ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
v.24, n.7, p.431-436, 2020
Campina Grande, PB, UAEA/UFCG – http://www.agriambi.com.br

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v24n7p431-436

Enthalpy thematic map interpolated with spline method for management of broiler chicken production

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ABSTRACT: Owing to the exponential growth of the human population and problems related to food supply, research focused on finding the most suitable approach to manage and geographically explore the environment using sustainable technologies stand out. The present study aims to produce a consistent interpolation of historical series of enthalpy (H) resulting in a thematic map of enthalpy, using the spline method as a kriging option in areas with few sampling points. The thematic map considers thermal comfort conditions to produce broiler chickens, that could be used as a management tool to reduce power consumption due to the cooling process of the facilities. It was verified that spline is an efficient method to create a suitable thematic maps representations of areas presenting a few sampled units. The geographical representation of enthalpy allowed the evaluation of the environments, concluding that the state of Mato Grosso do Sul, Brazil is inadequate for broiler chickens production without suitable thermal cooling systems. Evidence suggests introduction of aviculture in areas still unexplored, e.g., Chapadão do Sul and Sete Quedas.

Key words: map algebra, geo-technology, aviculture, climate changes

Mapa temático de entalpia interpolado com método spline para gerenciamento da produção de frangos de corte

RESUMO: Devido ao aumento exponencial da população humana e aos problemas relacionados ao suprimento de alimentos, destacam-se pesquisas que buscam encontrar a melhor maneira de gerenciar e explorar geograficamente o meio ambiente, utilizando tecnologias sustentáveis. Este estudo visa possibilitar uma interpolação consistente de séries históricas de entalpia (H), utilizando o método spline como opção de krigagem em áreas com poucos pontos de amostragem, a fim de produzir um mapa temático da entalpia, considerando as condições de conforto térmico para produzir frangos de corte, que poderá ser utilizado como ferramenta de manejo, visando reduzir o consumo de energia devido ao processo de resfriamento das instalações. Verificou-se que spline é um método eficiente para criar uma representação adequada de mapas temáticos de áreas que apresentam poucas unidades amostradas. A representação geográfica de entalpia permitiu a avaliação dos ambientes, concluindo que o Mato Grosso do Sul é um Estado onde a produção de frangos de corte torna-se inviável sem sistemas apropriados de resfriamento térmico, o que corrobora a sugestão de introdução da avicultura em áreas ainda inexploradas, como Chapadão do Sul e Sete Quedas.

Palavras-chave: álgebra de mapa, geotecnologia, avicultura, mudanças climáticas

Editor responsible: Walter Esfrain Pereira
Ref. 224329 – Received 21 May, 2019 • Accepted 05 May, 2020 • Published 30 May, 2020

Introduction

Inadequate climatic conditions reduce the productivity and reproduction performance of animals, especially in tropical regions. According to Mazahreh et al. (2019), climate databases created using Geographic Information System (GIS) enable to perform the bioclimatic zonation of a region, supporting the supervision of eventual changes and acting as an environment tool used to improve agricultural production.

Dornellas et al. (2017) used map algebra to calculate parameters which characterize spatial dependence structures of climatic variables through the elaboration of thematic maps that use the interpolation method. Greco et al. (2018) considered that when several environmental studies are involved, an alternative to kriging techniques is the spline method, since it interpolates the function f(x) in groups presenting few knots.

According to Mitchell et al. (2018), when thematic maps are used to assess the ecosystem and to perform spatial planning correctly, it is important to verify the accuracy in which they have been produced to ensure suitability for the intended purpose. Thus, map algebra stands out as a management tool for the animal production sector.

The world production of broiler chickens is estimated at 103.5 million tons of chicken meat in 2018, and the thermal stress causes economic losses from US$ 128 to US$ 165 million per year, only in the poultry industry. In this sense, innovations are increasingly necessary to improve the quality of products (Nawab et al., 2018).

