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Multiple Factor Analysis to identify correlated variables among microclimate, thermal comfort and infrared thermography in agroforestry systems

Análise Fatorial Múltipla para identificar variáveis correlacionadas entre microclima, conforto térmico e termografia por infravermelho em sistemas agroflorestais

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Abstract:

Goal was to use the Multiple Factor Analysis to reduce dimensionality of variables, to identify groups of correlated variables and to obtain a common assessment tool to evaluate microclimate, thermal comfort and infrared thermography in agroforestry systems. The experiment was conducted at the Embrapa Beef Cattle, Campo Grande, MS, from July 2015 to February 2016, corresponding to winter and summer seasons, in two agroforestry systems with different tree densities and spatial arrangements of native and planted trees. Readings were made from 8:00 a.m. to 4:00 p.m., for microclimate parameters (air temperature, dew point temperature, black globe temperature, relative humidity, wind speed, global solar radiation, photosynthetically active radiation and luminosity), thermal comfort (Temperature and Humidity Index, Black Globe and Humidity Index, Radiation Thermal Load), and infrared thermography (temperature and humidity of tree crown and soil surface), under full sun and shadow projection. Multiple Factor Analysis found three Synthetic Analytical Dimensions that explained 55.5% of the total observed variance. Strong and positive associations between infrared thermography, microclimate, thermal comfort and radiation were found. Thus, it is suggested that infrared thermography is a potential tool to be used for microclimate prediction and thermal comfort under agroforestry systems.

Keywords: Animal environment, animal production, animal welfare, thermal imagers.

Resumo

O objetivo foi utilizar a Análise Fatorial Múltipla para identificar grupos de variáveis correlacionadas, reduzir a dimensionalidade de dados e obter uma ferramenta de avaliação em comum para avaliar microclima, conforto térmico e termografia por infravermelho em sistemas agroflorestais. O experimento foi conduzido na Embrapa Gado de Corte, Campo Grande, MS, no período de julho de 2015 a fevereiro de 2016, compreendendo os meses correspondentes às estações de inverno e verão, em dois sistemas agroflorestais com diferentes densidades e arranjos espaciais de árvores nativas e cultivadas. Desse modo, das 08h00 às 16h00, foram registrados os parâmetros microclimáticos (temperatura do ar, temperatura do ponto de orvalho, temperatura de globo negro, umidade relativa, velocidade do vento, radiação solar global, radiação fotossintéticamente ativa e luminosidade), de conforto térmico (Índice de Temperatura e Umidade, Índice de Temperatura de Globo e Umidade e Carga Térmica de Radiação), e de termografia por infravermelho (temperatura e umidade das copas das árvores e da superfície do solo), nas posições a pleno sol e na projeção da sombra. A Análise Fatorial Múltipla encontrou três Dimensões Analíticas Sintéticas que explicaram 55,5% da variância total observada. Fortes e positivas associações entre termografia por infravermelho, microclima, conforto térmico e radiação foram encontradas. Assim, sugere-se que a termografia por infravermelho é uma potencial ferramenta a ser utilizada para a predição do microclima e conforto térmico animal em sistemas agroflorestais.

Palavras-Chave: *Ambiência animal, bem-estar animal, imagens térmicas, produção animal.*

Introduction

The use of technologies and tools for environmental surveys in the rural sector gains momentum as issues such as animal welfare and thermal comfort raise the interest and need for changes in the farming sector (Alves *et al*., 2017). In response to expanding demand, micrometeorological research has been carried out to better understand the effects of the different interactions that microclimatic parameters exert under animals, especially those produced on pasture (Karvatte Junior *et al*., 2016; Oliveira *et al*., 2017). Although efficient, these studies use a series of variables that, during the recording of data, require a large number of equipment and in some cases makes it impossible to optimize the study and to obtain rapid results.

In order to solve these problems, Multiple Factor Analysis (MFA) can reduce the concomitant dimensionality of quantitative and qualitative subsets of data within the same dataset, identifying associations between observational variables, in order to define a common factor between them and contribute decisively to facilitate data collection and interpretation of results (Abdi and Valentim, 2007).

In this research, we used MFA to identify groups of correlated variables, to reduce dimensionality of data and to obtain a common tool to evaluate microclimate, thermal comfort and infrared thermography in agroforestry systems.

Materials and methods

The study was conducted at the experimental station of the Brazilian Agricultural Research Corporation - Embrapa Beef Cattle, in Campo Grande - MS (20º27'S, 54º37'W, average elevation: 530 m). Climate of the region is in the transition between hot temperate (Cfa) and tropical humid (Aw), with rainfall and average annual temperature of 1560 mm and 23,0 °C (Köppen, 1949).

