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EFFECT OF THE DURATION OF HIGH AIR TEMPERATURE ON COW'S MILKING PERFORMANCE IN MODERATE CLIMATE CONDITIONS*

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Abstract

The main aim of the presented investigation was to determine the effect of the air thermal conditions variability on cow's milking performance in summer in a moderate climate. The analyses covered the summer months of 2012–2013 (June–September) and shorter, several-day periods characterized by the times of elevated or high air temperatures and by the declines and increases in milking performance. The research was conducted in a free stall barn for Holstein-Friesian cows. The study showed that the thermoneutral temperature for high yielding cows decreases gradually with the registered increasingly warmer summer periods. The decreases in milk yield already commence at an air temperature equal to 20°C and also depend on the dairy cattle sensitivity. July and August, with a high number of hot days, caused that in September the cows responded faster to a worsening of thermal conditions and the decline in milking performance happened almost simultaneously with the air temperature change, at milking yield recovery after the period of 3–4 d ($r=-0.84$, $P<0.04$). The percent duration in the individual temperature ranges which caused a decrease of milk yield was also determined. In June, and at the beginning of July, this was 90% of the time with temperatures above 20°C, and simultaneously 45% above 25°C occurred to milking performance decrease ($r=-0.89$, $P<0.02$). In September, this was only 30% of the time with temperatures above 20°C ($r=-0.91$, $P<0.01$).

Key words: dairy cows, heat stress, air temperature, milking yield

Climatic and meteorological studies demonstrate a serious hazard as a result of climate warming for the whole of Europe (Peltonen-Sainio et al., 2010). They predict that by 2050 the air temperature may rise by even 2°C (Trnka et al., 2011),

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whereas in some regions of Poland the increase is estimated to be at least 0.3°C per decade (Górski and Kozyra, 2011). Simulations conducted by Trnka et al. (2011) also suggest that the air temperature in Poland will already rise in the spring period. Considering the major influence of heat on the animal welfare and milk production of dairy cows (Cook et al., 2005; De Palo et al., 2006), it should be expected that in the perspective of more than a dozen years, climatic conditions for cattle husbandry will deteriorate even further.

High milk production by cows causes their organisms to produce a great amount of heat, whose excess must be removed into the environment (Radon et al., 2014). However, high temperatures and high relative air humidity make the process difficult, so a cow's body temperature increases (Allen et al., 2015), resulting in potential disturbances in thermal regulation leading to heat stress. On the other hand, a high air temperature combined with low relative air humidity causes drying of the upper respiratory system mucous membrane, leading to poorer resistance of the cow to viral infections (De Rensis and Scaramuzzi, 2003) and the use of protein concentrate supplement to improve parameters of milk quality (Horky, 2014; Horky et al., 2017). Therefore, maintaining the perceived temperature is a condition of high milk yield.

The temperature fluctuations between –0.5 and +20°C (West, 2003), assumed as the thermoneutral value for dairy cattle, affect cow milk performance only to some degree. However, an increase in the air temperature to so-called critical value, assumed on the level of 25–26°C (West, 2003), may cause a drop in milk production, change the animal's behaviour (Adamczyk et al., 2015; Angrecka and Herbut, 2017; Lendelova et al., 2012) or negatively affect its fertility. Furthermore, it may also weaken the immunological system and cause lameness in cows. In order to maintain cattle's healthiness and performance, more important than the air temperature itself is to keep it at a constant level, or to provide adequately long rest periods in lower temperatures with an efficiently functioning ventilation system (Perano et al., 2015; Herbut et al., 2015). However, in summer, in the conditions of a moderate climate, the most frequently applied gravitation ventilation does not function properly because the indoor temperature and the air pressure are at a similar level to that outside (Herbut et al., 2013). Therefore, suitable maintenance system and effective solution used in modern barns (Gaworski and Kowalska, 2013; Gaworski et al., 2017) during the period of summer heat waves are ventilators placed above the cows to cool them owing to the increased velocity of the ventilation air. However, high costs of mounting and exploitation prevent the common use of such a solution.

The main aim of the presented investigation was to determine the effect of the air thermal conditions variability on cow's milk performance in a moderate climate summer. The authors resolved to answer the following questions:

– how does the duration time of selected air temperatures influence a decrease in milking performance?

– after what time does the decline in cow milking performance occur; does it depend on a particular summer month?

– does an adequately long resting period in a lower air temperature allow for avoiding heat stress in cows?