Considering its importance in the Brazilian agriculture production and the reduced number of climate stations distributed over its large territorial extension, the state of Mato Grosso do Sul, Brazil can be used as a reference to evaluate the consistency of the spline method as an interpolator. Therefore, this research aimed to use the spline method to interpolate historical series of enthalpy means from summer periods in the state of Mato Grosso do Sul, Brazil to produce a thematic map of the enthalpy, providing an overview of the most suitable areas for production, considering energy expenditure for thermal cooling.

Material and Methods

The study was performed in the Mato Grosso do Sul (MS) state, Brazil (17º 0' 00" W, 58º 0' 00" S, altitude between 200 and 600 m), with climate Monsoon Am, dry winter, according to Köppen classification, annual mean precipitation of 1500 mm and annual mean temperature of 22 ºC (Alvares et al., 2013).

The thematic map has been produced based on the information provided by the Instituto Nacional de Meteorologia (INMET, 2018). In this context, the general of the 28 automated weather stations (Figure 1) in MS, Brazil has been established based on the hourly averages of the temperature of air (Ta) and the relative humidity of air (UR) - recorded 24 h a day, through official summer periods (90 days each), from 2001 to 2017.

Data provided by INMET were registered in electronic spreadsheets to be statistically assessed and read by GIS, in database format.

Figure 1. Mesoregions map showing INMET automated positions of the station in the state of Mato Grosso do Sul (MS), Brazil

Using the software Minitab 17® (Minitab, 2014), the maximum and minimum means of Ta have been analyzed, considering each summer period from 2001 to 2017. The mean, median, variance, kurtosis, and asymmetry have been estimated.

Theoretical estimators and the description of the spatial dependence structure are influenced by geodesic distance, shape, and sample size. Thus, since the geographical place presents few heterogeneous samples (different automated weather stations), the spline method adopted to be used in the research does not use a high order polynomial to interpolate data. The spline template adopted had a degree of one, which according to Kunoth et al. (2018), can be defined as a set of linear functions, where:

$$f(x) = f(x_0) + m_0(x - x_0), \text{ for } x_0 \le x \le x_1 \quad (1)$$

$$f(x) = f(x_1) + m_1(x - x_1), \text{ for } x_1 \le x \le x_2 \quad (2)$$

$$f(x) = f(x_{n-1}) + m_{n-1}(x - x_{n-1}), \text{ for } x_{n-1} \le x \le x_n \quad (3)$$

where:

f(x) - linear interpolator polynomial between points x_0 and x_{n-1};

$x_0, x_1, ..., x_{n-1}$ - consecutive points of interpolated geographical location;

m_i - angular coefficient of the straight line that connects the dots in the range $m_0 \le m_i \le m_{n-1}$;

n - 1, 2, 3, ..., natural numbers, each point in the range;

m_0 - first point in the range considered;

m - first point in the range considered; and,

$$m_i = \frac{f(x_{i+1}) - f(x_i)}{x_{i+1} - x_i}, \text{ with } 0 \le i \le n-1 \quad (4)$$

The function f(x) can be calculated using these equations at any given point between x_0 and x_n.

The general mean spatialization of the local meteorological data Ta and UR has been calculated using function Topo to Raster from ArcGis Desktop® (ESRI, 2015) as the interpolator of the 28 automated stations in MS, Brazil. The general mean index H for each station has been established by Raster calculator, adopting a similarity parameter of 32 pixels and using Eq. 5, proposed by Barbosa Filho et al. (2007).

$$H = \left[6.7 + 0.243Ta + \left(\frac{UR}{100} 10^{\frac{7.5Ta}{237.3+Ta}} \right) \right] 4.18 \qquad (5)$$

where:

H - enthalpy, kJ kg^{-1} dry air;
Ta - air temperature, ºC; and,
UR - air relative humidity, %.

Spatial dependence analysis was performed according to Dalchiavon et al. (2012), who use the ratio between nugget effect (C0) and baseline (C0 + C1) - where C1/(C0+C1) - to classify the Spatial Dependence Index (SDI) as very low (SDI < 20%), low (20 ≤ SDI < 40%), medium (40 ≤ SDI < 60%), high (60 ≤ SDI < 80%) and very high (80 ≤ SDI ≤ 100%).

