Classification of potential sheep heat-stress levels according to the prevailing meteorological conditions

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Abstract: Many researchers have found that physiology, welfare, health, and productivity of ruminants are significantly affected when they are exposed to heat-stress conditions. In such cases, heat-stress may also cause a reduction of farmers' profit in various ways. Heat-stress levels are significantly affected by the prevailing meteorological conditions. This paper aims to study the potential daily peak heat-stress conditions to which sheep are exposed and to classify them according to the prevailing meteorological conditions. For these purposes, temperature, relative humidity, wind speed and incoming solar radiation data were analyzed. The meteorological data were recorded during the summers of the period 2007 – 2012 by an automated meteorological station that operates in a rural area near the east coast of central Greece. Potential sheep's heat-stress was assessed using the Temperature Humidity Index (THI). The analysis showed that the daily maximum hourly (DMH) THI value exceeded the extreme severe heat-stress threshold (THI ⩾ 25.6) in 82% of the days. The average value of the DMH THI values during August was 29.0, being slightly higher than the corresponding value for July (i.e. 28.6) and 2.7 higher than the corresponding value for June. The classification of the DMH THI values according to the prevailing meteorological conditions was achieved by applying cluster analysis (CA). The 4 meteorological parameters mentioned above were used as variables in the CA. CA was performed by using the values of the meteorological parameters recorded when each DMH THI value was observed. CA is considered as an objective technique to group days with similar weather conditions. CA achieved to group extreme hot days (33.8 ^{o}C – 40.8^{o}C) and days characterized by high (28.5^{o}C – 32.3^{o}C), moderate (26.1^{o}C – 28.9^{o}C), relatively low (24.3^{o}C – 26.0^{o}C) and very low (20.1^{o}C – 20.6^{o}C) summer temperatures. In brackets, the first number corresponds to the average of DMH THI values calculated for the days included in each cluster. The second number corresponds to the average of temperature values recorded when the DMH THI values were observed, for each cluster of days. The impact of wind speed and incoming solar radiation on peak THI levels was also assessed. It was found that when wind speed and solar radiation increased, peak THI and temperature values also increased. The effect of wind speed to the thermal environment could be mainly attributed to mesoscale circulations that develop in the greater area. This paper showed that CA could be regarded as a useful tool to estimate the range of peak summer THI values, and consequently the magnitude of heat-stress, in relation to the prevailing meteorological conditions.

Keywords: Sheep, heat-stress, temperature humidity index, meteorological conditions, cluster analysis, Greece.

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1 Introduction

Unfavourable climate conditions can trigger heat-stress to ruminants, affecting their health, growth, productivity and welfare. Silanikove (2000) stated that in the long-term growth, milk production and reproduction of ruminants are impaired under heat-stress due to changes in biological functions. Sevi et al. (2001) stated that high temperatures induce adverse effects on the thermal and energy balance, the mineral metabolism, the immune function, the udder health, and the milk production of lactating ewes during summer under the Mediterranean climate. Finocchiaro et al. (2005) found that milk production yields of Mediterranean dairy sheep are affected by heat- stress. Panagakis and Chronopoulou

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(2010) found that under abnormally hot summer conditions, dairy ewes had respiration rates above normal altering their shade seeking behavior. Sevi and Caroprese (2012) stated that a reduction of thermal stress in dairy sheep results in cumulative beneficial effects such as lengthening of lactation, maintenance of good processing features of milk and a reduction in veterinary costs.

The influence of meteorological factors on animals' heat-stress has been studied by many authors. A widely accepted method to study animals' heat stress is the application of the Temperature Humidity Index, which is estimated by exploiting temperature and relative humidity values (Marai et al., 2007). It is well documented that a combination of high ambient temperatures and high relative humidity is unsuitable for sheep (Thwaites, 1985; Papanastasiou et al., 2013; Seedorf et al., 1998). Some authors have also incorporated measurements of solar radiation and wind speed to assess heat-stress conditions (Eigenberg et al., 2005; Mader et al., 2006).

