Ciência e Agrotecnologia
SCIENCE AND AGROTECHNOLOGY
Ciência e Agrotecnologia, 45:e008321, 2021
http://dx.doi.org/10.1590/1413-7054202145008321
Agricultural Sciences
eISSN 1981-1829

Thermal comfort of beef cattle in the state of Mato Grosso do Sul, Brazil

Conforto térmico de bovinos de corte no estado de Mato Grosso do Sul, Brasil

Rafaela Silva Cesca[1*], Rodrigo Couto Santos[1], Rafael Henrique de Tonissi e Buschinelli de Goes[1], Ana Paula Cassaro Favarim[1], Mario Sergio Garutti de Oliveira[1], Natália Coimbra da Silva[1]

[1]Universidade Federal da Grande Dourados/UFGD, Faculdade de Ciências Agrárias, Dourados, MS, Brasil
*Corresponding author: rafaela.s.cesca@gmail.com
Received in April 15, 2021 and approved in July 8, 2021

ABSTRACT

Evaluation of the comfort and animal welfare parameters enables determining the best environmental conditions for livestock creation. The present study was aimed to determine the thermal comfort index for beef cattle using interpolation techniques for the State of Mato Grosso do Sul during extreme summer and winter seasons for a period of 10 years. The analysis was performed on the climatic variables data provided by the National Institute of Meteorology, Brazil. The maximum (THI_{max}) and minimum (THI_{min}) temperature and humidity indices (THIs) of 28 weather stations distributed across the state were calculated, and the thematic maps of the THIs (maximum and minimum) calculated for the summer and winter seasons were prepared. The results revealed a state of emergency in the two largest animal-producing cities in the state; namely, Corumbá and Ribas do Rio Pardo, while two other cities, Chapadão do Sul and Costa Rica emerged as favorable regions for the production of beef cattle. The Spline method used in the present study, therefore, proved to be a suitable tool for analyzing a small number of weather stations distributed over a large territorial area.

Index terms: Ambience; animal welfare; Spline method; livestock.

RESUMO

A avaliação dos parâmetros de conforto e bem-estar animal permite determinar as melhores condições ambientais para a criação de gado. O presente estudo teve como objetivo determinar o índice de conforto térmico para bovinos de corte utilizando técnicas de interpolação para o Estado de Mato Grosso do Sul durante os períodos extremos de verão e inverno por um período de 10 anos. A análise foi realizada com base nos dados de variáveis climáticas fornecidos pelo Instituto Nacional de Meteorologia, Brasil. Foram calculados os índices máximo (ITUmax) e mínimo (ITUmin) de temperatura e umidade (ITUs) de 28 estações meteorológicas distribuídas pelo estado e elaborados os mapas temáticos dos ITUs (máximo e mínimo) calculados para os períodos de verão e inverno. Os resultados revelaram estado de emergência nas duas maiores cidades produtoras de animais do estado; a saber, Corumbá e Ribas do Rio Pardo, enquanto duas outras cidades, Chapadão do Sul e Costa Rica surgiram como regiões favoráveis à produção de gado de corte. O método *Spline* utilizado no presente estudo, portanto, mostrou-se uma ferramenta adequada para analisar um pequeno número de estações meteorológicas distribuídas em uma grande área territorial.

Termos para indexação: Ambiência; bem estar animal; método *Spline;* pecuária de corte.

INTRODUCTION

Brazilian agribusiness holds a prominent position globally due to its production systems, both grain, and animal, which account for over a quarter of the GDP (Gross Domestic Product) of Brazil (Centro de Estudos Avançados em Economia Aplicada - CEPEA, 2021). Animal production in Brazil includes the beef cattle industry, which boasts of the largest herd of cattle in the world, allowing Brazil to become the largest global exporter of meat and the second largest in terms of meat production after the United States of America (Associação Brasileira das Indústrias Exportadoras de Carne Industrializada - ABIEC, 2020).

The state of Mato Grosso do Sul (MS) is one of the largest beef producing regions in Brazil, ranking fifth in the country, with an inventory of approximately 20 million head, while its northernmost city Corumbá ranks second in the country, which demonstrates the economic representativeness of the state (Instituto Brasileiro de Geografia e Estatística - IBGE, 2019). There is a strong presence of beef cattle

ranching in all the physiographic regions of MS; however, the state is characterized by high temperatures throughout the year and high levels of insolation, and high solar incidence throughout the territory, as reported by Lovatto et al. (2020), and these inadequate climatic conditions could limit the productivity of beef cattle (Silva et al., 2020).

