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# The effect of non-genetic factors on reproduction traits of primiparous Polish Holstein-Friesian cows

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**The aim of this research was to estimate the influence of environmental factors, such as air temperature and milk production, on reproduction traits of primiparous Polish Holstein-Friesian cows. The following reproduction traits were considered: interval from calving to first insemination, interval from first to last insemination, interval from calving to conception, number of inseminations per conception, first insemination conception rate and first insemination non-return rate. The impact of several measures describing the level of milk production and climate on fertility was examined using linear models. The model for each trait contained fixed effects of herd-year, month-year, age at calving and a random additive genetic effect. Deterioration of fertility due to an increase in peak milk yield was observed, e.g. elongation of the interval from the first to last insemination by 6 days as peak milk yield increased by 10 kg. It was found that temperature strongly affected reproduction. However, the results concerning the direction of that influence were inconsistent. An increase in temperature during the month of insemination had a negative effect on the length of the interval from the first to last insemination: elongation by 13 days along with an increase in temperature by 10°C. The opposite influence of an increase in temperature during the month of calving on the length of the interval from calving to the first insemination and on the length of the interval from calving to conception was observed: reduction by 8 days along with an increase in temperature by 10°C in both traits. The relationship of fertility with temperature and milk yield suggests the need to include these factors in the model used for genetic analysis of reproduction traits.**

**KEY WORDS: air temperature / cow fertility / peak milk yield**

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Profitability of dairy herds is the main objective for farmers. Net profit per cow depends not only on the revenues from milk sales but also increasingly on the reduction of expenditure. Regardless of an increased milk production, there is a decrease in the cost-effectiveness of dairy industry due to financial losses caused by poor fertility. Many researchers have found unfavorable genetic and phenotypic correlations between milk yield and reproductive performance [see Pryce *et al*. 2004 for a review and also Averill *et al.* 2004, Jagusiak 2006, Tiezi *et al.* 2012, Albarrán-Portillo and Pollott 2013]. They linked the selection for milk production with negative side effects on fertility. Unsatisfactory reproductive performance results in increased costs related with additional inseminations, veterinary treatment and elongation of calving intervals. For this reason in recent years fertility traits have been included into the breeding goals of many dairy populations. Improvement of reproductive traits by animal selection is hindered by the influence of many non-genetic factors, such as herd management practices, milk production and environmental factors. The breeder's decision to extend the lactation together with poor estrus detection efficiency prolongs the length of the voluntary waiting period. Feeding practices are associated with the time of occurrence of the first postpartum ovulation. A negative energy balance during the early stage of lactation reduces fertility due to the fact that energy requirements for milk production are covered before reproductive functions are resumed. This is one of the negative effects of high milk production on fertility. The influence of metabolic changes connected with milk synthesis on reproductive physiology may be partially confirmed by differences and low correlations between fertility traits of heifers and cows [Roxström *et al*. 2001, Tiezzi *et al*. 2012]. Among the environmental factors leading to deterioration in reproductive performance, heat stress is particularly significant [Al-Katanani *et al*. 1999, Ravagnolo and Misztal 2002, García-Ispierto *et al*. 2007, Morton *et al.* 2007]. A warm ambient temperature on the day of insemination is associated with a decline in fertility. An increase in the ambient temperature can lead to the reduction of estrous manifestation intensity, a decrease in steroid secretion by dominant follicles and deterioration in oocyte quality and embryo survival [Wolfenson et al. 2000, Rensis and Scaramuzzi 2003]. High ambient temperature during early lactation affects reproduction also indirectly through a reduction in dry matter intake and deepening the nadir of negative energy balance. Energy balance is related to the milk production level which by itself is also associated with reproduction [Pryce *et al*. 2004].

The objective of this study was to investigate the influence of environmental factors, such as ambient temperature and maximum daily milk production on reproduction traits of primiparous Polish Holstein-Friesian cows.

## Material and methods

The data was obtained from primiparous Polish Holstein-Friesian cows, which calved between 2001 and 2008. Only records with data for all reproduction traits and milk yield, assigned to subclasses of herd-year of calving with a minimum of 10 observations, from cows which were daughters of sires having minimum 20 progeny, were subject to the analysis. This edits the yielded set of observations for all traits from 148,700 primiparous cows. The following fertility traits were defined on the basis of the available data:

– traits related to the ability to conceive: first insemination conception rate (FICR), number of inseminations (NI), non-return rate to 56th day (NR56), service period (interval between first and last insemination, SP);
– a trait related to the ability to resume luteal activity in the postpartum period: interval between calving and first insemination (CF);
– a trait combining the two abilities in one measurement: days open (DO).