Material and methods

Structures and management

The research was conducted during a 2-year period of measurements in a free stall barn located in southern Poland (N: 50° 8' 59" E: 19° 45' 12") in a typical moderate climate. The double cubicles had the dimensions 120 × 245 cm and single cubicles 120 × 260 cm, with the shoulder girdle at a height of 126 cm. All the cubicles were bedded with 15 cm long straw (5 kg straw per cow daily). The straw lining in the box area was on average 12 cm thick. Manure was removed mechanically from manure alleys once a day during morning milking.

The barn had a gravitation ventilation system with curtains in the longitudinal walls and an air exhaust through ridge vents. The mean space used by the experimental animal group was 8.3 m^2 per cow.

Animals and feeding

The experimental group was constituted of 60 Holstein-Friesian cows (minimum 57 and maximum 61) with an average daily milk yield of 31.9 kg. From the Afifarm 3.08 herd management system (Afimilk, Israel) was sourced the daily milk yield for whole research group. During the period of the experiment all the cows were between the 5th and 130th days of lactation (Table 1) and had similar body dimensions. The cows were placed under zootechnical and veterinary care during the period of the research.

Table 1. Percentage of cows in next lactation

Year	Percentage of cows in:		
	first lactation	second lactation	third lactation
2012	8.33	41.67	50
2013	6.67	53.33	40

The lactating cows were fed a total mixed ration – TMR (corn silage, haylage, alfalfa hay, corn grain, wheat, concentrate mixture, and mineral and energy components) throughout the year. The energy value of the feed ration for the studied cow group was 7.05 MJ NEL/kg DM. The animals had free access to feed for a 24-h period, except during milking. The cows were milked twice a day: at 07:00 h and at 17:00 h.

Environmental measurements

The temperature and relative air humidity were registered every 6 min by means of an integrated LB-710 sensor (Label, Reguły, Poland) with a measurement range for temperatures from –40 to +85°C and air relative humidity from 0 to 99.9%. The sensor was placed in the zone occupied by the cows, at the height of 1.0 m (Figure 1).

The analyses covered the summer months (June–September) and shorter, several-day periods (from 4 to 14 days), characterized by the times of elevated or high air temperatures and by the declines and increases in milking performance, selected from the summer periods of research conducted between 2012 and 2013. The air temperature values were classified against the time background within the ranges characterizing the levels of cow thermal comfort (Table 2). The intervals were selected on the basis of the thermal comfort levels for dairy cattle reported in scientific articles (West, 2003; Andre et al., 2011).

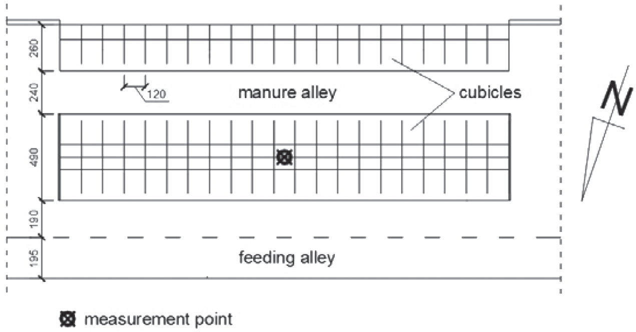

Figure 1. Research barn with measurement station

Table 2. Mean values of the barn air (temperature and relative humidity) and cow milking performance in regard to months of research

Month	2012			2013		
	T, °C (SE)	RH, % (SE)	milk, kg (SE)	T, °C (SE)	RH, % (SE)	milk, kg (SE)
June	19.7 (0.9)	69.1 (2.2)	33.3 (0.4)	19.8 (1.1)	76.0 (3.4)	34.3 (0.3)
July	22.2 (1.2)	67.4 (3.0)	30.7 (0.7)	21.7 (0.5)	67.6 (2.6)	33.0 (1.0)
August	21.3 (0.7)	66.2 (1.5)	30.1 (0.9)	21.6 (0.8)	54.8 (2.3)	31.9 (1.3)
September	17.3 (1.5)	70.2 (2.8)	30.2 (0.9)	16.8 (1.7)	69.5 (3.1)	31.6 (0.8)

Milking performance analysis used the data of the daily milk yield regarding:
- T – air temperature (°C),
- RH – relative air humidity (%),
- the duration of individual temperatures (h).

