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Edited by:
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CP: 037, CEP: 37200000
E-mail: nefor@ufla.br

Using mathematical models to simulate growth and future scenarios of tropical grasslands

Patricia Menezes Santos[1], José Ricardo Macedo Pezzopane[1], Tales de Assis Pedroso[1], Cristiam Bosi[4,6], Caroline Galharte[1,6], André Santa de Andrade[2], Bruno Pedreira[3], Fábio Marin[4]

Introduction

Global temperature may increase by up to 4.8°C until 2100, according to predictions from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2013). According to Calzadilla et al. (2013), global agricultural production is expected to decrease by 0.5% in the medium and 2.3% in the long term. Besides that, the distribution of harvested land is expected to change, implying modifications on production and international trade patterns (Calzadilla et al., 2013).

In Brazil, global climatic changes are supposed to influence agriculture, which is responsible for 22% of the Brazilian gross national product (CEPEA, 2013). Adaptation of production systems and mitigation of greenhouse gas emissions are the main challenges imposed by global climate changes to agriculture.

Beef and milk production in Brazil, mainly pasture-based (ABIEC, 2011; ASSIS, 2005), occupies near 160 million ha and represent 48% of the agricultural area (IBGE, 2006). Cultivated tropical grasslands represent more than 60% of the total pasture area and are located mainly in the North, Southeast, and Central west regions of Brazil (IBGE, 2006). Most of the pasture area is cultivated without irrigation, and that increases the potential effect of weather conditions on forage production.

Climatic risks associated with agriculture production may be assessed through crop growth modelling in association with geographic information

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[1] Embrapa Pecuária Sudeste
[2] Faculdade Cidade de Coromandel
[3] Embrapa Agrossilvipastoril
[4] Departamento de Engenharia de Biossistemas, Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo
[5] Bolsista de doutorado da Fapesp
[6] Bolsista de pós-doutorado do CNPq

systems, which are the bases of agro-climatic zoning methods. Based on these methods, it is possible to quantify climatic suitability for such species/crop growth and advise farmers and decision makers. The aim of this chapter is to describe some modelling approaches used to simulate plant growth and future scenarios of tropical grasslands in Brazil.

Empirical models

Empirical models, also called correlative or statistical models (Dourado-Neto et al., 1998), are usually designed to quantify the correlation between crop production with one or more variables such as temperature, radiation, water availability and nutrients, especially nitrogen. Empirical models are simple to develop and easy to apply. They are, however, more prone to error and are limited to the range of conditions under which they were calibrated (DOURADO-NETO et al., 1998).

Regression analysis is the most commonly used technique to generate empirical models to estimate crop production (dependent variable) as a function of environmental factors (independent variables). Empirical models are often also based on other derivative variables such as (i) Growing degree-days (GDD); (ii) Photothermal Units (PU) (Villa Nova et al., 1999), which considers GDD and daylength, and; (iii) Climatic Growth Index (CGI) (Fitzpatrick and Nix, 1973), which takes into account the solar global radiation (Rg), a thermal growth index and a drought attenuation factor.

Some of the empirical models already developed for tropical grasses have good predictive capability and are easy to apply because the input variables, especially temperature, are often easy to obtain in most tropical regions (Table 1). The major limitation of these studies is their geographic concentration, especially in southeastern Brazil and in the southeastern United States, which limits the range of environments (climatic conditions) represented.

Table 1. Univariate linear empirical models correlating dry matter production

Grass	Variable	Slope	Inter-cept	R^2	Reference
B. brizanta cv. Marandu	Tmin	11.93	-134.95	0.73	Cruz et al. (2011)
B. brizanta cv. Marandu	Tmin_{corr}	5.78	-17.24	0.75	Cruz et al. (2011)
B. brizanta cv. Marandu	GDD_{corr}*	12.9	6.52	0.75	Cruz et al. (2011)
Brachiaria Group 1[§]	Tmin	8.19	-94.92	0.55 to 0.5	Tonato et al. (2010)
Brachiaria Group 2[¶]	Tmin	10.66	-128.07	0.55 to 0.6	Tonato et al. (2010)
Cynodon Group 1[†]	Tmin	9.06	-84.69	0.6 to 0.7	Tonato et al. (2010)
Cynodon Group 2[§§]	Tmin	7.97	-67.01	0.6 to 0.7	Tonato et al. (2010)
Panicum Group1[¶¶]	Tmin	6.36	-55.22	<0.4	Tonato et al. (2010)
Panicum Group 2[††]	Tmin	5.93	-29.15	<0.4	Tonato et al. (2010)
P. maximum cv. Mombaça	ΣUF	0.226	600.01	0.86	Araujo et al. (2013)
P. maximum cv. Mombaça	ΣICC	368.14	-311.94	0.83	Araujo et al. (2013)
P. maximum cv. Mombaça	ΣGDD	11.52	-304.8	0.78	Araujo et al. (2013)
P. maximum cv. Tanzânia	AET	34.73	-21.58	0.87	Pezzopane et al. (2012)
P. maximum cv. Tanzânia	GDD_{corr}*	18.80	-17.02	0.84	Pezzopane et al. (2012)
P. maximum cv. Tanzânia	GDD_{corr}**	18.90	-6.38	0.87	Pezzopane et al. (2012)
P. maximum cv. Tanzânia	CGI	330.09	-12.88	0.84	Pezzopane et al. (2012)

