J. Dairy Sci. 98:4572–4579
http://dx.doi.org/10.3168/jds.2015-9331

The effect of heat waves on dairy cow mortality

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ABSTRACT

This study investigated the mortality of dairy cows during heat waves. Mortality data (46,610 cases) referred to dairy cows older than 24 mo that died on a farm from all causes from May 1 to September 30 during a 6-yr period (2002–2007). Weather data were obtained from 12 weather stations located in different areas of Italy. Heat waves were defined for each weather station as a period of at least 3 consecutive days, from May 1 to September 30 (2002–2007), when the daily maximum temperature exceeded the 90th percentile of the reference distribution (1971–2000). Summer days were classified as days in heat wave (HW) or not in heat wave (nHW). Days in HW were numbered to evaluate the relationship between mortality and length of the wave. Finally, the first 3 nHW days after the end of a heat wave were also considered to account for potential prolonged effects. The mortality risk was evaluated using a case-crossover design. A conditional logistic regression model was used to calculate odds ratio and 95% confidence interval for mortality recorded in HW compared with that recorded in nHW days pooled and stratified by duration of exposure, age of cows, and month of occurrence. Dairy cows mortality was greater during HW compared with nHW days. Furthermore, compared with nHW days, the risk of mortality continued to be higher during the 3 d after the end of HW. Mortality increased with the length of the HW. Considering deaths stratified by age, cows up to 28 mo were not affected by HW, whereas all the other age categories of older cows (29–60, 61–96, and >96 mo) showed a greater mortality when exposed to HW. The risk of death during HW was higher in early summer months. In particular, the highest risk of mortality was observed during June HW. Present results strongly support the implementation of adaptation strategies which may limit heat stress-related impairment of animal welfare and economic losses in dairy cow farm during HW.
Key words: heat wave, dairy cow, mortality, welfare, global warming

INTRODUCTION

The effect of weather on livestock health is a topic of increasing concern, especially in light of the future scenarios on climate change. Climatologists forecast that earth's temperature will rise over coming decades and that the frequency of heat waves, a prolonged period of excessively hot weather, will increase in terms of frequency, intensity, and length (Beniston et al., 2007).

Climate scenarios for the temperature-humidity index (**THI**), an index that combines the simultaneous effect of temperature and humidity and that has been widely used to assess the degree of heat stress in livestock, were recently described for the Mediterranean area (Segnalini et al., 2013). For the coming decades, the study forecasted an increase of THI during summer months, which will likely cause thermal discomfort in livestock species with consequences on animal welfare, performance, health, and survival. In a previous study, we highlighted a greater frequency of deaths during summer months and indicated that approximately 80 and 70 THI were maximum and minimum, respectively, above which the number of deaths in dairy farms starts to increase significantly (Vitali et al., 2009).

The effect of heat waves on human mortality has been studied in depth (Ostro et al., 2009; Schifano et al., 2009; Li et al., 2011); conversely, this topic has been poorly investigated in livestock species. To the best of our knowledge, one study reported an increase in cattle deaths as consequence of a week-long heat wave in the mid-central United States during July 1995 (Hahn, 1999), and recently a French study analyzed the effect of heat waves which occurred during 2003 and 2006 on cattle mortality (Morignat et al., 2014). Hahn (1999) reported that the exposure to heat wave resulted in death losses as high as 5 to 10%, whereas the French study (Morignat et al., 2014) indicated that

Received January 10, 2015.
Accepted March 26, 2015.
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the increase of mortality during the heat waves was between 12 and 24%. Our retrospective study investigated the effect of heat waves on dairy cows mortality during a 6-yr period.