Cluster analysis is a multivariate statistical method that can be applied to classify cases into groups that are relatively homogeneous within themselves and heterogeneous between each other, on the basis of a defined set of variables. Cluster analysis has been exploited by many disciplines. As far as its environmental applications concerns, indicatively is reported here that Sindosi et al. (2003) applied cluster analysis to determine the characteristic air mass types that affect the region of Athens, Greece, during the cold and the warm period of the year. Gramsch et al. (2006) applied cluster analysis to the PM10 and O3 data so as to classify the air quality monitoring stations in Santiago, Chile. Wan et al. (2010) exploited weather data to identify the prevailing bioclimatic zones across mainland China. Additionally, cluster analysis has been applied in many livestock studies. Indicatively is reported here that Ravagnolo and Misztal (2002) applied cluster analysis to quantify the effect of reducing the number of weather stations on accuracy of analyses of heat tolerance for milk in Holsteins. Milan et al. (2011) applied cluster analysis to group dairy sheep farms so as to study their structure and performance. Pereira et al. (2008) applied cluster analysis to characterize the short-chain and medium-chain free fatty acid profile in goat milk.

The aim of this paper was to study was the potential daily peak heat-stress conditions to which sheep are exposed during summer and to classify them by exploiting measurements of several meteorological parameters.

2 Materials and methods

2.1 Data

Hourly averaged values of temperature, relative humidity, incoming solar radiation and wind speed observed during the summers of the period 2007 – 2012 were exploited in this study. Data was recorded by an automated meteorological station that operates in Velestino, a rural area near the east coast of central Greece (Figure 1), by the Laboratory of Agricultural Engineering and Environment, Institute for Research and Technology of Thessaly, Centre for Research and Technology Hellas.

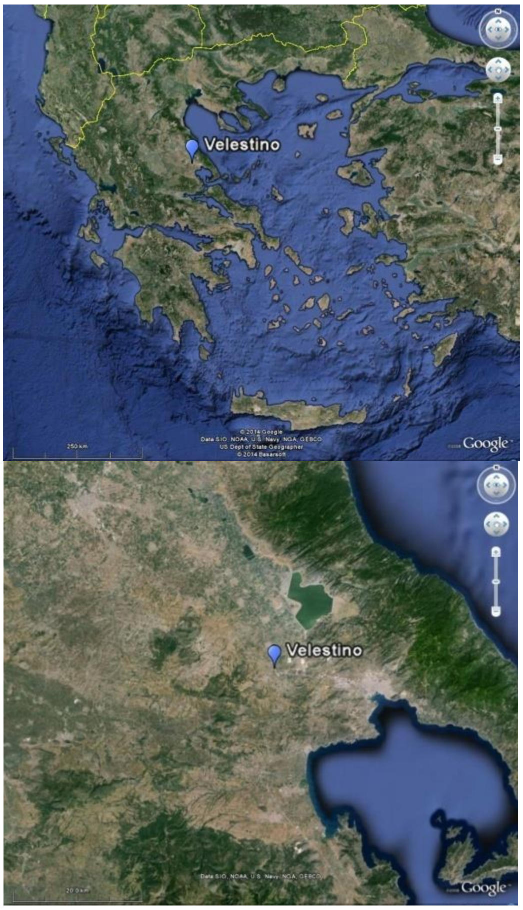

Figure 1 Location, where measurements were recorded (Velestino, 22^o 45΄ E, 39^o 24΄ N)

Left map: map of Greece; right map: focused on the greater Velestino area

2.2 Estimation of sheep's potential heat-stress

Marai et al. (2007) suggested that an appropriate climatic index to estimate the severity of sheep heat-stress is the THI given in equation 1, where T is the dry-bulb temperature (°C) and RH is the relative humidity (%). The same authors defined four heat-stress categories which are presented in Table 1.