The daily milk yield with corresponding total time of each air temperature range and relative humidity were processed using analysis of the Spearman's correlation coefficient (r) in the Statistica program (Version 12.0, 2013). The Student's t-test was applied to estimate the statistical significance of the obtained values. Data were considered significant at $P<0.05$.

Results

The results characterizing the microclimate in the barn represented by air temperature (T) and relative humidity (RH) in the summer of 2012 and 2013 are presented in Figure 2.

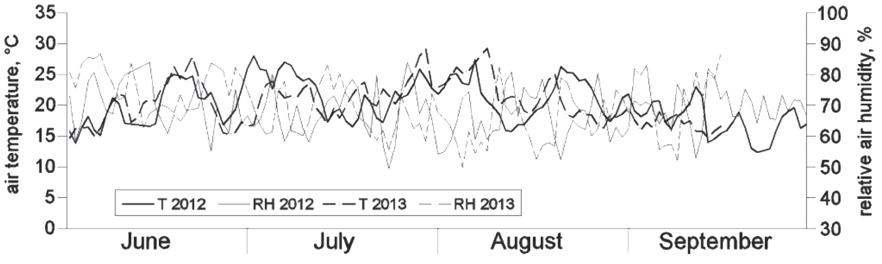

Figure 2. The course of mean daily air temperature in the barn during the research period

The period of June–September was characterized by a repeatability of between 5- and 9-d long hot spells (average T>20°C) occurring in different months. The warmest months were usually July and August, whereas September was the coolest. The average course of air temperature was approximate in both periods of research, however the summer of 2012 was warmer and characterized by a higher number of hours with T>20°C. During the analyzed period T and RH fluctuated from 10°C to 28°C and from 55% to 85% RH, respectively. The lowest T was usually registered at night and the highest during the day. The opposite relationship was noted for RH values.

Table 3. Number of hours in the temperature ranges of the research period

Month	Range of air temperature (°C)			
	<16	16–20	20–25	>25.0
	2012 (2013)			
June	101.8 (135.6)	260.1 (260.0)	227.4 (220.8)	130.7 (103.6)
July	39.6 (23.8)	205.7 (242.7)	314.3 (325.2)	184.4 (152.3)
August	60.2 (54.8)	238.9 (257.1)	299.8 (277.3)	145.1 (154.8)
September	262.2 (233.1)	316.1 (393.3)	127.0 (93.6)	14.7 (0.0)

A total of 117,120 results of T and RH measurements and 488 results of milking performance values were obtained. The results characterizing the mean parameters of the barn air and average cow milking performance during the investigated period of the 2012 and 2013 summers are presented in Table 3.

The obtained RH results fell within the range between 60 and 80%, i.e. the values optimal for cattle. Statistical analysis of RH and milk performance in the time series revealed no relationship between these parameters (P>0.05). Daily changes of relative air humidity had a similar course. Only on hot days did rapid declines of RH occur in the afternoon. In the analyzed 2012 and 2013 summer periods T was most frequently registered within the 16-20°C range – on average for 230 and 250 h. June was a warm month, characterized by a high number of hours with T within the 16–20°C and 20–25°C range. In July and August the number of hours with T within the 20–25°C range was increasing to about 300, whereas in the range >25°C to about 150. September was the most diversified regarding T, periodically hot in 2012 and warm in 2013. The last two weeks of May, both in 2012 and in 2013, were characterized by air temperatures mostly in the range of 16–20 (63%, SE 1.7), which had no significant effect on milk yield of cows (r=–0.47, P<0.06). A detailed analysis of the daily duration of air temperatures in the assumed time ranges and the milking performance trend line are presented in Figures 3 and 4.

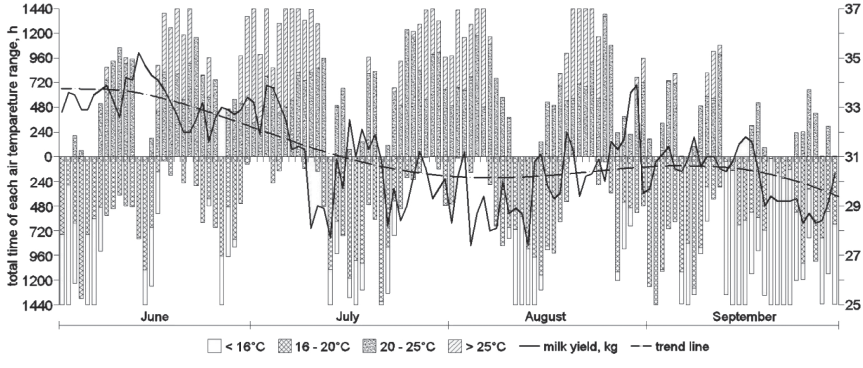

Figure 3. Duration time of daily air temperatures in individual ranges in relation to milking performance in 2012

