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Fertility measures in Polish Black-and-White cattle. 1. Genetic parameters of heifer fertility traits*

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ABSTRACT

Genetic parameters of heifer fertility measures were estimated. Data were records of 42 283 first-parity Black-and-White cows. The percentage of cows that did not repeat heat was 73 at the 56th day and 69 at the 72nd day after first insemination. Heritabilities of non-return rates to the 56th day and 72nd day were 0.012 and 0.010, respectively. Heritabilities of age at first insemination, age at conception and age at calving were 0.324, 0.312 and 0.296, respectively. Phenotypic correlations ranged from 0.78 between age at first service and age at conception to 0.98 between age at conception and age at calving. The genetic correlations were high (0.96 and higher). Genetic correlations between non-return rates and the remaining traits ranged from -0.11 to 0.10.

KEY WORDS: dairy cattle, fertility, genetic parameters, linear animal model

INTRODUCTION

Improvement of milk production traits has been a main breeding goal in the Polish Black-and-White cattle population. During the last 20 years, holsteinistion and selection have led to an increase of milk yield but have caused unfavourable trends in reproductive performance. Fertility traits are considered very important because of their impact on the economics of dairy cattle breeding. The following consequences of low fertility were listed by Hodel et al. (1995): higher insemination costs, decrease of milk and meat production (fewer progeny born), increase in

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culling rate, and less intensive selection. About 20-30% of all culling has been due to fertility problems (Boichard and Manfredi, 1992; Hoekstra et al., 1994). Measures of fertility are defined as intervals (calving intervals, days open, days to first service, service period); others illustrate the efficiency of insemination (e.g., conception rate, non-return rate, average number of services per conception) (Pryce et al., 1998). Cow fertility is affected by breed (Oltenacu et al., 1991; Antkowiak and Pytlewski, 1997), percentage of HF genes (Ziemiński et al., 1991; Hoekstra, 1994), age of cow (Kamieniecki et al., 1991) and year of calving (Brzozowski, 1985; Jansen; 1985; Bagnato and Oltenacu, 1994). Other factors such as feeding, health, oestrus detection, or determination of time of insemination, may be directly influenced by the breeder (Kuczaj, 1985; Boichard and Manfredi, 1992).

In practice, the main factor decreasing the fertility of dairy cows is increase of milk production traits, which is negatively correlated with fertility (Hansen et al., 1983; Nebel and McGiliard; 1993, Hoekstra et al., 1994; Pryce et al., 1998; Lucy, 2001; Veerkamp et al., 2001). High-producing cows have 12 days more from calving to the next conception and a significantly lower first service conception rate. Better herd management in high-producing herds can partly reduce the negative effect of high production on fertility (Bagnato and Oltenacu, 1994). Lawson et al. (2004) found moderate relationships between milk production efficiency and several reproductive disorders in the Danish dairy cattle population. A significant and unfavourable trend in fertility traits was observed in southeastern regions of the United States. The average interval from calving to conception increased from 120-130 days in 1976 to 160-180 days in 1999 (Washburn et al., 2002). In the same period the number of services per conception increased from 1.9-2.1 to 2.9-3.1. Average conception decreased from 52-53 to 33-35%. The genetic trend for female fertility in Israeli Holstein dairy cattle population was close to zero, and the annual environmental trend was 0.2% (Weller and Ezra, 2003). Simultaneous selection for milk production and fertility traits is necessary because of negative correlation between yield traits and fertility (Strandberg and Danell, 1989; Oltenacu et al., 1991; Roxström et al., 2001).

Many authors have found an unfavourable relation between the percentage of Holstein-Friesian genes and the reproductive performance of cows (Ziemiński et al., 1991; Hoekstra et al., 1994). This finding was not confirmed by Royal et al. (2002) in Great Britain.

