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A software to estimate heat stress impact on dairy cattle productive performance

C.G.S. Teles Jr.[1], R.S. Gates[2], M. Barbari[3,*], L. Conti[3], G. Rossi[3], M.O. Vilela[1], C.F.F. Souza[1] and I.F.F. Tinôco[1]

[1]Federal University of Viçosa, Department of Agricultural Engineering, Av. Peter Henry Rolfs, s/n Campus University of Viçosa CEP: 36570-900, Viçosa, Minas Gerais, Brazil
[2]University of Illinois, Department of Agricultural and Biological Engineering, 1304 West Pennsylvania Avenue, US61820, Urbana-IL, United States of America
[3]University of Florence, Department of Agriculture, Food, Environment and Forestry, Via San Bonaventura, 13, IT50145 Firenze, Italy
[*]Correspondence: matteo.barbari@unifi.it; carlosgutembergjr@hotmail.com

Abstract. The aim of this study is to develop a computational tool, based on the Temperature and Humidity Index value, to characterize the thermal environment in dairy cattle barns and to evaluate the impact of thermal stress on productive performance. The software for the thermal environment prediction, and determination of the influence of heat stress on dairy cow productivity (Ambi + Leite) was developed using the C# programming language in the Microsoft Visual C# 2010 Express Integrated Development Environment. The following scenario was considered for the program test: air temperature 32°C, relative air humidity 70% and milk production potential in thermoneutrality condition 20 kg cow^{-1} day^{-1}. The prediction of the thermal environment based on the simulated situations indicates that the animals are submitted to a moderate heat stress condition with THI equal to 82.81. In this condition a decrease of approximately 26% in milk production and a reduction of 4 kg cow^{-1} day^{-1} in food intake was calculated. In conclusion, the developed software can be a practical tool to assist the producer in making-decision processes.

Key words: thermal environment, THI, dairy cows, software.

INTRODUCTION

[illegible] constituting an important source of income and employment (Lopes et al., 2011). However farmers have to pay attention on the microclimatic conditions related to the production environment, particularly air temperature and relative humidity, which can have a negative influence on the welfare and consequently on the animal performance. A proper management of the thermal environment for the animals is of paramount importance, in order to reduce the influence of climatic conditions on the comfort and the performance of the animals. Dairy cows are highly productive animals, which produce heat in large amount. The excess of heat must be removed to the environment (Nóbrega et al., 2011; Radon et al., 2014; Herbut et al., 2015).

The occurrence of high temperatures throughout the day, especially during the summer, causes changes in the physiological mechanisms of the animals, with raise of body temperature and increase of respiratory rate and sweating. In addition some behavioural changes indicate that the animals are in conditions of thermal discomfort (Pinheiro et al., 2015; Heinicke et al., 2018; Herbut & Angrecka, 2018). Beyond physiological and behaviuoral changes, when subjected to thermal discomfort caused by heat, the cows reduce feed consumption and present a consequent decrease in milk yield (Rodrigues et al., 2010; Herbut et al., 2015).

According to Baêta & Souza (2010), the comfort of the animals inside a barn is expressed by several indexes, which generally consider two or more climatic variables. The most common index is the Temperature-Humidity Index (THI), which uses the dry-bulb temperature (Tdb) and the wet bulb temperature (Twb) to estimate the magnitude of heat stress (Thom, 1959). The THI was studied by several researchers, which defined formulas to calculate the index in relation to different conditions (Ingraham et al., 1979; Buffington et al., 1981; Mader et al., 2006; Gaughan et al., 2008; Herbut et al., 2018a). THI is commonly used to estimate the effects of climatic conditions on the dairy cows' thermal comfort (Heinicke et al., 2018), also by means of computer tools available on web.

Knowing how these environmental factors influence animal welfare and performance is crucial to obtain a successful production. Therefore, the use of some computer tools can help in the fast and accurate diagnosis of animal-environment interaction. Some of these tools can be found in the literature (Teles Junior et al., 2016; Teles Junior et al., 2018). The present work aims to develop a computational tool based on the Temperature and Humidity Index value, able to characterize the thermal environment in dairy cattle barns and to evaluate the impact of heat stress on the productive performance of the animals.

MATERIALS AND METHODS

The software for the prediction of thermal environment in dairy cows barns and for the determination of the heat stress influence on the performance (Ambi + Leite) was developed using the C # programming language in the Microsoft Visual C # 2010 Integrated Development Environment (IDE).

The thermal environment was classified on the basis of the Temperature and Humidity Index value (THI), calculated from input data of air temperature and relative humidity, by means of Eq. (1) proposed by Buffington et al. (1982):

$$THI = 0.8 \times T_{air} + \frac{RH \times \left(T_{air} - 14.3\right)}{100} + 46.3 \qquad (1)$$

where THI = Temperature-Humidity Index; T_{air} = Air Temperature (°C); RH = Relative Humidity (%).

