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ORIGINAL ARTICLE

Thermal comfort zoning and its impact on dairy production in Rio Grande do Sul state, Southern Brazil

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Abstract - Thermal comfort is one of the main factors that influence the productivity of dairy cattle. The temperature-humidity index (THI) is one of the most used indicators to evaluate thermal comfort levels. This work aimed to evaluate the levels of thermal comfort for bovine dairy production in Rio Grande do Sul state through the THI calculation and its impact on milk production, considering daily yields of 15 kg and 30 kg per cow. The THI values and decrease in milk yield were calculated using data between 1990 and 2021 from the National Institute of Meteorology (INMET). The observed results considering the average temperatures showed that conditions of thermal discomfort occur only in summer, intensifying in January. Milk production was most affected in the western border region of the state, corresponding in parts to the physiographic regions of Alto Uruguai, Missões, and Campanha, which have a warmer climate. The climate classification proposed by Maluf had the best spatial correspondence with the ITU. This classification may be used in the evaluation of places with greater suitability for dairy farming in the state and to indicate places where it is necessary to implement action to mitigate the effects of thermal discomfort in dairy cattle.

Keywords: Temperature-humidity index. Decrease in milk yield. Average temperature. Relative humidity.

Zoneamento do conforto térmico e seu impacto sobre a produção leiteira bovina no estado do Rio Grande do Sul, Sul do Brasil

Resumo - O conforto térmico é um dos principais fatores que influencia a produtividade do gado leiteiro. O índice de temperatura e umidade (ITU) é um dos indicadores mais utilizados para avaliar os níveis de conforto térmico. O presente trabalho teve como objetivo avaliar os níveis de conforto térmico para a produção leiteira bovina no estado do Rio Grande do Sul através do cálculo do ITU e seu impacto na produção de leite, considerando rendimentos diários de 15 kg e 30 kg por vaca. Os valores de ITU e diminuição da produção de leite foram calculados a partir de dados do Instituto Nacional de Meteorologia (INMET) entre 1990 a 2021. Os resultados observados considerando as temperaturas médias mostraram que as condições de desconforto térmico ocorrem apenas no verão, que se intensifica em janeiro. A produção de leite foi mais afetada na fronteira oeste do estado, correspondendo parcialmente às regiões fisiográficas do Alto Uruguai, Missões e Campanha, que possuem clima mais quente. A classificação climática proposta por Maluf apresentou a melhor correspondência espacial com os valores da ITU. Essa classificação pode ser utilizada na avaliação de locais com maior aptidão para a pecuária leiteira no estado e para indicar locais onde é necessário implementar ações para mitigar os efeitos do desconforto térmico sobre o gado leiteiro.

Palavras-chave: Índice de temperatura e umidade. Declínio da produção de leite. Temperatura média. Umidade relativa.

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Introduction

The State of Rio Grande do Sul is one of the main dairy centers of Brazil. In 2020, the state was responsible for the production of 3.32 billion liters of bovine milk, corresponding to 13.0 % of Brazilian production, which was 25.53 billion liters of milk in the same period. In this scenario, Rio Grande do Sul is the third Brazilian state by production volume, being surpassed only by the states of Minas Gerais and Paraná (IBGE, 2021).

However, to maximize dairy production and yield, the cattle must be in conditions that stimulate and facilitate metabolism and minimize energy expenditures. Beyond the nutritional factors and disease protection, thermal comfort is one of the main factors that impact milk production not only in cattle but in mammals in general (HAHN, 1993; KLOSOWSKI *et al.*, 2002; OLIVEIRA *et al.*, 2017a).

Thermal comfort is influenced by air temperature and relative humidity. Higher temperature and humidity tend to cause thermal discomfort because, under these conditions, the cooling mechanism through sweat evaporation loses efficiency, making it difficult for the animal to maintain thermal homeostasis through heat loss (OLIVEIRA *et al.*, 2017b).

Since lactation is an exothermic process, animals in conditions of thermal discomfort caused by high temperatures show impairments in lactation metabolism, causing a decline in milk production. In addition, under conditions of thermal discomfort, the activity of the thyroid gland is reduced, which leads to a decrease in the animals' appetite, which also negatively affects milk production (KLOSOWSKI *et al.*, 2002; OLIVEIRA *et al.*, 2018). Therefore, the effect of climate on thermal comfort and its impact on dairy production, by direct or indirect mechanisms, is indisputable and its quantification becomes important both at an economic level and aiming at animal welfare (FELBERG *et al.*, 2017; KEMER *et al*., 2020).

Alvares *et al.* (2013) and Valério *et al.* (2017) determined that the area of Rio Grande do Sul state encompasses the Cf climate type (humid subtropical climate), which is divided into three subtypes: Cf (hot summer), Cfb (warm/mild summer), and Cfc (cold summer). Most of the state is classified as Cfa (hot summer), except for the northeast area and smaller high-altitude areas to the south, which are classified as Cfb (mild summer). The Köppen climate classification for Rio Grande do Sul state is presented in Figure 1(A).

Fortes (1959) proposed the division of Rio Grande do Sul state into eleven physiographic regions, based on climatic and geographic factors. The physiographic regions of Rio Grande do Sul are shown in Figure 1 (B). Analyzing both maps, it is possible to note differences between the climatic and physiographic distributions, where the regions of Campos de Cima da Serra, Encosta Superior do Nordeste, and part of the regions of Encosta Inferior do Nordeste and Planalto Médio (regions of higher altitude) have a Cfb climate type (warm/mild summer), while the rest of the state is classified as Cfa climate (hot summer). In this sense, other climatic classifications for the state were proposed (Figure 2), such as those by Maluf (2000) and Rossato (2020), which considered other factors, such as water balance, altitude, acting atmospheric systems in the area, and other climatic factors, with more detailed data available to refine their models.