Cattle are homeothermic animals, i.e., they have the ability to control their body temperature within a limited range when exposed to huge variations in the environmental temperature, which is achieved via a physiological thermoregulation mechanism (Rashamol, 2018). Therefore, comfort indices are used for predicting the environmental conditions that the animals would be subjected to; this will avoid stress to the animals (Pezzopane et al., 2019).

Climate characteristics are among the factors that might limit meat production. According to Reis (2015) and Molento (2005), meat quality depends on various factors, such as animal race, transport, storage, and slaughter conditions, and is improved by the adoption of good animal management practices aimed at avoiding stress to animals and providing them welfare and better thermal comfort. The association of high temperature, high air humidity, and incident solar radiation might lead to undesirable behavioral and physiological changes in animals (Dash et al., 2016; Alam et al., 2013; Rashamol, 2018).

Owing to the productive potential of beef cattle in the state of Mato Grosso do Sul and the possibility of immense growth in this sector, it is necessary to advance the research related to animal welfare, along with the mapping of climatic conditions that these animals would be subjected to. Bioclimatic mapping is a technique that facilitates undertaking the right decisions regarding environmental management and thereby minimizing the stress caused to animals due to climatic conditions (Aparecido et al., 2016).

In this context, the present study was aimed to conduct the bioclimatic mapping for beef cattle in the state of Mato Grosso do Sul based on the Temperature and Humidity Index (THI) values.

MATERIAL AND METHODS

The state of Mato Grosso do Sul is the sixth largest state in Brazil, with a total area of 357,145 km². It is located in the central-western region of the country, between the coordinates LAT 20°45'0S and LONG 54°30'0W (IBGE, 2021). According to Köppen, the climatic classification of the state of Mato Grosso do Sul is Af (tropical equatorial), Am (tropical monsoon), Aw (tropical savanna), and Cfa (humid subtropical), with rainy summers and dry winters (Alvares et al., 2013).

In the present study, data on the average values of maximum temperature (T_{max}), minimum temperature (T_{min}), maximum relative humidity (RH_{max}), and minimum relative humidity (RH_{min}) of the air, at 28 automatic meteorological stations located in the state of Mato Grosso do Sul, were collected between January 2009 to December 2019. The data were provided by the National Institute of Meteorology (Instituto Nacional de Meteorologia - INMET, 2021) and are presented in Figure 1 depicted below.

The collected data were organized in spreadsheets and later developed into a database, which is being introduced as the International Geographic Coordinate System (IGS). Subsequently, using these data on T_{max}, T_{min}, RH_{max}, and RH_{min}, the values of maximum (THI_{max}) and minimum (THI_{min}) temperature and humidity indices were calculated for winter (June to September) and summer (December to March) seasons over a period of 10 years.

In order to verify the variability of the attributes, the descriptive statistics of T_{max}, T_{min}, RH_{max}, RH_{min}, THI_{max}, and THI_{min} were obtained using the Minitab 19® Statistical Software (MINITAB, 2017). The following were determined based on a comparison of summers and winters over the considered 10 years: mean, median, variation coefficient, asymmetry, and kurtosis.

Thematic maps and geoscience were employed for the climatic zoning of this region, including the Spline method, which is considered the best linear model adjusted in extensive regions with a reduced distribution of climatic seasons (Greco; Ventrucci; Castelli, 2018).

The Spline method was preferred for the present research as it provides better performance by dividing the polynomials into a series of data subsets and another series of small order polynomials for each of the subsets (Greco; Ventrucci; Castelli, 2018). The algorithm used in this kind of modeling is referred to as *Thin Plate Spline* (TIN) and is available in the QGIS 3.0.3® software. TIN interpolation uses sampling points to create a surface formed of triangles based on information from the nearest neighbor point (Duchon, 1976).

Therefore, interpolations of the values of temperature and humidity indices (THIs) were realized using the points of the meteorological stations and calculated using Equation 1, through map algebra, from the multiplication of all the factors in the equation using the *Raster* calculator tool in the QGIS 3.0.3® software. Equation 1 was originally proposed by Buffington, Collier and Canton (1982) and is presented below:

$$THI = 0.8dbt + RH\left(dbt - 14.3\right)/100 + 46.3 \quad (1)$$

where denotes dry bulb temperature (°C) and denotes relative humidity (%).