[§]Marandu, Basilisk and Arapoty; [¶]Capiporã and Xaraés; [†]Tifton 85 and Estrela; [§§]Coastcross, Florico and Florona; [¶¶]Atlas and Mombaça;[††]Tanzânia and Tobiatã; Tmin_{corr}=Minimum temperature corrected by a drought attenuation factor; GDD_{corr}= Growing Degree-Days (calculated based on Tb) corrected by a water penalty factor: *by the AET/PET ratio and **by the current/maximum soil Storage ratio; CGI= daily climatic growth index; ΣUF=sum of daily photothermal units; ΣICC=sum of CGI; ΣGD=sum of degree-days. Note.: *i)* The response variable (y) is the forage accumulation rate (kg DM/ha/day), except for the models of Araujo (2011), which were generated with the daily sums of the entire cycle, hence the response variable (y) is the total forage mass in each cycle. *ii)* The temperature values are given in degrees Celsius (°C).

Empirical agrometeorological models may be used to investigate the possible impacts of climate change on forage production. Andrade et al. (2014) used an empirical models, considering the sum of degree days corrected by a water availability index (ARM index), to evaluate the effects of regional climatic trends on *Brachiaria brizantha* cv. Marandu (CRUZ et al., 2011). The ARM index was calculated by the ratio between actual soil water store and soil water holding capacity, estimated by the climatological water balance (Thornthwaite and Mather, 1955) for three soil water holding capacities: 40, 60, and 100 mm. Climatological water balance was calculated based on potential evapotranspiration, estimated as described by Thornthwaite (1948), and real evapotranspiration, estimated by the 5-day sequential climatological water balance. Data from Brazilian weather stations from 1963 to 2009 were considered as current climate (baseline), and future scenarios, considering contrasting scenarios in terms of temperature and atmospheric CO_2 concentrations increase (high and low), were determined for 2013 to 2040 (2025 scenario) and for 2043 to 2070

(2055 scenario) using both PRECIS modelling system and ETA-CPTEC regional model (MARENGO, 2007; MARENGO et al., 2009; CHOU et al., 2012 and MARENGO et al., 2012). Future forage production scenarios were compared with actual forage production scenarios (baseline). Spatial interpolation of predicted annual forage production and of estimated percentage of change in annual forage production for each future climate scenario was carried out using kriging methods, with ArcGis 10.1 software tools (Figure 1).

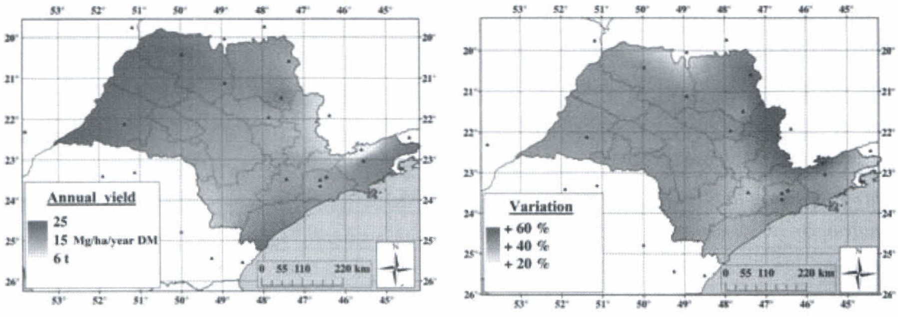

Figure 1. Spatial interpolation of the average predicted annual forage production and of the average estimated percentage of change in annual forage production of *Brachiaria brizantha*, based on projections of the PRECIS modelling system for the high GHG emission scenarios between 2043 and 2070. Soils with a water holding capacity of 60mm were considered. Adapted from Andrade et al. (2014).

Spatial interpolation allows the investigation of regional differences on predicted annual forage production and expected changes on annual forage productions in the future, and may be very useful for the identification of vulnerable areas. On the other hand, vulnerability of grassland-based livestock systems should not be assessed just by the average annual forage production, as variation between seasons and between years increases the system sensitivity. Sautier et al. (2013), studying the vulnerability of grassland-base livestock systems to climate changes in south-western France, predicted changes in seasonal boundaries, herbage production and production gaps between seasons with almost no impact on annual herbage production. Besides that, climatic impacts over grassland-based livestock systems depend on the strategies of animal and pasture management (LURETTE et al., 2013).

Simulations made by empirical model may also be used to estimate annual and seasonal variations on forage production. Andrade et al. (2014) observed that, despite the overall annual forage accumulation increase, variation on *Brachiaria brizantha* forage production between years (Figure 2) and between seasons (Figure 3) is expected to increase. The authors estimated that the baseline (1963 to 2009) means had a standard error from 0.18 to 0.19 Mg ha^{-1} dry matter per year, which were lower than that of the future projections means (2013 to 2040 and 2043 to 2070), which ranged from 0.26 to 0.33 Mg ha^{-1} dry matter per year, indicating higher forage yield variations between years and locations for São Paulo state, in the future. Besides that, the absolute increase in herbage accumulation rate 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 (Figure 3).

