Effects of high air temperatures on milk efficiency in dairy cows

J. Brouček, Š. Mihina, Š. Ryba, P. Tongeľ, P. Kišac, M. Uhrinčať, A. Hanus

Research Institute of Animal Production, Nitra, Slovak Republic

ABSTRACT: 26 herds with 71 586 individual records were used. We tested a hypothesis that milk efficiency was influenced by the elevation of the farm, housing system, breed, area of altitude, and by the cooling of dairy cows. There were 20 herds from lowlands and 6 herds from mountains, 20 herds from free-stall housing, 6 herds from tie-stall housing. 8 herds consisted of Slovakian Pied cattle, 4 herds of Red Holstein cattle, 11 herds of Black-Pied Lowland cattle and 3 herds of Slovakian Pinzgau cattle. The herds were divided into 4 groups according to the nearest meteorological station, and they were distributed according to the type of cooling. 10 herds were cooled by misting, 16 herds by fans. We recorded from 96 to 117 summer days and from 49 to 63 tropical days in lowlands for this summer period. Ninety days with temperature-humidity index (THI) above 72.0 were found in the lowest-elevation area. During 55 days we recorded the values higher than 78.0. Production of milk was higher in lowlands than in mountains (8 761.4 kg vs. 6 372.0 kg; $P < 0.01$). Differences were also recorded in the evaluation of fat and protein production (346.0 kg vs. 275.9 kg; $P < 0.01$; 282.6 kg vs. 205.9 kg; $P < 0.001$). Milk and protein production was higher in free-stall housing than in tie-stall housing (8 656.3 kg vs. 6 722.1 kg; $P < 0.05$; 278.7 kg vs. 218.9 kg; $P < 0.05$). The highest milk production was recorded in Black-Pied Lowland cattle (8 832.7 kg) and the lowest in dairy cows of Slovakian Pinzgau cattle (6 058.0 kg). The mist cooling of dairy cows increased ($P <$ 0.05) the amount of produced milk and protein (9 234.4 kg vs. 7 569.7 kg; 293.5 kg vs. 247.1 kg).

Keywords: dairy cows; milk production; milk composition; high air temperatures; elevation; housing; breed; cooling

The average temperature of the Earth surface keeps increasing and the hot summer 2003 may have a bearing on global warming. The majority of farmers were not ready to cope with such situation, so it could bring about significant economic losses. The number of days with extremely high temperatures which substantially influence the performance of animals is increasing, and this tendency will continue according to predictions. The above assumption will influence the management of dairy husbandry. We will have to consider housing and technological systems that will reduce this negative effect of climatic extremes when designing an optimum farm environment.

It is apparent that performance, welfare and health of the animal are influenced by biometeorological factors. The most important climatological factors are high temperatures and relative humidity during the hot season and the wind-chilling factor during the cold season of the year (Gregoriadesová and Doležal, 2000). In the majority of barns for cows and heifers, the limits of air relative humidity were exceeded (Šoch et al., 2000).

Summer climates cause the stress of dairy cows resulting in milk production depression. Heat stress occurs when the ambient temperature is higher than that of the animal's thermal neutral zone. The heat load is greater than their ability to lose heat (Šoch et al., 1997; Dolejš et al., 2000a). The potential for heat stress exists when the air temperature rises above the comfort zone, particularly if humidity is also high. When the temperature exceeds 27°C, even with low humidity the effective temperature is above the comfort zone for high producing dairy cows. The upper critical temperatures have been established for a number of production traits; these temperatures fall between 24 and 27°C (Brouček, 1997; Novák et al., 2000). Other authors reminded that the thermal stress for high-yielding (above 6 500 kg) and especially older cows developed from 21°C (Johnson, 1987; Doležal et al., 2004). Dairy cows respond to heat stress in several ways: reduced feed intake and increased water intake, changed metabolic rate and maintenance requirements, increased evaporated water loss, increased respiration rate, changed blood hormone concentration, and increased body temperature (Knížková and Kunc, 2002; Koubková et al., 2002). Higher producing and multiparous cows are especially susceptible to heat stress (Brouček et al. 1990; Bucklin et al., 1991).

