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Fuzzy simulation of bioclimatic indexes environments with and without cover for Santa Inês sheep farms

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This study aimed to analyze bioclimatic indexes: black globe temperature and humidity index (BGHI) and radiant thermal load (RTL) in Santa Inês sheep farms, with and without coverage to develop a fuzzy logical computational model to forecast variables analyzed experimentally. Ten Santa Inês sheep were placed in two cover paddocks, and one without cover. Data recorded were: air temperature schedules and black globe (°C), relative humidity (%) and wind speed (m s^{-1}), and BGHI and RTL were calculated. Computational models were developed using fuzzy logic which had as input variables, air temperature (°C) relative humidity (%) for the output variables BGHI and RTL. Based on the experimental data, there were also certain relevance curves that conform more to the results for the model generation via Fuzzy logic. The Mandani inference method was used for the preparation of rules and defuzzification of the center of gravity method was applied. The results showed that in the critical periods, 12 to 14 h, coverage was insufficient to differentiate between stress environments. It was also found that the Fuzzy models compared with the experimental data were highly correlated with R^2 equal to 0.99, proving it is suitable for implementation in practice.

Key words: Computational model, heat stress, shelter, simulation.

INTRODUCTION

In Brazil, sheep farming in the northeast is done in small farms, represents a source of resource generation (Ribeiro et al., 2008), being exploited with a low level of technology. Santos et al. (2011) reported that in this region, most sheep are raised in pastures with little or no shade and analyzing the effect of shading on the comfort of Santa Inês sheep, showed that the shade provided by the trees reduced the radiant heat load by up to 44.7%, providing a better thermal environment for the animals. Relative to the comfort of sheep Santa Inês, Neves et al.

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(2009) found the maximum temperature of 35°C, being above the thermal comfort zone (30°C) recommended for sheep, with values of black globe temperature index and humidity characterizing the situation of thermal discomfort. High BGHI values in the semi-arid region are also cited by Oliveira et al. (2013) and Leitão et al. (2013).

According to Pandorfi et al. (2012), considering the current demands, it is no longer possible to consider animal production or production chain, without considering the concept of well-being in production. Thus, the uses of new information technology tools favor the accuracy of research and the development of expert systems for decision making.

Several computational modeling techniques to predict animal-related variables from a mathematical knowledge base are being used (Schiassi et al., 2015). Among the possible models to be developed, those based on artificial intelligence, specifically, the Fuzzy methodology has been shown to be more adequate. The Fuzzy sets logics have been applied in estimating the comfort and well-being of animals confined by several researchers (Ferreira et al., 2010).

The objective of this research was to analyze the bioclimatic indexes, BGHI and RTL in environments for Santa Inês sheep breeding, with and without cover, and to develop a model using the Fuzzy set theory capable of predicting such variables.

MATERIALS AND METHODS

This research was carried out in two phases: the first one was an experiment in the field, in which 10 male Santa Inês sheep, average of 24 months old, were confined, distributed equally in two pickets of equal area of 24 m² each, one discovered (Treatment 1) and another provided with covering of asbestos cement tiles with 3 m ceiling (Treatment 2). The experimental data were used to develop the model able to predict the black globe temperature and humidity index (BGHI) and radiant thermal load (RTL).

This stage was performed in Caturité-PB, Brazil, (7° 25 '12' 'S and 36° 1' 3 '' O) with semi-arid climate (BSh) characteristics according to Köppen-Gieger classification with maximum temperatures of 37°C and the minimum of 16°C and annual rainfall of 500 mm. The experiment was carried out in April and May 2012, with a pre-experimental period of 77 days to adapt the animals to the test conditions and 46 days of collection. The animals were confined to rations composed of sorghum silage and balanced concentrate, based on soybean meal and corn, fed twice daily at 7 and 16 h. Water was supplied *ad libitum*.