MATERIALS AND METHODS

Weather Data

Temperature and relative humidity data from 1971 to 2007 were obtained from 12 weather stations located in 12 Italian provinces. The provinces were selected on the basis of a weather station present in the area in operation at least since 1970 as well as having a significant number of dairy cows. Basic quality-control procedures of weather data were carried out by following the guidelines provided by the World Meteorological Organization (Zahumenský, 2004). The control procedures performed were relative to completeness, extremes values, variability, and internal and spatial consistencies. The missing and incorrect values of temperature and relative humidity in the whole series were estimated on the closest point of a regular grid (30 × 30 km). Daily values of each point were calculated starting from data recorded in the Italian weather stations network as reported by Perini et al. (2004). For each station, about the 5.4% of the data were replaced. Finally, for each station, time series data only referred to years 2002 to 2007 when THI was calculated. Calculation of THI was carried out by using the Kelly and Bond (1971) formula.

A heat wave is generally defined as a prolonged period of excessively hot weather. The lack of an official definition of heat wave is based on average weather conditions in the area and on normal seasonal temperatures (Robinson, 2001; Beniston et al., 2007; Russo et al., 2014). In our study a heat wave was defined as a period of at least 3 consecutive days when the daily maximum temperature exceeded the 90th percentile of the reference distribution (1971–2000; Russo et al., 2014). Therefore, heat waves were identified and characterized from May 1 to September 30 during the years 2002 to 2007. The percentile thresholds were determined empirically from the observed stations series in the climate period 1971 to 2000. The values of percentile were calculated from 5-d periods centered on each calendar day to account for the mean annual cycle. A total sample of 150 values (30 yr × 5 d) for each day of the year was generated. This approach ensured that extreme temperature events, in terms of crossings of percentile thresholds, can occur with equal probability throughout the year (Klein Tank and Konnen, 2003). The analysis of weather data were performed by the R Core Team (2014) software.

The days from May 1 to September 30 (2002–2007) were classified as days in heat wave (**HW**) or not in heat wave (**nHW**). The length of exposure to heat was considered and the days within each HW were counted. The exposure to HW was categorized as short (1 to 3 HW days), medium (4 to 6 HW days), long (7 to 10 HW days), and very long (>11 HW days).

Prolonged effects following exposure to heat is an important health topic, and no evidences of the excess in mortality following heat waves in livestock species exists. In humans, Basu and Samet (2002) reviewed the lag times with the strongest association of heat with mortality range from the same day to 3 d following an HW. In light of this, we also investigated potential prolonged effects and the 3 nHW days following the end of HW, categorized as first (**nHWst**), second (**nHWnd**), and third (**nHWrd**).

Cow Data

Mortality data referred to 46,610 counts (deaths) recorded in the 12 provinces selected from May 1 to September 30 during a 6-yr period (2002–2007; Table 1). Data were extracted from the Bovine Spongiform Encephalopathy databases available at the Italian Reference Centre for Animal Encephalopathies (Turin, Italy) and at the National Reference Centre for Animal Welfare (Istituto Zooprofilattico Sperimentale Lombardia ed Emilia Romagna, Brescia, Italy) as previously described (Vitali et al., 2009). Briefly, databases contained records of cows older than 24 mo that died on a farm from all causes, were slaughtered in an emergency, or were sent for normal slaughter but were found to be sick in the preslaughter inspection. The latter 2 categories accounted for approximately 2% of total deaths. For each death reported, the databases provided cow identification number (official ear tag), date of death, the identification number of the farm where the cow was before death, and the province where the farm was located. In general, it can be assumed that farms where the deaths were recorded were homogeneous for the production system adopted (intensive), and for stall design and management (total confinement freestall housing with no time at pasture, TMR as a feeding practice, and year-round calving patterns).