The FICR was coded as 1 when the date of the first insemination was the date of conception, otherwise it was coded as 0. The date of conception was determined using the subsequent calving date, expected gestation length (253-297 days) and date of insemination. The NR56 was coded as 1 when a subsequent insemination was reported within 56 days (reinsemination during the same heat was not taken into account). The CF was restricted to 31-150 days, the shortest SP was set to 18 days and the longest DO was set to 305 days.

**Meteorological and Production Data**

Daily meteorological data was obtained from weather stations belonging to the Institute of Meteorology and Water Management and located throughout the country. A total of 36 regions were created by assigning each of 329 counties to the nearest weather station, which are evenly distributed across Poland (Fig. 1). The average


Fig. 1. Location of 36 regions created by assigning counties to the nearest weather station.

distance between weather stations was 103 km (SD=25), hence the distance between herds and the nearest weather station generally should not exceed around a half of this value. Weather information was linked to all herds located in a particular region. For reproduction traits several types of meteorological variables describing the weather conditions were analyzed: the daily average temperature-humidity index (**THI**) and daily average ambient temperature measured 1) in the month of calving, 2) in the month of the first insemination, 3) from 7 days before to 7 days after calving, 4) from 7 days before to 7 days after the first insemination. The mean ambient temperature and the mean THI (according to the formula proposed by Ravagnolo and Misztal 2002) were calculated for each month of each region on the basis of average daily temperatures and average daily relative humidity. Models for all fertility traits were tested to make a decision on including the effect of weather conditions and choose their definition of them. Climate variables were treated as fixed effects or included into the model as covariates. The model used as the basis for comparison accounted for the fixed effects of herd-year, month-year, age at calving and random additive genetic effect. The Akaike Information Criterion (AIC) was used to make the decision to include a given climatic effect into the model.

Several measures describing the level of milk production were calculated from test day records:

– means from the first two test-days after calving [Roxström *et al.* 2001, König *et al*. 2008];
– average for all test-days before 90 days in milk (DIM) [Ravagnolo and Misztal *et al*. 2002, Averill *et al.* 2004];
– closest test-day to 90 DIM [Sewalem *et al.* 2010];
– maximum test-day milk yield [Tiezi *et al.* 2012, Albarrán-Portillo and Pollott 2013];
– average milk production in the herd.

**Table 1**. Akaike information criterion for basic[1] and final model for each trait[2]

| Trait | Introductory model | Final model |
|---|---|---|
| FICR | 219 663 | 324 764 |
| CF | 1 443 923 | 1 441 438 |
| DO | 1 715 751 | 1 715 032 |
| NI | 613 402 | 613 200 |
| NR56 | 324 710 | 324 710 |

[1]Introductory model for each trait contained fixed effects of herd-year, month-year, age at calving and random additive genetic effect.
[2]CF – interval from calving to first insemination, SP – interval from first to last insemination, DO – interval from calving to conception, NI – number of inseminations to conception, FICR – first insemination conception rate, NR56 – first insemination non-return rate to day 56.

The decision to include the effect of milk production level into the model for each fertility trait and to find the most appropriate definition of that effect was based on AIC. The model with the fixed herd-year, month-year, age at calving effects and random additive genetic effect was used for comparison. In the next step the model with both selected effects of climate and milk production was compared with the best model for each of these effects and then the best model for trait was selected (Tab. 1).

**Linear models.** Linear models were applied for estimates of regression coefficients. The final models are listed below in a simplified scalar notation for single traits.