In both treatments, air temperature (AT), relative air humidity (RH), black globe temperature (BGT) and wind speed (WS) were recorded. The climatic data were collected every 60 min during the 24 h of each day of experiment, and the values were analyzed in the interval of 7 to 17 h. The AT and RH data were obtained by means of electronic sensors (datalloger HT500), the WS was collected by means of a digital thermohygranemometer and for collecting the BGT, black balloons calibrated with the standard globe, positioned in both environments, at the height corresponding to the center of mass of the animals were used. Thus, was possible to calculate the black globe temperature and humidity index (BGHI) for the environments, by the formula proposed by Buffington et al. (1981). The RTL was calculated using the Esmay (1969) methodology.

In the second stage of the research, the data for each treatment were tabulated and used to calculate the BGHI and RTL, which were used in the validation of the proposed mathematical model. The computational model was based on the theory of Fuzzy sets, having as input variables, the values of TA and UR and as output data, the bioclimatic variables BGHI and RTL for the covered and discovered environment. Figure 1A and B correspond to the BGHI and RTL pertinence curves for the covered environment, respectively, whereas Figure 1C and D correspond to the variables of the environment exposed to direct solar radiation.

The intervals adopted for the input and output variables were represented by triangular pertinence curves, as used by several authors such as Ponciano et al. (2012) and Tolon et al. (2010), and the intervals were defined based on the ranges established during the conduction of the experiment and through consultation with specialists.

In order to simulate the data, the Mamdani inference method was used, as proposed by Li and Gatland (1996) and also used by Ponciano et al. (2012) and Schiassi et al. (2015), response, a Fuzzy set originated from the interaction of the input values with their respective degrees of pertinence, through the minimum operator and then through the superposition of the rules, through the maximum operator. The Fuzzy number is the number of points in the center of gravity. A comparison of the output data of the model with the data acquired through the experiment was made to evaluate the accuracy of the proposed Fuzzy models using Xfuzzy software.

RESULTS AND DISCUSSION

The highest averages observed for ITGU were in the uncovered environment at 13 and 14 h, equal to 90.8 and 90.4, respectively. For the indoor environment, the highest values were recorded from 12 to 14 h and 81.7 (Figure 2).

When studying the comfort of Santa Inês sheep raised in uncovered environment and shaded with polypropylene tiles in the Petrolina region, PE, Brazil, Oliveira et al. (2013) found a significant effect between the two environments and shifts of the day for the BGHI in the dry season with values varying from 82 to 85 for the shaded and uncovered environment, respectively, where they concluded that values above 82 represented an alert condition for sheep Santa Inês.

Leitão et al. (2013) found ITGU values above 94 when keeping Santa Inês sheep in paddocks deprived of coverage in Juazeiro, BA, Brazil, in the dry period, concluding that the existence of a cover can have a significant effect on the reduction of the stress condition for sheep raised in the semiarid. This fact was corroborated by the present research since a reduction of up to 10% in the BGHI value between the two environments was found. However, according to Oliveira et al. (2013), although the coverage significantly reduced the BGHI values as compared to the uncovered environment, the authors did not observe a reflection of this in the behavioral parameters as feeding, rumination or idle activity when compared with the treatment without shading for sheep Santa Inês.