The failure of homeostasis at high temperatures may lead to reduced productivity or even death (Blackshaw and Blackshaw, 1994). Heat stress results from the combined effects of relative humidity and ambient temperature. Therefore, THI is commonly used to indicate the degree of stress in dairy cattle. THI values suggest that within the normal range up to 70, cattle show optimal performance. In the warning range of THI values 70–72, dairy cow performance is inhibited and the cooling of animals becomes desirable. Critical THI values are 72–78, when milk production is seriously affected. The dangerous category is at the THI values 78–82 (Du Prezz et al., 1990).

The heat stress can be reduced or eliminated by cooling methods. There is a number of methods available that can reduce air temperatures below the outside ambient temperatures. Fans are used for forced ventilation. If properly designed, this is a very effective method of providing air movement. However, it can also be expensive and need not provide an adequate heat stress relief unless combined with cooling methods. If the air is hot, the cattle get heat rather than lose heat. The wind speed varies with distance (Hsia, 2002). However, in hot summer conditions, dairy cows need more cooling than it can be provided by either natural or mechanical ventilation. As long as the air temperature is below the temperature of the cow's body, some relief will be provided, but if the air temperature is above the range of 21 to 27°C, cows will still be heat stressed (Blackshaw and Blackshaw, 1994; Dolejš et al., 1998; Doležal et al., 2004).

Several methods of evaporative cooling are available. They include mist, fog, and sprinkling systems. The difference between a mist system and a fog system is in droplet size. A mist droplet is larger than a fog droplet and will drop slowly to the floor, evaporating as it falls. A fog particle stays suspended in the air and evaporates before it touches the ground. Fog systems are very efficient methods of cooling air but they are also more expensive than mist systems and require more maintenance. A mist or fog system sprays small water droplets into the air, cooling the air as the droplets evaporate. When the animal inhales the cooled air, it can exchange heat with the air and remove heat from its body (Bucklin et al., 1991). This type of system can be effective, but it is difficult to use under windy conditions or in combination with fans. If the misting system does not wet the cow's hair coat to the skin, an insulating layer of air can be trapped between the skin and the layer of water. This effect can cause a harmful heat buildup (Hsia, 2002).

The sprinkler system is a type of spray system that offers advantages over mist and fog systems. This method does not attempt to cool the air, but instead it uses a large droplet to wet the hair coat and skin of the cow. The cow is then cooled as water evaporates from the hair and skin (Lin et al., 1998; Doležal et al., 2004). This allows the cow to lose heat more effectively through its skin than it is possible by sweating alone (Bucklin et al., 1991). Sprinkling is most effective when combined with forced air movement.

Often, a considerable heat stress occurs in the holding area while cows are waiting to be milked (Gregoriadesová and Doležal, 2000). To protect dairy cows against heat stress, several practical minimum precautions were proposed by Dolejš et al. (2000b) and Knížková and Kunc (2002). However, further research on heat stress in dairy cattle is essential if the dairy industry is determined to achieve more cost-effective milk production.

Dairy cows can benefit from microclimatic modifications to improve their comfort and performance, particularly under the climatic conditions prevailing in lowlands. Such modifications require a generally more complete appreciation of the occurrence and prevention of heat stress.

The aim of this paper was to evaluate the effect of high air temperatures on production of milk, fat and protein in dairy cows. We supposed that milk production would be influenced by the elevation above sea level, housing system, breed, area of altitude, and type of cooling of cows.

MATERIAL AND METHODS

We tested a hypothesis that milk efficiency would be influenced by elevation (factor E), system of housing (factor H), breed (factor B), area of altitude (factor A), and by the cooling of dairy cows (factor C).

We used data from test milk records of the State Breeding Institute of Slovakia (all lactations, milk in kg, fat in kg, protein in kg) for all months of the year 2003. We evaluated totally 26 herds with 71 586 individual records.