The mean enthalpy (H) thematic map was organized with ranges comprised of comfort and stress levels, established by Barbosa Filho (2008), considering the 6-weeks poultry, according to Table 1.

As an enthalpy (H) thematic map interpolated with the spline method has been created, geosciences and environment principles can be used to assess the thermal comfort conditions of the region studied, and to determine if the technique used elicits a precise management tool to this productive sector.

Table 1. Comfort ranges of enthalpy, considering the production of the 6-weeks fowls

Enthalpy (H) (kJ kg^{-1} dry air)	Comfort situation
37.4-52.1	NORMAL
52.2-63.0	CAUTION
63.1-72.6	WARNING
≥ 72.7	DANGER

Results and Discussion

According to Table 2, the maximum mean value of the temperature of air (Ta) observed in Mato Grosso do Sul state, Brazil, during the summer periods studied was 35.17º in Sonora (2013-2014), and de minimum, in Rio Brilhante, was 16.73º (2003-2004). The slightest temperatures among the minimum ones were recorded since the means were calculated considering daily values, probably recorded during nighttime.

Studies reported by Ibtisham et al. (2018) noticed a mean value reduction of 16.4% in the chicken feed consumed by the animals housed in an unsuitable environment when compared to those housed in thermoneutral ambiance, in which air temperature was around 20 ºC. Therefore, Table 2 shows that, historically, Mato Grosso do Sul state, Brazil presents an unsuitable environment for poultry production.

Maximum mean of the relative air humidity (UR) during the summer periods was 92.89% in Bataguassu (2007-2008) and the minimum mean 34.60% in São Gabriel do Oeste (2001-2002) (Table 2). Studies reported by Rico-Contreras et al. (2017) state that behavior variables are influenced by UR, increasing stress behavior occurrences in very humid environments, causing significant losses. According to Xiong et al. (2017), the UR recommended for broiler chickens ranges from 50 to 70%. Thus, the state of Mato Grosso do Sul, Brazil presents UR out of the comfort zone, which should be regulated by controlling ambiance procedures.

Table 3 presents the descriptive statistics of maximum (Tmax) and minimum (Tmin) temperatures, performed based on the assessment of their effects through mean, median, variance, kurtosis, and asymmetry.

From Table 3, it can be observed that the mean and median of Tmax are higher than it is recommended for broiler chicken production. Therefore, the state of Mato Grosso do Sul, Brazil presents, historically, an unsuitable thermal environment, which requires air-conditioning during summers.

A coefficient of variation is considered low if presents values less than 12%; medium, if ranging from 12 to 24%; and high, if higher than 24% (Massari et al., 2016). Thus, the coefficient of variation was recorded as high for Tmax (54.80%) and medium

Table 2. Mean maximum (Tmax) and minimum (Tmin) temperatures values and mean maximum (URmax) and minimum (URmin) relative air humidity during the summer periods of 2001_2002 and 2016_2017

Summer periods	Climatic variables							
	Tmax (ºC)	City	Tmin (ºC)	City	URmax (%)	City	URmin (%)	City
2001_2002	32.67	Coxim	17.13	Chapadão do Sul	91.67	Aquidauana	34.60	São Gabriel do Oeste
2002_2003	32.98	Corumbá	17.01	Costa Rica	91.84	Corumbá	37.40	Itaquirai
2003_2004	33.22	Sonora	16.73	Rio Brilhante	89.26	Porto Murtinho	38.40	Maracaju
2004_2005	32.81	Coxim	17.23	Chapadão do Sul	92.01	Nhumirim	34.83	Amambai
2005_2006	32.86	Aquidauana	17.42	Amambai	90.83	Corumbá	39.59	Maracaju
2006_2007	32.98	Miranda	17.94	Maracaju	92.08	Miranda	39.20	Coxim
2007_2008	33.04	Corumbá	17.61	Costa Rica	92.89	Bataguassu	40.05	Ponta Porã
2008_2009	33.92	Aquidauana	18.22	Rio Brilhante	90.91	Porto Murtinho	38.33	Cassilândia
2009-2010	34.03	Sonora	18.08	Amambai	91.81	Sonora	36.62	Juti
2010_2011	33.93	Bataguassu	17.52	Ponta Porã	91.65	Porto Murtinho	37.30	Paranaíba
2011_2012	33.52	Bela Vista	17.04	Sete Quedas	90.06	Nhumirim	40.10	Coxim
2012_2013	34.46	Miranda	17.52	Sete Quedas	89.98	Miranda	38.00	Coxim
2013_2014	35.17	Sonora	17.87	Ponta Porã	92.82	Nhumirim	39.38	Amambai
2014_2015	34.44	Miranda	17.14	Amambai	92.39	Aquidauana	41.08	Maracaju
2015_2016	34.11	Três Lagoas	17.45	Sete Quedas	93.41	Bataguassu	36.98	Juti
2016_2017	34.25	Aquidauana	17.41	Amambai	93.18	Porto Murtinho	37.68	Água Clara