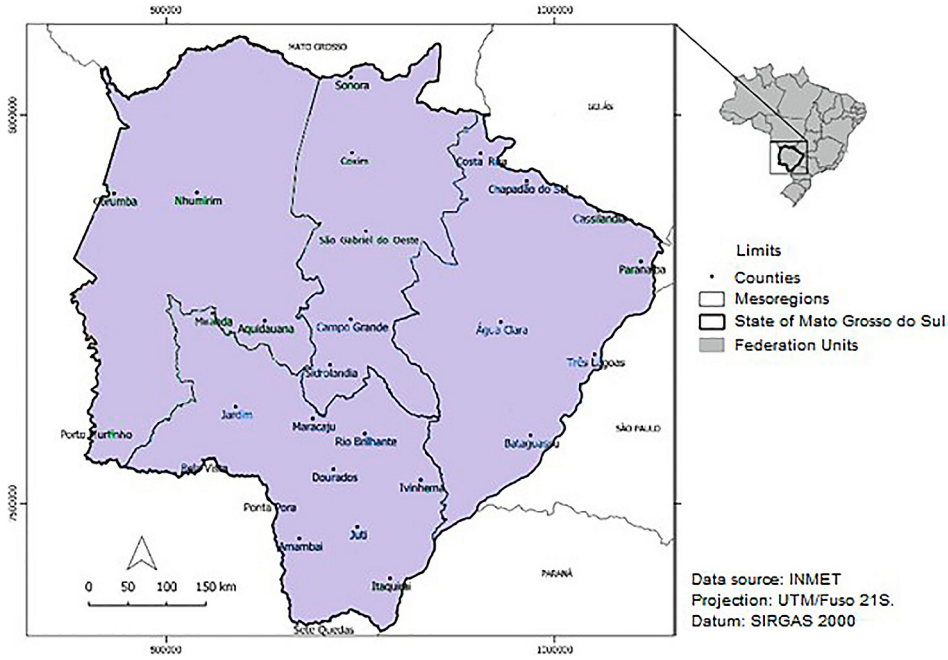


Figure 1: Automatic meteorological stations in the state of Mato Grosso do Sul.
Source: author.

After analyzing the values obtained from the values of THI_{max} and THI_{min}, thematic maps for the state of MS were prepared for summer and winter seasons, respectively, using the classification of limits proposed by Hahn (1985) for several breeds of beef cattle, as presented in Table 1.

Table 1: Temperature and humidity index (THI) levels for beef cattle.

THI level	Comfort situation
≤60.0	ALARMING
61.0–70.0	COMFORT
71.0–78.0	ALERT
79.0–83.0	DANGER
84.0	EMERGENCY

Adapted from Hahn (1985).

The THI classification corresponding to the comfort situation implies that the cattle are in an ideal state of well-being. The ALARMING situation implies that the cattle might have hypothermia. The ALERT situation indicates that the animals would exhibit stress and would be searching for water and shade. The DANGER situation implies that beef cattle are at the risk of death due to hyperthermia. The last classification, the EMERGENCY situation, indicates the death of the cattle.

The spatial dependence verification was realized according to the method reported by Dalchiavon et al. (2012), who used the ratio between the nugget effect (C0) and the threshold (C0 + C1), along with C1/(C0 + C1), to classify the Spatial Dependency Index (SDI) as follows: very low (SDI < 20%), low (20% ≤ SDI < 40%), medium (40% ≤ SDI < 60%), high (60% ≤ SDI < 80%), and very high (80% ≤ SDI ≤ 100%).

RESULTS AND DISCUSSION

The estimated values of the descriptive statistics corresponding to the average of the 10 years of the summer season are presented in Table 2.

Table 2 reveals that the mean and median values obtained for the summer season were close. The RH_{max} and THI_{max} values presented negative asymmetry, which demonstrated the negative oscillation of these variables. The kurtosis, which indicates the degree of concentration of a set of values distributed around a central value, was positive, which according to Giacalone (2020), is a Leptocurtic Kurtosis (kurtosis > 0). In other words, as the kurtosis presented values close to the obtained average, the THI data suggested a concerning situation in terms of thermal comfort.