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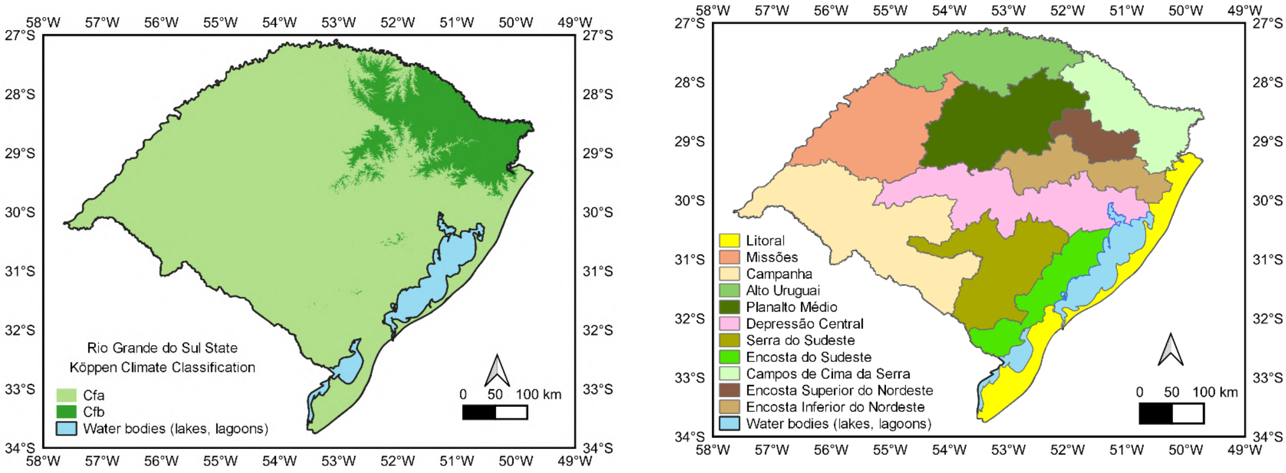
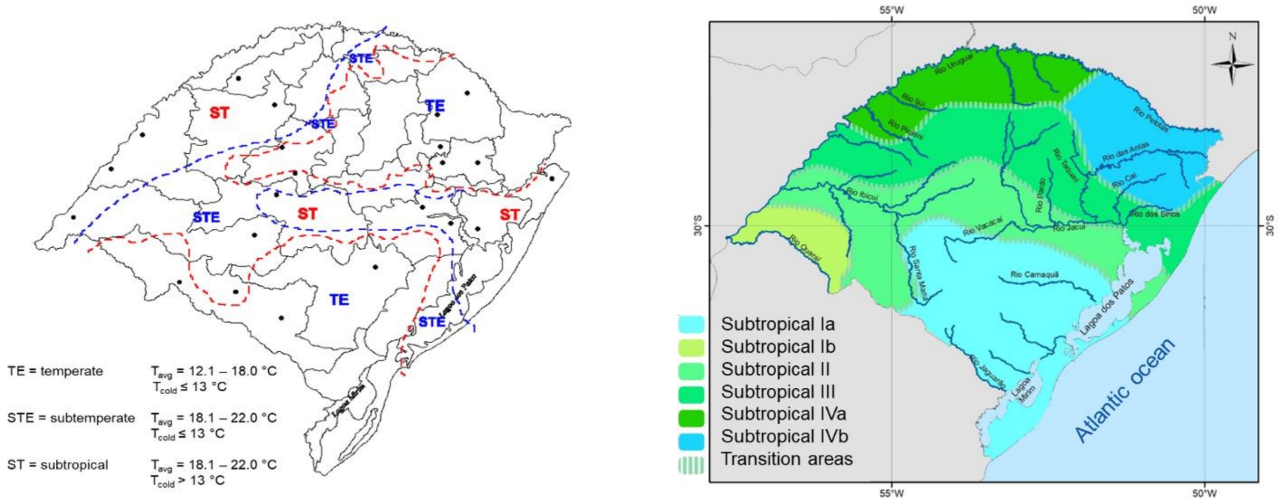


(A) (B)

Figure 1. Köppen climate classification for Rio Grande do Sul state according to Alvares *et al.* (2013) (A) and the distribution of the state physiographic regions in accordance with Fortes (1959) (B).



(A) (B)

Figure 2. Climate classifications proposed by Maluf (2000) (A) and Rossato (2020) (B) for Rio Grande do Sul state. T_{avg}: average yearly temperature; T_{cold}: average temperature of the coldest month. Subtropical Ia: dry with cold winter and mild summer; Subtropical Ib: dry with cold winter and hot summer; Subtropical II: average humidity with a longitudinal variation of the average temperatures; Subtropical III: humid with a longitudinal variation of the average temperatures; Subtropical IVa: very humid with mild winter and hot summer; Subtropical IVb: very humid with cold winter and mild summer.

Therefore, more recent and more detailed climatic classification can better reflect the regional particularities of the state, considering that thermal comfort (or discomfort) is the result of the interaction between several climatic parameters and the organisms exposed to these conditions. Among the climatic

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factors, air temperature and relative humidity are those with the highest influence on thermal comfort (HAHN, 1993; KLOSOWSKI *et a*., 2002; TURCO *et al*., 2006).

An indicator of thermal comfort commonly used is the temperature-humidity index (THI). This indicator is calculated from the combined effects of air dry bulb temperature and relative humidity (KLOSOWSKI *et al.*, 2002; TURCO *et al.*, 2006; OLIVEIRA, 2017a). Thus, the THI can be used as a parameter to assess the impact of thermal comfort on milk production (HAHN, 1993; TURCO *et al.*, 2006).