The experimental area, with 12 ha, has two silvopastoral systems with 6 ha each, both split into 4 paddocks of 1.5 ha each, having Piatã grass (Urochloa brizantha CV. BRS Piatã), being: (SS) silvopastoral system with eucalyptus trees (Eucalyptus grandis x E. urophylla, clone H 13) planted in single rows and density of 227 trees per ha (22x2m); and (SC) a conventional system containing some native species of the Brazilian Cerrado, baru (Dipteryx alata (Vogel)) and cambará (Gochnatia polymorpha (Less)), in random arrangement, with density of 3 adult trees per ha.

The experimental period was from June 2015 to February 2016, in correspondence to the winter (dry) and summer (rain) seasons in the region. Readings were carried out simultaneously in two paddocks, one for each system, for four consecutive days in each experimental month from 08h00 to 16h00, in one-hour intervals.

Thermal images were captured using an infrared thermographyc imager (Testo®, model 875 2i), configured with emissivity of 0.97, hot and cold data record palette and 7.5 mm lens (32° x 23° ; f/0.84), located at the height of the evaluator's eyes (approx. 1.75 m), distant approximately 10 m away from

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the trees, between tree rows of in the SS system and in front of the trees in the SC system.

The thermal images were analyzed through the IRSoft® program (Testo software), obtaining the maximum and minimum values of temperature (ºC) and humidity (%) of the pasture surface (TIVs and HTIVs) and tree crowns (TIVc and HTIVc), in the shadow projection and under full sun for calculating the respective averages.

At the same time, the microclimate parameters: air temperature (Ta, ºC), dew point temperature (Tdp, °C), black globe temperature (Tbg, °C), relative air humidity (RH, %) and wind speed (Ws, ms-1) were recorded for the subsequent calculation of the Temperature and Humidity Index (THI, Thom, 1958), Black Globe and Humidity Temperature Index (BGHI, Buffington, 1981) and Radiant Thermal Load (RTL, Esmay, 1979), considering the Average Radiant Temperature (ART). Equipment were allocated at 2.0 m of trees and to 1,5 m above ground, in the positions at full sun and projected shadows, in two repetitions per paddock, according to Karvatte Junior *et al*. (2016).

Radiation partitions were obtained through a LI-COR® spectroradiometer (LI-1400), connected to Quantum sensors (LI-190, measuring from 400 to 1100 nm), for evaluating global solar radiation (Q, W m-2). Pyranometer (Li, model LI-200, readings from 400 to 700 nm) for photosynthetically active radiation (P, µmol.m-2s-1) and Photometer (Liquor, model LI-210R) for luminosity (f, Lux). Monthly records were taken at five sample points in full sun and shadow projection, 1.5m high, with sensors facing solar direction.

The data set was subject to statistical analysis using the Multiple Factor Analysis (MFA) using the statistical package R (Fox, 2005). Multiple Factor Analysis (MFA) seeks to establish linear combinations among variables, as well as to create synthetic elements (factors) that add to the observed variance, in order to reduce the dimensionality of a multivariate data set, obtaining a common factor. Its striking difference against other factorial techniques is the assignment, a priori, of thematic groups of variables, both quantitative and qualitative, with the purpose of grouping the original variables to establish analysis strategy. During the statistics procedures, data are categorized and divided into different thematic groups, represented by the formation of Synthetic Analytical Dimensions (SAD), to explain relationship among variables within each group and among groups (Escofier and Pagès, 2008).

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Results and discussion

In this work, groups formed with their respective explanatory variables were: 1) Temperatures [Ta, Tbg, Tdp and ART]; 2) Wind and Humidity [Ws (max), Ws (min), Ws (md) and RH]; 3) Thermal Comfort Indices [THI, BGHI and RTL]; 4) Solar radiation [Q, P and f]; and, 5) Infrared Thermography (TIV) [TIVc, TIVs, HTIVc and HTIVs]. Together, these groups contributed to the formation of three different SAD and explained 55.5% of the total variance observed (Figure 1). Overall, the percentage of variance explained by the SAD was low, but able to demonstrate relationships among variables studied in the agroforestry systems, corroborating the data obtained by Barreto (2016), which obtained 72.4% of the variance observed by the set of three SAD, when using Multiple Factor Analysis to evaluate potential of microclimate characterization and farming thermal comfort, using thermal images of environments with scattered trees.