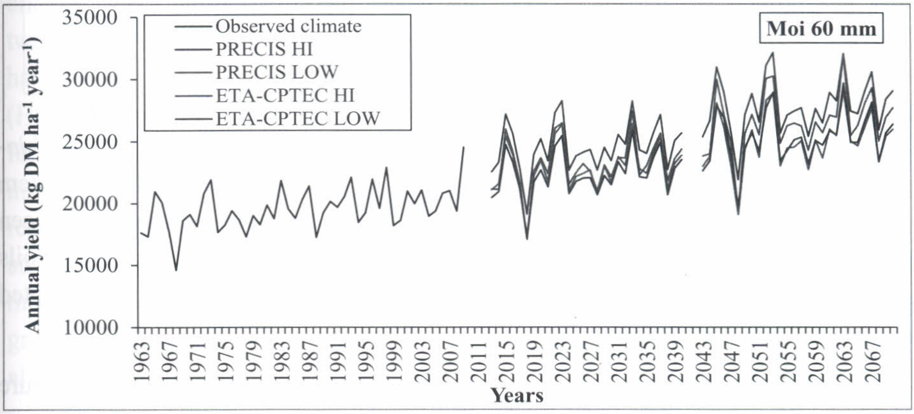

Figure 2. Average annual forage production of *Brachiaria brizantha* cv. Marandu from 1963 to 2067, simulated for the Sao Paulo state based on observed climate data and on climate projections by PRECIS and ETA-CPTEC models. HI and LOW = high and low GHG emissions and temperature scenarios. MOI 60 = soil water holding capacity of 60 mm. Adapted from Andrade et al. (2014).

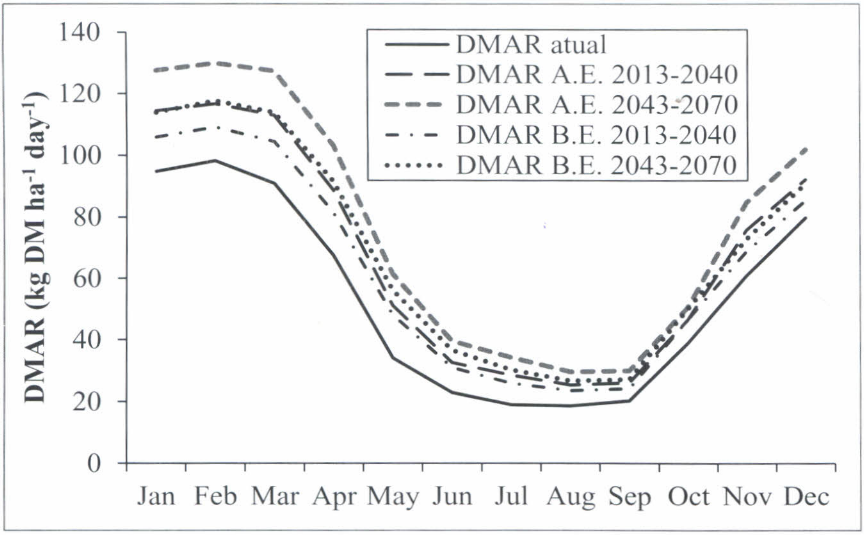

Figure 3. Dry matter accumulation rate (DMAR; kg DM $ha^{-1}day^{-1}$) of *Brachiaria brizantha*, based on projections of the PRECIS modelling system for the high (A.E.) and low (B.E.) GHG emission scenarios between 1963 and 2009 (actual), 2013 and 2040, and 2043 and 2070. Soils with a water holding capacity of 60mm were considered. Adapted from Andrade et al. (2014).

Although empirical models may be used to simulate growth and future scenarios for tropical grasslands, it is important to keep in mind its limitations. The forage production model used by Andrade et al. (2014), for example, does not consider the effect of physical and chemical properties of soil, fertilization, and pasture management on forage production. Besides that, forage production was predicted by an empirical model which considers just temperature and water balance as predictive factors, while other relevant environmental factors, like solar radiation and atmospheric CO2 concentration, have not been considered. The vulnerability of tropical grassland-based animal production systems to climate changes would be better assessed by the use of mechanistic models, which should be preferred whenever models have been properly adapted and tested, and datasets of input variables are available.

Mechanistic models

Mechanistic models consider the knowledge of physical, chemical, and biological processes that rule the phenomena under study. Sometimes they are considered explanatory because they express a cause-effect relationship between the variables (TEH, 2006). The development based on the understanding of the phenomena allows the use of mechanistic models under several conditions, but the need for information and data is also increased.

The adaptation of mechanistic models to accurately predict biomass accumulation in tropical grasses is still limited. Recent advances have been made on the plot-scale and farm-scale process-based models CROPGRO *Perennial Forage* and APSIM, with promising results.

CROPGRO model predicts the growth and composition dynamics of crops based on input data of the physiological plant processes, soil characteristics, climate, and management (BOOTE et al., 1998). These are included in the software DSSAT (Decision Support System for Agrotechnology Transfer), which has models for simulating the growth of 28 crops in its most recent version 4.5 (Hoogenboom et al., 2010). Rymph et al. (2004) adapted CROPGRO model for perennial grassland simulations (CROPGRO *Perennial Forage* model), including a perenniating storage organ (rhizome/stolon) for replenishment of reserves and use of stored carbohydrate and N for regrowth, as well as dormancy and partitioning that responded to daylength. The CROPGRO *Perennial Forage* model was recently calibrated and tested for simulations of tropical forages growth in Brazil (LARA et al., 2012; PEDREIRA et al., 2011; PEQUENO et al., 2014).