Age of cows were calculated and mortality counts were stratified by classes of age (expressed in months). The classes of age were ≤28, 29 to 60, 61 to 96, and ≥97 mo and were chosen according to those reported for cow consistency from Italian National Bovine Registry (BDN, 2010). In Table 1, statistics on the deaths and consistencies of cows stratified by age are reported. Table 1 also reports productive and reproductive statistics of dairy cows population involved in the study

Table 1. Consistencies, deaths, and productive and reproductive statistics of cows population[1]

Item	Mean (±SD)
Consistencies of cows for classes of age,[2] head	
Up to 28, mo	65,936 ± 2,805
29–60, mo	418,489 ± 22,681
61–96, mo	248,512 ± 36,300
+97, mo	164,021 ± 33,369
Total	896,958 ± 94,738
Deaths recorded for classes of age,[3] no.	
Up to 28, mo	2,586
29–60, mo	20,411
61–96, mo	15,611
+97, mo	8,019
Total	46,610
Cows productive and reproductive statistics[4]	
Milk yield, kg	8,587 ± 2,054
Fat, %	3.65 ± 0.48
Protein, %	3.29 ± 0.22
Age at parities, mo	
First	29.6 ± 6.6
Second	43.8 ± 7.6
Third	57.5 ± 8.2
Fourth	70.9 ± 8.9
Herd life, number of lactations[5]	2.54
Conception rates[5]	2.46
Days open[5]	141

[1]Data referred to 6-yr period (2002–2007) and to 12 Italian provinces.

[2]Annual average values (±SD) of cow consistencies (BDN, 2010).

[3]Number of deaths recorded from May 1 to September 30 (2002–2007) stratified for classes of age.

[4]Annual average values (±SD) were obtained by the Italian Breeder Association (AIA, 2010).

[5]Data referred to median values (AIA, 2010).

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Statistical Analyses

The relationship between HW and mortality was evaluated using a case-crossover design (Maclure and Mittleman, 2000). This approach allows us to assess the effect of transient exposure on acute events (Jaakkola, 2003) using only cases and compares each case's exposure during a time period-defining event (hazard days) with that subject's own exposure in other reference periods (control days). Because each subject serves as his or her own control, measured and unmeasured potential confounding factors are controlled by design (Jaakkola, 2003; Crescio et al., 2010). The referent days were selected from the same month and year and matched by day of week to the health outcome (Crescio et al., 2010; Wilson et al., 2013). This time-stratified method of selecting comparison days ensures unbiased conditional logistic regression estimates and avoids bias resulting from time trends (Janes et al., 2005).

In the model, HW, nHWst, nHWnd, and nHWrd were considered as high temperature exposure, whereas nHW were considered as low temperature exposure. A conditional logistic regression model was used to calculate odds ratio (**OR**) and 95% confidence interval (**CI**) for mortality recorded during hazard days compared with that recorded in control days pooled and stratified by duration of exposure, age of cows, and month of occurrence. The OR is statistically significant when the 95% CI does not include the unit. Statistical analysis was performed using Stata software 11.2 (StataCorp., 2009).

RESULTS

Mortality, cow data, and HW inventory are reported in Tables 1 and 2, respectively.

Climatic Conditions

Results indicated that, during the 6-yr period investigated, the territory under study was affected by several

Table 2. Heat waves inventory referred to data recorded on 12 Italian weather stations from May 1 to September 30 over a 6-yr period (2002–2007)

Heat waves inventory	Mean (±SD)
Annual heat waves, no.	5.09 ± 2.99
Annual days in heat waves	28.25 ± 12.34
Length of heat wave, d	6.81 ± 5.05
Daily maximum temperature in heat wave, °C	31.78 ± 3.79
Daily minimum temperature in heat wave, °C	18.33 ± 3.65
Daily maximum temperature in other summer days, °C	27.01 ± 4.03
Daily minimum temperature in other summer days, °C	15.8 ± 3.95
Daily maximum relative humidity in heat wave, %	86.2 ± 13.6
Daily minimum relative humidity in heat wave, %	32.1 ± 9.6
Daily maximum relative humidity in other summer days, %	90.8 ± 8.6
Daily minimum relative humidity in other summer days, %	42.7 ± 13.5
Daily maximum THI in heat wave[1]	77.40 ± 3.92
Daily maximum THI in other summer days[1]	73.24 ± 4.50

[1]Temperature-humidity index (THI) calculated from temperature and relative humidity data and using the Kelly and Bond (1971) formula.