Tested factors

Factor E: out of the total number of 26 herds 20 herds were from lowlands (57 927 monthly records) and 6 herds from mountains (13 929 monthly records).

Factor H: dairy cows of 20 herds were kept in a free-stall housing system (58 686 records) and of 6 herds in a tie-stall housing system (13 170 records).

Factor B: 8 herds consisted of Slovakian Pied cattle (22 936 records), Red Holstein cattle were represented in 4 herds (9 365 records), cows of Black-Pied Lowland breed were in 11 herds (32 339 records) and 3 herds were composed of Slovakian Pinzgau cattle (7 216 records). (Note: there were more breeds in some herds, therefore we classified such herd according to the prevalent breed).

Factor A: the herds were divided into 4 groups according to the nearest meteorological station (Area 1–4).

Area 1 = average of farms 165 m above sea level (from 138 to 226 m)

Area 2 = average of farms 182 m above sea level (from 138 to 192 m)

Area 3 = average of farms 211 m above sea level (from 160 to 263 m)

Area 4 = average of farms 644 m above sea level (from 502 to 787 m)

The meteorological data were obtained from the Slovakian Hydrometeorological Institute in Bratislava. The THI index for cattle was calculated as follows:

We determined the number of summer days (maximum temperature above 25.0°C) and tropical days (maximum temperature above 30.0°C) from 24 h records. Temperature-humidity index was calculated from maximum temperature and average relative humidity per day ((THI = (0.8 × Tmax) + ((% aver. RH/100) × (Tmax – 14.4)) + 46.4)) (Davis et al., 2003).

Factor C: the herds were distributed according to the cooling of cows at high temperatures. The first group of cows (10 herds) was cooled by means of mist cooling equipment installed in the waiting room of milking parlour. The fans with water misters were mounted at a height of 2.5 m and angled downward at about 20° from the vertical. The equipments were activated automatically (thermostatically) when the ambient temperature exceeded 24.0°C and ran continuously as this temperature lasted or milking was terminated. The speed reached a maximum flow rate at 30°C. Each fan was equipped with circular tubing (diameter 0.56 m, 1 420–1 500 cycles/min – revolutions per minute), slightly larger than the fan bell (diameter 0.61 m, 2 900–3 500 cycles/min) which contained four hollow cone nozzles. Housing and feeding areas were cooled using manually controlled fans without misting. The second group of cows (16 herds) was cooled using only forced ventilation (manually controlled fans in housing and feeding areas without misting).

Dairy cows were fed twice daily. Feed rations were balanced according to the Slovakian nutrient requirements of dairy cattle, including the factors and equations adopted for maintenance, growth, reproduction and lactation. Milking was done twice daily with a milking interval of 12 hours and individual milk yields were recorded once a month by Tru-tests. Proportional milk samples were collected also once a month (at the morning and afternoon milking) and analyzed for milk fat and protein by infrared analysis in the Milk Laboratory of the State Breeding Institute of Slovakia.

Statistical evaluation

The data were analyzed by a statistical package STATISTIX (Analytical Software, P.O. Box 12185, Tallahassee, FL 32317-2185, USA). The normal distribution of data was evaluated by Wilks-Shapiro/Ranking Plot procedure. All data confirmed normal distribution. Between-group comparisons of milk production and milk composition in each factor were analyzed using a General linear model ANOVA (General AOV/AOCV). Milk production and components were dependent variables while

Table 1. The number of summer and tropical days according to the area of altitude

Area	May		June		July		August		September		Total	
	SD	TD	SD	TD	SD	TD	SD	TD	SD	TD	SD	TD
1	20	10	28	15	27	12	30	22	12	4	117	63
2	19	8	27	15	25	11	31	22	11	3	113	59
3	17	6	23	14	19	9	29	18	8	2	96	49
4	13	2	18	2	15	5	26	5	7	0	79	14

Area 1 = 165 m above sea level; SD = summer day (maximum temperature above 25.0°C)
Area 2 = 182 m above sea level; TD = tropical day (maximum temperature above 30.0°C)
Area 3 = 211 m above sea level
Area 4 = 644 m above sea level

independent variables were the factors elevation (factor E), housing system (factor H), breed (factor B), area of altitude (factor A), and the type of cooling of dairy cows (factor C).