Recently, many countries participating in international bull breeding value evaluation have made significant improvements in cattle fertility. It is assumed that the genetic variability of some fertility traits is large enough to include them in the breeding goal. In many countries the fertility traits of dairy cattle have been routinely evaluated (Boichard et al., 1997; Cermák et al., 1997; Hyppänen and Juga, 1997; de Jong, 1997; Miglior et al., 1997; Pasman and Reihardt, 1997;

Ranberg et al., 1997). The estimated breeding values of sires based on daughters' fertility are included in the total merit index in Germany (Miesenberger et al.; 1997, Thaller, 1997). In Denmark, five fertility traits are evaluated and combined in one index which is included in the total merit index. Two fertility traits are included in the total merit index in Finland (Hyppänen and Juga, 1997) and the Netherlands (de Jong, 1997). Fertility is also routinely evaluated in Germany (Pasman and Reihardt, 1997), France (Boichard et al., 1997), Italy (Miglior et al., 1997), Norway (Ranberg et al., 1997) and the Czech Republic (Cermák et al., 1997).

In Poland the fertility traits of dairy cattle have not been evaluated recently. Genetic parameters estimated for large populations using a relationship matrix as well as correlations between fertility and other economically important traits are also not available.

The purpose of this paper was to estimate the heritabilities of several fertility traits and the genetic and phenotypic correlations between them.

MATERIAL AND METHODS

Data were 763,073 records of Polish Black-and-White cows born between 1996 and 2000. Each record consisted of the cow registration number, pedigree (parents and grandparents), date of birth, date of first insemination, date of conception and date of calving. Mean inbreeding for Polish Black-and-White cows born between 1996 and 1999 was less then 0.5% and could be ignored (Jagusiak and Ptak, 2003). After formal edits, records of the cows with incomplete data were removed and a file with 289,500 records of cows were created. The cows were daughters of 3927 sires. The records of daughters of sires with less than 20 progeny were deleted and from the total of 2018 sires with 20 or more daughter records, 1018 bulls were randomly chosen. A random number generator was used to draw the bulls. Probability for drawing each single bull was set to 0.5. Cows assigned to herd-year-season subclasses with less than 10 contemporaries were removed from the file with daughters of the chosen bulls.

The final data set contained 42,283 records of cows that were daughters of 1018 sires. The cows calved for the first time in 785 herds and were allocated in 2217 herd-year-season and 1657 herd-year subclasses.

Most cows were born in 1998 and 1999 (Table 1). The average age of first service was highest for the oldest cows (582.2 days), and decreased to 511.9 days for the youngest cows born in 2000. The standard deviation for the youngest cows was the lowest (66 days); for the remaining groups it was higher but did not exceed 76 days. Age at conception showed a similar pattern: cows born in 1996 conceived on average 70 days later than cows born in 2000.

TABLE 1
Means and standard deviations for age at first service, age at conception, age at calving, NR56 and NR72 by birth year

Year of birth	n	Age at first service		Age at conception		Age at calving		NR56		NR72	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
1996	2943	582.2	75.8	597.3	76.9	887.1	81.2	0.72	0.40	0.68	0.44
1997	8535	550.9	74.9	568.6	78.4	846.6	83.2	0.73	0.39	0.67	0.43
1998	10407	538.5	75.6	559.6	79.1	835.9	84.2	0.72	0.39	0.69	0.42
1999	11869	534.7	73.1	555.2	77.9	836.4	82.5	0.74	0.39	0.69	0.42
2000	8529	511.9	66.0	529.7	71.5	806.5	74.0	0.73	0.39	0.69	0.42
Total	42283	537.6	75.5	556.8	79.0	835.8	83.2	0.73	0.39	0.69	0.42

The differences between age at conception and age at first service (service period), which will be analysed in the next paper, were higher for cows born in 1998 and 1999 than for cows born in 1996. Age at first calving is highly correlated with age at conception and depends on days of pregnancy. Average ages at calving decreased for cows born in consecutive years, and ranged from 887.1 days for the oldest down to 806 for the youngest cows.

