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Institute of Genetics and Animal Breeding, Jastrzębiec, Poland

Factors affecting first insemination success in Polish Holstein-Fresian cows

Kamil Siatka, Anna Sawa, Dariusz Piwczyński, Mariusz Bogucki, Sylwia Krężel-Czopek*

Department of Cattle Breeding, [2]Department of Genetics and Animal Breeding,
UTP University of Science and Technology, Mazowiecka 28, 85-084 Bydgoszcz, Poland

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The effects parity, herd production level, number of cows per herd, insemination season and lactation stage on the relationships between daily milk and first insemination success of 55 685 cows were examined. The statistical analysis was performed using the χ^2 test and the decision tree technique. The χ^2 test showed that all the experimental factors affected the insemination success as a function of the daily milk yield of the cows; as it increased from ≤20 kg to >40 kg, first insemination success decreased by more than 7% in primiparous cows, and by as much as over 16% in second lactation cows. With the herd production level going up from ≤7000 kg to >9000 kg, the unfavourable effect of the increasing daily milk yield on fertility decreased almost 4-fold. Summer was the least favourable period for insemination. Cows yielding >40 kg milk/day were particularly sensitive to heat stress, as evidenced by their first insemination success decreasing by over 13% in relation to the cows producing ≤20 kg milk. In winter this difference was 9.5%. Considering the lactation stage, as daily milk yield increased, first insemination success decreased by around 9% when performed up to 60 days of lactation, and by as much as over 15% during 151-180 days of lactation. Cows in bigger herds exhibited lower fertility, but the increase in daily milk yield caused first insemination success to decrease by 16% in very small herds (≤20 cows) and by 4.6% in larger herds. Classification tree analysis showed that similar factors (lactation period, number of cows per herd, daily yield, parity) were moderating the first insemination success in cows. At the same time, the applied methods showed that the determinants of fertility in cows are highly complex. This complexity may be well explained using the classification tree technique.

KEY WORDS: cows / daily milk yield / decision trees / insemination success

*Corresponding author: krezel@utp.edu.pl

Decent reproductive results are not easy to achieve, as they are determined by many factors [Stratman *et al.* 2016]. Because fertility traits have low heritability [e.g. Banos and Coffey 2010, Strucken *et al*. 2012], they are largely moulded by environmental [Strucken *et al.* 2012] and physiological factors [Morek-Kopeć *et al.* 2009, Smith *et al*. 2014] of which calving season [Ismael *et al*. 2016], insemination method, semen storage method, or the female reproductive tract environment [Green *et al*. 2012, Smith *et al*. 2014, Zebeli *et al*. 2015] make their mark.

Fertility is measured by, amongst others, the first insemination success (also known as the non-return rate), which is calculated as the conception rate of cows or heifers after the first insemination [Ghiasi *et al.* 2015, Morek-Kopeć *et al*. 2009]. At present, first insemination success is at 40-44% [Ferguson and Skidmore 2013, Ghiasi *et al*. 2015]. According to Mordak [2008], in well-managed herds it should reach 50-60%.

Decision trees are one of the data mining techniques which enable the results obtained to be intuitively and easily interpreted and presented as simple graphic models [Midla and St-Pierre 2015, Piwczyński *et al*. 2012]. They facilitate analyses of the effect of single factors in a model and the interactions between them [Piwczyński and Sitkowska. 2012]; thus they may be used to make complex decisions involving many alternatives [Midla and St-Pierre 2015].

The aim of the study was to estimate the relationships between daily milk yield and first insemination success in Polish Holstein-Friesian cows.

Material and methods

The study used data from the SYMLEK database on 55 685 Polish Holstein-Friesian primiparous cows that calved in 2005-2012; the second lactation cows amounted to 33 060.

The following information was recorded:
- date of first insemination in the first and second reproductive cycles;
- number of inseminations in the first and second production cycles;
- daily milk yield.