Oliveira *et al.* (2017a), in a similar study using historic data from 1961 – 1990, observed that, even in the hottest period of the year (December to February), the THI in the state would not exceed 76. This indicates that although thermal discomfort causes a decline in milk production, the losses would be restricted to the northwest border area of the state, with maximum losses in the range of 14 – 17 % in January, the hottest month of the year.

Kemer *et al*. (2020) observed for Santa Catarina state (Southern Brazil) that, except for specific periods in summer, the THI levels would be considered 'ideal'. Thus, the variation of climatic conditions would have a minimal impact on the thermal comfort of dairy cattle in this Brazilian state, with no negative effects on milk production in this region. Felberg *et al.* (2017) also observed similar behavior in the State of Espírito Santo (Southeast Brazil).

However, as raised by Oliveira *et al.* (2018), climate change caused by global warming can have long-term deleterious effects on dairy production in Rio Grande do Sul state. These authors, extrapolating data from the climate normal of 1961 – 1990, studied potential scenarios caused by global warming and observed, in the simulations performed, that THI values in summer would move to alert (THI between 70 and 80) and danger (THI above 80) ranges, with production losses of up to 30 % in the periods with higher temperature and humidity. In addition, it is also important to note that there are no specific studies in the literature that addressed the climate data of Rio Grande do Sul state for the period of 1991 – 2021, in which the changes caused by increasing global warming can be evaluated and their impact on dairy production quantified.

The present study aimed to determine the THI and decline in milk yield (DMY) values for Rio Grande do Sul state in all four seasons, as well as in the hottest month of summer (January), to determine the impact of the variation in air temperature and relative humidity on the thermal comfort and dairy production in the state.

Materials and Methods

Daily weather data from INMET (2022) from all available weather stations of Rio Grande do Sul state, corresponding to the period of the last 30 years (1991 – 2021), were used in the determination of THI and DMY values. At stations where 30-year data was not available, the available data from the period between 1991 and 2021 was used.

The THI values were calculated using the data of compensated average air temperature and compensated relative air humidity, following the formula proposed by Buffington (TURCO *et al.*, 2006), presented in equation 1.

$$THI = 0.8 \times T + 0.01 \times H \times (T - 14.3) + 46.3 \quad (1)$$

Where ‘THI’ is the temperature-humidity index, ‘T’ is the dry bulb air temperature (°C), and ‘H’ is the relative air humidity (%).

As proposed by Silva Júnior (2001), THI values lower than 70 imply thermal comfort (normality), THI values between 70 and 72 indicate a critical level (threshold of thermal comfort with a negative impact on milk yields), THI values between 72 and 78 indicate an alert state, in which there is a reduction of milk production). THI values higher than 78 indicate levels of danger and emergency, in which the basic metabolic processes of animals are significantly impaired by extreme thermal discomfort.

The estimate of the decline in milk yield (DMY) was calculated using the model proposed by Hahn (1993), as presented by Turco *et al.* (2006) in equation 2.

$$DMY = -1.075 - 1.736 \times Y + 0.02474 \times Y \times THI \quad (2)$$

Where ‘DMY’ is the absolute decline in milk yield ($kg \cdot day^{-1} \cdot cow^{-1}$), ‘Y’ is the normal level of milk yield ($kg \cdot day^{-1} \cdot cow^{-1}$), and ‘THI’ is the temperature-humidity index calculated in the zoning (dimensionless).

The DMY values were determined using as a basis the yield levels of 15 $kg \cdot day^{-1} \cdot cow^{-1}$ and 30 $kg \cdot day^{-1} \cdot cow^{-1}$, considering these production potentials under conditions of thermal comfort. These values were considered because they correspond roughly to the average yields of rustic cattle (15 $kg \cdot day^{-1} \cdot cow^{-1}$) and dairy cattle (30 $kg \cdot day^{-1} \cdot cow^{-1}$) (MIRANDA; FREITAS, 2009).

To evaluate the impact of the variation of temperature and relative air humidity on dairy production, the THI and DMY values were determined for the four seasons (summer, winter, spring, and autumn), as well as for the month with the highest average temperatures (January). With the calculated THI and DMY results, and the geographical data of latitude and longitude of the weather stations, it was possible to spatialize the THI and DMY values in a grid.

The gridded data were interpolated using the IDW (Inverse Distance Weighting) algorithm for all variables evaluated (THI and DMY), covering the entire area of Rio Grande do Sul state, and using a weighting factor of two. The interpolations were calculated, and the maps were rendered using the QGIS software, version 3.26.

The DMY data (15 and 30 $kg \cdot day^{-1} \cdot cow^{-1}$) underwent Pearson correlation analysis ($p < 0.05$) relative to the average dry air temperature and relative air humidity values, following the analysis proposed by Kessler *et al.* (2014) and Figueiredo *et al.* (2018).

The determination of the average daily milk production for each physiographic region was carried out by surveying the individual production of each municipality of Rio Grande do Sul state, according to production data made available by the Department of Agriculture, Livestock, and Rural Development (SEAPDR/RS, 2015). No more recent data were found treating individual municipalities after 2015 so the data used in this study concerning the daily and accumulated production of each region were based on the year 2015.

