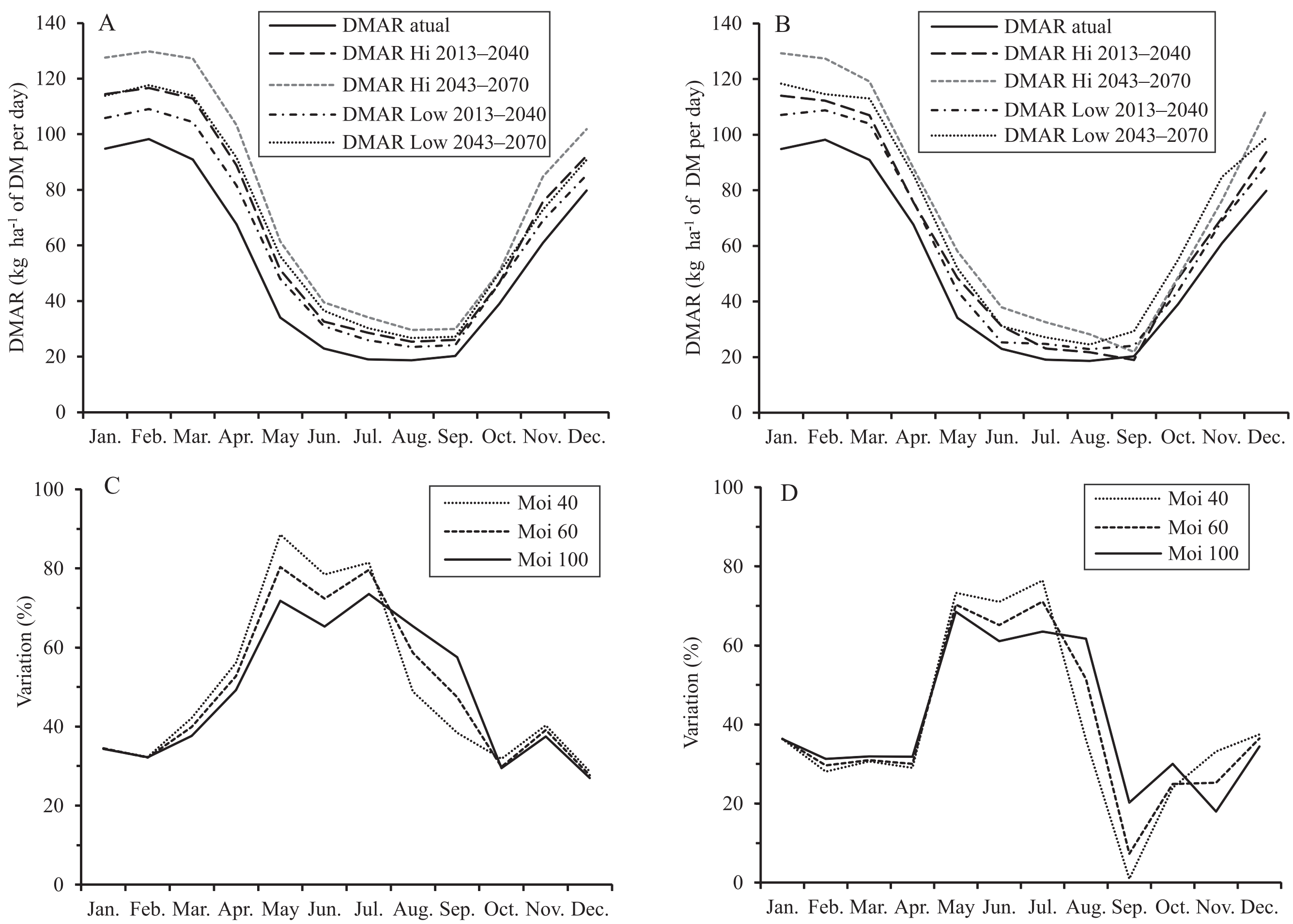

Figure 2. Dry matter accumulate rate (DMAR) of palisade grass (*Urochloa brizantha* 'Marandu'), considering Moi 60, according to projections of the climate models Precis (A) and ETA-CPTEC (B), for the state of São Paulo, Brazil. Future variation (%) related to the current climate, considering: Precis (C) and ETA-CPTEC (D) models. High and low, high- and low-greenhouse gas emissions; Moi 40, 60, and 100 represent soil-water storage capacity of 40, 60, and 100 mm.

The simulations based on the Precis model, high-scenario and 2043–2070 period, indicate mean increases of 39.8, 72.0 and 36.2% in forage yield, in comparison to the base line for the following periods: January to April; May to August; and September to December, respectively. According to the ETA-CPTEC model, average increases will be respectively of 31.9, 64.1 and 24.4%. The increase is more pronounced from May to August for soils with lower water storage capacity (sandy soils), in comparison to soils with higher capacities (clayey soils). A reversed situation occurs from September to December, when soils with lower capacities indicate a small increase, especially for projections of the ETA model, and the increment is close to zero (Figure 1).

Changes on forage production seasonality reflect climate and plant characteristics. Except for the spring, the simultaneous effect of temperature and evapotranspiration increase affected positively the potential yield because, in the rainy season, moisture is excessive and, in the dry season, yields are already low. In the spring, the reduced soil-water availability suppressed (or even nullified) the thermal effect.