The first artificial insemination was considered successful if it resulted in pregnancy and was analyzed as affected by:
- parity (first, second);
- herd production level (≤7000, 7001-9000 and >9000 kg milk);
- season of insemination (March-May, June-August, September-November, December-February);
- lactation stage at insemination (≤60, 61-90, 91-120, 121-150, 151-180 days);
- herd size (≤20, 21-50, 51-200 and >200 cows).

Daily milk yield was determined from 88745 test-day records from the period up to 180 days of the first and second lactations. The test-day preceded the insemination by 0-30 days.

The relationship between daily milk yield and first insemination success with regard to the above factors was analysed using the χ^2 test, applying the FREQ procedure (SAS Institute Inc., 2014).

In the next stage of the experiment, first insemination success was modelled using the decision tree method. The decision tree model was constructed by dividing the whole dataset into subsets (leaves) that were maximally homogeneous in terms of the dependent variable. The algorithm creating the decision tree used for this purpose two criteria of division, i.e. a function of entropy reduction and the χ^2 test. These divisions resulted in a graphic model, the structure of which resembles a tree (stump, branches, leaves). In the graphical tree model the percentage distribution of effective inseminations of the training set of 53246 records was presented. The resulting model was generated based on the reduction of entropy rate and the χ^2 test.

Statistical analysis with decision trees was performed using the SAS Enterprise Miner Workstation 13.1 [SAS Institute. Inc. 2014].

For the statistical analysis, the observations were divided into two sets: the training set (60%) and the validation set (40%). The training data set was used for preliminary model fitting, while the validation data were used to prevent a modelling node from overfitting. These sets were generated by means of random sampling. When building the classification tree, the minimum terminal node size was set to 30, with the maximum depth of 5. It was also assumed that a binary tree would be created. When determining the leaf size and tree depth criteria, we wanted to avoid overfitting the tree to the training data, which could result in the reflection of random relationships in the validation set.

The following factors were included in the statistical analysis of the first insemination:

- daily milk yield;
- herd size;
- lactation stage at first insemination;
- herd production level;
- parity;
- season of first insemination.

The following information was added to each created node and a resulting leaf: the number of observations (53246), percentage of ineffective first inseminations (56.00%) and effective first inseminations (44.00%).

Results and discussion

The first insemination success of approximately 44% (Tab. 1), observed in this study, is consistent with the results obtained by other authors [e.g. Ferguson and Skidmore 2013, Ghiasi *et al*. 2015]. Within the lactation, as daily milk yield increased, the first insemination success decreased (P≤0.01), especially for cows in the second production cycle. As milk yield increased from ≤20 kg to >40 kg, first insemination

Table 1. The effectiveness of the first insemination (%)

Factor		The effectiveness of the first insemination (%)						
		n	total	performance of daily milk (kg)				
				≤20.0	20.1-30.0	30.1-40.0	>40.0	significance
Lactation	1	55685	43.9	49.2	43.3	41.3	41.7	***
	2	33060	44.3	53.5	46.9	41.6	37.3	***
The level of herd productivity (kg)	≤7000	34869	46.2	50.8	44.7	38.6	26.9	***
	7000-9000	36708	42.5	48.3	44.0	40.8	36.2	***
	>9000	17168	42.7	46.3	45.4	43.4	40.2	***
The season of insemination	winter	20384	44.4	49.0	45.1	42.2	39.5	***
	spring	24811	44.4	50.2	45.4	42.1	40.1	***
	summer	21339	42.1	49.9	42.5	39.0	36.6	***
	autumn	22211	45.1	51.9	44.6	42.2	38.2	***
Lactation period (days)	≤60	35022	40.0	44.7	40.8	38.3	35.9	***
	61-90	27047	45.3	52.5	45.8	42.7	40.9	***
	91-120	15199	47.2	52.2	47.5	45.2	40.1	***
	121-150	7638	48.9	53.3	48.5	45.2	43.9	***
	151-180	3839	49.5	52.9	49.6	45.1	37.5	***
Herd size (number of cows)	≤20	14976	47.6	51.8	46.5	41.6	35.8	***
	21-50	32270	46.3	51.0	46.1	43.3	39.0	***
	51-200	20691	41.9	47.3	42.0	41.1	38.3	***
	>200	20808	40.0	43.4	40.5	40.1	38.8	