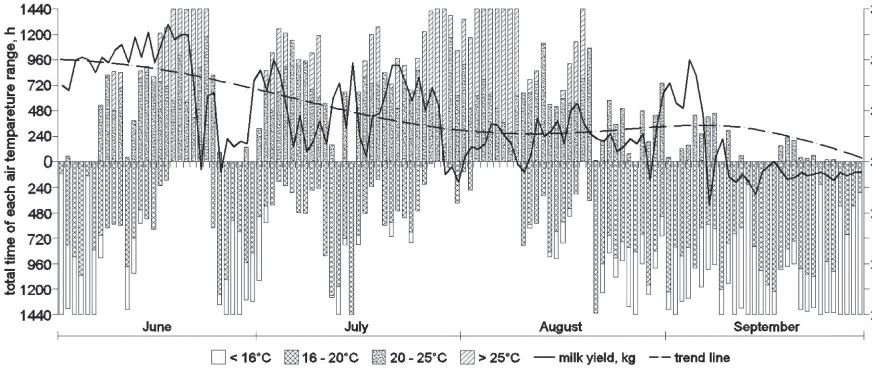

Figure 4. Duration time of daily air temperatures in individual ranges in relation to milking performance in 2013

The longest hot day series with T>20°C was registered in mid-June, at the beginning of July, at the turn of July and August, and in mid-August 2012 and 2013. However, the periods differed with T value within individual ranges, their duration and decreases in milking performance – from 1.5 to 3 kg registered by the herd management system. The presented milk performance trend line indicates a repeatable seasonal, about 3 kg, decrease in milk production, whereas its detailed course depends on the number of hot days in the first two summer months.

On the basis of the above presented daily T graphs, the analysis was conducted for selected periods forming a time series characterized by:

– continuous time duration of minimum 24 h with air temperature of T >20°C,
– continuous time duration with at least 12 h with T>25°C,
– the above-mentioned periods divided by the resting time with T<20°C,
– a connection with the decline and recovery of milk production exceeding 1 kg.

The analysis revealed a 1.5 kg decline in milk production between June 18 and 22, connected with the occurrence of 40 h periods with T>20°C. During the subsequent heat wave period June 30 to July 11, even 84–90 h unbroken series with T>20°C were registered. The decline in milk production by about 4 kg registered by the herd management system had a strong correlation with T 20–25°C range (r=–0.89 at P<0.02 during the period from June 30 to July 5 and r=–0.78 at P<0.04 between July 6 and 11). A significant correlation r=–0.90 (P<0.04) was observed during the period July 3 to 7 for the T>25°C range. After the heat wave period in July (19 to 26) a recovery of milk production by about 2.5 kg was observed resulting from the air cooling and 48-h share of the period with T<20°C. On the subsequent days (July 27 to August 7) irregular losses were observed, connected with occasional recovery of milking performance, finally resulting in a decrease in milk yield by 2.5 kg by the end of this period. During that time already 20 h duration of T>20°C caused declines in milk yield (Table 4).

A reconstruction of milking performance at the turn of July and August was associated with the duration of T<20°C for 52 h. A very long, 114-h duration of very high temperature T>20°C (92.5% of the time), registered between August 18 and 25, caused a decrease in milk yield by about 2.1 kg. T>25°C revealed the strongest correlation with milking performance (r=–0.88; P<0.03). In September T<20°C was dominant, which resulted in a gradual rebuilding of the milk yield level. At the beginning of September the air temperature was correlated with milk yield more strongly than in the second half of the month, when the air temperature was already much lower (mostly T<16°C) (Table 4).