The values of standard deviation and coefficient of variation which are measures of dispersion and indicate uniformity of the data were small, i.e., the data were close to the mean and could be considered uniform (Giacalone, 2020).

Similarly, the descriptive statistics corresponding to the average of 10 years of the winter season are presented in Table 3.

The analysis of the T_{min} and RH_{min} values revealed that these variables have high variation coefficient values, which indicates variability in the analyzed data. Asymmetry presented values close to zero, which indicates proximity between the mean and the median. The distribution (asymmetric) was positive during the winter season studied, which justifies applying the interpolation using the Spline method.

All the variables presented in Table 3 demonstrated Platicurtic Kurtosis (kurtosis < 0), with the T_{min} closer to the normal distribution.

In general, the statistics for the summer season (Table 2) and winter season (Table 3) demonstrated a weak spatial dependence of the analyzed indices. This could be because, as observed by Silva et al. (2020), when the distributions of the thermal variables and the indices in space are random, the studied variables present different degrees of spatial dependence.

The values obtained for T_{max} indicated that the state of MS has summers with high temperatures, ranging from 28.65 °C in Chapadão do Sul to 34.65 °C in Porto Murtinho stations. The maximum relative humidity (RH_{max}) values of 90.26% and 82.79% were obtained for Porto Murtinho and Sete Quedas stations, respectively.

The T_{min} values obtained indicated that the state of MS has winters with temperatures varying between 13.24 °C and 19.35 °C, in Amambai and Corumbá cities, respectively. The minimum relative humidity (RH_{min}) values were between 35.91% and 54.74%, in Nhumirim and Sete Quedas stations, respectively.

The ideal Thermal Comfort Zone (TCZ) for beef cattle must be delimited by the Upper Critical Temperature (UCT) of −6 °C and the Lower Critical Temperature (LCT) of 27 °C. In the TCZ, the animals do not require putting any effort in the form of thermoregulatory mechanisms and, therefore, do not feel hot or cold and are in total comfort (Oliveira; Knies, 2019).

When an animal is subjected to a temperature below the LCT, it is considered to be under cold stress. On the other hand, when it is subjected to a temperature above the UCT, it suffers from heat stress. Therefore, in the summer and winter seasons, the less adapted animals might feel serious discomfort or could even die due to the temperature conditions and relative humidity in the air (Avalo et al., 2019).

According to the IBGE (2019) data, Zebu (*Bos taurus indicus*) is the main genetic resource utilized in beef cattle production in the state of MS. Therefore, based on the report of Baêta and Souza (2010), who reported the UCT of 10 °C and the LCT of 27 °C, the T_{max} and T_{min} values obtained for the state of MS indicate situations of heat stress and cold stress to the animals.

Table 2: Descriptive statistics of the environmental variables and THI for the average summers.

Variable	N	Mean	SD	VC	Median	Asymmetry	Kurtosis
T_{max}	28	31.752	1.448	4.56	31.439	0.19	0.24
RH_{max}	28	87.228	1.824	2.09	87.585	-1.02	0.69
THI_{max}	28	86.900	2.140	2.46	86.522	-0.08	0.27

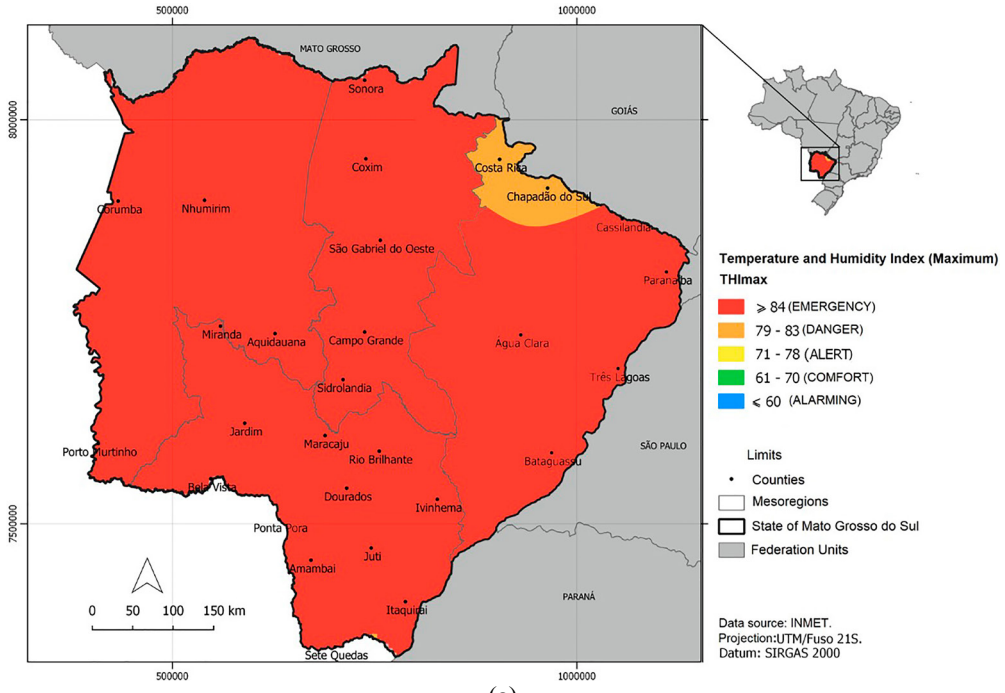
T_{max} (°C): Maximum air temperature; RH_{max} (%): Maximum relative humidity in the air; THI_{max}: Maximum Temperature and Humidity Index; N: Number of weather stations studied; SD (%): Standard deviation; VC (%): Variation Coefficient. N: Number of weather stations used for data acquisition.

