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Climate risk and seasonal forage production of Marandu palisadegrass in Brazil

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Abstract: This study aimed to characterize *Brachiaria brizantha* cv. Marandu seasonal production (seasonality) and its variation (climate risk) yearlong throughout Brazil. Data from weather stations in Brazil (1963-2009), were associated with an empirical herbage accumulation rate (HAR; kg DM ha^{-1} day^{-1}) model which considers growing degree-days adjusted by a drought attenuation index. Simulations were performed under 20, 40, 60 and 100 mm of soil water holding capacities (SWHCs). HAR's means and standard deviations were calculated for the seasons of the year. Thereafter, cluster analysis and calculations were performed to gather similar weather stations and characterize seasonality and climate risk indexes. Cluster analysis resulted in four Groups per SWHC. The north of Brazil (Group 1) presented the lowest seasonality and climate risk indexes and low need for precautions. In the middle west (Group 2), the seasonality index ranged from medium-high to high. Winter and Summer presented the lowest and highest production, respectively. In the south of Brazil, some regions in the southeast and northeast (Group 3), Winter presented the lowest production and highest climate risk index, probably due to low temperatures. The northeast (Group 4) presented a seasonality index that ranged from medium-high to very high and low productions.

Key words: *Brachiaria brizantha*, climate risk, forage production model, seasonality of production.

INTRODUCTION

Livestock plays a crucial economic, social and environmental role in Brazil. It was responsible for more than 30% of the agribusiness Gross Domestic Production (GDP) and about 6.6% of national GDP in 2017 (CEPEA 2018). According to the last Brazilian Agricultural Census, pastures occupy 158 million hectares, which correspond to 45% of the country's total farming area (IBGE 2016). *Brachiaria brizantha* cv. Marandu is the most cultivated forage grass in Brazil, with an estimated area of 50 million hectares (Jank et al. 2014).

Season-to-season forage production variability is acknowledged in Brazil, but not well characterized due to the edaphoclimatic variation throughout the country. Variation on forage allowance may reduce animal performance and yield, and causes changes in sward structure and composition, which affects the next grazing cycles. Seasonal forage production is also related to variations in products availability to industry (e.g. milk and beef) and in prices to consumers (Viana et al. 2010, Gaio et al. 2011). In this context, not only farmers are negatively affected by the seasonality of forage production, but the whole market chain.

Besides the characterization of the seasonal production patterns, it is important to characterize the variation around these patterns.

The range and frequency of the pattern's variation represents the uncertainty of the system and brings the necessity of planning. Uncertainty is generally caused by climate variations and, in such situations, the term climate risk can be adopted (Harwood et al. 1999). According to the World Bank (2015), Brazil loses annually more than 1% of agribusiness GDP due to extreme risks in which weather-related events contribute significantly. Furthermore, the weather-related financial consequences are felt more by vulnerable people in rural areas, frequently involved in agriculture and other ecosystem-dependent livelihoods. Hence, climate risk has a profound effect on the country economics and social sustainability (Davies et al. 2009).

This study aimed to characterize the seasonal pattern and climate risk of Marandu palisadegrass daily herbage accumulation rate throughout the year in Brazil and discuss alternatives for animals feeding in periods of low forage production and/or high climate risk. This kind of study could support the planning of pasture livestock production systems, and give overall directions for agricultural credit policies.

MATERIAL AND METHODS

Climate data and plant model

Observed climate data were associated with an empirical model of monthly herbage accumulation rate (HAR; kg DM ha^{-1} day^{-1}) of *Brachiaria* (syn. *Urochloa*) *brizantha* cv. Marandu for simulation of HARs in Brazil. Rainfall and maximum and minimum temperature data from 286 weather stations throughout Brazil, between the years 1963 and 2009, were used. The dataset was provided by INMET, INPE, ANA, EMBRAPA and other research institutes, private companies and state universities, and was compiled in the Agritempo system database (www.agritempo.gov.br).

The empirical crop model used was the univariate linear equation developed by Cruz et al. (2011) and used by Andrade et al. (2014) for studies on future scenarios for *Brachiaria brizantha* cv. Marandu production in Brazil. Briefly, the growing degree-days adjusted by a drought attenuation factor (GDDadjusted) was used as forage accumulation estimator. The drought attenuation factor was determined by the ratio of the actual available soil water/soil water holding capacity (ASWactual/SWHC), based on the water balance calculated according to Thornthwaite and Mather (1955), considering four soil water holding capacities: 20, 40, 60, and 100 mm. The base temperature of 17.2°C was used to calculate the GDD as DMAR = 15.34 × GDDadjusted, in which: DMAR is the dry matter accumulation rate (kg dry matter ha^{-1} day^{-1}), and; GDDadjusted is the growing degree days adjusted for drought attenuation factor (°C) (Andrade et al. 2014).