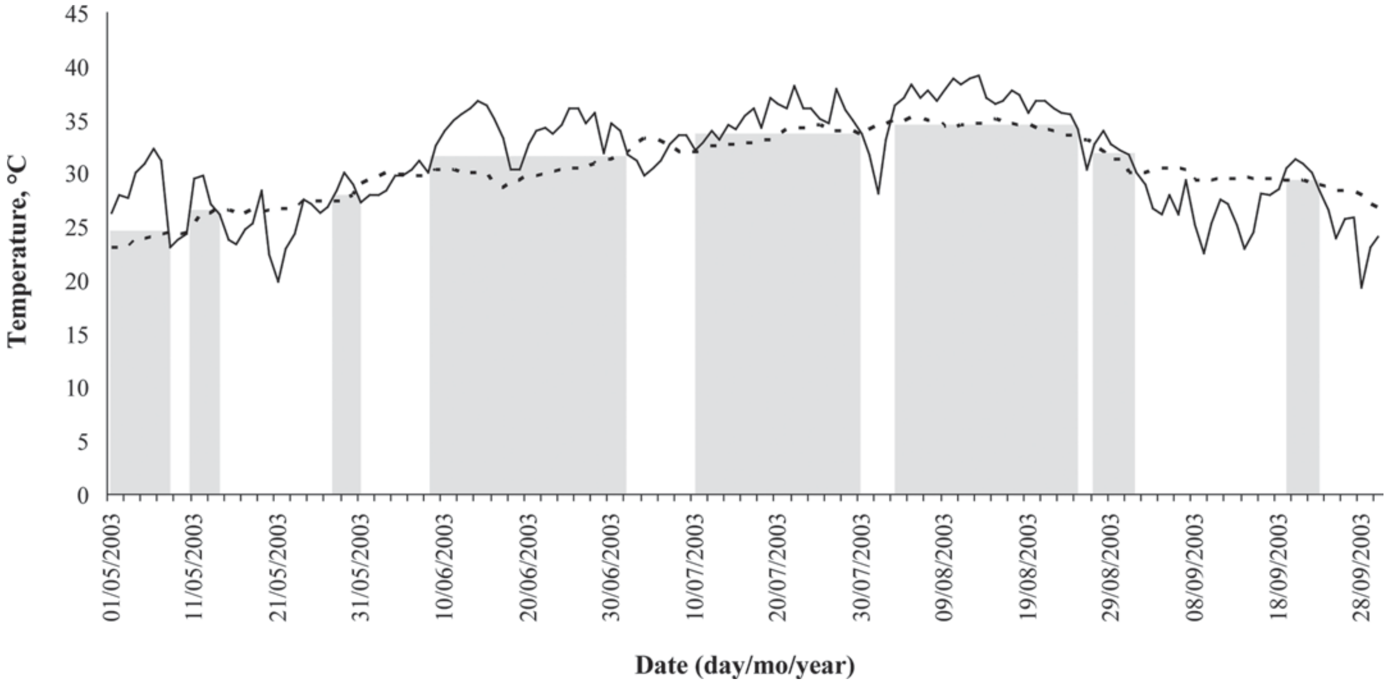

Figure 1. The 90th percentile of the reference temperature distribution calculated on climate period 1971 to 2000 (- - -) and daily temperatures (—) observed in 1 weather station involved in the study from May 1 to September 30, 2003. The gray bands indicate the days in heat wave over the period investigated.

prolonged HW. In total, the HW days accounted for approximately 20% of total days investigated. Our data also indicated that summer 2003 was particularly hot in the study area. Figure 1 shows HW recorded during summer 2003 by one of the weather stations used in the study, which registered 8 long HW corresponding to 96 d (62% of the total days considered).