Results and Discussion

The distribution of the THI values calculated for Rio Grande do Sul state in the four seasons of the year is shown in Figure 3. As can be seen, THI values were in the range of 52 – 61 in winter, 57 – 68 in spring, 59 – 69 in autumn, and 64 – 76 in summer. Bearing in mind that the critical THI range varies between 70 and 72 (SILVA JÚNIOR, 2001; OLIVEIRA *et al.*, 2018), only in summer would milk production be affected due to thermal discomfort. In addition, it was also possible to note that the smallest THI occurred in the northeast and extreme south of the state, partially corresponding to the Köppen classification (Cfa climate in the northeast region), and also being in accordance with the 'temperate' classification in the model proposed by Maluf (2000) (Figure 2A). According to this author, areas with a temperate climate have lower yearly average temperatures, including the hottest season, and more rigorous winters, with the average temperature of the coldest month (July) below 13 °C. The distribution also partially followed the model proposed by Rossato (2020), in which the regions with smaller THI values were classified as subtropical Ia (northeast) and subtropical IVb (extreme south).

In physiographic terms, only the region of Campos de Cima da Serra had lower THI values to its full extent. On the other hand, the highest THI values occurred in the western region, encompassing the physiographic regions of Missões, Depressão Central, and the western parts of Alto Uruguai and Campanha regions, respectively. The areas with higher THI values have a subtropical climate, according to Maluf (2000), which is characterized by higher average yearly temperatures and an average temperature in the coldest month (July) above 13 °C. These areas are partially classified by Rossato (2020) as subtropical Ib, II, and III.

Oliveira *et al.* (2017a), in a similar study, observed maximum THI values in January (75.2), with the highest values occurring in the western border region of the state. The same authors noted a negative relationship between THI and altitude, as can be seen in this work. In addition, it is important to highlight that short periods of thermal stress may occur outside summertime due to weather or management factors. This may also be considered when establishing and/or maintaining the productivity and well-being of herds.

Specifically, the highest THI values can be observed in the center of the state (Depressão Central) and its coastline (Litoral) relative to high-altitude regions, such as the regions of Campos de Cima da Serra, Planalto Médio, and Serra do Sudeste.

Oliveira *et al.* (2017b), zoning the THI values for Rio Grande do Sul state, reported a similar distribution of THI, commenting that, under extreme temperature conditions (daily maximums), THI values can exceed 80, indicating important danger to animals and workers of the affected areas. The spatialization of the THI values for Rio Grande do Sul state in January, the hottest month of summer, is shown in Figure 4.

In the hottest month of the summer, the observed trend follows the behavior seen in summer, but with higher THI values. It is important to note that the area of the western border has high THI values (> 73), whereas the center of the state and the coastline have moderate THI values (72 – 74). On the other hand, higher altitude regions have lower THI values, such as the northeast and south-southeast areas of the state. The region of Planalto Médio, although influenced by higher temperature due to the western border area, has lower THI values (67 – 71) due to the higher altitude.

Oliveira *et al.* (2017a) also observed similar behavior, commenting that the greatest potential losses due to the decline in milk yield caused by thermal discomfort would occur mainly in January. Turco *et al.* (2006), carrying out the bioclimatic zoning for the state of Bahia (Northeast Brazil), also reported summer as the season with the greatest THI and greatest impact on dairy production, although the seasonal variations in this Brazilian state are much smaller than in Rio Grande do Sul. The same authors also noted that, in high-altitude regions, the THI values remained below the critical levels (70 – 72), with no potential production losses due to thermal discomfort effects. The estimate of the decline in milk yield for the state of Rio Grande do Sul in the summer and in January, considering the average daily productions of 15 kg·cow^{-1} and 30 kg·cow^{-1}, is presented in Figure 5.