The crop model was obtained under the conditions of the experimental area of Embrapa Southeast Livestock (21°57'S, 47°51'W), São Carlos, SP, Brazil, in 2009 and 2010, which were: Cwa climate (Köppen classification), Oxisol, range of monthly average temperature between 16.8 and 27.1°C, average incoming solar radiation of 17.9 MJ m^{-2} day^{-1} (minimum of 12.7 MJ m^{-2} day^{-1} in June, and maximum of 21.8 MJ m^{-2} day^{-1} 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 herbage residue height.

After simulations with the model, HARs were calculated for each season of the year as averages of their respective months (eq.1).

$$\overline{HAR}_{ijk} = \frac{1}{3}\sum_{m_{ijk}} HAR_{m_{ijk}} \quad (1)$$

$\overline{HAR}_{ijk}$ is the HAR of the season i, i = {Summer, Autumn, Winter, Spring} in weather station j, j = {1, 2, ..., 286}, and year k, k = {1963,

1964, ..., 2009}, and m_{ijk} are the months of the season *i* in weather station *j* and year *k*, *m* = {January, February, ..., December}, considering January, February, and March as Summer; April, May and June as Autumn; July, August and September as Winter; and October, November and December as Spring.

Statistical Analysis and calculated parameters

In order to characterize the magnitude and interannual variation of HAR in each weather station and to perform statistical analysis, HARs of given season ($\overline{HAR}_{ijk}$) were averaged among years in each weather station ($\overline{HAR}_{ij}$; eq2) and standard deviation was calculated analogously ($sd_{HAR_{ij}}$; eq3).

$$\overline{HAR}_{ij} = \frac{1}{47}\sum_{k}\overline{HAR}_{ijk} \quad (2)$$

$$sd_{HAR_{ij}} = \sqrt{\frac{1}{47-1}\sum_{k}\left(\overline{HAR}_{ijk} - \overline{HAR}_{ij}\right)^2} \quad (3)$$

$\overline{HAR}_{ij}$ is the average of HAR of the season *i* for station *j* between the years *k*, from 1963 to 2009, and $sd_{HAR_{ij}}$ is the standard deviation of the season *i* in the weather station *j* between the years *k*.

Multivariate analysis was performed for each soil water holding capacity (i.e. 20, 40, 60, 100 mm) using the R software (R Core Team 2015). The response variables were mean herbage accumulation rate (HAR; kg DM ha^{-1} day^{-1}; eq. 2) and the respective standard deviation (eq.3) in each season of the year calculated for the 286 weather stations, totalizing eight variables abbreviated as m_sum, sd_sum, m_aut, sd_aut, m_win, sd_win, m_spr, and sd_spr.

The variables were standardized and then cluster analysis was performed to gather most similar weather stations according to the variables evaluated. The k-medoids clustering method was utilized, with the number of groups defined according to *scree-plot*, creating four groups for each soil water holding capacity. The Principal Components Analysis (PCA) was performed to characterize the relations among weather stations of each group and studied variables.

Each group of weather stations was characterized by their climate risks and seasonality of herbage accumulation rate. Average HAR of each season between years ($\overline{HAR}_{ij}$) were averaged between weather stations of the same group ($\overline{HAR}_{ig}$; eq.4), *g* = {1, 2, 3, 4}. Subsequently, standard deviation of HAR of seasons between years ($sd_{HAR_{ij}}$) were averaged between stations of the same group ($\overline{sd}_{HAR_{ig}}$; eq.5).

$$\overline{HAR}_{ig} = \frac{1}{n_g}\sum_{j_g}\overline{HAR}_{ij_g} \quad (4)$$

$$\overline{sd}_{HAR_{ig}} = \frac{1}{n_g}\sum_{j_g} sd_{HAR_{ij_g}} \quad (5)$$

$\overline{HAR}_{ig}$ is the mean HAR in group *g* and season *i*, averaged between *n* weather stations of group *g*, $\overline{sd}_{HAR_{ig}}$ and is the mean standard deviation in group *g* and season *i* averaged between standard deviations of *n* stations of group *g*.