Figure 2 shows average monthly values of maximum and minimum temperatures recorded during the study. Values of minimum and maximum temperatures recorded over the study period were correlated significantly (r = 0.7; $P < 0.05$). Maximum and minimum temperatures in HW were 4.4 and 2.5°C, respectively, higher than those recorded during nHW. Heat waves that occurred in June showed the greatest anomalies between HW and nHW. In June, the anomalies for maximum and minimum temperatures were 5.7 and 3.7°C, respectively.

HW-Related Mortality

The analysis of pooled data indicated a greater probability of death for dairy cows during HW. Considering the events recorded in HW versus those recorded in nHW, our analysis pointed out a significant risk of death for dairy cows exposed to HW (OR = 1.196; $P < 0.0001$; CI: 1.161–1.231; Figure 3). Furthermore, the mortality risk continued to be significantly higher during the 3 d following the end of heat wave even if the temperature recorded in these days was similar to that recorded in nHW days.

Duration of Exposure

The duration of HW affected dairy cow mortality and data indicated the highest risk of death in correspondence of a prolonged exposure (Figure 4). As shown in Figure 4, compared with nHW, the mortality risk increased proportionally from short (first 3 HW days) to very long (more than 11 HW days) heat exposure.

Age

Odds ratios stratified for classes of age are reported in Table 3. Results show that risk of death of younger cows (up to 28 mo) was not affected by HW ($P > 0.05$). Conversely, older cows had a greater risk of death during the occurrence of HW compared with nHW ($P < 0.05$). Within cows older than 28 mo, the class of age with the highest risk to die was observed in the 61 to 96 mo class ($P < 0.0001$).

Month of HW Occurrence

Mortality in HW was evaluated also considering the month of occurrence. The deaths observed in HW days

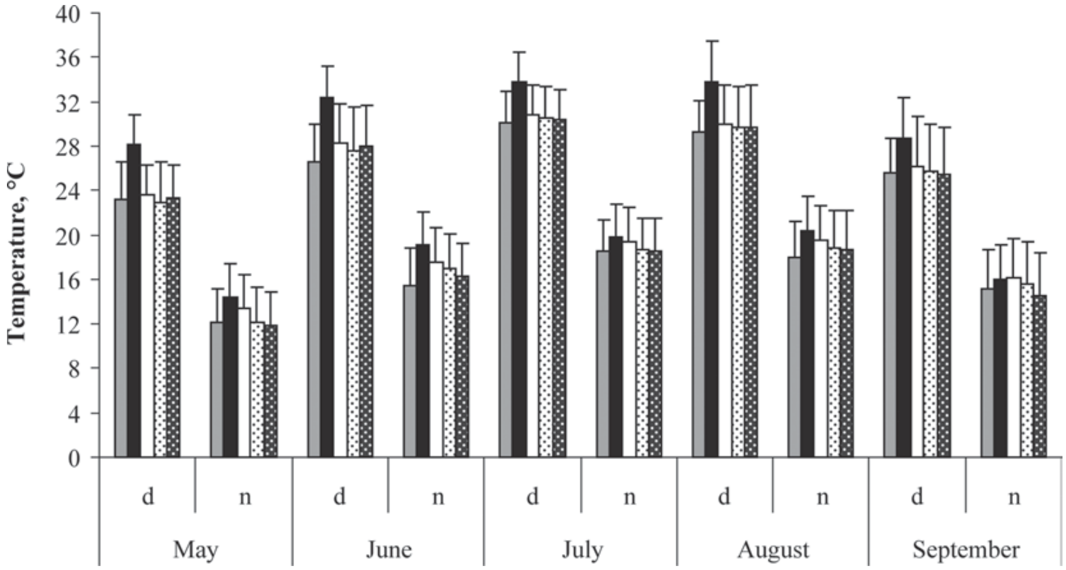

Figure 2. Average values of maximum and minimum temperatures (±SD) recorded in summer days during the daytime (d) and nighttime (n), respectively. The gray columns refer to day not in heat wave (nHW), the black columns refer to day in heat wave (HW), the white columns refer to first nHW day after the end of heat wave (nHWst), the white columns with black dots refer to second nHW day after the end of heat wave (nHWnd), and the black columns with white dots refer to third nHW day after the end of heat wave (nHWrd).