$$THI = T - (0.31 - 0.0031 \cdot RH) \cdot (T - 14.4) \quad (1)$$

Table 1 Definition of heat-stress categories according to THI values

THI class	Heat-stress category
$THI < 22.2$	absence of heat-stress
$22.2 \le THI < 23.3$	moderate heat-stress
$23.3 \le THI < 25.6$	severe heat-stress
$THI \ge 25.6$	extreme severe heat-stress

2.3 Cluster analysis

There are two types of clustering techniques: the hierarchical and the non-hierarchical. In this study, the hierarchical technique was applied as the number of clusters was not known a priori. The average (between-group) linkage clustering procedure was selected, which minimizes within cluster variance (Kalkstein et al., 1987). The squared Euclidean distance was used as a measure of similarity. Data was standardized by converting it to a Z-score so as each variable to contribute equally. This procedure was necessary as the variables were measured on different scales. This fact affects the Euclidean distance measure, as variables with large values contribute more to the distance measure than variables with small values.

2.4 Applied methodology

The hourly averaged values of temperature and relative humidity were exploited to calculate the hourly values of THI which were analyzed in this study. Then, the daily maximum hourly (DMH) THI values were extracted, along with the values of temperature, relative humidity, incoming solar radiation and wind speed recorded when each DMH THI value was observed. The statistical analysis performed in this study mainly refers to temperature, relative humidity, incoming solar radiation, and wind speed values recorded when each DMH THI value was observed. The classification of the DMH THI values according to the prevailing meteorological conditions was achieved by applying cluster analysis, as described above. The values of temperature, relative humidity, incoming solar radiation and wind speed recorded when each DMH THI value was observed were used as variables in the cluster analysis.

3 Results and discussion

3.1 Daily maximum THI levels

The DMH THI values were grouped according to the heat-stress categories. Descriptive statistics for them, as well as for temperature, relative humidity, incoming solar radiation and wind speed values recorded when each DMH THI value was observed are presented in Table 2.

The analysis showed that the DMH THI value exceeded the extreme severe heat-stress threshold (THI ≥ 25.6) in 82% of the days. Table 2 shows that the aggravation of heat-stress conditions is related to an increase of the average of temperature and incoming solar radiation values and to a decrease of the average of relative humidity and wind speed values.

Figure 2 presents the distribution of DMH THI values, along with the distribution of DMH temperature values that were observed between 1100 and 1900 local time. This time period was selected as all DMH THI and DMH temperature values were observed between 1100 and 1900 local time. Figure 2 shows that the DMH THI and the DMH temperature values exhibited similar distributions, a fact that shows that THI values were significantly affected by temperature values, the correlation coefficient being 0.99. However, the impact of relative humidity on THI is also significant in some cases. Papanastasiou et al. (2014) found that the effect of relative humidity on THI was more pronounced than the effect of temperature, when cold air rich in moisture was advected to the area, when sea breeze blew.

The average value of the DMH THI values during August was 29.0, being slightly higher than the corresponding value for July (i.e. 28.6) and 2.7 higher than the corresponding value for June. The DMH temperature value varied similarly during the summer months. The corresponding values for the DMH temperature value were 32.8°C, 32.6°C and 29.5°C for August, July and June, respectively.

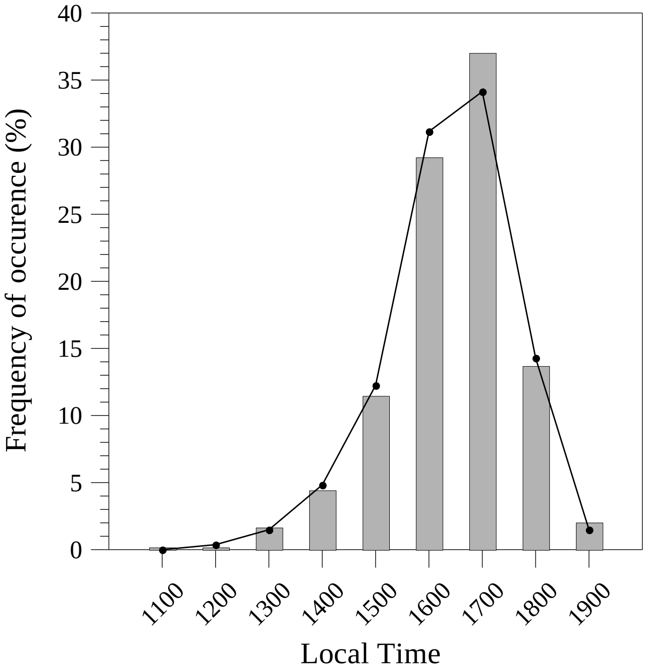

Figure 2 Distribution of DMH THI values (bars) and DMH temperature values (solid line).