The homogeneity of variance of the observed variables in groups whose average values were compared was calculated by preliminary variance tests which determined whether the variabilities were equal. Bartlett's test for the equality of variance tests was applied with an unequal size of samples. The ratio of the largest within-group variance to the smallest was also tested (Pearson and Hartley test). Significant differences between means were tested by Bonferroni's test. We chose Bonferroni's method from Multiple Comparison Procedures since the number of dairy cows in groups was unequal. This test is generally more conservative than the others from STATISTIX package.

RESULTS

The evaluated summer was extremely hot and high temperatures occurred since May. In this month, there were 20 summer and 10 tropical days in the lowest-elevation Area 1 (Table 1). These numbers decreased with the rising elevation and 13 summer and 2 tropical days were found at the highest level above sea. High temperatures were recorded also in September. It was for this reason that we considered not only the usual June to August period but also the months of May to September as a summer period.

So, we recorded from 96 to 117 summer days and from 49 to 63 tropical days in lowlands for this summer period (Table 1). The values of THI for the months of June to August are shown in Table 2. Ninety days with the value above 72.0, which is already a stressor, were found in the lowest-elevation Area 1. We recorded the values higher than 78.0 during 55 days, which was a substantial stress. What is striking is that an alarming number of days with the temperature-humidity index higher than 72.0 (65 days) and 78.0 (38 days) was also recorded in the mountainous area (Area 4).

Production of milk was statistically significantly higher in lowlands (Table 3) in comparison with mountains (8 761.4 ± 1 295.6 kg versus 6 372.0 ± 1 612.3 kg; $P < 0.01$). Significant differences were

Table 2. Temperature-humidity index

Month	Area	Average	Number of days	
			>72	>78
June	1	79.04	29	17
	2	78.44	28	16
	3	76.99	25	13
	4	73.93	19	11
July	1	78.23	31	14
	2	76.66	26	12
	3	76.15	24	12
	4	73.45	19	11
August	1	80.91	30	24
	2	80.79	30	23
	3	78.81	29	20
	4	76.85	27	16
Total	1		90	55
	2		84	51
	3		78	45
	4		65	38

also recorded in the evaluation of fat and protein production (346.0 ± 42.1 kg versus 275.9 ± 77.6 kg; $P < 0.01$; 282.6 ± 37.5 kg versus 205.9 ± 54.6 kg; $P < 0.001$).

Milk production was significantly different also for the factor housing system (Table 4). Milk and protein production was significantly higher in free-stall housing than in tie-stall housing (8 656.3 ± 1 533.4 kg versus 6 722.1 ± 1 363.5 kg; $P < 0.05$; 278.7 ± 46.2 kg versus 218.9 ± 46.9 kg; $P < 0.05$).

The highest milk production was found in Black-Pied Lowland cattle in the distribution according to breeds (8 832.7 ± 1 877.6 kg) and the lowest in dairy cows of Slovakian Pinzgau cattle (6 058.0 ± 1 635.5 kg). Fat and protein production was insignificantly highest in Red Holstein cattle (358.1 ±

Table 3. Milk performance according to the elevation

Elevation	n	$\bar{x}$	sd	Significance
Milk (kg)				
lowlands	57 927	8 761.4	1 295.6	$F = 14.09^{**}$
mountains	13 929	6 372.0	1 612.3	$P = 0.0010$
Total	71 856	8 210.0	1 688.1	
Fat (kg)				
lowlands	57 927	346.0	42.1	$F = 8.53^{**}$
mountains	13 929	275.9	77.6	$P = 0.0075$
Total	71 856	329.9	58.8	
Protein (kg)				
lowlands	57 927	282.6	37.5	$F = 15.68^{***}$
mountains	13 929	205.9	54.6	$P = 0.0006$
Total	71 856	264.9	52.5	