APSIM is a modular modelling system developed by the Agricultural Production Systems Research Unit in Australia to simulate biophysical processes in whole farming systems (APSIM, 2013). The modular structure is flexible and currently the system is able to simulate the growth of 30 different crops and pasture species (HOLZWORTH et al., 2014). APSIM-Growth is a module for simulating forage growth and it was previously used to simulate the aboveground DM production of Bambatsi colored guineagrass (*Panicum coloratum* L.) in Australia. The model was subsequently parameterised for Brazilian conditions (*Panicum maximum* cv. Mombaça) by ARAÚJO et al. (2013).

Preliminary tests were performed to evaluate the suitability of CROPGRO *Perennial Forage* model and APSIM model to simulate growth and future scenarios of tropical grasslands in Brazil. Parameterizations made by Araújo et al. (2013) for *Panicum maximum* cv. Mombaça and by Pequeno et al. (2014) for *Brachiaria brizantha* cv. Marandu were used for APSIM and CROPGRO *Perennial Forage* models, respectively. The created scenarios were chosen to partially replicate Marin et al. (2012), in which the air temperature, CO_2 levels and precipitation were changed in a deterministic way. Moreover, irrigation was included as a factor in order to have a better understanding of the interaction between temperature and water requirements.

CROPGRO Perennial Forage model

A couple of limitations of CROPGRO *Perennial Forage* for long-term simulations were observed. The model is time-bound and cannot properly simulate systems for a period longer than 10,000 days. Moreover, it cannot handle intense water stress. To avoid those problems, simulations were split into shorter periods and then properly joined together again.

Besides that, in order to simulate the harvest events in CROPGRO *Perennial Forage* model, one has to specify in advance the dates in which the forage will be cut, alongside with the stubble biomass (kg $DM.ha^{-1}$), their leaf percentage and their number of leaves per stem inside the Mow file. So, when the simulation reaches the harvest date, the software will read the values specified beforehand and trigger a harvest, leaving the stubble with its proper leaf percentage and leaf number per stem. The harvested biomass is considered exported from the system and so, the forage will proceed to regrow (RYMPH, 2004). Nonetheless, if the specified stubble value is lower than the biomass on the harvest day, the program will not cut the forage, but it will change the number of leaves per stem inadvertently, inserting an unwanted variation in the results. To avoid this problem, a script was implemented in R language (R Core Team, 2013) and used to set some criteria to allow harvest events.

Brachiaria brizantha cv. Marandu growth was simulated over a 29 -year long period (1981 – 2009) for 16 scenarios (rainfaal, temperature and CO_2 scenarios), using a climate dataset (precipitation, solar radiation, maximum and minimum temperature, all of them in a daily basis) coupled with site-specific soil information from São Carlos (SP), southeastern Brazil.

APSIM model

Long-term simulations of *Panicum maximum* cv. Mombaça production were performed for six locations with different climatic characteristics (Pelotas, RS, São Carlos-SP, Votuporanga, SP, Sobral-CE, Porto dos Gaúchos-MT, and

Aragarças-GO). Forage production was simulated for a 30-years period (1981-2010), considering five scenarios of temperature and three scenarios of rainfall, and standard conditions of soil and plant management for all six locations.

Rainfall scenarios

Under rainfed conditions, an increase of precipitation leads to an increase in annual forage production predicted by both CROPGRO *Perennial Forage* model and APSIM model, while a rainfall decrease leads to losses of higher magnitude (Figures 4 and 5). These results were expected, based on specialists' experience. Although more tests are necessary, it suggests that both models are sensitive to precipitation levels and could be used to investigate the impacts of changes on rainfall over forage production.

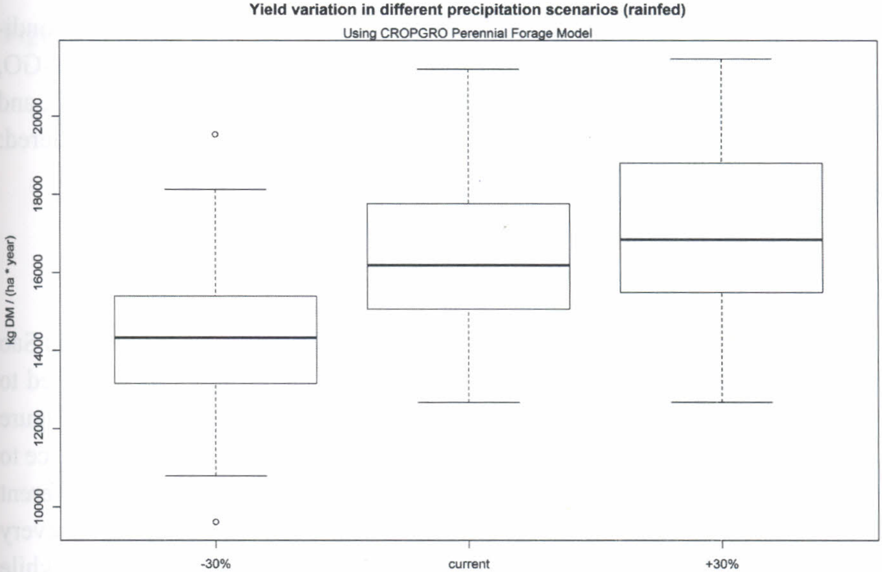

Figure 4. Mean annual *Brachiaria brizantha* cv. Marandu under rainfed conditions, predicted by CROPGRO *Perennial Forage* model, due to changes on the precipitation (-30%; 0%; +30% of current rainfall levels).