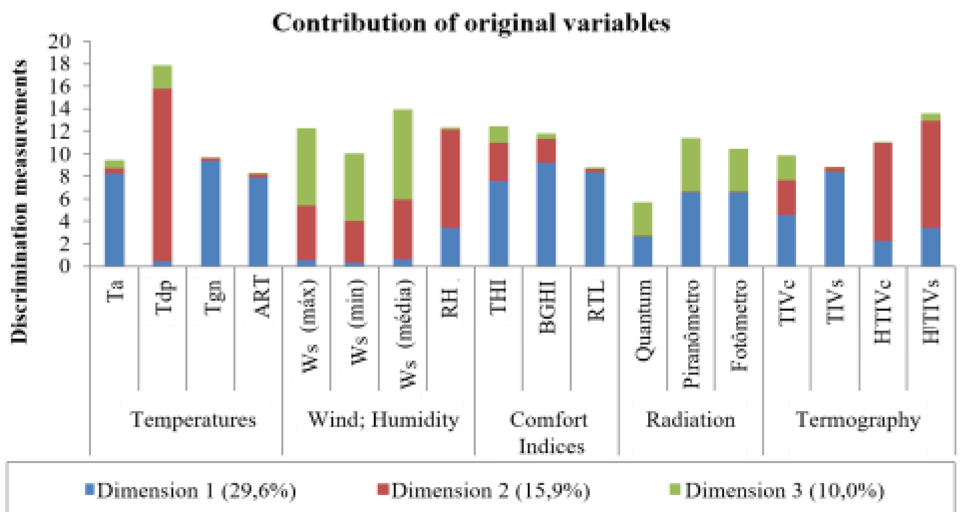

Figure 1: Contribution of original variables, within each group, to the formation of Synthetic Analytical Dimensions 1, 2 and 3.

It was observed that the SAD 1, represented by the variables air temperature (Ta, 8.26%), black globe temperature (Tbg, 9.40%), average radiant temperature (ART, 7.93%), Temperature and Humidity (THI, 7.61%), Black Globe and Humidity Temperature Index (BGHI, 9.24%), Radiant Thermal Load (RTL, 8.38%) and surface infrared thermography (TIVs, 8 , 47%) and in smaller percentage by Solar Radiation measured by Quantum (2.7%); (6.6%) and Photometer (6.6%), explained the largest portion of the total variance observed (29.6%), suggesting that, within the experimental conditions studied, these were the variables that most influenced the establishment of the thermal environment.

Afterwards, with formation of SAD 2, represented by the variables dew point temperature (Tdp, 15.3%), relative humidity (RH, 8.67%), humidity by infrared thermography of canopy (HTIVc, 8.78 %) and surface (HTIVs, 9.5%), a contribution of 15.9% was observed for the explanation of the total variance, and 10.0% for the DAS 3 formation, represented by the variables maximum wind speed [Ws (max), 6.87%], minimum [Ws (min), 6.0%] and mean [Ws (md), 7.96%].

With these results it was possible to generate the bidirectional graph of the factorial plane defined by the coordinates of two orthogonal dimensions (Figure 2). In this illustration, it is possible to observe that the infrared thermography of tree crown (TIVc) and the surface (TIVs) are strongly and positively associated to the variables that make up the group of Temperatures (Ta, Tbg and ART), Thermal Comfort Indexes (THI, BGHI and RTL) and Solar Radiation (Q, P and f), positioned near the X axis of DAS 1 (29.6%), suggesting that infrared thermography can be used as an alternative tool for microclimate evaluation and prediction of thermal comfort in agroforestry systems.