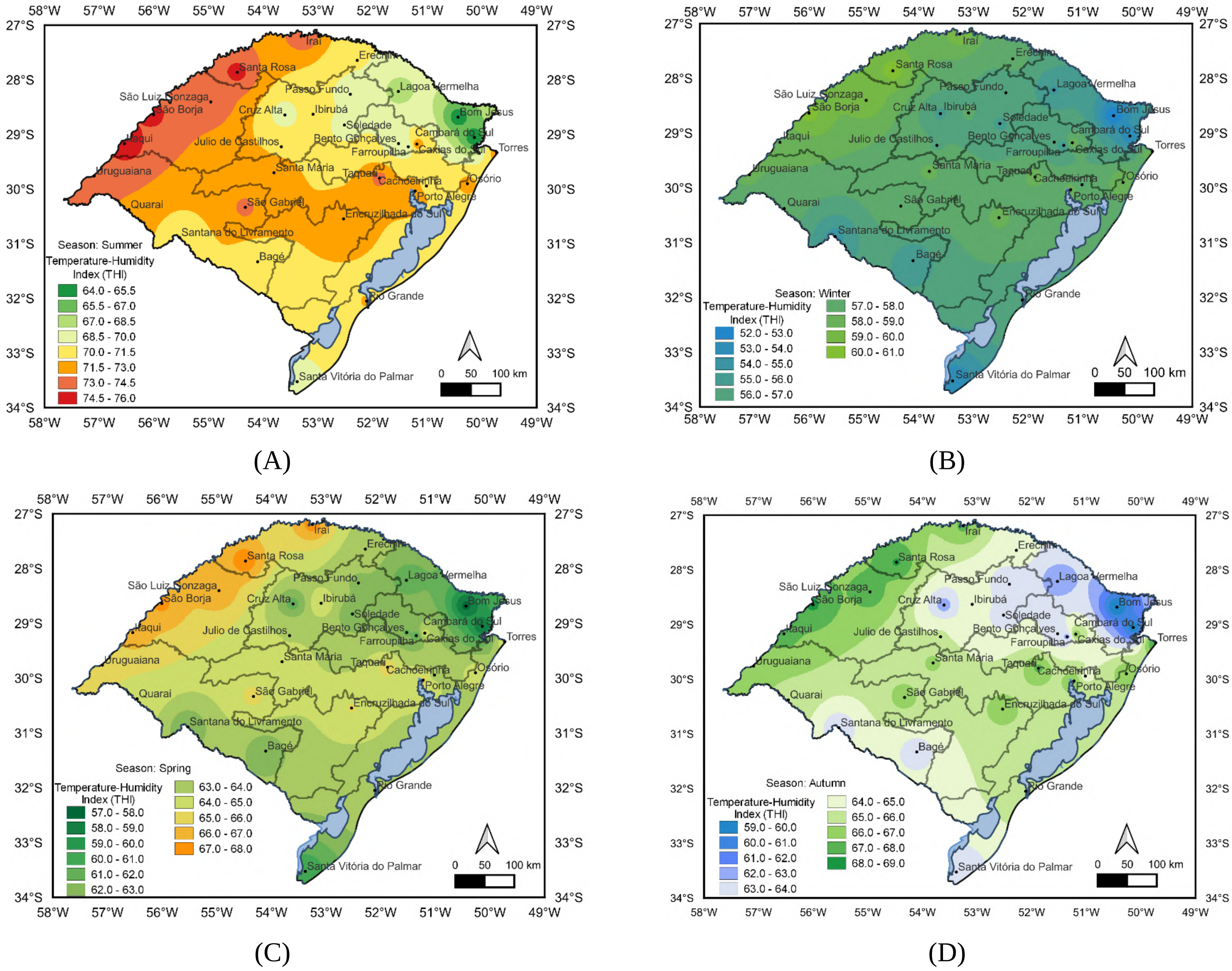

Figure 3. Distribution of the THI values in summer (A), winter (B), spring (C), and autumn (D) for the Rio Grande do Sul state, with the contours of the state physiographic regions shown. ITU < 70: adequate thermal comfort; ITU between 70 and 72: critical level; ITU > 72: alert level (decline in milk production).

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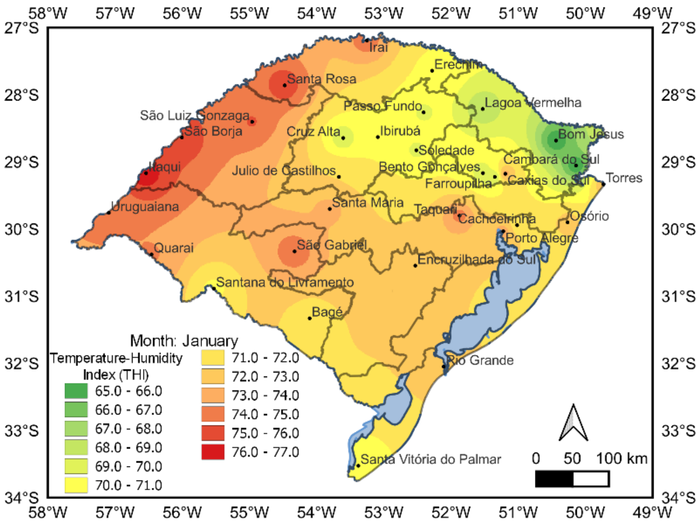

Figure 4. Distribution of THI values for January (the hottest month of summer) in Rio Grande do Sul state, with the contours of the state physiographic regions shown.