The climate risk index was estimated as inter annual variation of HAR in each season ($\overline{sd}_{HAR_{ig}}$) in relation to the respective mean ($\overline{HAR}_{ig}$; *Eq.6*).

$$\textit{climate risk} = \frac{\overline{sd}_{HAR_{ig}}}{\overline{HAR}_{ig}} \quad (6)$$

$\overline{HAR}_{ig}$ is the mean HAR in group *g* and season *i*; $\overline{sd}_{HAR_{ig}}$ is the standard deviation in group *g* and season *i*. Seasonality, on the other hand, is considered as a pattern of variation

of forage production among seasons, without taking into consideration variations around the pattern. In this sense, HAR of seasons in the same group ($\overline{HAR}_{ig}$) were averaged ($\overline{HAR}_{g}$; eq. 7) as mean yield of the year and then standard deviation of this mean was calculated ($\overline{sd}_{HAR_{ig}}$; eq. 8). Subsequently, the coefficient of variance (eq. 9) was used as an estimate of seasonality of herbage accumulation rate for each group of weather stations, guaranteeing that results were less dependent on the magnitude of data and allowing comparisons among groups.

$$\overline{HAR}_{g} = \frac{1}{4}\sum_{i}\overline{HAR}_{ig} \quad (7)$$

$$sd_{HAR_{g}} = \sqrt{\frac{1}{4-1}\sum_{i}\left(\overline{HAR}_{ig} - \overline{HAR}_{g}\right)^{2}} \quad (8)$$

$$seasonality = \frac{sd_{HAR_{g}}}{\overline{HAR}_{g}} \quad (9)$$

Finally, climate risk and seasonality of forage production numerical indexes were classified empirically (Table I) in order to make comparisons among Groups of weather stations easier.

RESULTS

Cluster analysis successfully divided Brazilian weather stations into four groups, according to herbage accumulation rate mean (HAR; kg DM ha^{-1} day^{-1}) and standard deviation, and then the PCA allowed the characterization of the groups. For all the SWHCs, three principal components were required to explain more than 80% of the variance and to characterize the groups properly. As the results for SWHCs were similar, only results from 60 mm SWHC are presented.

The first principal component (PC1), the second (PC2) and the third (PC3), explained 35.42%, 27.50% and 19.47% of the variance, respectively, totalizing 82.39%. In Figure 1a, one can see the first two principal components and, in Figure 1b, one can see PC1 and PC3. Since there was no overlap, the differences among groups can be seen by comparing the mean vector confidence ellipses (the ones with smaller diameter) and the characterization was made according to the projection of the groups in the axes of the principal components. The origin of the axes corresponds to the mean of all variables and the vectors (arrows) represent

Table I. Indexes for classification of climate risk and seasonality of Marandu palisade grass herbage accumulation rate (indexes were determined empirically).

parameter			
climate risk		seasonality	
value	classification	value	classification
≤ 0.1	extreme low (EL)	≤0.3	very low (VL)
0.1<v≤0.25	very low (VL)	0.3<v≤0.4	low (L)
0.25<v≤0.4	low (L)	0.4<v≤0.5	medium (M)
0.4<v≤0.55	medium (M)	0.5<v≤0.6	medium-high (MH)
0.55<v≤0.7	medium-high (MH)	0.6<v≤0.7	high (H)
0.7<v≤0.85	high (H)	>0.7	very high (VH)
0.85<v≤1	very high (VH)		
>1	extreme high (EH)		

the coefficients of the variables on the principal components.

Thus, Group 1 (black) is located in the third quadrant of the graph, the lower-left one, in Figure 1a and in the same direction of the vectors of Winter's HAR mean and standard deviation (m_win and sd_win), which means that it had higher values of these variables than the other groups. Group 2 (red) is located above the other groups in Figure 1a and was characterized by higher values of HAR mean in Spring and Summer (m_spr and m_sum) as well as higher HAR standard deviation in Spring (sd_spr) than the other groups. This group also had lower values of standard deviation in Summer (sd_sum), once it is in the opposite direction of the vector of this last variable. Group 3 (green) is located in the opposite direction of all vectors, so it presented the lowest HAR means and standard deviations at all seasons of the year (Figure 1a, b). Finally, one can see in Figure 1a that Group 4 (blue) was characterized by higher HAR standard deviation in the Summer (sd_sum) and lower HAR mean in this season (m_sum).

Distribution of weather stations among groups obtained by Cluster analysis and PCA were similar for 20, 40, 60 and 100 mm SWHC (Figure 2). Group 1 comprised weather stations from the northern region of Brazil. Group 2, on the other hand, corresponded to most of the central area of Brazil (southeastern, central-western and some states of the northeast and north). Group 3 was formed by some weather stations located on the northeast, several from the southeast and the majority of stations located in the south of the country, encompassing a high range of latitudes. Finally, Group 4 comprised of the northeast region of Brazil (Figure 2).

Characterization of the groups (Figure 1) and distribution of weather stations into Groups (Figure 2) showed similar results among SWHCs. Despite that, seasonality indexes of Groups 1, 2, and 4 were inversely proportional to SWHCs, while remained equal in Group 3 in all SWHCs (Table II).