***p≤0.01.

success decreased by more than 7% in primiparous cows, and by as much as over 16% in second lactation cows. Miller *et al.* [2001] reported age vs. number of calvings as a factor significantly (P≤0.01) affecting the non-return rate. König *et al*. [2006] concluded that conception at the first insemination is less likely in primiparous than for multiparous cows, due to problems with maintaining energy balance. In turn, Miller *et al.* [2001] reported insemination success to decrease with the increasing number of calvings, attributing it to the milk yield that increases with age.

First insemination success was found to decrease (P≤0.01) by around 4% with the increasing herd production level (from ≤7000 kg to 7000-9000 kg milk). At the same time, the increasing herd production level was paralleled by a decrease in the unfavourable effect of increased daily milk yield of the cows on their fertility. The decrease in the first insemination success with the increasing daily milk yield was highest (by 23.9%) in herds producing ≤7000 kg milk, while it was lowest (by 6.1%) in herds yielding >9000 kg milk. Our findings, which show that first insemination success decreases with increasing daily milk yield support the widespread view on the declining fertility of high-yielding cows [Piccardi *et al.* 2013, Smith *et al*. 2014]. A factor predisposing high-producing cows to reduced fertility is their increased ability to mobilise energy reserves, mainly from the adipose tissue [Bisinotto *et al*. 2012, Roy *et al*. 2011, Strucken *et al*. 2012], but in some cases also from the muscle tissue [Strucken *et al.* 2012] as well as the increased utilisation of amino acids, minerals and vitamins [Bisinotto *et al.* 2012] during the critical, initial period of lactation. The excessive emaciation of animals may result in metabolic changes that lead to a deterioration of reproductive parameters, resulting from functional changes in the reproductive system and reflected in lower conception rates and an increased likelihood of pregnancy loss [Green *et al.* 2012, Stratman *et al.* 2016]. Řehák *et al.* [2009] observed first insemination success to fall by as much as 10% when comparing cows producing 29.5-37.2 kg milk/day with those yielding more than 37.2 kg fat-protein corrected milk.

The very low (26.9%) first insemination success in the cows with a daily milk yield of >40 kg coming from herds producing ≤7000 kg of milk may be due to a weak adaptation of these herds to the high production potential and high nutrient requirements of these cows, which are difficult to meet. The supplied nutrients are used in the first place for maintenance and production of milk [Drackley and Cardoso 2014, Zebeli *et al.* 2015]. This leads to a competition between milk yield and fertility, as indicated by the findings of Strucken *et al*. [2012].

When analysing the effect of the season of first insemination it was found that the worst period to inseminate cows is the summer. Cows with the highest milk yields (>40 kg/day) were particularly sensitive to heat stress, because their first insemination success decreased by over 13% compared to the cows producing ≤20 kg milk. In winter this difference was 9.5%. Heat stress is one of the environmental factors that adversely affect reproductive performance [Miller *et al*. 2001]. The negative effect of high temperatures on reproductive efficiency was confirmed by Chebel *et al.* [2004] and Hertl *et al*. [2010], who reported a several percent decrease in the conception rate of American Holstein cows exposed to high temperatures while the latter team of researchers indicated the spring and autumn, characterised by mild climatic conditions, are most favourable seasons for insemination. Also the results obtained in the Republic of South Africa [Muller *et al.* 2014], Argentina [Piccardi *et al*. 2013] and Egypt [El-Tarabany and El-Tarabany 2015] indicate that the months with lower temperatures are more favourable to produce a pregnancy. Data from Israel show a decrease in first insemination success due to increasing ambient temperatures, from 38.7% in winter to 28.9% in autumn and 22.0% in summer [Friedman *et al.* 2011]. The decrease in first insemination success with the increasing daily milk yield, found in the present study, may be attributed to the increased sensitivity of high-yielding cows to heat stress. It was found previously that the increase in daily milk yield of the cows leads to a decrease in the temperature stress threshold [Lambertz *et al*. 2014, El-Tarabany and El-Tarabany 2015].