The beginning of June 2013 (June 1 to 8) was characterized by T<20°C, when the milk yield grew by about 1 kg. On the next days (June 16 to 23) as many as 159 h of constant T>20°C with a decrease in milking performance on the 5th day of heat wave were registered. A decrease in T<20°C during the period June 25 to July 1 led to an increase in milk yield by 4 kg. Regarding the long time series, the period from July 17 to August 11 seems interesting. On the first days (July 18 to 24), despite prevailing T>20°C, an increase in milk production by 2.5 kg occurred. It resulted from the previously registered quite long period and occasional 6–10 h declines in T<20°C during which the cows could cool down and avoid greater heat stress. A visible 3.5 kg decline in milk yield happened between July 21 and 30, when T>20°C revealed the strongest relationship with the declines in milking performance. On the subsequent hot days August 1 to 8, an unbroken 186 h series with T>20°C was noted and the ensuing decline in milking performance revealed the strongest relationship with T>25°C (Table 4).

Between August 17 and September 15 cows were more sensitive to the effect of shorter periods with T in the 20–25°C range. The example was a decline in milk production by 2 kg between August 18 and 20 at T 20–25°C lasting for 46 h with 5-h resting time at T<20°C. A similar situation was observed also between September 3 and 6 but the decrease in milk yield reached even 5 kg. Stabilization and an increase in milking performance on August 22 to 31 revealed the highest correlation with T from the 16–20°C range, similar as during the period from September 7 to 13 (Table 4).

Table 4. Percentage of time duration of air temperature and the statistical values for selected periods

Period	Percentage of time duration of air temperature for range:				Δmilk (kg)	r	P
	<20°C		>20°C				
	<16°C	16–20°C	20–25°C	>25°C			
2012							
June 18–22	1.6	13.6	52.9*	31.9*	–1.5	–0.98	0.01
June 30–July 11	0.5	8.6	45.3*	45.6*	–4.0	–0.83	0.02
July 19–26	6.3*	37.7*	47.2	8.8	+2.5	–0.76	0.03
July 27–August 7	0.0	12.1	57.7*	30.2*	–2.5	–0.89	0.02
August 19–25	0.0	7.5	53.2*	39.3*	–2.0	–0.86	0.01
August 30–September 9	6.7*	65.4*	24.3	3.6	–3.3	–0.80	0.01
September 13–26	61.3*	28.5*	10.2	0.0	–2.3	–0.55	0.04
2013							
June 1–8	49.4*	44.8*	5.8	0.0	+1.0	–0.81	0.03
June 16–23	0.0	3.7	50.8*	45.5*	–4.5	–0.81	0.02
June 25–July 1	42.8*	51.7*	5.5	0.0	+4.0	–0.79	0.04
July 18–24	1.9	31.3	48.8*	18.0*	–2.5	–0.99	0.01
July 25–30	1.6	20.7	45.0*	32.7*	–3.5	–0.79	0.01
August 1–8	0.0	0.0	36.7	63.3**	–1.1	–0.90	0.01
August 18–20	1.2	17.4	53.8**	27.6	–1.4	–0.81	0.03
August 22–31	20.3	55.6**	24.1	0.0	+2.5	–0.76	0.03
September 3–6	30.1	48.3	21.6**	0.0	–5.0	–0.89	0.02
September 7–13	40.6	46.4**	13	0.0	–1.5	–0.94	0.01

Δmilk – change of milk production, where: – is decrease, + is increase.

* Correlation relating to the whole range of T>20°C (sum of 20–25°C and >25°C) or for T<20°C (sum of <16°C and 16–20°C).

** Correlation relating only to the selected range.

The analysis of the declines in milk performance and time shift after which the declines occurred in relation to individual months and T ranges was conducted for both summer periods in 2012 and 2013 (Figures 5 and 6).

The obtained results indicate inversely proportional relationship between declines in milking performance and the time of their occurrence depending on the summer months. The lowest decreases in milk production – about 1 kg – usually appeared in June. Despite the occurrence of quite long (7–14 d) ranges of T>20°C, the cows had a strong "resistance" to heat, which resulted in a decrease in milking performance only 4–5 d after the advent of a heat wave. In the subsequent months of July and August, increasingly more numerous days with T>20–25°C and T>25°C occurred, resulting in greater declines in milk production between 2–2.5 kg in July and 3–4 kg in August, noted after 2 d in July and 1 d in August from the time of onset of the heat wave. In September, the last month of summer, a decrease in milk yield reached about 3 kg and occurred simultaneously with the onset of T>20°C. Decreases noted in the milking performance of the cows in September depended on the heat waves' severity and their duration in the previous months. While July and August were characterized by numerous hot days, in September the cows responded to brief periods with T>20°C, with milking performance declining faster (r=–0.84, P<0.04) but for a shorter time.