Table 3. Descriptive statistics of maximum (Tmax) and minimum (Tmin) temperatures in different summer periods

	Tmax	Tmin
	(ºC)	
Number of stations	28	28
Number of summers	16	16
Mean	33.65	17.46
Median	33.72	17.44
Coefficient of variation (%)	54.80	17.13
Standard error	0.74	0.41
Kurtosis	-0.80	-0.50
Asymmetry	0.38	0.26

for Tmin (17.13%). Considering that variance shows how far from the mean the values are, it can be affirmed that the thermal amplitude around Tmax were higher, which is confirmed by the values for both differences between mean and median of Tmax and Tmin values.

The smaller the standard deviation, the more homogeneous it is a sample. That is, Tmax thermal amplitude was higher than Tmin. From the mean environment variables of summer periods in the state of Mato Grosso do Sul, Brazil registered in Table 2, it can be observed that there was no climate variation pattern through the years. However, heat islands were observed. According to studies performed by De-Salamanca et al. (2017), the presence of heat islands is characterized by thermal amplitude variation of environments, which suggests a process of adaptation to climate changes.

Kurtosis measures indicate the concentration degree of a set of values distributed around a central value. Both cases are called Platykurtic (kurtosis < 0), and Tmin is closer to ordinary distribution values. Silva et al. (2017) state that when thermal variable distribution and indexes in space are random, they present a low spatial dependence degree.

Positive values of Tmax asymmetry (0.38) and Tmin asymmetry (0.26) indicate that the right tail is larger than the left one. This can be regarded as a positive oscillation of temperatures during the period studied, where Tmax increased more than Tmin.

Due to the small number of climate stations in the state of Mato Grosso do Sul, Brazil, Ta and UR data used for enthalpy (H) calculation, presented a great spatial variability. According to Tang et al. (2018), the smaller the spatial dependence, the higher is the nugget effect over data oscillation consequently, the worse kriging estimates when producing the maps. This fact vouches for spline method usage in this mapping research with few sampling points.

Based on the spatial dependence analysis, the semivariograms fitted the presented mean SDI (40 ≤ SDI < 60%). Similar results were elicited by Barbieri et al. (2016), who detected more incidence of mean SDI values among the variables analyzed, considering the automated weather stations when working with the climate classification in Mato Grosso Sul, another Brazilian state. The results show low spatial dependence.

The thematic map represented by Figure 2 was produced interpolating mean enthalpy (H) values, from the summer periods under analysis with the spline method and curves following spherical and exponential patterns. Based on spatialization analysis using geostatistical methods, Kestring et al. (2015) stated that places where spatial dependence is not