The model for FICR was:

$$y_{ijklmp} = HY_i + MY_j + AGE_k + L_{1\text{-}4}(DIM_l) + b_{MM}MM_m + AG_p + E_{ijklmp}$$

The model for CF and DO was:

$$y_{ijklmp} = HY_i + MY_j + AGE_k + b_{TC}TC_n + b_{MM}MM_m + AG_p + E_{ijklmp}$$

The model for SP was:

$$y_{ijklmp} = HY_i + MY_j + AGE_k + b_{TI}TI_o + b_{MM}MM_m + AG_p + E_{ijklmp}$$

The model for NI was:

$$y_{ijklmp} = HY_i + MY_j + AGE_k + b_{MM}MM_m + AG_p + E_{ijklmp}$$

The model for NR56 was:

$$y_{ijklmp} = HY_i + MY_j + AGE_k + AG_p + E_{ijklmp}$$

where:

$y_{ijklmnop}$ – a particular reproduction trait;

$HY_i$ – the fixed effect of herd by year of calving;

$MY_j$ – the fixed effect of month by year of the first insemination;

$AGE_k$ – the fixed effect of age at calving (two classes, the threshold value between them was 24 months);

$L_{1\text{-}4}(DIM_l)$ – Legendre polynomials for $DIM_l$ with 4 parameters;

$TC_n$ – an average ambient temperature in the month of calving;

$TI_o$ – an average ambient temperature in the month of the first insemination;

$MM_m$ – the maximum test-day milk yield in lactation;

$b_{MM}$, $b_{TC}$ and $b_{TI}$ – linear regression coefficients of $MM_m$, $TC_n$ and $TI_o$, respectively;

$AG_p$ – a random animal additive genetic effect;

$E_{ijklmnop}$ – a random residual error.

The variance-covariance structure of the random effects for each model is defined as:

where:

$$V\begin{bmatrix} a \\ e \end{bmatrix} = \begin{bmatrix} A\sigma_a^2 & 0 \\ 0 & I\sigma_e^2 \end{bmatrix}$$

A – the relationship matrix, I is the identity matrix;

$\sigma_a^2$ – additive genetic variance;

$\sigma_e^2$ – variance of the random residual effect.

Regression coefficients were estimated with the BLUP method after variance component estimation by the Gibbs sampling algorithm [Misztal *et al*. 2002]. Uniform priors were assumed for fixed effects and (co)variance components and normal distributions for random effects.

## Results and discussion

#### Descriptive statistics

The occurrence of the first insemination and maximum milk yield (**MM**) was observed at the same stage of lactation. Figure 2 shows the distribution of the incidence of MM and the first insemination. In the second month of lactation most cows reached peak milk yield. The first insemination most often occurred on the 80$^{th}$ day after calving. Due to the fact that the first insemination initiated SP, the same values of SP could be observed at different stages of lactation, depending on the date of the first insemination. At the final stage of lactation only 3 traits were observed (SP, DO and NI) and their high values indicated poor fertility. A total of 44.5% of the cows were pregnant after the first insemination, while on average 2.1 inseminations per cow were required to conceive and the service period lasted 45.5 days. The lowest FICR, the longest SP and the greatest NI were observed when the first insemination occurred in the second month of lactation (Fig. 3). At that time most cows reached the peak milk yield.

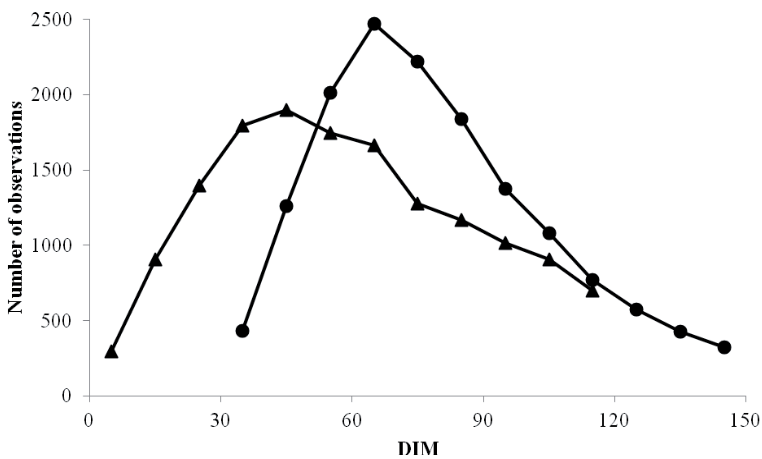


Fig. 2. The number of cows with peak milk yield (▲) and first inseminations (●) on selected DIM during the first lactation of Polish Holstein-Friesian cows.