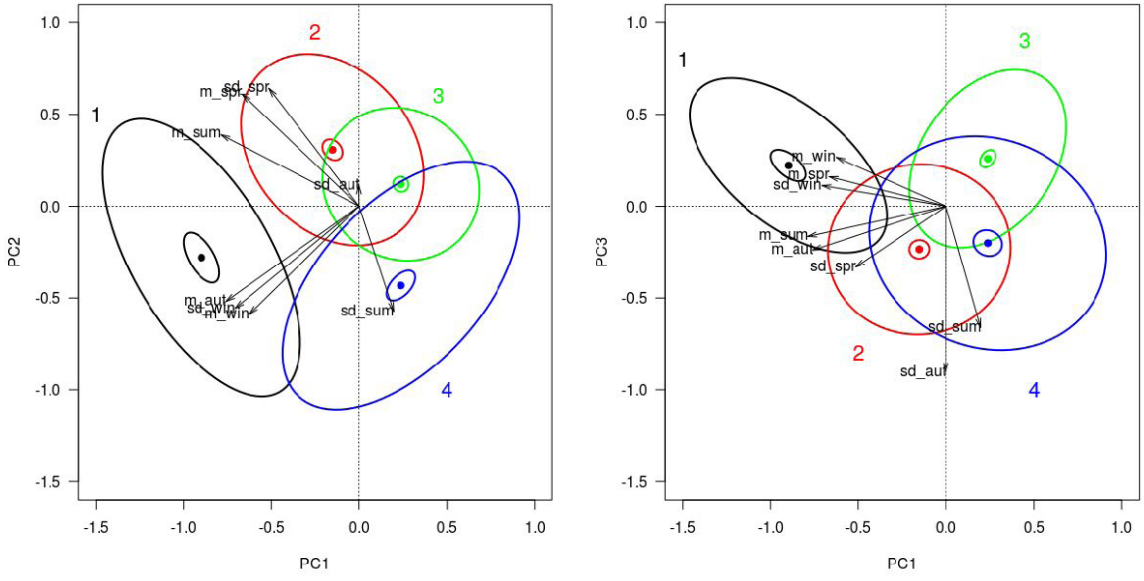

Figure 1. Biplot of the first two principal components PC1 and PC2 (a) and first and third principal components PC1 and PC3, with 95% confidence ellipses for prediction (larger diameter) and mean vector (smaller diameter) of each group considering 60mm soil holding capacity. As results for different soil water holding capacities were very similar, only results from 60 mm soil water holding capacities are presented.

Group 1 had the highest annual mean HAR and forage production was better distributed along the year, classified as having low and very low seasonality index for soils with 20/ 40 and 40/ 60mm SWHCs, respectively (Table II). Group 3, on the other hand, had the lowest mean HAR of the year with seasonality index higher than that estimated in Group 1 and lower when compared to Groups 2 and 4, once presented medium-high seasonality indexes, independent of its SWHC. Group 2 and 4 were the second most and second less productive, respectively, and had the highest seasonality index in 40 and 60 mm (classified as high) SWHCs. When SWHC was of 20 mm, Group 4 presented the highest seasonality index classified as very high, followed by Group 2 classified as high (Table II).

Seasonality index classification in Group 1 was due to lower HARs in Winter and Spring, and higher HARs in Summer and Autumn, as forage production in former months was estimated as being only ~ 60 % of that registered in latter