Table 3: Descriptive statistics of the environmental variables and THI for the average winters.

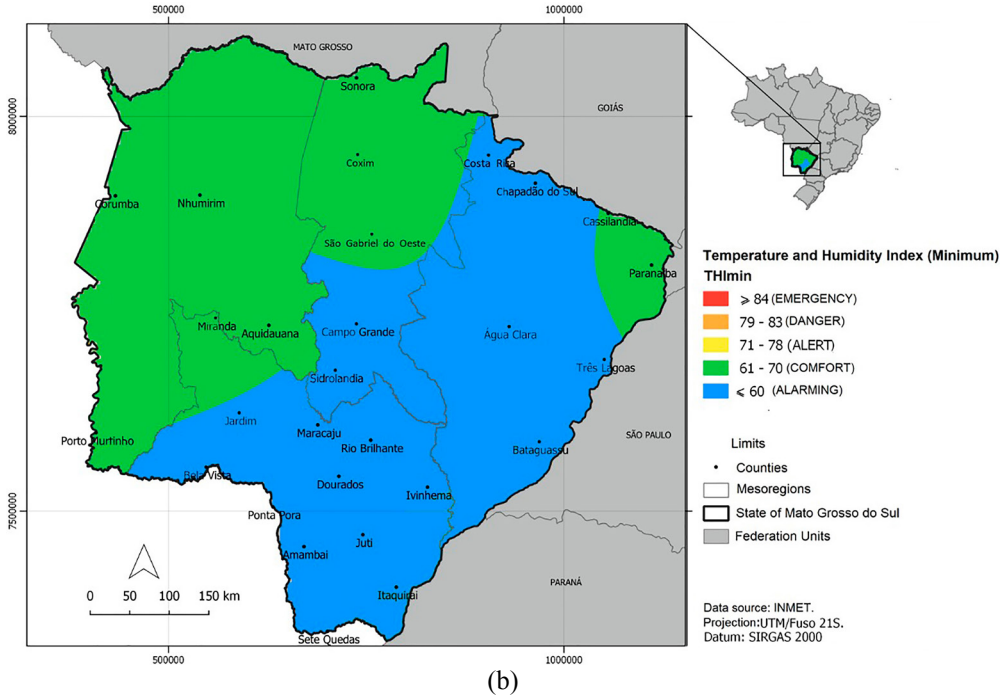
Variable	N	Mean	SD	VC	Median	Asymmetry	Kurtosis
T_{min}	28	15.885	1.648	10.37	15.770	0.33	-0.48
RH_{min}	28	44.78	5.53	12.34	45.36	0.03	-0.75
THI_{min}	28	59.551	1.971	3.31	59.608	0.35	-0.54

T_{min} (°C): Minimum air temperature; RH_{min} (%): Minimum relative humidity in the air; THI_{min}: Minimum Temperature and Humidity Index; N: Number of weather stations studied; SD (%): Standard deviation; VC (%): Variation Coefficient. N: Number of weather stations used for data acquisition.

Thematic maps prepared using the averages of the 10 years of the summer season and 10 years of the winter season are depicted in Figure 2 (a) and Figure 2 (b), respectively.