The thermal environment was classified according to the calculated THI value, following the guidance of Armstrong (1994), as shown in Table 1.

After characterization and evaluation of the thermal environment based on the THI value, if the animals are in a heat stress condition, the next step is to evaluate the heat stress influence on their productive performance. For this purpose, we estimated the decline in milk production and food intake as a function of the calculated THI value, based on Hahn (1993) and Hahn & Osburn (1969) equations (2) and (3).

Table 1. Dairy cows thermal environment classification based on the value of the Temperature-Humidity Index (THI)

Thermal environment classification	THI values range
Thermal Comfort	≤ 72
Mild Stress	72–78
Moderate Stress	79–88
Severe Stress	> 88

$$DMP = -1.075 - 1.736 \times SMP + 0.02474 \times THI \times SMP \quad (2)$$

where DMP = Decline in milk production (kg cow^{-1} day^{-1}); SMP = Standard Milk Production (kg cow^{-1} day^{-1}); THI = Temperature-Humidity Index.

$$RFI = -28.23 + 0.391 \times THI \quad (3)$$

where RFI = Reduction in feed intake (kg cow^{-1} day^{-1}).

For testing the program, a simulation was performed considering a critical scenario related to the thermal comfort of animals, kept under the following conditions: average air temperature 32°C; average relative humidity 70%. The animals considered in the simulation were Holstein cows with milk production potential in thermoneutrality condition of 20 kg cow^{-1}. day^{-1}.

The results of the simulation were compared with the data searched in the literature, that depict the real production conditions in dairy cows facilities, in order to verify the reliability of the proposed software.

RESULTS AND DISCUSSION

The algorithm for the prediction of thermal environment and evaluation of the heat stress influence on the productive performance of the cows follows the steps outlined in Fig. 1.

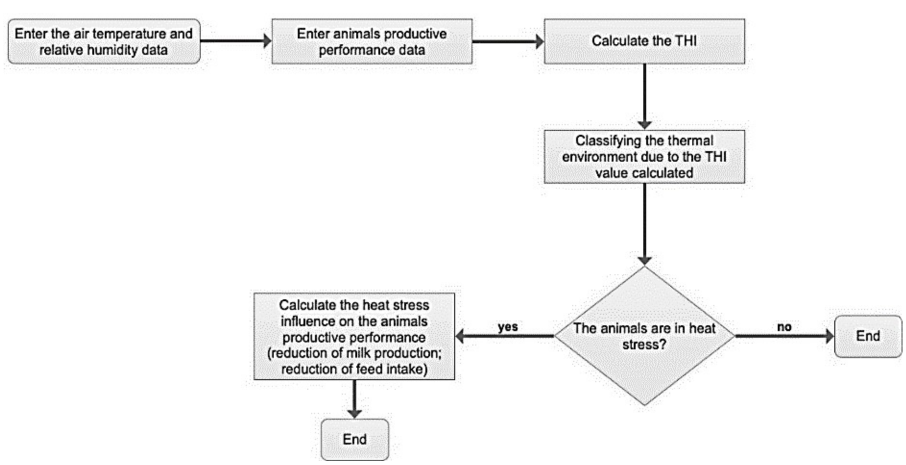

Figure 1. Algorithm execution steps flowchart.

The first stage of algorithm execution consists of data entry, where data are entered referring to the climatic variables and the animals standard productive performance. After entering the input data, the next step is to calculate the Temperature-Humidity Index. From the THI value the thermal environment for the cows is calculated and classified. If the animals' thermal environment is classified as stressful, based on the calculated THI value, the next step is to evaluate the impact of this stress on the productive performance of the cows, based on the calculation of the reduction in milk production and the reduction of food intake.

The developed software is compatible with operational system Windows XP or up. The software graphical user interface is basically divided into three windows, the first of which is shown in Fig. 2. This is a first window (splash screen) for program initialization, from which the main data entry window is opened (Fig. 3). In this window the input data are inserted and processed for THI calculation, for the thermal environment classification and for the evaluation of the heat stress influence on the productive performance of the animals.

Figure 2. Program initialization window (splash screen).

The main window (Fig. 3) is divided into three parts. The first is for data entry (climate data and animals' standard performance data) (A), the second for climate data processing to calculate THI and classify the animal thermal environment based on THI (B), and the third for calculation of the heat stress influence on the performance of the animals (C).