compared with those in nHW days were higher ($P < 0.05$) in all months analyzed (Figure 5). At the same time, OR highlighted that the HW recorded in early summer had higher risk of death than those that occurred later. The HW in June showed the greatest excess mortality (OR = 1.298; $P < 0.001$; CI: 1.233–1.366). Deaths recorded in the HW in May (OR = 1.116; $P = 0.001$; CI: 1.045–1.193) and July (OR = 1.156; $P < 0.001$; CI: 1.091–1.226) were higher compared with those which occurred in August (OR = 1.083; $P = 0.027$; CI: 1.009–1.161) and September (OR = 1.078; $P = 0.035$; CI: 1.005–1.155).

DISCUSSION

Climatic Conditions

The analysis of weather data indicate that Italian summer may be critical for animal health and welfare due to the occurrence of a significant number of HW. Climate predictions for future decades are not encouraging either. For the geographic area of Europe, it has been predicted that regional surface warming will increase the frequency, intensity, and duration of HW over Europe. In particular, by the end of the 21st century, countries in central Europe are expected to experience the same number of hot days as are currently experienced in southern parts of the continent (Beniston et al., 2007). Recently, an Italian study forecasted the THI in the Mediterranean basin over the next decades and indicated that, with respect to the reference period 1971 to 2000, the values of maximum THI during summer season in the decade 2041 to 2050 are expected to be higher, ranging between 3 and 4 units (Segnalini et al., 2013).

Table 3. Odds ratio with 95% CI related to the effect of heat waves on dairy cow mortality stratified by age

Classes of age, mo	Odds ratio	95% CI	P-value
Up to 28	1.119	0.996–1.258	0.059
29–60	1.170	1.122–1.219	<0.0001
61–96	1.200	1.145–1.259	<0.0001
97+	1.092	1.022–1.167	0.009

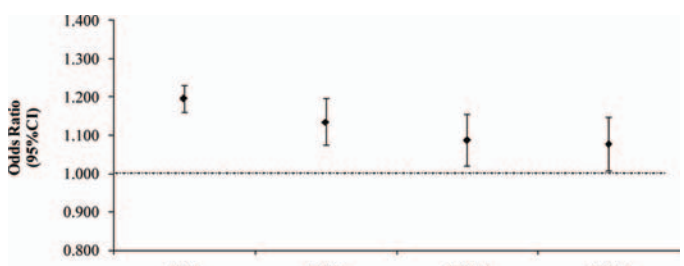

Figure 3. Odds ratio and 95% CI calculated for dairy cow mortality during heat wave (HW) and in the 3 not heat wave days (nHW) after the end of heat wave (d 1, 2, and 3 defined as nHWst, nHWnd, and nHWrd, respectively). Odds ratio are statistically significant when 95% CI does not include the unit (dashed line).

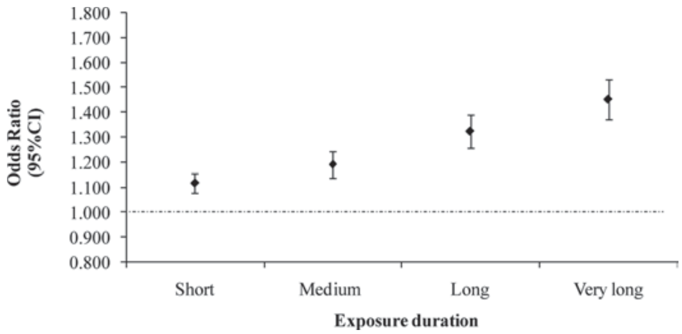

Figure 4. Odds ratio and 95% CI calculated for dairy cow mortality in relation to the duration of exposure to heat. The duration of exposure was classified as short (1 to 3 heat wave days), medium (4 to 6 heat wave days), long (7 to 10 heat wave days), and very long (>11 heat wave days). Odds ratio are statistically significant when 95% CI does not include the unit (dashed line).