The group of pure Black-and-White cows was quite small (2.5% of all cows) (Table 2). Most cows were assigned to groups with small (0.1-25%) and average (25.1-50%) contribution of Holstein-Friesian (HF) genes; 3122 (7.4%) cows had more than 50% HF genes. Black-and-White cows and cows with a small contribution of HF genes were younger than cows with 25.1-75% HF genes when first-time inseminated. Average age at first service was the lowest for the group of pure Holstein-Friesians (530.4 days).The following fertility measures were

TABLE 2
Means and standard deviations for age at first service, age at conception and age at calving, by percentage of HF genes

Percent-age of HF genes	n	Age at first service		Age at conception		Age at calving		NR56		NR72	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
0	1058	535.5	69.3	551.9	72.7	830.3	74.9	0.73	0.39	0.68	0.42
0.1-25	25625	533.6	72.2	552.7	76.5	831.5	80.2	0.73	0.39	0.69	0.42
25.1-50	12478	545.8	81.4	565.1	83.5	844.7	88.4	0.73	0.39	0.68	0.42
50.1-75	1732	544.3	82.2	564.3	82.8	843.8	88.3	0.73	0.40	0.69	0.43
75.1-100	1390	530.4	70.0	551.2	77.8	829.7	81.4	0.73	0.39	0,70	0.42
Total	42283	537.6	75.5	556.8	79.0	835.8	83.2	0.73	0.39	0.69	0.42

calculated for each cow: non-return rate to 56th day (NR56), non-return rate to 72nd day (NR72), age at first service, age at first conception, and age at first calving. Non-return rates were defined as binary traits based on whether or not the cow had a second insemination within 56 (or 72) days after first insemination. Neither NR56 and NR72 changed in consecutive birth years (Table 1), and they did not depend on the percentage of HF genes (Table 2).

(Co)variance components of the fertility traits were estimated by restricted maximum likelihood (REML) (Misztal and Perez-Enciso, 1993) with a relationship matrix, based on the following linear model:

$$\mathbf{y = Xb + ZQg + Zu + e}$$

where **y** is the vector of observations, **g** is the vector of fixed effects of genetic groups, **b** is the vector of fixed effects of herd-year of calving and month of calving, **u** is the vector of additive animal genetic effects, **e** is the vector of residual error, and **X**, **Z** and **Q** are coincidence matrices. Matrix $\mathbf{G} = \mathbf{A}^{-1} \otimes \mathbf{G}_0$, where $\mathbf{A}^{-1}$ is a numerator relationship matrix and $\mathbf{G}_0$ a genetic (co)variance matrix between traits.

It is assumed that, E(**u**) = **0**, E(**e**) = **0**, V(**u**) = **G**, V(**e**) = **R**, Cov(**u**,**e**) = **0**, and E(**y**) = **Xb,** V(**y**)=**ZGZ'**+**R**. Matrix $\mathbf{R} = \mathbf{I} \otimes \mathbf{R}_0$, where $\mathbf{R_0}$ is a residual (co)variance matrix between traits and $\otimes$ is the Kronecker product.

Genetic groups were created according to the rules given by Westell et al. (1988). Animals with unknown parents were assigned to genetic groups by birth year and percentage of Holstein-Friesian genes. Five groups for male and eight for female unknown parents were formed.

Variance components for NR56, NR72, age at first service, age at conception and age at calving were estimated using the single trait animal model. Estimated variances were used as prior values to estimate genetic and residual covariances between studied traits, using the multitrait animal model. Genetic and phenotypic correlations were computed based on estimated (co)variances.

RESULTS

The non-return rates at the 56th or 72nd days after insemination are very important traits used in selection indexes in some European countries (Thaller, 1997). These traits indicate the cow's ability to maintain a pregnancy over the period of early gestation. Interbull recommends using these traits in national evaluation systems. Gianola and Foulley (1983) suggested estimating genetic parameters for traits scored to two or several categories using a threshold model. Hansen et al. (2003) estimated genetic parameters for stillbirth using both threshold and linear approaches and found heritabilities estimated by the threshold model on average twice those obtained by the linear model. Increased computing time is a main disadvantage of threshold approach. The linear model was used for all traits analyzed in this paper.