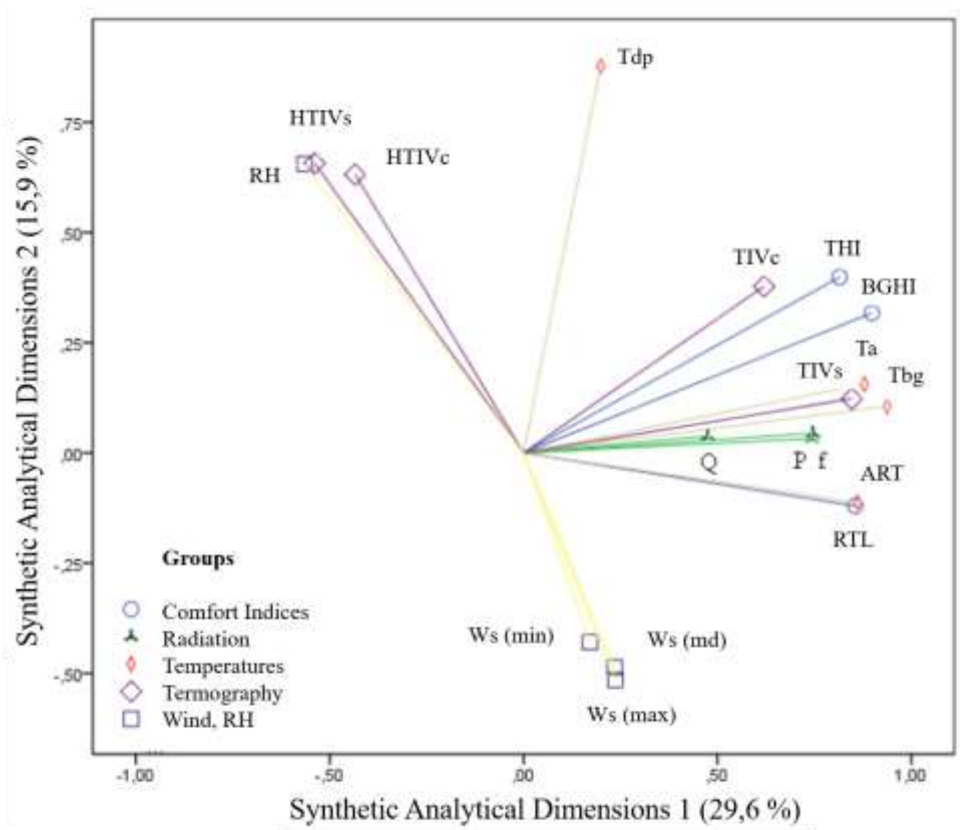

Figure 2: Bidirectional contribution of the original variables to orthogonal dimensions and their interactions.

Also in this figure, the relative humidity through crown infrared thermography (HTIVc) and surface (HTIVs) had a strong association with the relative humidity (conventional evaluation), but negatively associated with the variables related to wind speed (Ws max, Ws min and Ws med). Grouping these modalities on the Y axis of DAS 2, in opposite quadrants, indicates that the wind speed interferes with the relative air humidity fluctuations of the evaluated environments.

In fact, wind is the climatic variable related to the removal of air moisture from a system, and, when it presents different tree densities, variation of this microclimatic parameter happens (Brow *et al*., 1995). However, results obtained support the hypothesis of using infrared thermography as a tool to evaluate thermal environment in agroforestry systems. In addition to being portable, lightweight and easy to handle equipment, infrared thermal imagers are highly accurate sensitive, capable of storing large amounts of data and reducing the number of field devices (Barreto, 2016).

Likewise, groups formed by the original variables (Figure 1) collaborated for the emergence of DAS 3, represented by the associated variance (eigenvalue) to each original variable. With formation of this DAS, the emergence of the group called Systems (0.61%) [formed by the variables: integration systems (SS, SC), season of the year (dry and rainy), local (shade and sun) and times of the day], suggests that factors such as experimental arrangement, seasons of the year, time of day and equipment arrangement have critical influence on establishment of microclimate conditions and thermal comfort in agroforestry systems (Figure 3).

In fact, Karvatte Junior *et al*. (2016), when evaluating microclimate and thermal comfort in crop-livestock-forest integration systems, observed that during hours of greater thermal stress, between 11:00 am and 2:00 p.m., different tree spacing and densities allowed for reduction of 2 to 8 °C of temperature with an increase of 1.4 to 4.5% of relative humidity and variation from 0.0 to 4.8 ms-1, providing considerable changes in animal thermal comfort under canopy.

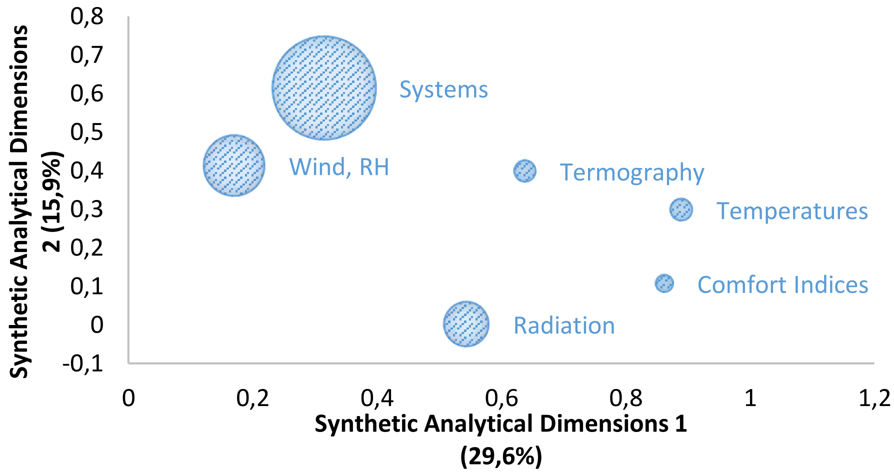

Figure 3. Contribution of original variables to the formation of Synthetic Analytical Dimension 3.

Conclusions

Multiple factor analysis explained 55.5% of the total variance observed in this study. Infrared thermography showed strong and positive associations with the microclimatic parameters, thermal comfort and radiation. Infrared thermography is a tool with potential to be used for prediction of microclimate and animal thermal comfort in agroforestry systems.

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