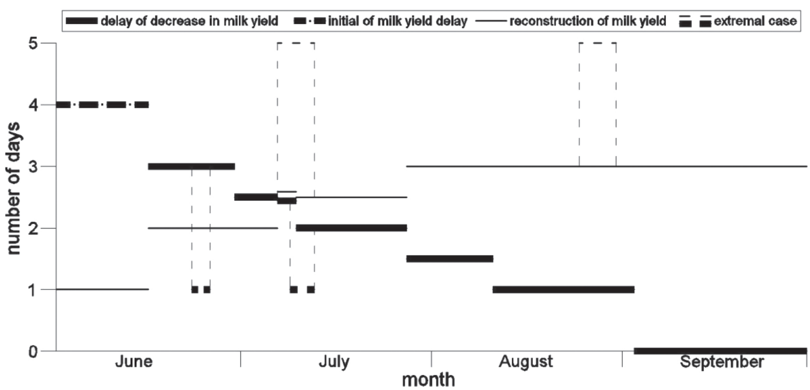

Figure 5. Decline and reconstruction of milking performance in summer 2012

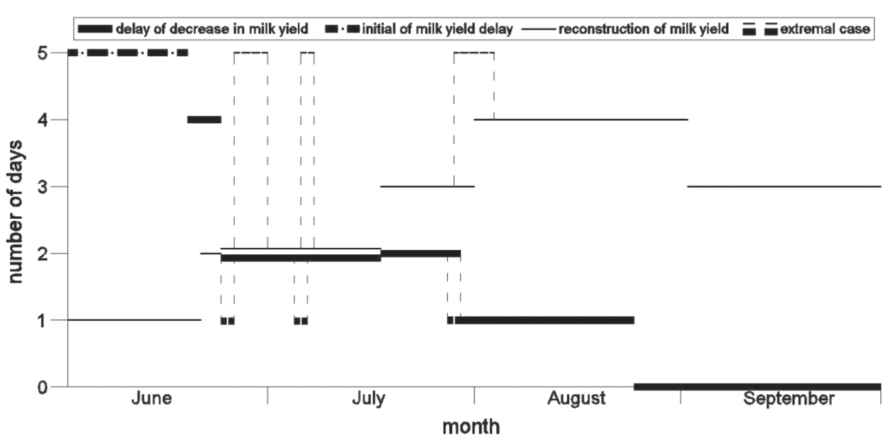

Figure 6. Decline and reconstruction of milking performance in summer 2013

The dotted lines marked in Figures 5 and 6 show the time range of extreme cases, both regarding the declines and reconstruction of cow milk yield. Long time series with T>20°C between 114 and 240 h with brief (about 3 h) resting periods caused rapid and considerable declines in milk performance. Several such cases were indicated during the presented research periods, when already in June and July the decrease in milk yield was shifted only by 1 d.

A persistent high air temperature made impossible the reconstruction of milking performance even for 5 d. Regarding the turn of July and August 2013 it led to a long term delay in recovery in the milk yield.

Discussion

The risk of heat stress in cows appears when the temperature does not fall below 21°C for at least 3–6 h a day (Igono et al., 1992). However, on the basis of the obtained results it may be stated that heat stress in the Holstein-Friesian cow breed in the moderate climate occurs already at the air temperature of 20°C. On the other hand, the effectiveness of resting time (T<20°C) depends on the summer month and thermal conditions preceding the rest.

The conducted analyses demonstrated that, in June, the total time of 100 h with T>20°C interrupted by a maximum of 3–4 h of rest may cause a decline in milk yield by approx.1.5 kg. If the total duration of T>20°C is 200 h, with a potential 3 h with T<20°C, the decrease in cow productivity will increase even by 5 kg. In July, 80–90 h spells with T>20°C and resting times of at least 4 h caused a decrease in milk production by ca. 2 kg, whereas almost 200 h with T>20°C and a max. 3 h with T<20°C – a decline by 4 kg. If, after such a heat wave, an unbroken series of approx. 20 h with T<20°C occurs within the first week, the decline in milk production will reach 1 kg or the recovery period will take a few days more. The turn of July and August, when already 20 h periods with T>20°C may lead to a 1.5–2.0 kg decline in milk yield, whereas a series of 110 h periods with T>20°C with a maximum one 4 h long resting period (T<20°C) causes a decrease in the herd's productivity by 6 kg. It is characteristic that in August already a 5-d period with T<20°C between the succeeding 110 h series with T>20°C did not cause any further decrease in milking performance. Declines in milk yields observed by the end of August and beginning of September referred to T>20°C were referred to T in the 20–25°C range because at that time neither hot nor very hot days occurred. However, already about a 45 h duration of T>20°C affected a decrease in milk yield. Still, the highest declines occurred in July and August, i.e. at the peak lactation period in the studied cows.