Table 2 Descriptive statistics of DMH THI, temperature, relative humidity, wind speed and incoming solar radiation values per heat-stress category

Heat-stress category	Percentage of days	Value	DMH THI	Temperature	Relative humidity	Wind speed	Incoming solar radiation
	%			°C	%	$m\ s^{-1}$	$W\ m^{-2}$
Extreme severe heat-stress	82	Maximum	35.0	42.8	57	8.2	971
		Minimum	25.6	27.6	12	1.3	266
		Average	28.9	32.7	33	2.8	663
Severe heat-stress	15	Maximum	25.6	28.9	76	6.0	938
		Minimum	23.4	24.1	22	1.7	196
		Average	24.6	27.0	38	2.9	656
Moderate heat-stress	2	Maximum	23.2	25.3	57	4.9	976
		Minimum	22.3	23.8	28	1.0	325
		Average	22.9	24.7	43	3.1	651
Absence of heat-stress	1	Maximum	22.0	23.3	79	2.9	510
		Minimum	19.9	20.3	42	1.1	78
		Average	20.8	21.6	65	2.0	297

3.2 Application of cluster analysis

The application of cluster analysis revealed five clusters of days as far as it concerns DMH THI values, corresponding to five groups of days with similar weather characteristics within each group. Cluster analysis achieved to group days characterized by extreme high, high, moderate, relatively low and very low summer temperatures. Two clusters appeared for very few days (1% of the total number) and were related to extreme weather conditions (days with extreme high temperatures and days with very low temperatures). Another cluster (days with relatively low temperatures) appeared for few days (3% of the total number), while the dominant cluster (days with high temperatures) appeared for 82% of the total number of days. The fifth cluster (days with moderate temperatures) appeared for 13% of the total number of days. Descriptive statistics for the DMH THI values and the temperature, relative humidity, incoming solar radiation and wind speed values recorded when each DMH THI value observed for the days included in each cluster are presented in Table 3. In general, Table 3 shows that when temperature, wind speed and incoming solar radiation increased and when relative humidity decreased, peak THI values increased. However, the impact of mesoscale circulations that develop in the greater area on relative humidity (as mentioned above), wind speed and incoming solar radiation (as it is mentioned below) should be taken into account when studying the effect of meteorological parameters on THI levels. The frequency of occurrence of every heat-stress category per cluster is presented in Table 4. A description of the five clusters and the corresponding weather conditions are given in the following.

Table 4 Frequency of occurrence (%) of heat-stress category per cluster

Heat-stress category	Cluster				
	1	2	3	4	5
Extreme severe heat-stress	100	90	49	13	0
Severe heat-stress	0	10	41	43	0
Moderate heat-stress	0	0	10	31	0
Absence of heat-stress	0	0	0	13	100

Table 3 Descriptive statistics of DMH THI, temperature, relative humidity, wind speed and incoming solar radiation values per cluster

Parameter	Value	Cluster				
		1	2	3	4	5
DMH THI	Maximum	35,0	34,3	31,5	27,5	20,3
	Minimum	31,9	22,8	22,8	21,7	19,9
	Average	33,8	28,5	26,1	24,3	20,1
Relative humidity (%)	Maximum	27	56	57	70	79
	Minimum	12	15	25	37	67
	Average	16	32	38	52	75
Temperature (^oC)	Maximum	42,8	40,6	36,0	29,5	21,0
	Minimum	37,0	24,8	24,7	23,2	20,3
	Average	40,8	32,3	28,9	26,0	20,6
Wins speed ($m\ s^{-1}$)	Maximum	8,2	4,6	6,2	5,7	2,9
	Minimum	1,3	1,4	1,6	1,0	1,1
	Average	4,7	2,7	4,5	3,5	1,9
Incoming solar radiation ($W\ m^{-2}$)	Maximum	917	939	976	784	225
	Minimum	606	266	460	196	78
	Average	736	651	753	485	176