$^{**}P < 0.01$; $^{***}P < 0.001$; sd = standard deviation

Table 4. Milk performance according to the housing system

Housing	n	$\bar{x}$	sd	Significance
Milk (kg)				
tie-stall	13 170	6 722.1	1 363.5	$F = 7.68^{*}$
free-stall	58 686	8 656.3	1 533.4	$P = 0.0106$
Total	71 856	8 210.0	1 688.1	
Fat (kg)				
tie-stall	13 170	300.2	64.1	$F = 2.07$
free-stall	58 686	338.8	55.7	$P = 0.1627$
Total	71 856	329.9	58.8	
Protein (kg)				
tie-stall	13 170	218.9	46.9	$F = 7.59^{*}$
free-stall	58 686	278.7	46.2	$P = 0.0110$
Total	71 856	264.9	52.5	

$^{*}P < 0.05$; sd = standard deviation

Table 5. Milk performance according to the breed

Breed	n	$\bar{x}$	sd	Significance
Milk (kg)				
S	22 936	7 809.5	954.7	$F = 3.15^{*}$
R	9 365	8 912.3	973.3	$P = 0.0453$
N	32 339	8 832.7	1 877.6	
P	7 216	6 058.0	1 635.5	
Total	71 856	8 210.0	1 688.1	
Fat (kg)				
S	22 936	319.7	32.1	$F = 1.59$
R	9 365	358.1	37.9	$P = 0.2213$
N	32 339	342.4	65.1	
P	7 216	273.2	92.8	
Total	71 856	329.9	58.8	
Protein (kg)				
S	22 936	257.0	31.8	$F = 2.83$
R	9 365	282.9	31.2	$P = 0.0621$
N	32 339	282.7	58.0	
P	7 216	196.9	55.1	
Total	71 856	264.9	52.5	

*$P < 0.05$; sd = standard deviation

S = Slovakian Pied cattle; R = Red Holstein cattle; N = Black-Pied Lowland cattle; P = Slovakian Pinzgau cattle

Table 6. Milk performance according to the area of altitude

Area	n	$\bar{x}$	sd	Significance
Milk (kg)				
1	18 996	8 361.2	1 409.9	$F = 4.79^{*}$
2	24 138	9 038.3	1 403.5	$P = 0.0102$
3	14 793	8 878.5	1 045.7	2.3:4*
4	13 929	6 372.0	1 612.3	
Total	71 856	8 210.0	1 688.1	
Fat (kg)				
1	18 996	334.6	26.5	$F = 3.40^{*}$
2	24 138	364.8	43.9	$P = 0.0356$
3	14 793	331.9	53.0	2:4*
4	13 929	275.9	77.6	
Total	71 856	329.9	58.8	
Protein (kg)				
1	18 996	268.9	41.5	$F = 5.42^{**}$
2	24 138	291.1	39.1	$P = 0.0060$
3	14 793	288.3	30.2	2:4**
4	13 929	205.9	54.6	3:4*
Total	71 856	264.9	52.5	

*$P < 0.05$; **$P < 0.01$; sd = standard deviation

Area 1 = 165 m above sea level; Area 2 = 182 m above sea level; Area 3 = 211 m above sea level; Area 4 = 644 m above sea level

Table 7. Milk performance according to the cooling of cows

Cooling	n	$\overline{x}$	sd	Significance
Milk (kg)				
mist	28 700	9 234.4	1 226.4	$F = 7.55^*$
fan	43 156	7 569.7	1 646.2	$P = 0.0112$
Total	71 856	8 210.0	1 688.1	
Fat (kg)				
mist	28 700	352.1	50.9	$F = 2.45$
fan	43 156	315.9	60.6	$P = 0.1303$
Total	71 856	329.9	58.8	
Protein (kg)				
mist	28 700	293.5	32.9	$F = 5.71^*$
fan	43 156	247.1	55.3	$P = 0.0251$
Total	71 856	264.9	52.5	

$^*P < 0.05$; sd = standard deviation

37.9 kg; 282.9 ± 31.2 kg) and lowest in Slovakian Pinzgau cattle (273.2 ± 92.8 kg; 196.9 ± 55.1 kg) (Table 5).