In the present research, the highest air temperature

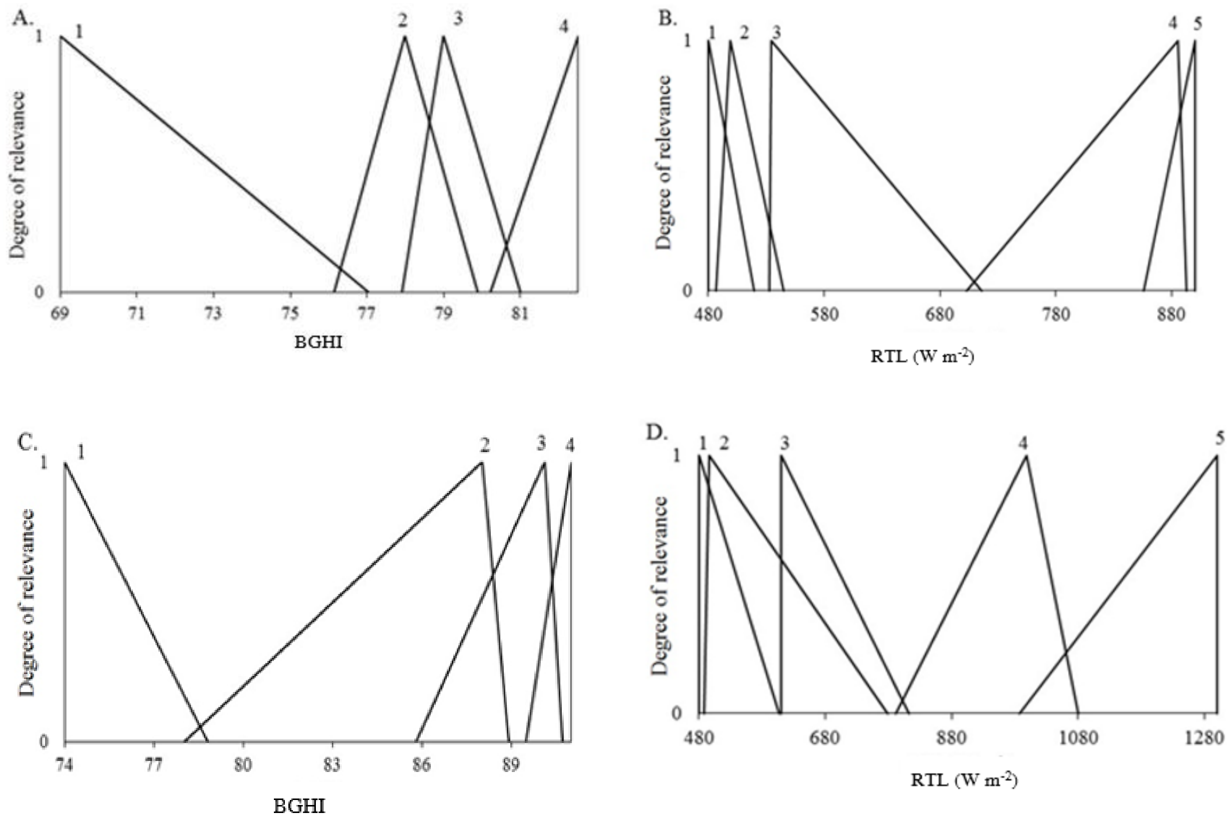

Figure 1. A. Relevance curves for BGHI; B. Relevance curves for RTL for the indoor environment; C. Relevance curves for BGHI; D. Relevance curves for RTL for the discovered environment.

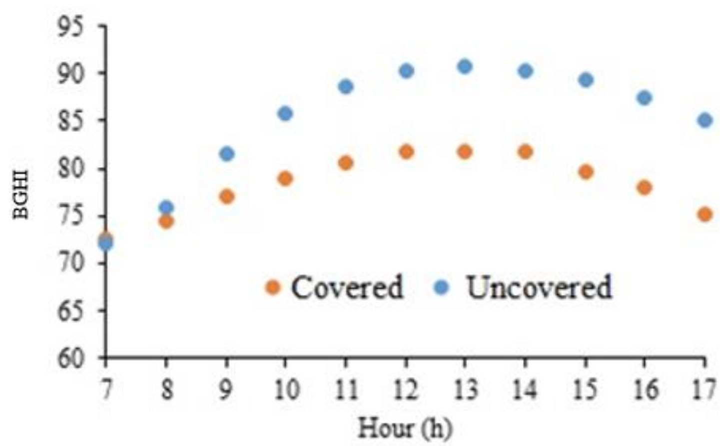

Figure 2. Globe and humidity temperature index in the two environments.

value was found for the uncovered environment at 12 pm (34.2°C), being close to the temperature predicted as a stressor of 35°C found by Neves et al. (2009) for Santa Inês sheep raised in the agreste region of Pernambuco, Brazil, which confirms an alert situation, independent of the studied environment.