Cluster 1 includes extreme hot summer days which account for the 1% of the total number of days. This cluster includes days when severe heat waves occurred, as happened in June and July of 2007 (Papanastasiou et al., 2015). The average of the DMH THI values for the days included in this cluster was 33.8, while the average of the temperature values recorded when the DMH THI values were observed was 40.8°C). Sheep experienced extreme severe heat-stress during all the days included in this cluster (Table 4).

Cluster 2 includes days characterized by high summer temperatures, which account for the 82% of the total number of days. The amount of incoming solar radiation covered a wide range of values, while wind speed was low in the majority of these days (Table 3). The variation of the incoming solar radiation could be attributed to sea breeze development. Sea breeze develops frequently in the area and is characterized by low wind speeds (Papanastasiou and Melas, 2009). Papanastasiou et al. (2010) found that sea breeze front can reach Velestino area. Ahrens (2009) stated that a line of clouds forms along the sea breeze front, resulting in the reduction of the amount of solar radiation that reached the ground. The average of the DMH THI values for the days included in this cluster was 28.5, while the average of the temperature values recorded when the DMH THI values were observed was 32.3°C). Sheep experienced extreme severe heat-stress during the 90% of the days included in this cluster (Table 4).

Cluster 3 includes days characterized by moderate summer temperatures, which account for the 13% of the total number of days. Based on the average wind speed and incoming solar radiation values (Table 3), these days were characterized by low or absence of cloudiness and by high wind speed. The average of the DMH THI values for the days included in this cluster was 26.1, while the average of the temperature values recorded when the DMH THI values were observed was 28.9°C). Sheep experienced heat-stress during all the days included in this cluster, being extreme sever in almost half of them (Table 4).

Cluster 4 includes days characterized by relatively low summer temperatures, which account for the 3% of the total number of days. Based on the average wind speed and incoming solar radiation values (Table 3), these days were characterized by moderate cloudiness and by relatively high wind speed. The average of the DMH THI values for the days included in this cluster was 24.3, while the average of the temperature values recorded when the DMH THI values were observed was 26.0°C. Sheep did not experience heat-stress during the 13% of the days included in this cluster (Table 4).

Cluster 5 includes days characterized by very low summer temperatures, which account for the 1% of the total number of days. This cluster includes cold summer days (noon temperatures did not exceed 21°C) with high cloudiness and very low wind speed (Table 3). The average of the DMH THI values for the days included in this cluster was 20.1, while the average of the temperature values recorded when the DMH THI values were observed was 20.6°C. Sheep did not experience heat-stress during all the days included in this cluster (Table 4).

Figure 3 shows the monthly variation of each cluster. The variation of cluster 1 is rather not objective, as it is related to the extreme heat waves that occurred during the study period. The days included in the dominant cluster (cluster 2) are almost homogenously distributed in the three summer months. Clusters 3 and 4 were observed more frequently in June, as June is the colder summer month. Cluster 5 is not shown in Figure 3, as all days included in it appeared in June.