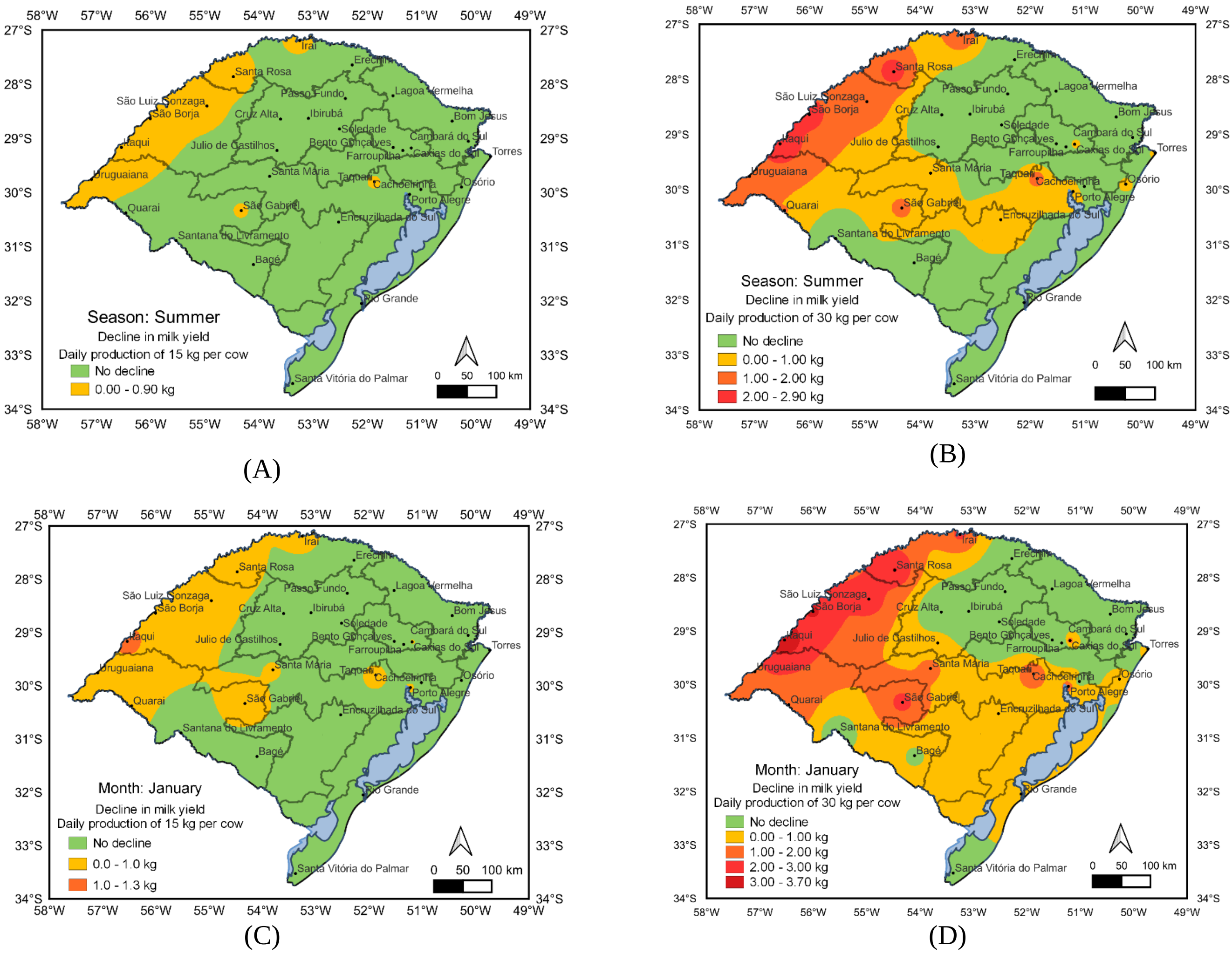

Figure 5. Estimate of decline in milk yield in Rio Grande do Sul state (with the contours of the state physiographic regions shown) for summer (hottest season) and for January (the hottest month of summer), considering average daily milk yields of 15 kg and 30 kg per cow.

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As can be seen in the summer, potential losses in cattle with a daily milk yield of 15 kg due to thermal discomfort effects occur in the western border area (Figure 5A), partially covering the Alto Uruguai, Missões, and Campanha regions, in addition to losses in isolated areas. However, when considering cattle with higher milk yields (daily production of 30 kg), it is possible to notice an increase in losses due to thermal discomfort, with decline in milk yields in the entire area of the western border and the central region of the state (Figure 5B).

For January, it is possible to observe that the losses increase due to greater thermal discomfort. Concerning the average daily milk production of 15 kg per cow, there is an enlargement of the area with a decline in milk yield in January compared to the summer average (Figure 5C). In addition, a sharper decline in daily milk yields occurs in January (up to 1.3 kg daily) compared to summer (up to 0.9 kg daily). The same behavior is observed when considering an average daily yield of 30 kg per cow, with greater losses (Figure 5D). It is also important to note that there is a decline in milk yield in almost the entire state, except for the northeast and extreme south of the state, and small isolated areas.

It is noteworthy to comment that dairy production is partially associated with cattle rusticity. Cattle with higher dairy yields tend to be less rustic, suffering more under conditions of thermal discomfort and, consequently, having a greater decline in milk yield. More rustic cattle, although with lower dairy productivity, can more easily adapt and withstand situations of thermal discomfort, with less impact on production (CARVALHO, 2002; MIRANDA; FREITAS, 2009; SILVA, 2010). The correlation graphs regarding the DMY values determined and the dry air temperature and relative air humidity are presented in Figure 6.

As can be observed in Figure 6, there is a strong relationship between the average dry bulb air temperature and the DMY, showing the trend of reduction in milk yield with the increase in temperature, which is associated with thermal stress (TURCO *et al.*, 2006; OLIVEIRA *et al.*, 2017b; 2018). On the other hand, the relationship seen between DMY and relative air humidity was much less strong, with wide variability. As observed by Oliveira *et al.* (2017b) and Kemer *et al.* (2020), the influence of relative humidity is dependent on temperature. Its influence is linked with heat removal by transpiration: at high relative humidity values, the removal of heat by sweat is impaired, reducing the efficiency of sweating as a temperature regulation mechanism and increasing thermal discomfort. The results of the Pearson correlation analysis for the DMY values regarding the average dry bulb air temperature and the relative air humidity are compiled in Table 1.

The Pearson correlation analysis showed a statistically significant relationship between both the dry bulb air temperature and the relative air humidity and the DMY values. Oliveira *et al.* (2018) and Kemer *et al.* (2020) also observed a positive correlation between THI values (which are dependent on the temperature and humidity of the air) and DMY values for data collected in Rio Grande do Sul and Santa Catarina states, respectively. The weak negative correlation between relative humidity and DMY values may be linked to the stronger dependence on temperature since relative air humidity, unlike absolute air humidity, is also influenced by air temperature.