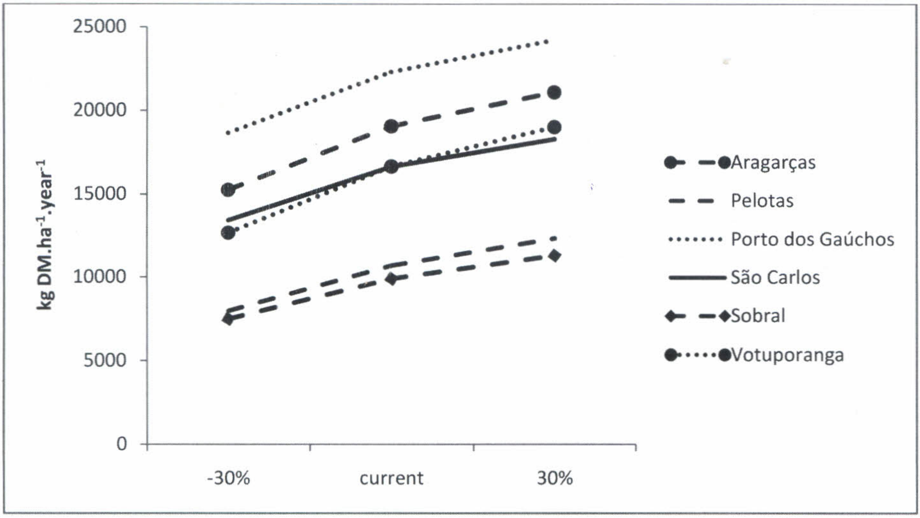

Figure 5. Mean annual *Panicum maximum* production under rainfed conditions, predicted by APSIM model for six locations (Aragarças-GO, Pelotas-RS, Porto dos Gaúchos-MT, São Carlos_SP, Sobral-CE, and Votuporanga-SP). Three rainfall-level scenarios were considered: -30%; 0%; +30% of current rainfall levels.

Temperature scenarios

Annual *Brachiaria brizantha* production under rainfed conditions in Sao Carlos-SP, predicted by CROPGRO *Perennial Forage* model, is expected to decrease due to temperature changes for most of the scenarios studied (Figure 6). Only the +3°C scenario (Figure 6) had a somewhat similar performance to the actual scenario. The irrigated scenarios (Figure 7) present a very different pattern than the rainfed ones (Figure 6). Higher yields were observed in every increase of temperature (+3 °C; +6 °C; and +9 °C of current temperature), while a decrease in temperature (-3°C of current temperature) can drastically reduce production (mean losses of ca. 3000 kg / ha * year; Figure 7).

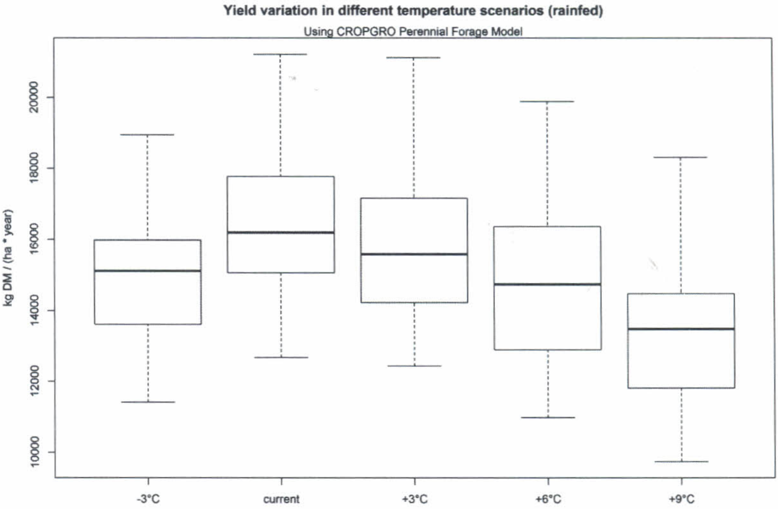

Figure 6. Mean annual *Brachiaria brizantha* cv. Marandu under rainfed conditions, predicted by CROPGRO *Perennial Forage* model, due to changes on the air temperature (-3°C; 0 °C; +3 °C; +6 °C; and +9 °C of current temperature).

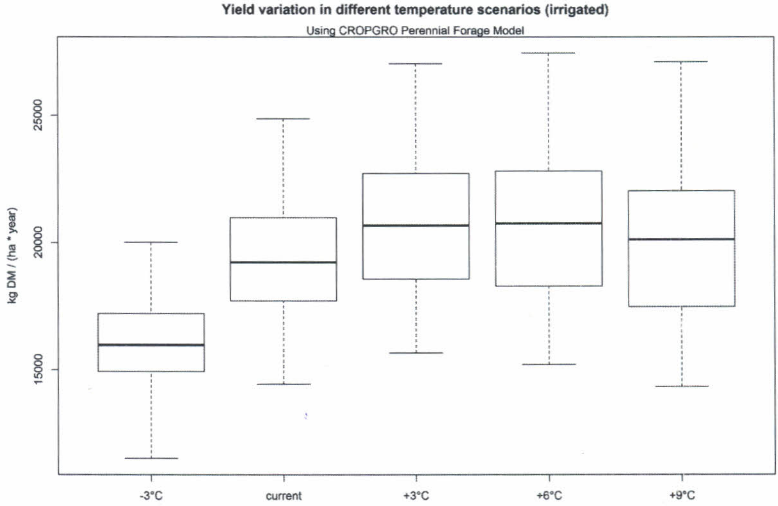

Figure 7. Mean annual *Brachiaria brizantha* cv. Marandu under irrigated conditions, predicted by CROPGRO *Perennial Forage* model, due to changes on the air temperature (-3°C; 0 °C; +3 °C; +6 °C; and +9 °C of current temperature).

gation timing is precise, conditions that may not be possible in real world cases.