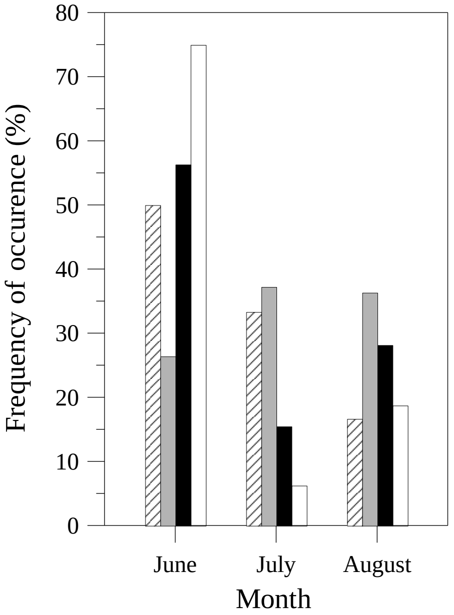

Figure 3 Distribution of days included in each cluster per month. Forward slashed bars, gray bars, black bars and white bars correspond to cluster 1, 2, 3 and 4, respectively.

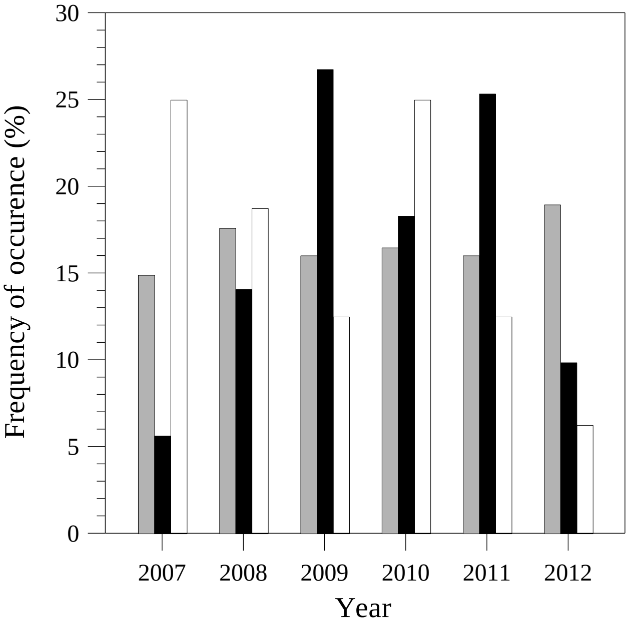

Figure 4 Distribution of days included in each cluster per year. Gray bars, black bars and white bars correspond to cluster 2, 3 and 4, respectively

Figure 4 shows the annual variation of each cluster. The days included in the dominant cluster (cluster 2) are almost homogenously distributed in the examined years. The appearance of clusters 3 and 4 varied between the examined years but, definitely, more data are required so as to identify a trend. Clusters 1 and 5 are not shown in Figure 4, as they were related to extreme weather conditions.

4 Conclusions

Cluster analysis was applied in this study to classify potential sheep heat-stress levels according to the meteorological conditions that prevail in a rural area near the east coast of central Greece. Data collected during the summers of a 6-year period (2007 – 2012) were analyzed. Heat-stress levels were estimated by means of THI, while temperature, relative humidity, incoming solar radiation and wind speed were the meteorological parameters that were exploited.

Outdoor weather conditions in the area are not favourable for sheep. Sheep experienced heat-stress in the 99% of the examined days, while extreme severe heat-stress conditions were established during the vast majority of the examined days (82%).

The application of cluster analysis identified five clusters, each one characterized by different weather characteristics. Cluster 1 and 5 includes the extreme hot and the extreme cold days, respectively. Cluster 2, includes those days which were characterized by high temperatures, a variety of incoming solar radiation values and low wind speed values. The meteorological conditions during the days that are included in cluster 2 were often influenced by the sea breeze circulation that frequently develops in the greater area. Cluster 2 is the dominant cluster, including the 82% of the days. Cluster 3 includes those days which were characterized by moderate temperatures, low or absence of cloudiness and high wind speed. Cluster 4 includes those days which were characterized by relatively low temperatures, moderate cloudiness and relatively high wind speed. Heat-stress conditions were very unfavorable during the days included in cluster 1 and 2, became better during the days included in clusters 3 and 4, while no heat-stress was observed during the days included in cluster 5.

Concluding, this paper showed that CA could be regarded as a useful tool to estimate the magnitude of heat-stress, based on the observation of the prevailing meteorological conditions.

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