Regarding the percent duration in the individual temperature ranges, the decrease in milking performance caused by the thermal stress occurred in June and at the beginning of July (in conversion to 7 d) at T>20°C, lasting at least for 90% of the time and simultaneous T>25°C for approx. 45% of that time. By the end of July and beginning of August only 80% of the time with T>20°C and 30% with T>25°C was enough to cause the decline. By the end of August a decrease in milking performance happened at T>20°C, reaching 70%, and T>25°C of 30%. In September even single days with a 30% duration of T>20°C caused a slight decrease in milk production.

Dairy cattle sensitivity to thermal conditions in individual periods/months reflects the number of hot and very hot days. In June, the number of such days is still low, moreover they are preceded by neutral weather conditions. July is crucial, when at least 60% of the days are classified as at least hot. Taking into consideration also the duration of T>20°C we obtain the conditions which negatively affect the perceivable temperature and cow welfare, as evidenced by increasing declines in milking performance. After a thermally disadvantageous July, 47% of the days with the maximum temperature higher than 25°C occurred in August, which caused that at the beginning of September the cows responded with a decrease in milk yield already at the temperature slightly higher than 20°C. Registered extreme cases as very hot days or a long time series with T>20°C caused rapid and, at the same time, large drops in milking performance different to the presented pattern. This shows that the thermoneutral temperature in high yielding cows decreases gradually with the registered increasingly warm summer periods. The study revealed decreases in milking performance starting already at 20°C. The aforementioned observations are consistent with the results of Andre et al. (2011), who observed lower milking performance in cows in Holland at the air temperatures even 5°C lower in relation to the temperature commonly assumed as critical.

A delay of a decrease in milking performance as a result of thermal stress was demonstrated in numerous scientific publications. The measurements conducted by West et al. (2003) in June and July revealed a decline in cow milk yield after 3 d. West (2003) observed a decrease in milking performance after 2 d, but the studies were conducted in the humid subtropical climate of the southern United States. The research of Spiers et al. (2004) conducted in the tie stalls of a climatic laboratory also revealed a 2-d delay in milking performance decline. However, in the studies mentioned above, a 3-d delay occurred only in June, and over the summer the delay time was diminishing.

The investigations demonstrated that decreases in cow milking performance depend also on the severity of the heat wave and the length of heat during the preceding periods. July and August, with a high number of hot and very hot days, caused that in September the cows responded faster to a worsening of thermal conditions, because the decline in milking performance happened almost simultaneously with the T change and milking performance recovery after the period of 3–4 d.

On the basis of two year analysis, it may be stated that different research results concerning the declines in milking performance obtained by scientists and their duration may depend on the month of the measurements and thermal conditions in the months preceding the research. These conditions may influence an increase or decrease in cow resistance to heat, and therefore distort the obtained results, particularly if the research has been conducted in real production conditions.

References

Adamczyk K., Górecka-Bruzda A., Nowicki J., Gumułka M., Molik E., Schwarz T., Earley B., Klocek C. (2015). Perception of environment in farm animals – a review. Ann. Anim. Sci., 15: 565–589.

Allen J.D., Hall L.W., Collier R.J., Smith J.F. (2015). Effect of core body temperature, time of day, and climate conditions on behavioral patterns of lactating dairy cows experiencing mild to moderate heat stress. J. Dairy Sci., 98: 118–127.

Andre G., Engel B., Berentsen P.B.M., Vellinga Th.V., Oude Lansink A.G.J.M. (2011). Quantifying the effect of heat stress on daily milk yield and monitoring dynamic changes using an adaptive dynamic model. J. Dairy Sci., 94: 4502–4513.

Angrecka S., Herbut P. (2017). Eligibility of lying boxes at different THI levels in a freestall barn. Ann. Anim. Sci., 17: 257–269.

Cook N.B., Bennett T.B., Nordlund K.V. (2005). Monitoring indices of cow comfort in free-stall-housed dairy herds. J. Dairy Sci., 88: 3876–3885.