Annual forage production of *Panicum maximum* under rainfed conditions, predicted by APSIM model, was reduced by the increase on temperature levels in Aragarças-GO, Porto dos Gaúchos-MT, Votuporanga-SP and Sobral-CE, where higher annual productions were obtained for the -3°C scenario (Figure 8). In Sao Carlos-SP higher productions were observed under the current climate; either a decrease or increases on temperature levels are expected to reduce forage production (Figure 9). In Pelotas-RS, with current lower mean temperature levels, forage productions is expected to be higher on the +6°C scenario (Figure 9).

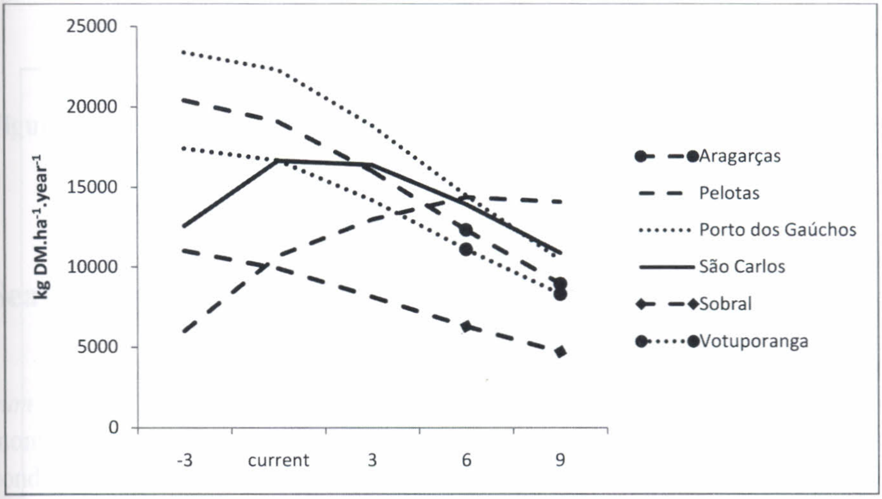

Figure 9. Mean annual *Panicum maximum* production under rainfed conditions predicted by APSIM model for six locations (Aragarças-GO, Pelotas-RS, Porto dos Gaúchos-MT, São Carlos_SP, Sobral-CE, and Votuporanga-SP). Five temperature scenarios were considered: -3°C; 0°C; +3°C; +6°C; and +9°C of current temperature.

Results obtained with APSIM model were not expected (Figure 9), based on specialists experience, and suggest that temperature parameters obtained by Araújo et al. (2013) should be reviewed. Araújo et al. (2013) established a relative narrow range of temperatures for optimum growth of *Panicum maximum*. Besides that, temperature parameters recommended by Araújo et al. (2013) seem to be low, since higher values have been described to *Panicum maximum* in the literature (MUIR and JANK, 2004; LARA et al., 2012).

CO_2 scenarios

Simulations performed with the CROPGRO *Perennial Forage* model suggests that CO_2 increases (Figures 10 and 11) lead to higher production when compared against the other scenarios. Although CROPGRO *Perennial Forage* model have been parameterized for tropical forages (Pedreira et al., 2011; Lara et al., 2012; Araújo 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 atmospheric CO_2 concentration, requires further experimentation.

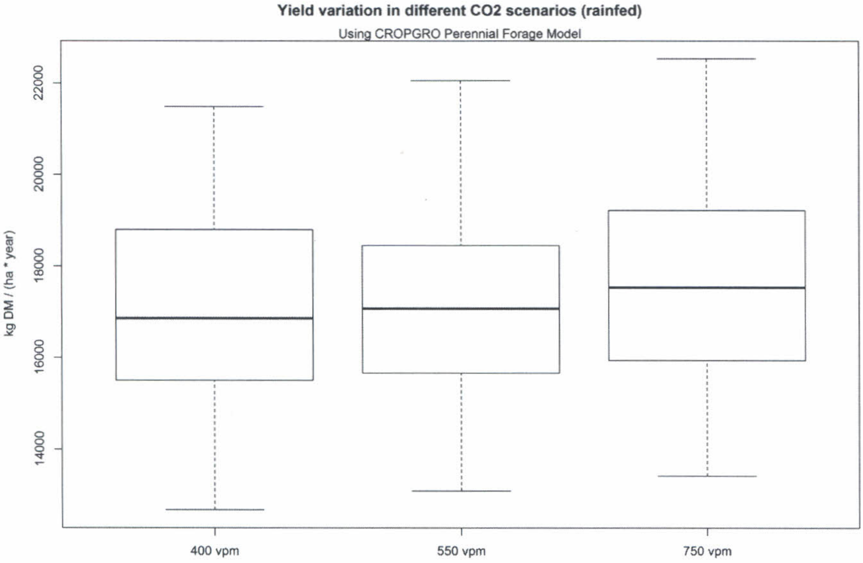

Figure 10. Mean annual *Brachiaria brizantha* cv. Marandu under rainfed conditions, predicted by CROPGRO *Perennial Forage* model, due to changes on the CO2 levels (400, 550 and 750 ppm).