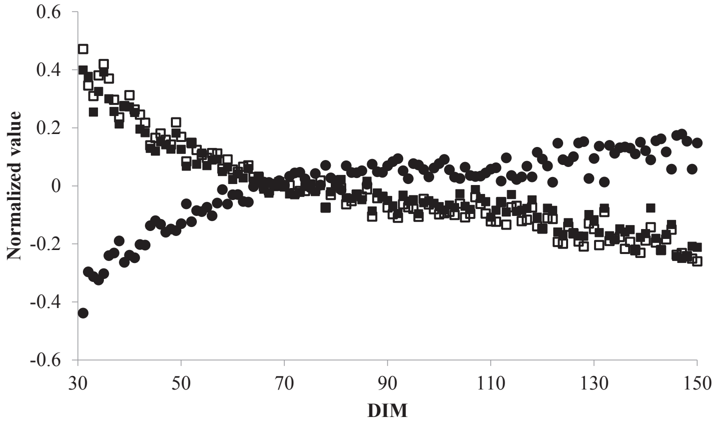


Fig. 3. Average values of first insemination conception rate (FICR, ●), interval from first to last insemination (SP, ■) and number of inseminations for conception (NI, □) in cows where the first insemination occurred on a given DIM.

**The Effect of Milk Yield**

Maximum test-day milk yield (MM) was chosen as the best indicator of the production level during early lactation. The maximum test-day milk yield was observed on average on 59 DIM (SD =29) and amounted to 25.0 kg (SD =9.0). Based on solutions estimated for the model parameters it was found that the SP was lengthened by 6 days as the maximum daily milk yield increased by 10 kg (regression coefficient $b_{MM}$=0.59), which accounted for 1.3% of the average length of SP. The milk yield was observed to have a much smaller effect on CF rather than SP. The first insemination took place less than one day later when the MM increased by 10 kg (regression coefficient $b_{MM}$=0.08), which accounted for 0.1% of the average length of CF. A positive association between MM and CF confirmed that high milk production was antagonistic to the resumption of ovarian activity and expression of estrus [Harrison *et al.* 1990, Beam and Butler 1997]. Furthermore, cows with higher productivity required more inseminations to conceive and had lower FICR. The increase in the MM by 10 kg caused a decrease in the conception rate by 3% (regression coefficient $b_{MM}$=-0.003) and a 0.1 increase in the number of inseminations needed for fertilization (regression coefficient $b_{MM}$=0.01). A similar regression coefficient for the early milk yield on FICR (-0.005) was estimated by Averill *et al.* [2004]. The negative relationship between production and fertility also has a genetic background, which was shown in earlier studies [Jagusiak 2006, VanRaden 2006, Sewalem *et al*., 2010, Tiezzi *et al.* 2012, Albarrán-Portillo and Pollott 2013]. However, many researchers indicated that delays at the time of the first ovulation and the first detected estrus were related to a negative energy balance [Beam and Butler 1998, Butler 2000, de Vries and Veerkamp 2000]. The cow first has to recover the energy requirements for milk production rather than for the reproductive function. That could be a cause for the unfavorable influence of peak milk yield on fertility. Furthermore, an intensification of adipose tissue mobilization observed during negative energy balance is associated with the accumulation of triacyloglycerols in the liver, which affects the growth hormone-insulin growth factor I axis and prolongs the interval from parturition to the first ovulation [Rukkwamsuk *et al*. 1999, Diskin *et al*. 2003, Wathes et al. 2007]. Cows enter a state of negative energy balance early in the postpartum period, which could explain a lower conception rate at the beginning of lactation. The observed SP elongation, NI increase (regression coefficient $b_{MM}$=0.012) and FICR decrease result from the increase in the peak milk yield, which suggests that a high yield diminishes the conception ability rather than the cows' ability to recycle. In turn, a lesser antagonistic relationship between productivity and CF rather than between productivity and SP may indirectly indicate that the impact of farmers' performance-related decisions on the prolongation of a voluntary waiting period was not often practiced in the Polish population of Holsteins.

**The Effect of Air Temperature**

Among the environmental factors affecting fertility, ambient temperature is particularly significant. To describe climatic factors affecting fertility some authors recommend the use of THI [Ravagnolo and Misztal 2002]. This system of measurement takes into account both effects, namely ambient temperature and relative humidity, on a cow's thermoregulation. However, our study did not confirm that THI is better than measuring ambient temperature only, which is consistent with the results of Al-Katanani *et al*. [1999]. That may be due to the temperate climate in Poland. The average ambient temperature in the month of calving (TC) was selected for the traits measured from the day of calving (CF and DO). For SP, which is measured from the day of the first insemination, the average ambient temperature in the month of the first insemination (TI) was included in the model. The average TC and TI was 8.6°C (SD=7.5°C) and 9.5°C (SD=7.4°C), respectively. For both effects the minimum was -8.9°C and the maximum was 24.2°C.