Sautier et al. (2013) studied the vulnerability of grassland-base livestock systems to climate changes in South-Western France, and also predicted changes in seasonal boundaries, herbage production, and production gaps between seasons with almost no impact on annual herbage production. Vulnerability of grassland-based livestock systems should not be accessed just by mean annual forage production, as variation between seasons and between years increases the system sensitivity. Besides, climate impacts over grassland-based livestock systems depend on the strategies of animal and pasture management (Lurette et al., 2013).

Annual forage yield zoning predominantly followed the normal temperature in São Paulo state (Figure 3). Considering soils with water storage capacity of 40, 60 and 100 mm, yield ranged respectively from 5,448 to 24,858, 5,585 to 25,886, and 5,739 to 28,418 Mg ha^{-1} dry matter per year. The accumulation variation (%) for 2043 to 2070 clearly showed a response pattern. Change was more positive for colder regions with lower climatic yield potentials. The absolute difference was between -3.4 and +113.7% and occurred with ETA-CPTEC outputs. The lowest extreme (-3.4%) occurred in the Frutal, MG – at 20°S, 49°W, 546 m altitude, a region next to the Triângulo Mineiro region –, in the high-scenario for 40 mm soil-water storage capacity. The highest extreme (+113.7%) occurred in Campos do Jordão, SP – at 23°S, 46°W, 1,661 m altitude, in Vale do Paraíba Paulista region – in the high-scenario for 100 mm soil-water storage capacity. The results from the Precis model were more stable, and the variation ranged between +9.5 and +75.4% for Frutal, MG (high emission scenario for 100 mm soil-water holding capacity), and Caldas, MG (22°S,

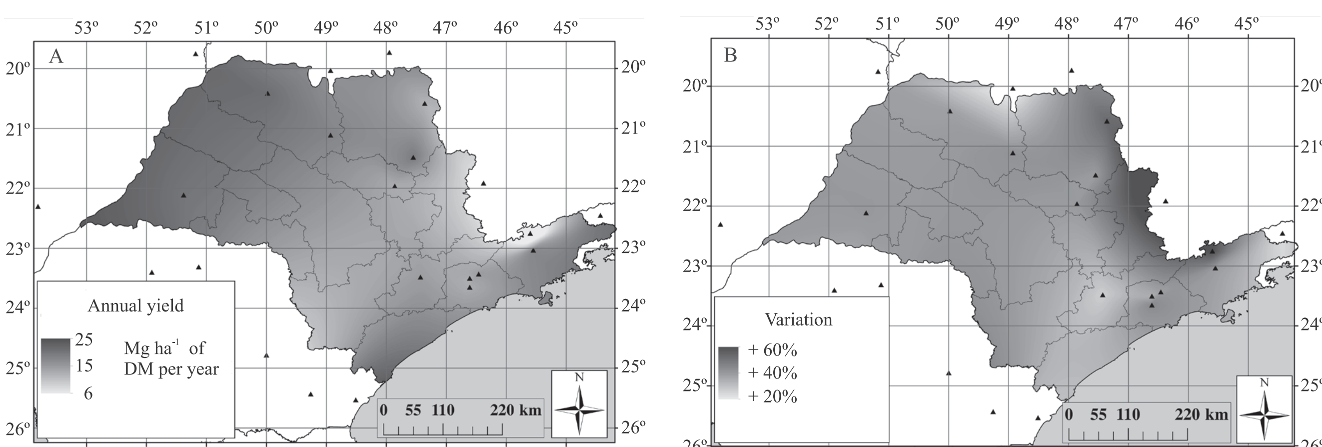

Figure 3. Current annual climatic potential yields (A) of palisade grass (*Urochloa brizantha* 'Marandu') and future annual medium variations (B) based on climate projections of the Precis model (high emissions scenario of greenhouse gases for 2043-2070), considering soil-water storage capacity of 60 mm. ▲, meteorological stations.

46°W, 1,080 m altitude) stations (low emission scenario for 100 mm soil water holding capacity), respectively.

Livestock production is concentrated in the southwest of São Paulo, including Presidente Prudente, Araçatuba, Marília, Bauru, and Itapetininga regions, which have about 4 million ha of pastures (approximately 50% of the pastures are in São Paulo state, according to Governo do Estado de São Paulo (2008). In these regions, pastures are the most important culture for occupied area (more than 40% of total farm areas), with the highest bovine density – more than 60 bovines km^{-2} (Instituto Brasileiro de Geografia e Estatística, 2006). Around 40% increase on annual forage production is expected in these areas, due to climate changes, considering that no other factor limits plant growth, as soil fertility and pasture management.

Despite the expected positive effect of climate change on annual forage production on these areas, the increased variation on forage production between seasons may limit the animal production. Thus, efforts for forage conservation between seasons, better control of the relationship between feed demand and feed production (production planning, cattle buying, and selling etc.), and adequate pasture management (fertilization, grazing control, irrigation etc.) will be increasingly important for maintaining or enhancing animal production.

Conclusions

1. Climate change will affect, in a predominantly positive condition, forage yields of palisade grass (*Urochloa brizantha* 'Marandu') in São Paulo state, Brazil.
2. The absolute forage accumulation increase will be higher in summer than in winter, enhancing yield seasonality.
3. Adverse effects will occur in the spring, due to increased water restriction, which will be more pronounced in soils with lower water storage capacity.
4. Colder locations, particularly higher altitude regions (next to the extreme south of Minas Gerais), tend to have a sounder relative yield increase.

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