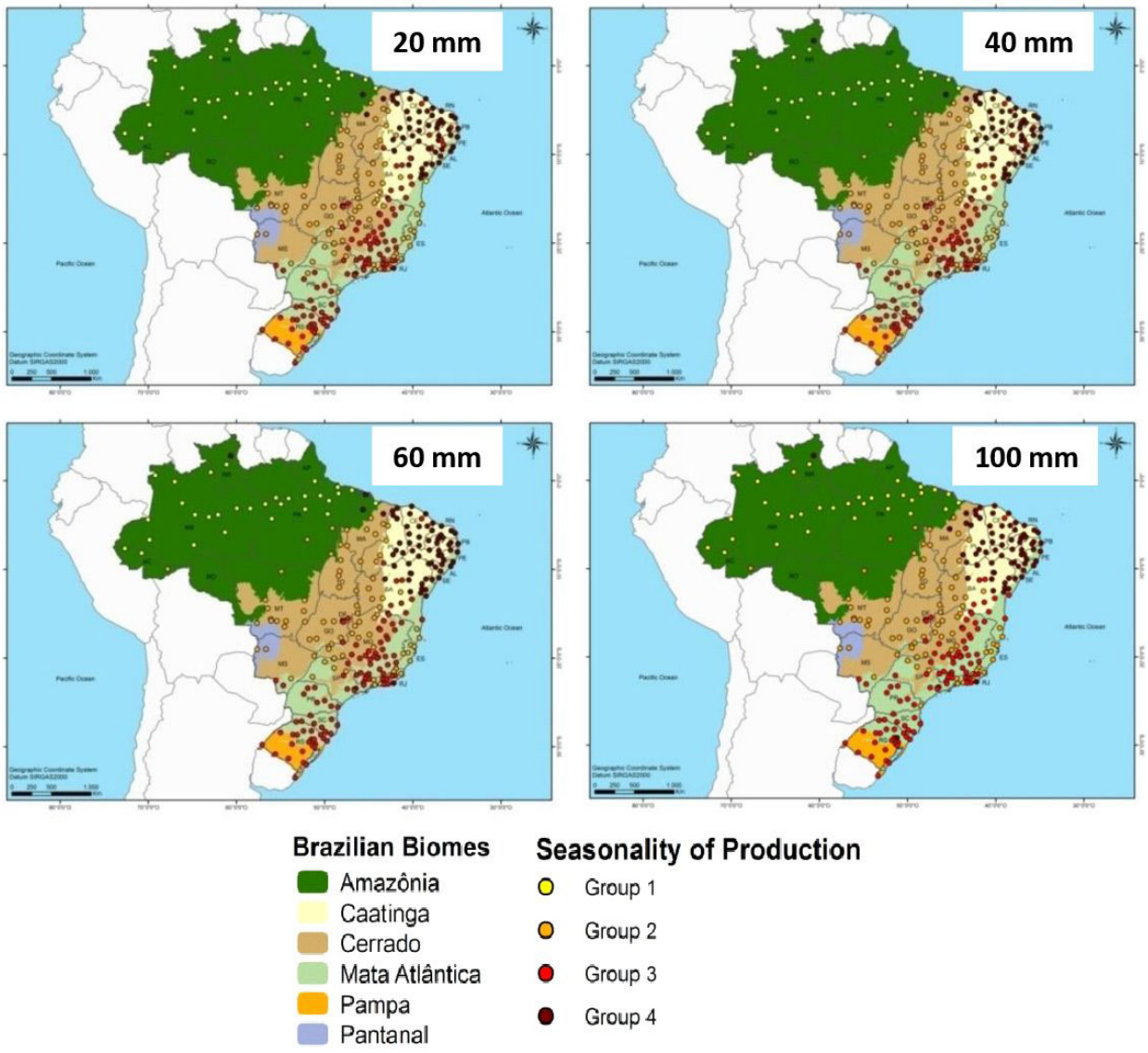

Figure 2. Classification and distribution of meteorological stations in Brazil according to cluster analysis. Cluster analysis was done according to Marandu palisade grass herbage accumulation rate mean and standard deviation in each season of the year.

ones (Figure 3). Seasonality index classification in Groups 2 and 3, on the other hand, were mainly due to lower HARs in Winter, but also in Spring and Autumn, compared with higher productions in Summer. Summer forage production was ~ 10 and five times higher than that registered in Winter in Groups 2 and 3, respectively, while Spring and Autumn were estimated to have intermediate HARs in both Groups. Seasonality in Group 4 is caused by low HAR in Spring and Winter when compared with higher productions in Summer and Autumn. Maximum and minimum HARs in Group 4 are achieved in Autumn and Spring, respectively, as HAR is ~ six times higher in the former when compared to the latter (Figure 3).

Climate risk indexes decreased in all Groups as SWHC increased, but differences among Groups were maintained (Table II). Group 1 had the lowest estimated climate risk indexes for the Summer, Autumn, and Winter in all SWHCs, ranging from extremely low to low in the two first seasons and medium to very low in Winter. It presented similar climate risk indexes in Spring when compared to Group 3 in all SWHCs and with Group 2 in 20/ 100 mm SWHCs. Conversely, it presented lower climate risk indexes in Spring than Group 2 in 40/ 60 mm SWHCs and Group 4 in all SHWCs, being classified as medium and low for the SWHCs of 20 and 40/ 60/ 100 mm, respectively. Group 2 presented the highest climate risk indexes of production in Winter

Table II. Indexes of climate risk and seasonality of Marandu palisade grass herbage accumulation rate associated with Groups of meteorological stations in Brazil, created by cluster analysis.