In this study we found a negative impact of higher TI on SP, which describes the ability to conceive. An increase in the temperature by 10°C during the month of insemination (TI) was associated with an increase in SP by 13 days (regression coefficient $b_{TI}$=1.32). High ambient temperature leads to hyperthermia. That decreases oocyte quality and modifies the environment of the uterus, which results in an increase in the mortality of embryos [Kadzere *et al*. 2002, Rensis and Scaramuzzi 2003]. Although the negative influence of an increase in TI on SP was observed, an increase in TC had a positive impact on CF and DO. Instead, the length of CF and DO decreased by about 8 days when the ambient temperature during the month of calving (TC) increased by 10°C (regression coefficient $b_{TC}$=-0.83 and $b_{TC}$=-0.79, for CF and DO, respectively). This result is surprising, as Silvia *et al*. [2002] found the effect of season on the length of CF and DO and linked it with the heat stress pattern during the year. In this study the influence of both the month and the temperature were analyzed at the same time, and the effect of increase in the temperature on the prolongation of CF and DO was not confirmed. It should be noted that in the model for each reproduction trait the effect of month-year of the first insemination was included. When the first insemination took place in the summer or early fall, the length of SF and DO increased (results not shown). The calving pattern throughout the year was different from the insemination pattern: more calvings were observed in the winter and fall and more first inseminations were observed in the fall and summer, when the risk of heat stress is greater. It may have influenced the estimation of the effect of temperature in the month of calving on CF and DO. Although ambient temperature had an impact on continuous traits measured as intervals, we did not confirm the adverse effect of heat stress on the conception rate and non-return rate, which was reported in literature [Al-Katanani *et al*. 1999, Ravagnolo and Misztal 2002, García-Ispierto *et al*. 2007, Morton *et al*. 2007]. That may have been caused by the fact that average monthly ambient temperatures observed in Poland did not exceed 24°C, which indicates that heat stress does not occur often and does not last long.

Relationships between fertility and non-genetic factors found in this study suggest that ambient temperature and peak milk yield should be taken into account when the conducting genetic analysis of reproduction traits.

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**REFERENCES**

1. ALBARRÁN-PORTILLO B., POLLOTT G. E., 2013 – The relationship between fertility and lactation characteristics in Holstein cows on United Kingdom commercial dairy farms. ***Journal of Dairy Science*** 96, 635-646.
2. AL-KATANANI Y. M., WEBB D. W., HANSEN P. J., 1999 – Factors affecting seasonal variation in 90-day nonreturn rate to first service in lactating Holstein cows in a hot climate. J***ournal of Dairy Science*** 82, 2611-2616.
3. AVERILL T. A., REKAYA R., WEIGEL K., 2004 – Genetic analysis of male and female fertility using longitudinal binary data. ***Journal of Dairy Science***, 87, 3947-3952.
4. BEAM S. W., BUTLER W. R., 1997 – Energy balance and ovarian follicle development prior to the first ovulation postpartum in dairy cows receiving three levels of dietary fat. ***Biology of Reproduction*** 56, 133-142.
5. BEAM S. W., BUTLER W. R., 1998 – Energy balance, metabolic hormones, and early postpartum follicular development in dairy cows fed prilled lipid. ***Journal of Dairy Science*** 81, 121-131.
6. BUTLER W. R., 2000 - Nutritional interactions with reproductive performance in dairy cattle. ***Animal Reproduction Science*** 60, 449-457.
7. DE VRIES M. J., VEERKAMP R. F., 2000 – Energy balance of dairy cattle in relation to milk production variables and fertility. ***Journal of Dairy Science*** 83, 62-69.
8. DISKIN M. G., MACKEY D. R., ROCHE J. F., SREENAN J. M., 2003 – Effects of nutrition and metabolic status on circulating hormones and ovarian follicle development in cattle. ***Animal Reproduction Science*** 78, 345-370.
9. GARCÍA-ISPIERTO I., LÓPEZ-GATIUS F., BECH-SABAT G., SANTOLARIA P., YÁNIZ J. L., NOGAREDA C., DE RENSIS F., LÓPEZ-BÉJAR M., 2007 – Climate factors affecting conception rate of high producing dairy cows in northeastern Spain. ***Theriogenology*** 67, 1379-1385.