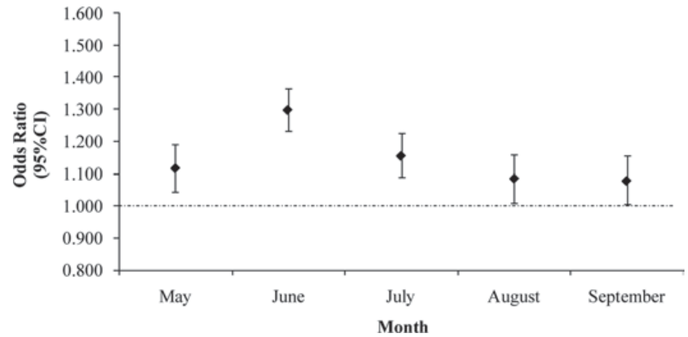

Figure 5. Odds ratio (OR) and 95% CI related to the effect of heat waves (HW) on dairy cow mortality as function of the month of heat wave occurrence. Odds ratio are statistically significant when 95% CI does not include the unit (dashed line).

HW-Related Mortality

The present study indicated that the exposure of dairy cows to hot weather (approximately 32°C) for at least 3 consecutive days increased the risk of death during summer months. This result is in line with what has been described in studies from France and the United States with cattle (Hahn, 1999; Morignat et al., 2014). However, it may be speculated that, to a certain extent, such greater risk may also be linked to the greater values of the minimum temperature during HW, which may limit the ability of cows to dissipate heat during the night.

Our previous findings indicated 79.6 THI as the threshold above which mortality in dairy cows started to increase significantly (Vitali et al., 2009). Considering the THI recorded herein during HW (77.4), it is interesting to note that it was about 2 units lower than 79.6. In other words, the THI associated with deaths in HW was lower than that associated with the mortality following the exposure to a single hot day. This would suggest that a prolonged heat stress would lower the THI threshold referred to the risk of death.

The significant probability of death recorded during the 3 d following the end of HW indicated the presence of a prolonged association between heat and mortality. Lower OR observed in the second and third nHW compared with first nHW seems to indicate that the exposure to normal temperatures of the period helps cows to recover from heat loaded in heat wave and allows them to restore the normal body functions.

In conclusion, these results support the assumption that the greater cow mortality observed during summer (Vitali et al., 2009) should not be considered as related to single hot day, but rather more linked to episodes of HW. The prolonged heat challenge may impede the cows recouping from the heat load as well as impair performance and physiological functions that may trigger clinical or subclinical health conditions until the death of animal (Hahn, 1999; Silanikove, 2000).

Duration of Exposure

The duration of heat wave affected excess mortality in that the prolonged exposure of cows to heat stress would overcome their ability to cope with high temperatures. When heat stress in cattle was studied with a bidimensional approach, intensity × duration of exposure, results indicated that the susceptibility to heat was affected by heat load balance (Gaughan et al., 2008). Those authors reported that when cattle were exposed to a high temperature in the daytime and had poor recovery in the nighttime, then cattle would not have had sufficient time to recover from the excessive heat gained during the day. If the following day was cold, then cattle could recover from the heat gained previously, but if the following day was still hot they could enter the day with a carryover heat load and could be susceptible to heat stress at a lower threshold than expected.