(a)



(b)

Figure 2: Thematic maps of the THI (a) maximum for the summers and (b) minimum for the winters in the state of MS during the studied 10 years.

The red color in the thematic map depicted in Figure 2 (a) indicates a situation of great emergency in the state of MS during the summer season. The regions highlighted in red included the Pantanal Sul-mato-grossense meso region, where the Corumbá city, which has the second-largest cattle herd in the country, is located, and the eastern meso region, where the Ribas do Rio Pardo city, which has the third-largest cattle herd in the country, is located (IBGE, 2019).

The other regions important for the livestock that were indicated in the situation of emergency were the Center–North and the Southwest meso regions; these regions contain a high number of municipalities and together rank second among the meso regions in terms of the number of cattle head (IBGE, 2019). The danger situation was indicated for only two regions – the Chapadão do Sul and Costa Rica. These data demonstrate that the animals in the state of MS are exposed to high-stress conditions during the summer season.

The winter season in the state of MS is mostly dry, with occasional frosts occurring in the months of July and August (Correa et al., 2020). The blue color in the thematic map depicted in Figure 2 (b) indicates an alarming situation for the state of MS during the harsh winter period. According to Hanh (1985), this situation corresponds to animals suffering from cold stress. The regions classified in the alarming situation included most of the Southwest meso region and the East, as well as the cities of Chapadão do Sul and Costa Rica.

However, for the harsh winter period, most regions in the state, including the Pantaneira meso region and part of the Northern meso region, were classified in the comfort situation, which is considered the best condition for cattle. These results indicate the possibility of stress to animals and even animal death due to hypothermia, mainly during the period of thermal inversion.

The Spatial Dependency Index (SDI) considers the geometric aspects of the semivariogram and encompasses all the characteristics of spatial dependence (Pinto et al., 2019). The semivariogram was calculated and subsequently utilized to obtain the medium spatial dependence index ($40\% \leq SDI < 60\%$). Barbieri et al. (2016) and Silva et al. (2020) also obtained similar results, separately, when working with the climatic classification of the states of Mato Grosso (MT) and Mato Grosso do Sul (MS), both with reference to the automatic weather stations.

CONCLUSIONS

The mean maximum and minimum values obtained in the present study indicate that Mato Grosso do Sul (MS) is a state with compromised regions for beef cattle production, where systems that would assist in providing adequate thermal comfort to the animals are required to be established. On the other hand, the regions of Porto Murtinho and Nhumirim in the state of MS are suitable for cattle production. Furthermore, the THI-based thematic map proved to be an efficient tool for analysis in the present study as it enabled the visualization and representation of the climate in the regions in relation to temperature and relative humidity in the air. In addition, the Spline method proved to be valuable for representing the thematic maps when there were few sampling units in the location being studied. It is noteworthy that the use of THI enabled a better understanding of the thermal comfort and welfare of beef cattle. However, to improve the production level of these animals, proper management strategies, such as specific diets and supplementations, animal race, shading, and good quality water, etc., are required.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contribution of Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-Brasil (CAPES), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Universidade Federal da Grande Dourados (UFGD) in the structural and financial support for the development of the present research.

REFERENCES

ALAM, M. et al. Effect of heat stress on behavior, physiological and blood parameters of goat. **Progressive Agriculture**, 22(2):37-45, 2013.

ALVARES, C. A. et al. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, 22(6):711- 728, 2013.

APARECIDO, L. E. D. O. et al. Köppen, thornthwaite and camargo climate classifications for climatic zoning in the State of Paraná, Brazil. **Ciência e Agrotecnologia**, 40(4):405-417, 2016.

ASSOCIAÇÃO BRASILEIRA DAS INDÚSTRIAS EXPORTADORAS DE CARNE INDUSTRIALIZADA - ABIEC. **Beef Report perfil da pecuária no Brasil 2020 (relatório anual)**. 2020. Available in: <http://abiec.com.br/publicacoes/beef-report-2020/>. Access in: January, 20, 2021.

AVALO, H. et al. Study of environmental thermal variation in vineyards harvested by different curtain colors used as lateral closure. **Interações**, 20(4):1139-1147, 2019.

BAÊTA, F. C.; SOUZA, C. F. **Ambiência em edificações rurais**. Viçosa: Editora da UFV. 2010. 246p.