The maximum radiant thermal Load values observed were 956.2 and 887.3 W.m^{-2} for the uncovered and covered environments, respectively, both at 12 pm (Figure 3). Ribeiro et al. (2008) evaluated the RTL in environments covered with ceramic tile in the confinement of native sheep in São João do Cariri, PB, Brazil, and

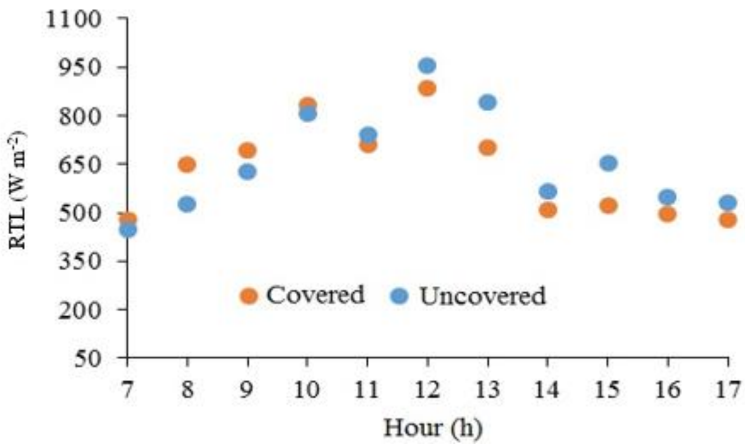

Figure 3. Radiant thermal load in both environments.

found at 15 h the highest value equal to 543.5 W m^{-2}. This means that even considering the asbestos cement tile with higher values of absorptivity and thermal transmittance than the ceramic tile, the RTL values of the present research still present stressors, especially for the uncovered environment.

When studying RTL variation between the internal and external environment in reduced models with different coverages, Cardoso et al. (2011) concluded that the existence of cover can dampen up to 40% of the radiant heat energy during the hottest times of the day, which is not corroborated by the present research since the reduction of RTL to the internal environment was only 8%.

This can be explained by the existence of side walls in the covered environment that may have acted as a barrier to ventilation, resulting in increased storage of thermal energy throughout the day and consequently increasing the black globe temperature. Another factor that is important to highlight was the existence of vegetation cover in the soil in the experiment carried out by Cardoso et al. (2011) and the lack of this in the current research, which certainly contributed to higher values of RTL and smaller differences between the environments analyzed.

The values of BGHI and RTL observed and simulated by the Fuzzy model are shown in Figure 4, as well as the regression equations and determination coefficients to estimate these indices. No research was found on the creation of Fuzzy models for bioclimatic prediction of sheep facilities and, therefore, the results found here were compared to the models developed for other species.

When analyzing Figure 4, it is possible to notice that the values of the determination coefficient for BGHI in covered and uncovered environment was 0.99 and 0.99, respectively. For the RTL in covered and uncovered environment, in this order, R^2 values were 0.97 and 0.99. It can be observed that for the two treatments and bioclimatic indices, the proposed model was shown with good precision, being able to realistically portray the same as a function of the temperature and relative humidity of the air.

Similar results were found by Marques et al. (2016) where, when developing a Fuzzy model to predict values of BGHI and RTL in an environment destined to confinement of quails, in the Brazilian semi-arid region, they verified R^2 values equal to 0.97 and 0.98, respectively. These authors also adopted, for the output variables (BGHI and RLT), intervals represented by triangulated pertinence curves, used by several authors (Ponciano et al., 2012).

It can be noticed that the adjustment of the four proposed models to the bioclimatic data were distributed approximately, with coefficients of determination (R^2) higher than 0.97. Thus, the R^2 report that the Fuzzy models explain more than 97% of the variance for all the evaluated situations, which means the numerical reliability as a specialist model to be used as a decision-making mechanism in the control of bioclimatic variables in facilities for sheep.