De Palo P., Tateo A., Zezza F., Corrente M., Centoducati P. (2006). Influence of free-stall flooring on comfort and hygiene of dairy cows during warm climatic conditions. J. Dairy Sci., 89: 4583–4595.

De Rensis F., Scaramuzzi R.J. (2003). Heat stress and seasonal effects on reproduction in the dairy cow – a review. Theriogenology, 60: 1139–1151.

Gaworski M., Kowalska M. (2013). Effect of maintenance system on the selected aspects of dairy cattle health. Annals of Warsaw University of Life Sciences-SGGW. Agriculture., 62: 63–70.

Gaworski M., Kamińska N., Kic P. (2017). Evaluation and optimization of milking in some Polish dairy farms differed in milking parlours. Agron. Research., 15: 112–122.

Górski T., Kozyra J. (2011). Agroclimatic normals of mean air temperature in Poland over the years 2011-2020 (in Polish). Polish. J. Agron., 5: 21–28.

Herbut P., Angrecka S., Nawalany G. (2013). Influence of wind on air movement in a free stall barn during the summer period. Ann. Anim. Sci., 13: 109–119.

Herbut P., Angrecka S., Nawalany G., Adamczyk K. (2015). Spatial and temporal distribution of temperature, relative humidity and air velocity in a parallel milking parlour during summer period. Ann. Anim. Sci., 15: 517–526.

Horky P. (2014). Effect of protein concentrate supplement on the qualitative and quantitative parameters of milk from dairy cows in organic farming. Ann. Anim. Sci., 14: 341–352.

Horky J., Skladanka J., Nevrkla P., Falta D., Caslavova I., Knot P. (2017). Effect of protein concentrate supplementation on the composition of amino acids in milk from dairy cows in an organic farming system. Potravinarstvo Slovak J. Food Sci., 11: 88–95.

Igono M.O., Bjotvedt G., Sanford-Crane H.T. (1992). Environmental profile and critical temperature effects on milk production of Holstein cows in desert climate. Int. J. Biometeorol., 36: 77–87.

Koźmiński C., Michalska B. (2011). Variability in the numbers of cold, cool, warm, hot, and very hot days in Poland in the April–September period (in Polish). Polish Geographical Review., 83: 91–107.

Lendelova J., Botto L., Pogran S., Szaboova T. (2012). Effect of different cooling systems on lying time of dairy cows in cubicles with separated manure solids bedding. J. Cent. Europ. Agricult., 13: 717–728.

Peltonen-Sainio P., Jauhiainena L., Trnka M. (2010). Coincidence of variation in yield and climate in Europe. Agric. Ecosyst. Environ., 139: 483–489.

Perano K.M., Usack J.G., Angenent L.T., Gebremedhin K.G. (2015). Production and physiological responses of heat-stressed lactating dairy cattle to conductive cooling. J. Dairy Sci., 98: 5252–5261.

Radon J., Bieda W., Lendelova J., Pogran S. (2014). Computational model of heat exchange between dairy cow and bedding. Comput. Electron. Agric., 107: 29–37.

Spiers D.E., Spain J.N., Sampson J.D., Rhoads R.P. (2004). Use of physiological parameters to predict milk yield and feed intake in heat-stressed dairy cows. J. Therm. Biol., 29: 759–764.

St. Pierre N.R., Cobanov B., Schnitkey G. (2003). Economic losses from heat stress by US livestock industries. J. Dairy Sci. 86 (E. Suppl.): E52–E77.

Trnka M., Olesen J.E., Kersebaums K.C., Skjelvag A.O., Eitzinger J., Seguin B., Peltonen-Sainio P., Rötter R., Iglesias A., Orlandini S., Dubrovský M., Hlavinka P., Balek J., Eckersten H., Cloppet E., Calanca P., Gobin A., Vučetić V., Nejedlik P., Kumar S., Lalic B., Mestre A., Rossi F., Kozyra J., Al-

exandrov V., Semerádová D., Žalud Z. (2011). Agroclimatic conditions in Europe under climate change. Glob. Change. Biol., 17: 2298–2318.
West J.W. (2003). Effects of heat-stress on production in dairy cattle. J. Dairy Sci., 86: 2131–2144.
West J.W., Mullinix B.G., Bernard J.K. (2003). Effects of hot, humid weather on milk temperature, dry matter intake and milk yield of lactating dairy cows. J. Dairy Sci., 86: 232–242.

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