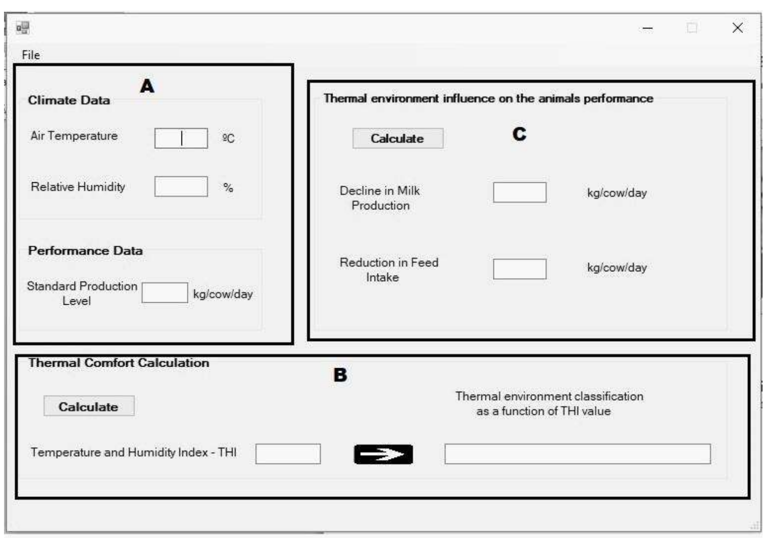

Figure 3. Software main data entry window. A: Data entry field; B: Data processing field to calculate THI and classify the thermal environment; C: Data processing field to calculate the heat stress influence on the animals.

The results of simulation carried out following the program test scenario (average air temperature 32 °C, average relative humidity 70%, Holstein cows with milk production potential in thermoneutrality condition 20 kg cow^{-1} day^{-1}) are shown in Fig. 4.

The prediction of the thermal environment, performed considering the entry conditions reported in the program (air temperature and relative humidity), indicates that the cows are subjected to a moderate heat stress condition with THI equal to 82.81.

Taking into account that the animals considered in the simulation present a milk production potential in thermoneutrality condition of 20 kg cow^{-1} day^{-1}, it is calculated that in the simulated thermal condition a reduction of approximately 26% in milk production potential occurs. This result is consistent with what was verified by Oliveira et al. (2013), which observed a 15% reduction in milk production in dairy cows with potential production of 20 kg day^{-1} submitted to mild heat stress. In the simulated thermal stress condition, the animals show a reduction of food intake of about 4 kg day^{-1}. Porcionatto et al. (2009) argue that this reduction in food intake is the main cause of the reduction in milk production of cows on heat stress.

It is important to note that this decrease in milk production by the cows does not occur immediately after the beginning of stress conditions. There is a delay in this process that can take about 2 to 3 days after the occurrence of heat stress (West et al., 2003; Spiers et al., 2004). In addition, Herbut et al. (2018b) affirm that the reduction in the productive performance of dairy cows also depends on the severity of the heat wave and the duration of heat during the previous periods.

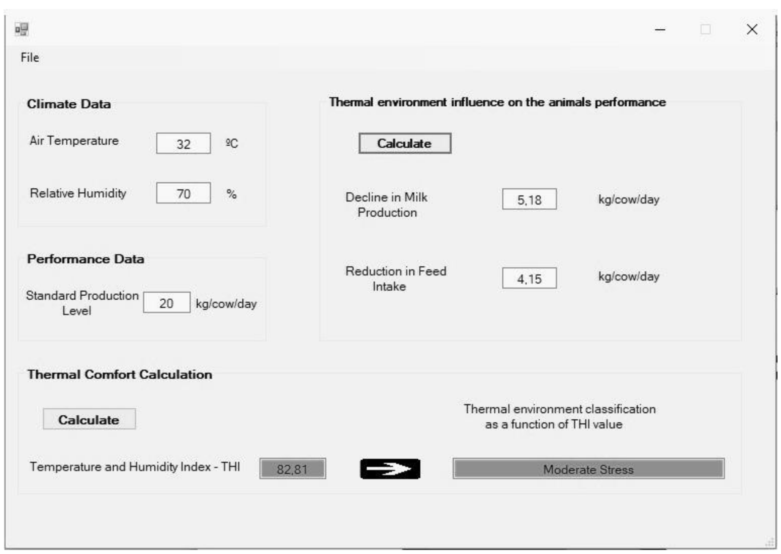

Figure 4. Simulation results.

CONCLUSIONS

The computational program developed is a practical tool to help producers in decision-making, helping to evaluate the thermal environment and the effect of thermal stress on the productive performance of the cows, in order to improve the farming management.

After the first version of the software, presented in this paper, the developers are working on new updates. In particular, the goal is to realize a software able to communicate with a data acquisition system (temperature and relative humidity sensors), for the real-time evaluation of thermal conditions in the barn, and to affect the decision-making process for control of the heating, ventilation and cooling systems.

Other improvement of the software has to consider new input variables, such as dairy cattle breeds, length of stress conditions, lactating phase and animal age.

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