Conclusions

At the critical times between 12 and 14 h, the thermal environment was considered as an alert situation for both environments and the existence of asbestos cement cover in one of the environments was insufficient for the damping of the radiant thermal load. In the simulation models reproduced with fidelity, the experimental values with coefficients of determination superior to 0.97 indicate that Fuzzy logic can be applied with efficiency in the prediction of BGHI and RTL in covered environment and discovered as a function of the temperature and relative humidity of the air. Thus, it can be implemented in

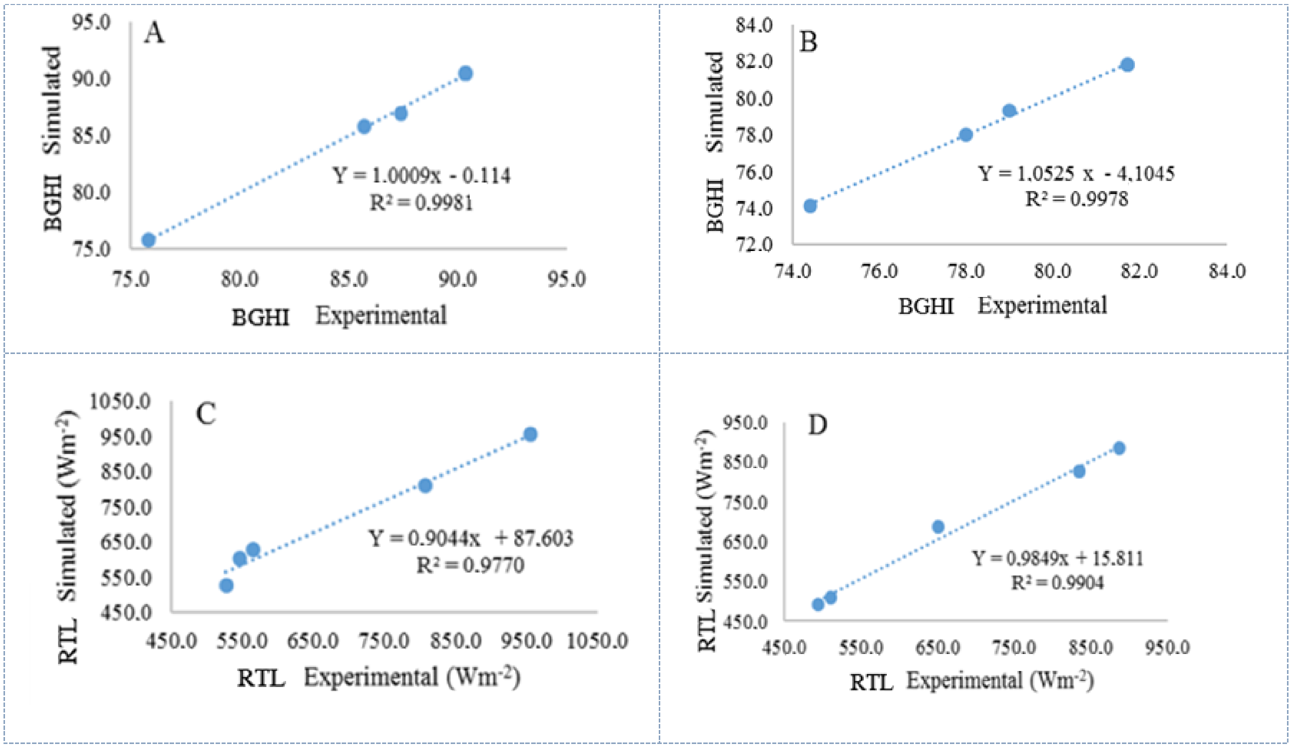

Figure 4. Simple linear regressions for the output variables: (A) BGHI environment covered; (B) BGHI uncovered environment; (C) RTL covered environment; (D) RTL uncovered environment.

systems of automation and control of zootechnical facilities.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

Abreviations

BGHI, Black globe temperature and humidity index; **RTL,** radiant thermal load; **AT,** air tempeaure; **RH,** relative humidity; **BGT,** black globe temperature; **WS,** wind speed.

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