	climate risk index				seasonality index
	Summer	**Autumn**	**Winter**	**Spring**	**year long**
	20mm				
Group 1	0.2 (VL)	0.16 (VL)	0.44 (M)	0.46 (M)	0.35 (L)
Group 2	0.3 (L)	0.51 (M)	1.19 (EH)	0.47 (M)	0.67 (H)
Group 3	0.38 (L)	0.56 (MH)	0.64 (MH)	0.44 (M)	0.60 (MH)
Group 4	0.61(MH)	0.41 (M)	0.55 (M)	1.66 (EH)	0.73 (VH)
	40mm				
Group 1	0.16 (VL)	0.12 (VL)	0.36 (L)	0.39 (L)	0.32 (L)
Group 2	0.24 (VL)	0.39 (L)	0.97 (VH)	0.43 (M)	0.64 (H)
Group 3	0.31(L)	0.46 (M)	0.53 (M)	0.37 (L)	0.59 (MH)
Group 4	0.59 (MH)	0.35 (L)	0.42 (M)	1.22(EH)	0.67 (H)
	60mm				
Group 1	0.15 (VL)	0.1 (EL)	0.3 (L)	0.36 (L)	0.28 (VL)
Group 2	0.2 (VL)	0.33 (L)	0.82 (H)	0.41(M)	0.63 (H)
Group 3	0.26 (L)	0.39 (L)	0.47 (M)	0.33 (L)	0.58 (MH)
Group 4	0.57 (MH)	0.33 (L)	0.36 (L)	0.99 (VH)	0.62 (H)
	100mm				
Group 1	0.15 (VL)	0.09 (EL)	0.23 (VL)	0.32 (L)	0.25 (VL)
Group 2	0.17 (VL)	0.26 (L)	0.54 (M)	0.4 (L)	0.58 (MH)
Group 3	0.22 (VL)	0.33 (L)	0.38 (L)	0.31 (L)	0.54 (MH)
Group 4	0.54 (M)	0.31(L)	0.35 (L)	0.75 (H)	0.56 (MH)

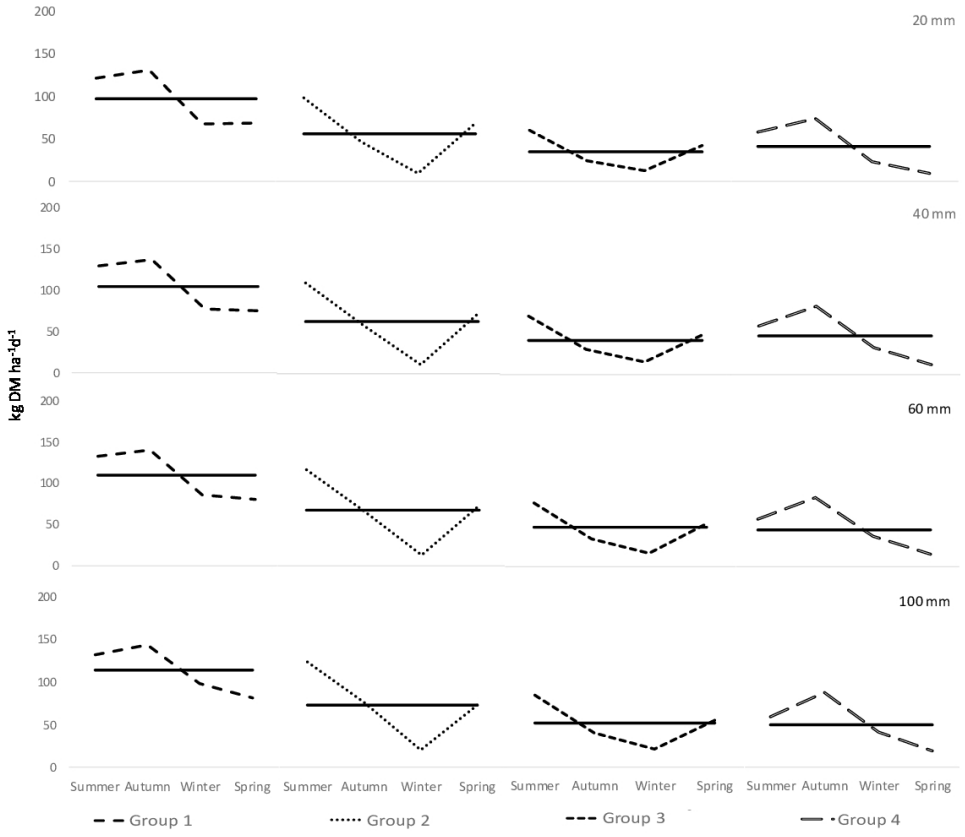

Figure 3. **Herbage accumulation rate (HAR) in seasons of the year and annual mean HAR of Groups of meteorological stations in Brazil, created by cluster analysis. Dashed and solid lines correspond to season and annual mean HAR, respectively. HARs were simulated using data of 286 meteorological stations from years 1963 to 2009 by mathematical empirical model, considering four soil water holding capacities (20, 40, 60 and 100mm).**

for all SWHCs, decreasing from extreme high to medium as the SWHC raised. On the other hand, Summer in Group 2 had higher climate risk index only than that registered in Group 1 in 20 mm SWHC, and ranged from low in 20 mm to very low climate risk indexes in higher SWHCs, while Autumn and Spring presented medium to low climate risk indexes depending on SWHC. Group 3 showed higher climate risk indexes in Autumn and Winter when compared to other seasons, which ranged from medium-high to low climate risk indexes in both seasons, whereas it ranged from low to very low in Summer and medium to low in Spring. When compared to others, Group 3 presented the highest climate risk index in Autumn in the two lowest SWHCs, ranging from medium-high to medium, whereas in higher SWHCs, climate risk indexes in these seasons were similar than that estimated for Groups 2 and 4. Group 4 was marked by having the highest climate risk in Spring and Summer, ranging from extremely high to high and medium high to medium, respectively. On the other hand, climate risk indexes in Winter and Autumn ranged from medium to low, despite having low productions in Winter (Table II; Figure 3).