Age

In dairy cows, it may be useful to discuss the age effects, considering also the phase of the productive life. Relative to the population under study, we do not have information on health, physiological status, or parity of cows at the time of death. Data indicated that the exposure to HW did not affect mortality in younger cows. Reproductive statistics indicated that, in our cow population, this class of age may correspond to heifers in the middle-late stage of pregnancy. Results showed that older cows were affected by HW, resulting in death. Considering reproductive statistics, the more susceptible age class was 61 to 96 mo, which may correspond to cows on third, fourth, and fifth parity. Cows aged 29 to 60 mo, corresponding to first, second, and third parity, also presented a higher risk to die during HW. What we may thus affirm on the basis of data in our possession, is that during HW the mortality among heifers that have not yet calved was lower than in older animals who had already given birth. This result is in line with previous reports indicating that heifers are less susceptible to heat stress because they generate far less metabolic heat than cows and have greater surface area relative to internal body mass (West, 2003).

The effect of age on heat-related mortality in dairy cows has been already considered in a previous study (Crescio et al., 2010); those authors considered several age classes, from 24 to 107 mo, and found the risk of death increased significantly with increase of THI for all groups. A French study reported that during heat waves there were not differences in excess mortality between types of production (meat or milk) and classes of age considered (Morignat et al., 2014). Other studies aimed at investigating factors associated with cattle mortality reported that deaths were higher in summer among older dairy cows (parity 3 and older), in the first 30 d of lactation (independently of parity about 30% of deaths occurred in this physiological status), and corresponding to illness classified as infections, metabolic disorders, and other disorders (Miller et al., 2008; Alvasen et al., 2012).

Month of HW Occurrence

The assessment of mortality in relation to the period of HW occurrence indicated a greatest risk for cows to die during June HW. Studies aimed at investigating HW-related mortality in humans reported a greater effect corresponding to heat waves in early summer, especially those that occurred in June and July. What was hypothesized in humans is that the greater health effect recorded during early HW compared with that recorded in the later HW could be attributable to a harvesting effect. The subsequent reduction in mortality observed in the late summer suggests that the early HW had especially affected individuals whose health was already so compromised that probably they would have died in the short term anyway (Hajat et al., 2002; Laschewski and Jendritzky, 2002).

In our population, it is reasonable to think that something analogous to what has been described for humans has occurred. The death of vulnerable cows may contribute to the harvesting effect and lead to lower mortality observed in the later HW. In other words, susceptible cows die during early HW, thus the number of individuals at risk in cows' population decreases throughout the season and this leads to a lower mortality in the later HW. At same time, we cannot exclude that the phenomenon was also related to a certain ability of dairy cows to acclimatize to heat over summer season.

CONCLUSIONS

The analysis of climatic conditions indicated that during summer months the Italian territory may be affected by severe and prolonged HW. Heat waves were associated with a higher risk of death in dairy cows, which also extends to few days after the end of the waves. Older cows had a higher risk of death during heat waves, even if physiological and health status likely played a more important role in their mortality. The lower mortality risk indicated for later months of the season should be better investigated to ascertain if it is related to the ability of cows to adapt over time to heat challenges or if it is due to harvesting effect related to the death of more vulnerable cows during the early HW. Climate scenarios of the Mediterranean basin allowed us to predict an increase of frequency, intensity, and length of HW; this should elicit support for the implementation of adaptation strategies that may help mitigate the adverse consequences of exposure to high temperatures among dairy cows. Structural modifications, feeding management, genetic selection, insurance policies, and proactive measures may represent functional instruments to ensure animal welfare and limit economic losses in dairy cow farm during periods of HW.

ACKNOWLEDGMENTS

This study was financially co-supported by Italian Ministry of Agriculture (CLIMANIMAL and FACCE-MACSUR Projects). The authors gratefully acknowledge Giuseppe Ru at the Reference Centre for Animal Encephalopathies (Turin, Italy) and Mariagrazia Guerini at Istituto Zooprofilattico Sperimentale Lombardia and Emilia Romagna (Brescia, Italy) for provision of the mortality data; Dr. Edmondo Di Giuseppe at the Research Unit for Agricultural Climatology and Meteorology (CRA- CMA); and the Italian Animal Breeders Association for providing productive and reproductive data.

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