The percentage of cows that did not repeat heat was 73% at the 56th day and 69% at the 72nd day after first insemination. Heritabilities for non-return rates were very low: 0.012 for NR56 and 0.01 for NR72. The highest heritability was found for age at first service (0.324). Heritabilities for age of conception and age at calving were slightly smaller and amounted to 0.312 and 0.296, respectively (Table 3).

TABLE 3

Means and standard deviations of first-parity fertility traits (n=42,283)

Trait	$\bar{x}$	SD	h^2	SE
Non return rate to 56. day	0.73	0.39	0.012	0.009
Non return rate to 72. day	0.69	0.42	0.010	0.009
Age at first service	537.6	75.5	0.324	0.033
Age of conception	556.8	79.0	0.312	0.021
Age at calving	835.8	83.2	0.296	0.019

Relations among ages at first insemination, conception and calving are shown in Table 4. The largest genetic correlation was found between age at first service and age at calving (0.98). The correlation between age at first service and age at conception was slightly smaller (0.96).

TABLE 4

Genetic (above diagonal) and phenotypic (below diagonal) correlations of fertility traits

No.	Trait	1	2	3	4	5
1	Non return rate to 56. day		0.80	0.10	0.05	-0.11
2	Non return rate to 72. day	0.48		-0.05	-0.08	-0.05
3	Age at first service	0.12	-0.02		0.96	0.98
4	Age at conception	-0.12	-0.02	0.78		0.98
5	Age at calving	-0.20	-0.08	0.80	0.98	

estimated SE for r_g ranged from 0.05 to 0.15

The genetic correlation between NR56 and NR72 was high (0.80) whereas the correlations between non-return rates and the remaining traits were low. The highest and negative correlation was found for NR72 and age at conception (-0.11). A positive correlation was obtained for NR56 and age at first service (0.10).

Phenotypic correlations among age at first service, age at conception and age at calving were positive and large. The highest correlation was found between age at calving and age at conception (0.98), and the lowest between age at first service and age at conception (0.78). A lower phenotypic correlation was found between NR56 and NR72 (0.48). Correlations between non-return rates and the remaining traits, were low and ranged from -0.20 for NR56 and age at calving to 0.12 for NR56 and age at first service.

DISCUSSION

The decrease in age at first insemination for cows born in consecutive years, from about 19 months in 1996 to 17 in 2000, reflects the trend in Polish dairy cattle breeding. The average age at calving decreased in the same period from 29 to 27.5 months. Pirlo et al. (2000) showed a positive effect of age at first calving on milk, and a negative effect on protein percentage, concluding that the optimal age at first calving is between 23 and 24 months. Gill and Allaire (1976) found that the optimal age of first calving for total lifetime performance occurs at 23 months, and for maximum profit per day for herd life at about 25 months.

Hibner et al. (1993) showed that the optimal age of first calving for Black-and-White heifers increased with the percentage of HF genes. In our data the average age of calving for pure Black-and-White cows and cows with 0.1-25% HF genes was in general 10 days less than for cows with 25.1-75% HF genes. However, age at calving of pure Holstein-Frisians was similar to that of pure Black-and-White cows.

One of the most important fertility traits included in total merit indices in many countries is non-return rate. The non-return rate found by Ranberg et al. (2003) in a population of heifers in Norway was 74.6%, very similar to NR56 reported in this paper. The heritability of NR56 in the Norwegian population varied from 0.012 to 0.014 depending on the model applied. Heritability of NR56 estimated by Wall et al. (2003) in a population of British Holsteins was slightly higher (0.018). Heritability for non-return rate to 90th day estimated by Hodel et al. (1995) was lower for heifers (0.011) and higher for cows (0.021). In populations of Israeli Holstein dairy cattle, Weller and Ezra (2003) estimated heritability of the trait defined as the inverse of the number of inseminations to conception for parities from the first through fifth. In general the heritabilities did not exceed 0.02, and only in the second parity were slightly higher (0.03). All heritabilities reported in the literature were higher than these obtained in our study, which did not exceed 0.01.