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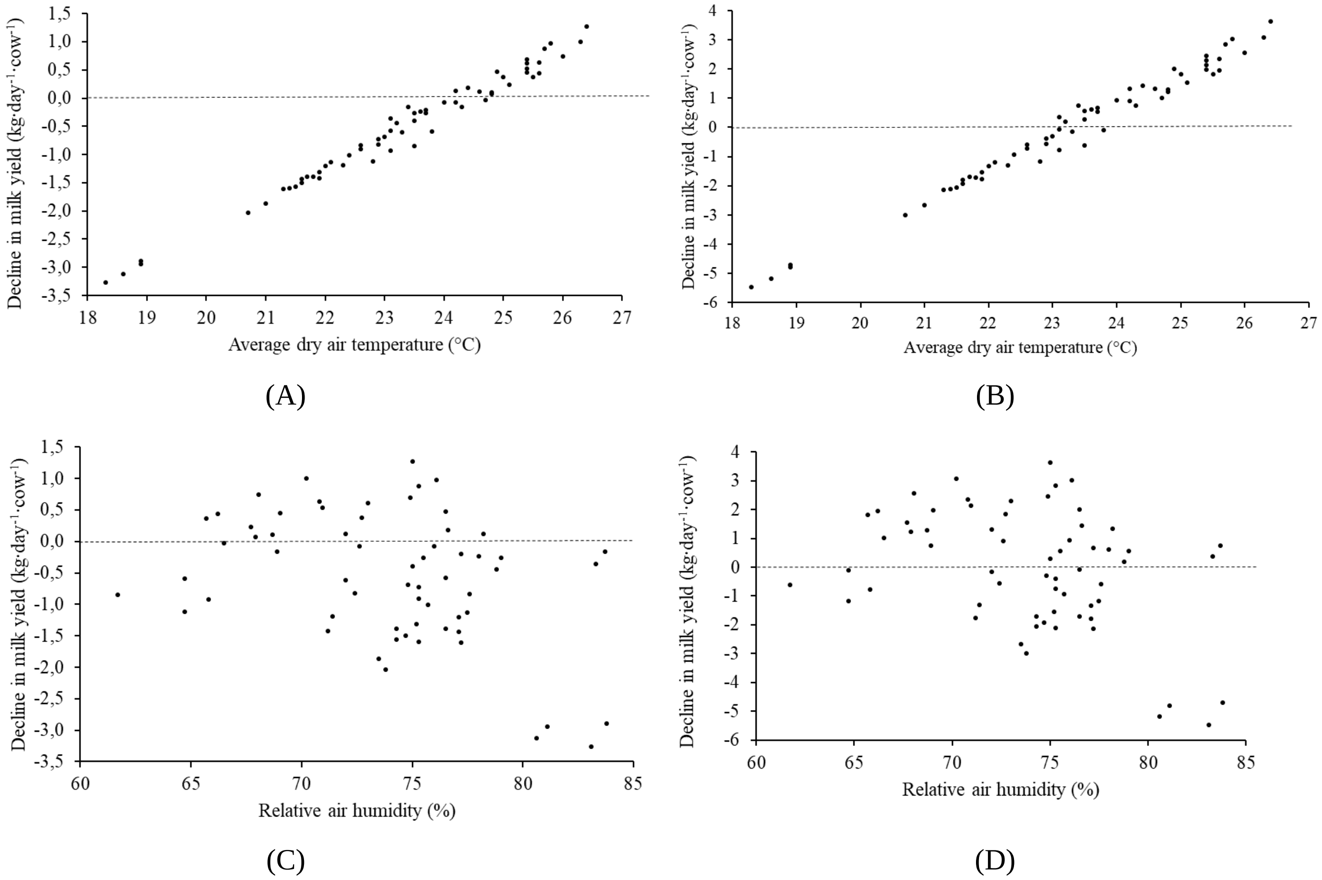

Figure 6. Pearson correlation graphs of the decline in milk yields for daily average productions of 15 kg per cow (A; p < 0.0001) and 30 kg per cow (B; p < 0.0001) relative to the average dry bulb air temperature and relative air humidity (C, p = 0.002; and D, p = 0.002).

Table 1. Results of Pearson correlation analysis relative to the decline in milk yield (DMY) for the daily milk productions of 15 kg and 30 kg per cow, considering the dry bulb air temperature and relative air humidity obtained from weather data from INMET.

Parameter	DMY – 15 kg·day^{-1}·cow^{-1}	DMY – 30 kg·day^{-1}·cow^{-1}
Dry bulb air temperature	0.9897	0.9897
p-value	< 0.0001	< 0.0001
Relative air humidity	-0.3809	-0.3809
p-value	0.002	0.002

The predominant climate type in each physiographic region of the state of Rio Grande do Sul, as well as their THI values in summer and January and the yearly and average daily milk productions are compiled in Table 2.

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According to Table 2, the regions with the highest THI values were classified as Cfa climate by Köppen climate classification, while the lowest THI ranges were classified as Cfb, with maximum THI values of 73 in January. Regarding the classification proposed by Maluf (2000), the areas classified as ST tend to have higher THI values, whereas those classified as TE present the lowest THI values. According to Rossato (2020), areas classified as subtropical Ib/II/III/IVa have greater THI values while areas classified as IVb present the lowest ones. The estimated average daily milk yields for each physiographic region of the state of Rio Grande do Sul are presented in Figure 7.

Table 2. Predominant climate classification, THI ranges, yearly dairy production, and estimated average daily milk production for the physiographic regions of Rio Grande do Sul state, based on the year 2015.

Physiographic region	Predominant climate type			THI range (summer)	THI range (January)	Yearly dairy production* (thousand tonnes)	Average daily milk production* (kg·cow^{-1})
	Köppen[1]	Maluf (2000)	Rossato (2020)				
Alto Uruguai	Cfa	ST/STE	IVa	67.0 - 74.5	70.0 - 76.0	1492.86	8.63
Campanha	Cfa	ST	Ib/II	70.0 - 76.0	70.0 - 76.0	139.84	5.82
Campos de Cima da Serra	Cfb	TE	IVb	64.0 - 70.0	65.0 - 71.0	300.01	9.56
Depressão Central	Cfa	ST	II/III	70.0 - 74.5	71.0 - 75.0	173.33	5.93
Encosta do Sudeste	Cfa	TE	Ia	70.0 - 73.0	72.0 - 74.0	122.50	6.93
Encosta Inferior do Nordeste	Cfa	STE/ST	III	70.0 - 73.5	70.0 - 73.0	499.77	7.13
Encosta Superior do Nordeste	Cfb	TE	IVb	68.5 - 71.5	68.0 - 73.0	488.21	10.20
Litoral	Cfa	TE/ST	Ia/III	68.5 - 73.0	70.0 - 74.0	19.13	6.17
Missões	Cfa	ST	II/III	71.5 - 76.0	73.0 - 77.0	309.07	6.61
Planalto Médio	Cfa	TE	III	68.5 - 71.5	68.0 - 73.0	1156.49	10.95
Serra do Sudeste	Cfa	TE	Ia	70.0 - 73.0	70.0 - 74.0	45.90	4.23
Rio Grande do Sul state				64.0 - 76.0	65.0 - 77.0	4737.92	8.67