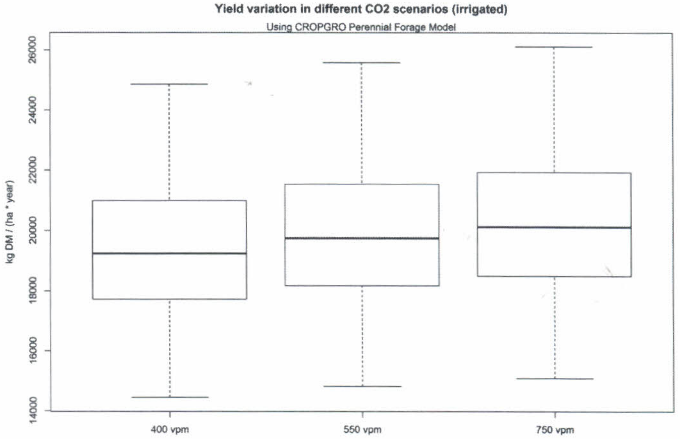

Figure 11. Mean annual *Brachiaria brizantha* cv. Marandu under irrigated conditions, predicted by CROPGRO *Perennial Forage* model, due to changes on the CO2 levels (400, 550 and 750 ppm).

Seasonal production

The suitability of APSIM to simulate seasonal forage production of *Panicum maximum* on different scenarios was also investigated. A decrease on mean monthly forage accumulation due to lower temperature levels under irrigated conditions was observed for those areas where low temperatures currently limits tropical grasslands development (São Carlos-SP, Votuporanga-SP, Aragarças-GO, and Porto dos Gaúchos-MT; Figure 12), mainly during the winter time. Just in Sobral-CE an increase on average monthly herbage accumulation was observed through the seasons due to a reduction on temperature levels (Figure 12). During spring and summer time, an increase on temperature levels determined a decrease on mean monthly forage accumulation, except in Pelotas-RS, where low temperature currently limits plant growth. In Pelotas-RS, a reduction on monthly forage accumulations was observed with an increase of 6°C in temperature levels during summer time.

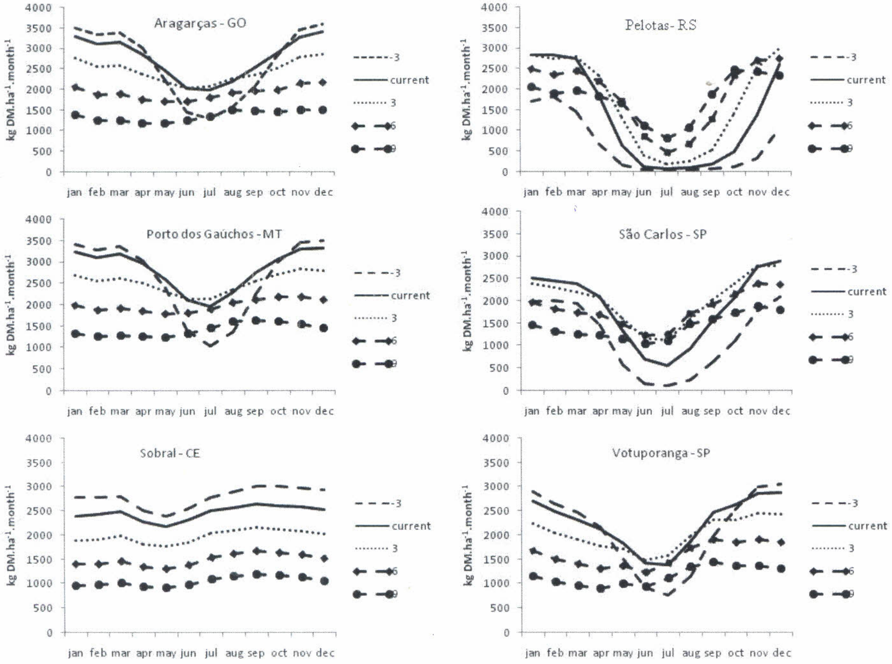

Figure 12. Mean monthly forage accumulation of *Panicum maximum* cv. Mombaça under irrigated conditions considering five temperature scenarios (-3°C; 0 °C; +3 °C; +6 °C; and +9 °C of current temperature).

The negative effects of increased temperature on *Panicum maximum* forage production when drought stress is not present (Figures 12) was not expected by specialists and reinforces the need for further calibration of temperature parameters in APSIM model.

Under rainfed conditions, no benefits of increased temperature levels during autumn and winter were observed due to drought stress (Figure 13). In Pelotas-RS, where there is almost no water deficit during these seasons, seasonal forage production was similar to those simulated for irrigated areas (Figures 12 and 13). An increase on temperature levels also reduced mean monthly herbage accumulation during spring and summer in all locations studied (Figure 13).