10. HARRISON, R. O., S. P. FORD, J. W. YOUNG, A. J. CONLEY, AND A. E. FREEMAN, 1990 - Increased milk production versus reproductive and energy status of high producing dairy cows. ***Journal of Dairy Science*** 73, 2749-2758.
11. JAGUSIAK W, 2006 – Fertility measures in Polish Black-and-White cattle. 3. Phenotypic and genetic correlations between fertility measures and milk production traits. ***Journal of Animal and Feed Science*** 15, 371-380.
12. KADZERE C. T., MURPHY M. R., SILANIKOVE N., MALTZ E., 2002 – Heat stress in lactating dairy cows: a review. ***Livestock Production Science*** 77, 59-91.
13. KÖNIG S., CHANG Y. M., BORSTEL U. U.V., GIANOLA D., SIMIANER H., 2008 – Genetic and phenotypic relationships among milk urea nitrogen, fertility, and milk yield in Holstein cows ***Journal of Dairy Science*** 91, 4372-4382
14. MISZTAL I., TSURUTA S., STRABEL T., AUVRAY B., DRUET T., LEE D. H., 2002 – BLUPF90 and related programs BGF90. In Proceedings of the 7th World Congress on Genetics Applied to Livestock Production, Montpellier, France, August 2002. Session 28. pp. 1-2. Institut National de la Recherche Agronomique INRA.
15. MORTON J. M., TRANTER W. P., MAYER D.G., JONSSON N.N., 2007 – Effects of environmental heat on conception rates in lactating dairy cows: critical periods of exposure. ***Journal of Dairy Science*** 90, 2271-2278.
16. PRYCE J. E., ROYAL M. D., GARNSWORTHY P. C., MAO I. L., 2004 – Fertility in the high-producing dairy cow. ***Livestock Production Science*** 86, 125-135.
17. RAVAGNOLO O., MISZTAL I., 2002 – Effect of heat stress on nonreturn rate in Holsteins: fixed-model analyses. ***Journal of Dairy Science*** 85, 3101-3106.
18. RENSIS F. D., SCARAMUZZI R. J., 2003 – Heat stress and seasonal effects on reproduction in the dairy cow – a review. ***Theriogenology*** 60, 1139-1151.
19. Roxström A., Strandberg E., Berglund B., Emanuelson U., Philipsson J., 2001 – Genetic and environmental correlations among female fertility traits and milk production in different parities of Swedish Red and White dairy cattle. Acta Agriculturae Scandinavica 51, 7-14.
20. RUKKWAMSUK T., WENSING T., KRUIP T. A., 1999 – Relationship between triacylglycerol concentration in the liver and first ovulation in postpartum dairy cows. ***Theriogenology*** 51, 133-1142.
21. SEWALEM A., KISTEMAKER G. J., MIGLIOR F., 2010 – Relationship between female fertility and production traits in Canadian Holsteins. ***Journal of Dairy Science*** 93, 4427-4434.
22. SILVIA W. J., HEMKEN R. W., HATLER T. B., 2002 – Timing of onset of somatotropin supplementation on reproductive performance in dairy cows. ***Journal of Dairy Science*** 85, 384-389.
23. TIEZZI F., MALTECCA C., CECCHINATO A., PENASA M., BITTANTE G., 2012 – Genetic parameters for fertility of dairy heifers and cows at different parities and relationships with production traits in first lactation. ***Journal of Dairy Science*** 95, 7355-7362
24. VANRADEN P.M., 2006 – Fertility trait economics and correlations with other traits. ***Interbull Bulletin*** 34, 53-56.
25. WATHES D. C., FENWICK M., CHENG Z., BOURNE N., LLEWELLYN S., MORRIS D. G., KENNY D., MURPHY J., FITZPATRICK R., 2007 – Influence of negative energy balance on cyclicity and fertility in the high producing dairy cow. ***Theriogenology*** 68, S232-S241.
26. WOLFENSON D., ROTH Z., MEIDAN R., 2000 – Impaired reproduction in heat-stressed cattle: basic and applied aspects. ***Animal Reproduction Science*** 60, 535-547.