BARBIERI, J. D. et al. Classificação de risco climático para o cultivo do amendoim no Estado de Mato Grosso. **Revista Espacios**, 37(8):25-36, 2016.

BUFFINGTON, D. E.; COLLIER, R. J.; CANTON, G. H. Shade management systems to reduce heat stress for dairy cows in hot, humid climates. **Transactions of the American Society of Agricultural Engineers**, 26(6):1798-1802, 1982.

CENTRO DE ESTUDOS AVANÇADOS EM ECONOMIA APLICADA - CEPEA. **PIB do agronegócio alcança participação de 26,6% no PIB brasileiro**. 2021. Available in: <https://cepea.esalq.usp.br/br/releases/pib-agro-cepea-com-avanco-de-24-3-no-ano-pib-agro-alcanca-participacao-de-26-6-no-pib-brasileiro-em-2020.aspx>. Access in: January, 20, 2021.

CORREA, H. C. R. et al. Agroclimatic zoning to species of eucalyptus genus in the State of Southern Mato Grosso do Sul. **Research, Society and Development**, 9(12):e4691210741, 2020.

DALCHIAVON, F. C. et al. Variabilidade espacial de atributos da fertilidade de um latossolo vermelho distroférrico sob sistema plantio direto. **Revista Ciência Agronômica**, 43(3):453-461, 2012.

DASH, S. et al. Effect of heat stress on reproductive performances of dairy cattle and buffaloes: A review. **Veterinary World**, 9(3):235-244, 2016.

DUCHON, J. Interpolation des fonctions de deux variables suivant le principe de la flexion des plaques minces. **RAIRO Analyse Numérique**, 10(12):5-12, 1976.

GIACALONE, M. A combined method based on kurtosis indexes for estimating p in non-linear Lp-norm regression, **Sustainable Futures**, 2:100008, 2020.

GRECO, F.; VENTRUCCI, M.; CASTELLI, E. P-spline smoothing for spatial data collected worldwide. **Spatial Statistics**, 27(1):1-17, 2018.

HAHN, G. L. Compensatory performance in livestock: Influence on environmental criteria. In: YOUSEF, M. K. (ed.). **Stress physiology in livestock**. Boca Raton: CRC Press, v.2, p.52-145, 1985.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. **Pesquisa da Pecuária Municipal**. 2019. Available in: <https://sidra.ibge.gov.br/tabela/3939>. Access in: January, 20, 2021.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. **Portal de mapas do IBGE**. 2021. Available in: <https://portaldemapas.ibge.gov.br/portal.php#mapa408>. Access in: January, 20, 2021.

INSTITUTO NACIONAL DE METEOROLOGIA - INMET. **Mapa das estações**. 2021. Available in: <https://mapas.inmet.gov.br/>. Access in: January, 20, 2021.

LOVATTO, J. et al. Use of linear programming for decision making: An analysis of cost, time and comfort of rural housing dwellings. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 24(9):622-629, 2020.

MINITAB. **Statistical software for windows**. Release 19.1 (64-bit). 2017. MINITAB. State College: Minitab Inc. Available in: <https://minitab.com/>. Access in: July, 15, 2021.

MOLENTO, C. F. M. Welfare and production animal: Economic aspects-review. **Archives of Veterinary Science**, 10(1):1-11, 2005.

OLIVEIRA, Z. B.; KNIES, A. E. Análise bioclimática e investigação do conforto térmico em ambiente externo na região central do RS. **Energia na Agricultura**, 34(3):377-388, 2019.

PEZZOPANE, J. R. M. et al. Animal thermal comfort indexes in silvopastoral systems with different tree arrangements. **Journal of Thermal Biology**, 79:103-111, 2019.

PINTO, L. O. et al. Avaliação de índices de dependência espacial de modelos geoestatísticos sobre a krigagem. **Enciclopédia Biosfera**, 16(29):339-352, 2019.

RASHAMOL, V. P. Adaptabilidade fisiológica da pecuária ao estresse térmico: Uma revisão atualizada. **Journal of Animal Behavior and Biometeorology**, 6(3):62-71, 2018.

REIS, J. G. M. et al. Financial losses in pork supply chain: A study of the pre-slaughter handling impacts. **Engenharia Agricola**, 35(1):163-170, 2015.

SILVA, N. C. et al. Enthalpy thematic map interpolated with spline method for management of broiler chicken production. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 24(7):431-436, 2020.