* – Parameters determined with data from SEAPDR/RS (2015). Cfa – humid subtropical climate with hot summer; Cfb – humid subtropical climate with warm summer; ST – subtropical; STE – subtemperate; TE – temperate; Ia: dry with cold winter and mild summer; Ib: dry with cold winter and hot summer; II: average humidity with a longitudinal variation of the average temperatures; III: humid with a longitudinal variation of the average temperatures; IVa: very humid with mild winter and hot summer; IVb: very humid with cold winter and mild summer. [1] – According to Alvares *et al.* (2013).

As can be seen in Figure 7, the physiographic regions of Planalto Médio, Encosta Superior do Nordeste, Campos de Cima da Serra, and Alto Uruguai have an estimated average daily milk yield greater than the state average. These regions have the same climate type (TE), according to Maluf (2000).

On the other hand, the remaining physiographic regions had an average daily yield smaller than the state average (8.67 kg·cow^{-1}). Among these regions, those of Serra do Sudeste, Depressão Central, and Campanha stand out, with an average yield of fewer than 6 kg·cow^{-1}. The regions of Campanha and Depressão Central have a similar climate type (ST, according to Maluf) and subtropical Ib/II/III according to Rossato

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(2000). However, the Serra do Sudeste region differs from others because it has a different type of climate (TE according to Maluf and subtropical Ia according to Rossato).

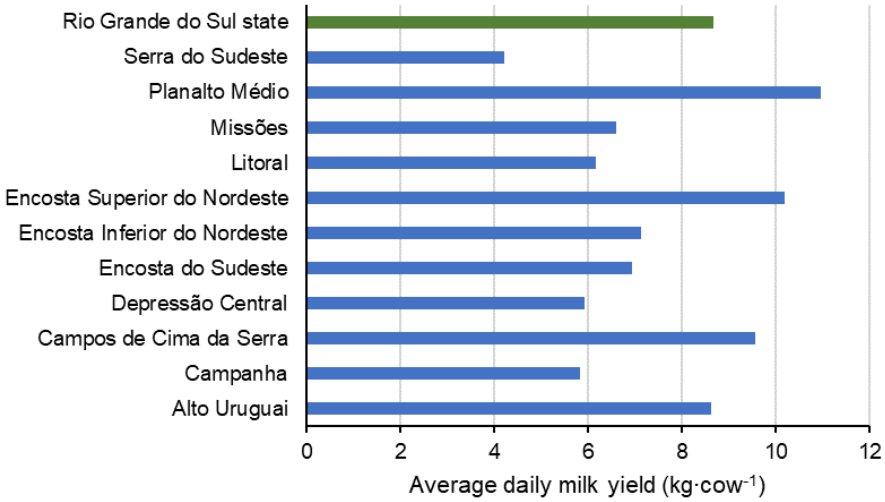

Figure 7. Average daily milk yield for the different physiographic regions of Rio Grande do Sul State, determined with data from SEAPDR/RS (2015), compared to the state average (green bar).

As can be seen in terms of total gross production (Table 1), the Serra do Sudeste region has the second lowest production, after the Litoral region, which also has a ST/TE climate (MALUF, 2000) and subtropical Ia/III (ROSSATO, 2020). Thus, these regions do not cover dairy production centers, indicating that most of the activities related to dairy farming are performed by small farmers and subsistence activities, with a lower degree of investments and technification compared to regions with higher production volumes (SILVA *et al.*, 2014; TELLES *et al.*, 2018). Almeida *et al.* (2022), analyzing annual dairy production data from municipalities in the state of Rio Grande do Sul since 1980, observed that the highest yields occurred in the central and northern areas of the state (Planalto Médio, Alto Uruguai), while the lowest yields were observed in the Campanha, Serra do Sudeste, and Missões regions, and in parts of the Depressão Central and Serra do Sudeste.

As observed by Telles *et al.* (2018), the microregions specialized in milk production in the state of Rio Grande do Sul are located in the central and northern parts of the state, corresponding approximately to the physiographic regions of Alto Uruguai, Planalto Médio, and Encosta Superior do Nordeste. These regions have a higher annual milk production and average daily milk yields above the state average. This indicates that other factors, such as herd management and technification level, also exert substantial influence on dairy production, in addition to the effects caused by thermal comfort.

The present study aimed to evaluate and assess the impact of average temperature and relative air humidity on the THI and, consequently, the decline in milk yields in the State of Rio Grande do Sul. According to climatic data and the models used, only in summer are there conditions of thermal discomfort

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that impact the dairy production of Rio Grande do Sul state, which intensifies in January. In addition, the decline in milk yields was greater for higher productions, which is linked to cattle rusticity. The most significant declines in milk production occur in the western border area of the state, encompassing the physiographic regions of Alto Uruguai, Missões, and Campanha, which are characterized by a warmer climate. Among the climate classifications addressed in this work, the one proposed by Maluf had the highest match with the THI values. This classification may be used to determine places with better suitability for dairy farming or indicate areas where it would be necessary to implement actions to mitigate the effects of thermal discomfort in the animals.

Conflict of Interests

The authors declare that the research was conducted in the absence of any potential conflicts of interest.

Ethical Statements

The authors confirm that the ethical guidelines adopted by the journal were followed by this work, and all authors agree with the submission, content and transfer of the publication rights of the article to the journal. They also declare that the work has not been previously published nor is it being considered for publication in another journal.

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