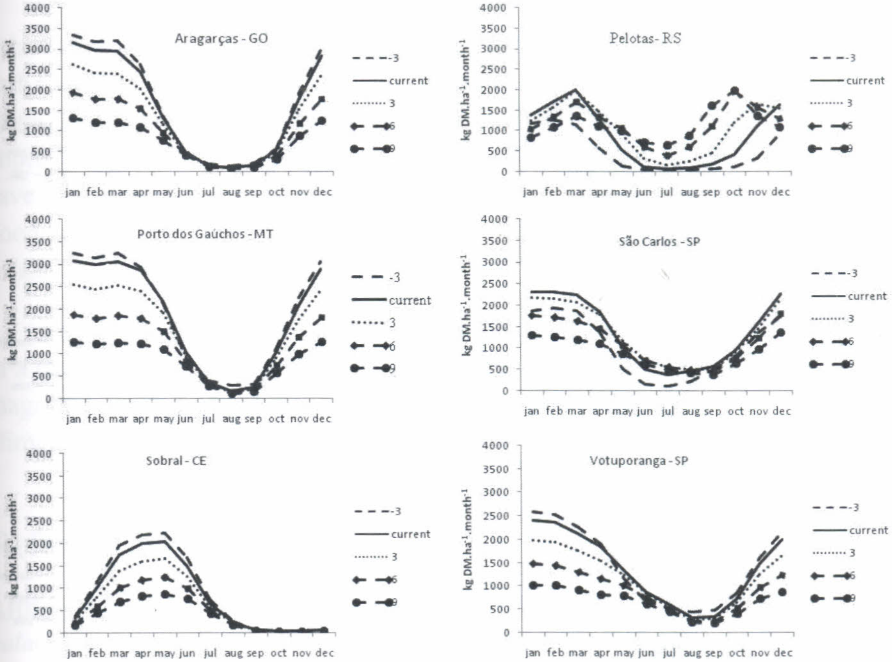

Figure 13. Mean monthly forage accumulation *Panicum maximum* cv. Mombaça under rainfed conditions considering five temperature scenarios (-3 °C; 0 °C; +3 °C; +6 °C; and +9 °C of current temperature).

Mean monthly herbage accumulation was slightly increased by an increase on precipitation levels, except for those periods when temperature restricted grass growth or when current rainfall levels were so low that a 30% increase on it was not enough to overcome drought stress (Figure 14).

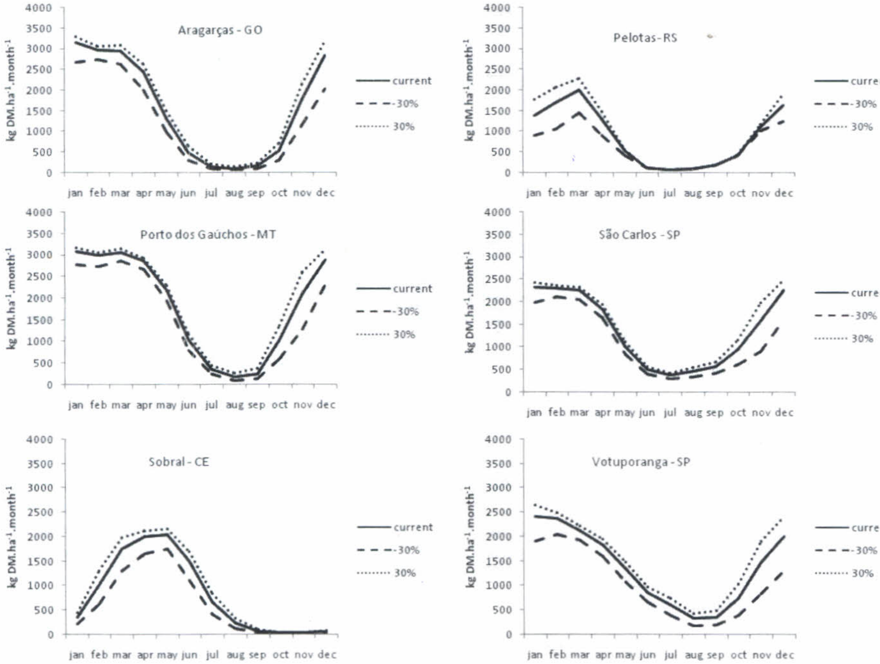

Figure 14. Mean monthly forage accumulation *Panicum maximum* cv. Mombaça under rainfed conditions considering four rainfall scenarios (-30%; 0%;+30% of current rainfall levels).

Conclusions

Empirical models may be used to estimate annual and seasonal forage production, and help on the identification of areas vulnerable to global climate changes. Anyway, it is important to keep in mind its limitations. Agrometeorological empirical models usually do not consider the effect of physical and chemical properties of soil, fertilization, and pasture management on forage production. Besides that, most of them will consider just a couple of predictive factors, while other relevant environmental factors may not been considered. The vulnerability of tropical grassland-based animal production systems to climate changes and alternatives to mitigate its negative impacts would be better assessed by the use of mechanistic models. Those models should be preferred whenever they have been properly adapted and tested, and datasets of input variables are available.

The CROPGRO *Perennial Forage* and APSIM models have been parameterised to simulate tropical forages growth under Brazilian conditions. Although both models seem to predict properly the effects of different changes on precipitation levels, further parameterisation of APSIM model will be necessary to improve simulations of temperature scenarios. Besides that, both models still have to be tested for tropical grasses under extreme climatic conditions (e.g., flooding, drought, and extreme temperatures) and increased atmospheric CO_2 concentration scenarios.

Finally, it is worth to consider that the climatic factors were changed in a deterministic way, and as a consequence, extreme events frequency and magnitude remained controlled, a premise that is questionable in the real world climatic changes.

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