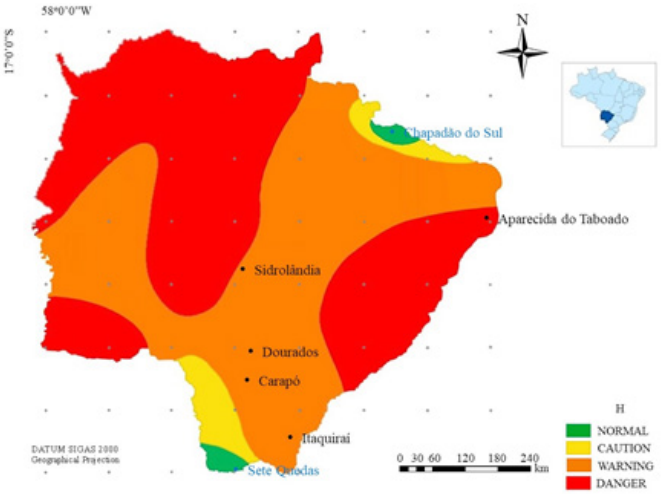

Figure 2. The enthalpy thematic map presenting the mean of summer periods from 2001 to 2017 in the state of Mato Grosso do Sul, Brazil

high, kriging should be avoided, and where it is medium, the best models to adjust curves in thematic maps are the spherical and the exponential.

The enthalpy represents an exothermal reaction and can be used as a tool to indicate the amount of thermal energy in the air, over the animal, and to be removed from the ambiance to improve comfort conditions. It also provides welfare rates and productive and reproductive outcomes, assessing management decision-making (Fournel et al., 2017).

Figure 2 shows the different comfort levels in poultry production in the state of Mato Grosso do Sul, Brazil, based on the mean H index, presented in different colors according to a specific stress situation: comfort, caution, warning, and danger. Similar to research reported by Santana et al. (2018), the obtained values of H classified as caution and warning, causing the reduction of: feed and water consumption and production of endogenous heat and feed conversion, directly affecting poultry production.

As Mato Grosso do Sul, Brazil is geographically well located and presents an elevated grain production, it has great potential to advance in poultry production. However, one of the major barriers is the inadequate climate. Five major production centers are located in the cities of Sidrolândia, Dourados, Caarapó, Itaquiaraí, and Aparecida do Taboado, and due to demand rise, there is a possibility of expanding poultry sector to other areas still unexplored (FAMASUL, 2018).

It can be observed from Figure 2 that among the major broiler chicken producers, in MS, Brazil Sidrolândia, Dourados, Caarapó, and Itaquiraí face a warning situation (from 63.1 to 72.6 kJ kg^{-1} dry air). Aparecida do Taboado is classified as in a dangerous situation (≥ 72.7 kJ kg^{-1} dry air). Rovaris et al. (2014) suggest using comfort indexes with parameters to activate and control thermal cooling systems and mitigate external environment effects overproduction to obtain a more effective environment control.

According to the thematic map presented in Figure 2, from the climatic point of view, Chapadão do Sul (North) and Sete Quedas (South) present a more adequate climate to broiler chicken production than the other cities, with mean H considered normal (from 37.4 to 52.1 kJ kg^{-1} dry air). This

indicates that these regions are new productive centers since they require less power consumption for facility cooling, which causes costs reduction. Constantino et al. (2018) demonstrated that the intensive production of broiler chickens consumes high levels of power, when aiming the welfare of animals. This endorses expanding poultry to areas with a more appropriate climate.

When using H to assess comfort, it can be observed from Figure 2 that most parts of the regions were classified as warning and danger levels. Tavares et al. (2016) also used H to map comfort levels in Brazil and concluded that most regions were classified as discomfort levels. This confirms that H index thematic maps used to analyze thermal environments are also useful to sustainably manage the production.

Conclusions

1. Spline method is an adequate GIS tool for interpolating historical series and generating thematic maps of the state of Mato Grosso do Sul, Brazil.

2. It was observed that there was no pattern of climate variation over the years, but it is possible to state that there were heat pockets with historical highs concentrated in the Northern Mato Grosso do Sul, Brazil.

3. Based on the enthalpy thematic map produced in this study, it can be concluded that the five major centers producing broiler chickens in the state of Mato Grosso do Sul, Brazil are located in areas where climate is inadequate.

4. From the data, places that have not yet been explored, may be suggested for the introduction of aviculture as Chapadão do Sul (North) and Sete Quedas (South).

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