Heritabilites for number of services per conception reported in the literature are higher than for non-return rate. Dematewewa and Berger (1998) estimated heritability of 0.028 for number of inseminations per conception in the Holstein population in Iowa. Heritability of 0.039 for the same trait in the population of cattle in the Netherlands was estimated by Veerkamp et al. (2001). Lower heritability (0.020) was found by Wall et al. (2003). Only dates of first and last services were available in our data, so the heritability of number of inseminations per conception could not be estimated.

Heritabilities of age at first service, age at conception and age at first calving estimated in this paper were high and similar to these given by Jagusiak and Żarnecki (2001). Published heritabilities are inconsistent, and range from 0.034 for age at first calving (Moore et al., 1990) and 0.06 for age at first service (Pryce et al., 2001) to 0.22 and 0.43 for age at first service and age at first calving, respectively (Simerl et al., 1991).

As expected, age at first service, age at conception and age at calving were highly correlated. Many cows are inseminated and conceived on the same day, but for other cows the inseminations must be repeated. The interval between insemination and conception depends on many factors, and decreases the phenotypic correlation between age at first service and the remaining traits. Very high (close to 1.0) genetic and phenotypic correlations between age at conception and age at calving were expected because of the very small variance of number of pregnancy days.

In general, genetic and phenotypic correlations between non-return rates and other traits were low. Early inseminated heifers more often repeated heat, which resulted in a positive correlation between non-return rate and age of first insemination. Negative correlations of non-return rates with age of conception and age of calving imply that heifers that did not repeat heat conceived earlier and calved earlier.

Other fertility traits such as service period, days open and calving interval will be analysed in the next paper.

CONCLUSIONS

Age at first insemination and age at calving decreased in consecutive years and were close to optimal for cows born in 2000. Heifers with intermediate percentages of HF genes were inseminated and calved slightly earlier than pure Black-and-White and pure Holstein-Friesians. Heritabilities of age at first insemination, age at conception and age at calving were within the range of published results. Due to high genetic and phenotypic correlations, only one of these traits should be evaluated and included in cow fertility index. Heritabilities of NR56 and NR72 were low but enough to include non-return rates in the national evaluation system.

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STRESZCZENIE

Cechy płodności w polskiej populacji bydła czarno-białego. 1. Parametry genetyczne cech płodności pierwiastek

Na podstawie danych dotyczących pierwszych laktacji 42 283 krów czarno-białych oszacowano parametry genetyczne następujących cech płodności: wieku pierwszego zabiegu inseminacyjnego, pierwszego zacielenia, oraz ocielenia, a także wskaźników nie powtarzania rui do 56 (NR56) i do 72 dnia (NR72) po pierwszym zabiegu unasienienia. Krowy, u których nie stwierdzono objawów rui do 56 i 73 dnia po zabiegu stanowiły odpowiednio 73 i 69% badanej populacji. Odziedziczalności NR56 i NR72 wynosiły 0,012 i 0,010. Odziedziczalności wieku pierwszego zabiegu inseminacyjnego, pierwszego zacielenia i pierwszego ocielenia wynosiły odpowiednio: 0,324, 0,312 i 0,296. Korelacje fenotypowe wahały się od 0,78 (pomiędzy wiekiem pierwszego zabiegu i wiekiem zacielenia) do 0,98 (pomiędzy wiekiem zacielenia i wiekiem ocielenia). Korelacje genetyczne pomiędzy tymi trzema cechami były wyższe od 0,96. Korelacje genetyczne między współczynnikami niepowtarzalności rui były bliskie zera. Duże odziedziczalności wysoko skorelowanych: wieku pierwszej inseminacji, pierwszego zacielenia i pierwszego ocielenia oznaczają, że dla jednej z tych cech należy szacować wartość hodowlaną. Odziedziczalności cech niepowtarzalności rui są niskie, ale również wystarczające dla celów szacowania wartości hodowlanych i uwzględnienia ich w programie selekcji.