DISCUSSION

Meeting demand and forage allowance is crucial for pasture-fed livestock, once excess or lack of forage can not only reduce animal performance and yield, but also determine changes in the sward structure affecting the subsequent grazing cycles and pastures persistency as well. Empirical agrometeorological plant growth models have been used to estimate regional annual and seasonal herbage production from historical climate series (Pezzopane et al. 2016). However, climate variables, and consequently

HAR, vary from year-to-year. Magnitude and frequency of weather variation around normal weather in time and space are associated with climate risk of pasture-fed livestock systems. In this context, climate risk characterized just as seasonal forage production along the year may lead to inappropriate planning and decision-making. Some studies have already highlighted climate variability (i.e. risk) importance for agricultural activities. In such studies, stochastic models (Semenov & Barrow 1997, Parsch et al. 1997, Semenov & Porter 1995) were used to predict climate spatial and temporal variability and, in some cases, standard deviation, and coefficient of variation were used as indicators of such variability (Semenov & Porter 1995). In our study, coefficient of variation was considered a more trustable index, as comparisons among standard deviations of highly different HARs could be misunderstood.

As livestock is predominantly pasture-fed in Brazil, farmers should be prepared to cope with seasonal patterns of forage production and climate risk. Besides buying and/or selling animals, forage conservation, pasture irrigation, and the combination of forage species/cultivars are technologies that may be helpful for the adjustment of forage production and animal demands. Milk and beef industries prices are inversely proportional to regional yield (Viana et al. 2010, Gaio et al. 2011), which in turn depends on climate variations. The characterization of forage annual and seasonal production may be helpful for farmer´s decisions, reducing risks and improving economic returns. Alvares et al. (2014) found 12 types of climate, according to Köppen´s climate classification, throughout Brazil. In this context, characterization of forage production and climate risk must consider space and time variations. Cluster analysis successfully managed to split Brazil into 4 Groups (Figure 1), according to its forage production patterns and variations (Figure 3).

The north of Brazil (Group 1) had the least season-to-season variation among all groups, and its seasonality and risk indexes varied from very low to low (Table II). This can be explained by proximity to the Equator line and the Amazon rain forest, which guarantees lower variations in temperatures and water availability for plants growth (Alvares et al. 2014). Besides that, high mean temperatures and rainfall, characteristic of this area, resulted in the highest expected HARs throughout the year (Figure 3). Despite of being less seasonal than the rest of the country, HAR during Winter/Spring in North of Brazil was just 60% of that predicted for Summer/Autumn (Figure 3), reinforcing the importance of planning forage production at the farm level. Postponing pasture utilization from the end of the rainy period to the dry period and forage conservation may be helpful to guarantee adequate forage availability for animals along the year. Autumn and Summer seem to be the best seasons to conserve forage, as they are not only the most productive, but also the less climatically risky. Besides that, as Winter and Spring present climate risk varying from medium to very low, it is relatively easy to estimate the amount of forage to be conserved to feed animals during these seasons.

The zone which comprehends the north of São Paulo and the northwest of Minas Gerais states, the middle-west and part of the northeast and the north of the country (Group 2; Figure 2) had a well-characterized pattern of HAR yearlong, with high seasonality and necessity to adjust better forage production and demand in Winter. High HAR associated with low to very low climate risk were predicted for the Summer (Table II). On the other hand, predicted Winter HAR was ~10 times lower than that predicted in the Summer, associated with extreme high to

medium climate risk indexes (Table II; Figure 3). Lack of forage can lead to overgrazing, loss of storage carbohydrates and less vigorous plants regrowth on subsequent cycles and, in extreme cases, pasture degradation. On the other hand, excess of forage can modify sward structural characteristics, morphological composition and forage quality, mainly in tropical forage grasses, also affecting animal performance and yield. In this sense, forage production planning is necessary to guarantee pastures persistence and production in this Group. As low HAR in the Winter is due to both low water availability and low temperatures, irrigation does not seem to be a good alternative to mitigate the effects of seasonal forage production over animal production, and may even intensify forage production seasonality, as responses to irrigation tends to be higher during the Summer, when temperatures are higher (Rassini 2004). On the other hand, forage conservation during the Summer seems to be a good alternative due to the high forage production predicted for this period and very low climate risk index associated with it (Table II; Figure 3). As the months of transition between dry and rainy seasons are associated with low to medium climate risk indexes, animal feeding could be supplemented in these periods too.