The comparison of milk production according to the area of altitude is given in Table 6. The highest production of milk was recorded in Areas 2 and 3 (9 038.3 ± 1 403.5 kg; 8 878.5 ± 1 045.7) and the lowest in Area 4 (6 372.0 ± 1 612.3 kg). The difference was significant ($P < 0.05$). A similar tendency was found by the evaluation of fat and protein production.

The file of the test monthly records of 26 herds was also divided according to the type of cooling of dairy cows during the summer period (Table 7). The mist cooling of dairy cows significantly ($P < 0.05$) increased the amount of produced milk and protein (9 234.4 ± 1 226.4 kg versus 7 569.7 ± 1 646.2 kg; 293.5 ± 32.9 kg versus 247.1 ± 55.3 kg).

DISCUSSION

The purpose of our research was to determine as precisely as possible the impact of surprisingly high air temperatures on the milk performance of dairy cows.

The period from the beginning of May to the end of September was extraordinarily hot in the observed year. We found an enormous number of summer and tropical days. However, the evaluation of the temperature is not sufficient; it is important to consider also relative humidity. After all, there is a difference in the effects of high temperatures in damp or dry environment (Blackshaw and Blackshaw, 1994).

We recorded 55 days with the value of THI above 78.0 in the lowland area, which is close to the conditions in the southern states of the USA (Mader and Davis, 2004). Evidence of thirty-eight days with THI above 78.0 in the mountains was interesting. Comparable data are missing in world literature; nobody has studied the effects of high temperatures on dairy cows in highly elevated areas.

Cows were fed twice a day on all observed farms. However, it would probably be better to feed 3 times a day or to shift the feeding time to evening hours when the air is getting colder, as Kudrna et al. (2001) noted.

The effect of housing proved to be highly significant; the cows kept in loose housing yielded more milk than the animals from tie housing in all periods. It is known that loose housing provides cows with more comfort and welfare (Brestenský et al., 1989; Brouček, 1997). The difference in milk production can be partly distorted by the fact that there was not a single farm with tie housing among the ten farms with the mist cooling of cows. We did not find such a farm.

The differences in the milk performance of individual breeds are known. However, it is obvious that breed had significant effects on the lower yield of cows kept in mountainous areas in our assessment. Three out of the six observed farms from this area had Slovak Pinzgau breed. And this could have an influence on the result.

Foreign authors who studied the evaporative cooling of cows reported a higher benefit of mist cooling for the milk amount than we found (West et al., 2003). The importance of evaporative cooling was emphasized also in our conditions (Nový et al., 1997; Dolejš et al., 1998, 2000b). However, those experiments were conducted on a lower number of animals. Therefore, our results obtained on a large number of cows could be beneficial.

They confirmed the fact that our conditions of housing, nutrition and performance were approaching those in the USA. It will probably be necessary to study more closely the functionality, optimal adjustability and spacing of the cooling equipment in barns.

CONCLUSIONS

We can conclude that high air temperature is a negative factor of dairy cow environment. The occurrence of heat stress can be determined by the monitoring of weather conditions and by measuring some parameters in dairy cows, especially rectal temperature and respiration rate.

The heat stress increases maintenance energy requirements and lowers dry matter intake, making it difficult to meet energy needs. Therefore, feeding management and composition of feed become important. Feed rations should be changed gradually, and sufficient space for feeding should be provided.

Appropriate housing facilities and equipment to protect dairy cows from climatic extremes are of significant importance for production maintenance. The cooling of cows by misting combined with air movement should be used. Evaporative cooling is the best for protection against high temperature stress.

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Corresponding Author

Ing. Jan Brouček, DrSc., Research Institute of Animal Production, Hlohovská 2, P.O. Box 30 c, 949 92 Nitra, Slovak Republic
Tel. +421 376 546 483, e-mail: broucek@vuzv.sk