Group 3 comprised the south of the country, majority of Minas Gerais state (located in the southeast of the country), and some spots in the northeast (Figure 2). In lower latitudes, high altitudes influenced thermal regime turning it similar to that observed in the south of Brazil (Alvares et al. 2014). Temperature is probably the main limiting factor for forage growth in these areas, therefore low HARs were predicted mainly in the Winter, but also in the Spring (Figure 3). This group was characterized by having a medium-high seasonality index (Table II). Predicted HAR was lower in the Winter, and climate risk indexes were higher in Winter and Autumn (Table II; Figure 3) compared to other seasons. In this sense, in Group 3, forage feeding complementation is necessary for the Winter, and climate risks in Winter and Autumn must be accounted for forage production planning at farm level, mainly in areas of low SWHCs. The Summer seems to be the best season to conserve forage, due both to its higher predicted production and lower predicted climate risk, when compared to other seasons. As low temperatures are the most limiting factor from the middle of Autumn until the middle of the Spring (Alvares et al. 2014), the use of temperate species, with lower basal temperature (e.g. ryegrass [*Lolium perenne* (L.)], oats [*Avena sativa* (L.)], and vetch [*Vicia sativa* (L.)]), in areas where low rainfall levels does not restrict its cultivation or where it is possible to irrigate may be an alternative to improve animal production (Oliveira 2007).

The northeast of Brazil (Group 4; Figure 2) had very high to medium-high seasonality, due to high predicted productions in Summer and Autumn and low predicted productions in Winter and, mainly, in Spring (Table II; Figure 3). Seasonal variation in predicted HARs are inversely proportional to SWHC (Table II) pointing that water availability is the main factor restricting pasture growth in this area. According to Alvares et al. (2014), mean annual rainfall in this area is less than 800 mm, and its occurrence is concentrated mainly in the first half of the year. Furthermore, while Winter presents medium to low climate risk indexes, Spring presents extreme high to high climate risk indexes as a consequence of interannual rainfall variation in the latter season. The cultivation of plant species better adapted to semiarid conditions (e.g. buffel grass (*Cenchrus ciliaris* (L.) and cactus pear *(Opuntia spp.)*), pasture management practices, forage conservation, irrigation, and animal feeding supplementation

are some alternatives to mitigate the risks of pasture-based animal production in this area (Leite 2002).

In our study, an empirical agrometeorological model was used to characterize forage production variation in space and time in Brazil. The use of empirical models limits its application to the same range of conditions as that of the independent variable for which it was parameterized. The forage production model used here was generated from data obtained with mean daily temperatures between 16.8 and 27.1° C, that is within the range of temperatures of the studied region (Marengo 2007, Chou et al. 2012, Alvares et al. 2014). Despite the parameterization of the model has been done with data of cycles with temperatures of up to 31.2 °C, there are uncertainties about model performance under temperatures closer or higher than this value, which could diminish performance in warmer regions. Unfortunately, no supra-optimal temperature studies have been performed for tropical grasslands. Furthermore, data used for the model parameterization were obtained from fertilized experiments with nitrogen at 300 kg ha^{-1} $year^{-1}$ of N and K_2O. The forage production model used here does not consider the effect of physical and chemical soil properties and pasture management and fertilization in forage production. Although empirical models using similar approach have provided good predictive capacity of HAR of tropical grasses under rainfed conditions (Cruz et al. 2011, Araujo et al. 2013, Pezzopane et al. 2013, 2016), there are limitations and uncertainties associated with the methods adopted by this work, once it considered only temperature and water balance as predictive factors (Pezzopane et al. 2016).

More mechanistic approaches and further investigations could improve the results and characterization of forage production in Brazil, and support decisions to reduce risks and improve returns of pasture-based animal production systems.

CONCLUSIONS

The characterization of *Brachiaria brizantha* cv. Marandu is helpful for the decision making process both at farm and regional levels. Cluster analysis successfully divided the country into four Groups for each soil water holding capacity (SWHC), according to its forage production patterns and variations. Forage production in the North of Brazil (Group 1) is less seasonal and associated with lower climate risk indexes than in the rest of the country. In the Middle West (Group 2) seasonal forage production is well determined, with HARs in the summer around 10 times higher than in the winter. *Brachiaria brizantha* cv. Marandu production is lower in the south of Brazil, in the north of the state of São Paulo, in the state of Minas Gerais and some regions in the northeast of the country (Group 3), mainly in the Winter. In the northeast (Group 4) *Brachiaria brizantha* cv. Marandu pastures are characterized by a low forage production associated with a high seasonality index and climate risk indexes.

The cultivation of plant species better adapted to each condition, pasture management practices, forage conservation, irrigation, and animal feeding supplementation are some alternatives to mitigate the risks of pasture-based animal production in the different areas of the country.

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