As expected, insemination success improved from 40 to 50% for all the cows with an increased interval between the preceding calving and the first insemination service. The increase in daily milk yield from ≤20 to >40 kg reduced first insemination success by 9% when performed up to ≤60 days of lactation to over 15% between 151 and 180 days of lactation. Our finding that the first insemination success increases with a prolonged interval between the preceding calving and the date of the first AI service is confirmed by the results of other authors [Miller *et al*. 2001, Řehák *et al.* 2009]. Yusuf *et al.* [2011] observed a favourable effect of extending the interval between calving and the first insemination service on first insemination success; during the period up to 100 days of lactation this relationship was linear, although the differences were not significant. Every 20 additional days between calving and first insemination within the 100 days postpartum increased the probability of first insemination success by 2.4%. In that population a lower first insemination success (30.1-38.0%) was obtained during the corresponding periods of lactation when compared to our study (40.0-49.5%) (Tab. 1).

The increase in daily milk yield in very small herds (≤20 cows) reduced first insemination success by 16%. As the number of cows per herd increased, the difference between the conception rates of cows with extreme daily milk yields decreased to 4.6%. The first insemination success in very small herds (≤20 cows) and small herds (21-50 cows) was higher compared to large herds (50-200 cows) and very large herds (>200 cows). With the increase in the number of cows per herd from ≤20 to >200, success of first insemination was decreased by 7%. El-Tarabany and El-Tarabany [2015] demonstrated that keeping a large number of animals under one roof may adversely affect climatic conditions inside buildings. Particularly during periods of high temperatures and when animal cooling systems are not sufficiently efficient, this may lead to poorer reproductive performance.

Analysis of the factors in the classification tree model describing the first insemination success showed that it was influenced by such factors as lactation period (variable = 1 on a scale of 0-1), followed by herd size (variable = 0.98), daily milk yield (2 times) (variable = 0.6578) and lactation (variable = 0.2668). The first partition was based on the day of lactation variable, resulting in nodes 2 and 3 (Fig. 1). Premature insemination, before 44 days of lactation (node 2) resulted in lower success compared to the service performed 44 days post-calving or later (37.27% *vs*. 45.68%). Node 2 was not further partitioned and became a leaf, whereas node 3 was partitioned in terms of the herd size variable. A greater first insemination success was observed in animals from herds with <93 cows (node 4) (48.47% *vs*. 40.48%). The subset of cows from these herds was divided with regard to their daily milk yields into <17.85 kg (node 6, which became a leaf) and ≥17.85 kg (node 7), with greater insemination success found at a lower milk yield (54.86% *vs*. 47.38%). Again, the factor differentiating fertility of the cows with higher milk yield was daily milk yield (<27.95 kg node 8 and ≥27.95 kg node 9, which became a leaf), with first insemination success being more uniform (48.81% *vs*. 45.22%). The results of the latter division (nodes 10 and 11) show that first insemination success in second lactation cows was greater than in primiparous cows.

The analysis of a simple model of the decision tree for first insemination success made it possible to evaluate both the effect of daily milk yield and factors such as lactation period during the first insemination, herd size, daily milk yield, age of cows These results are consistent with those reported by Řehák *et al.* [2009], who showed that in terms of first insemination success, it is more favourable (by 10%) to perform the first insemination at least two months after calving when the milk yield of the cows is below 37.2 kg of FPCM. Ferguson and Skidmore [2013], based on studies conducted in the best American herds in terms of fertility, showed that

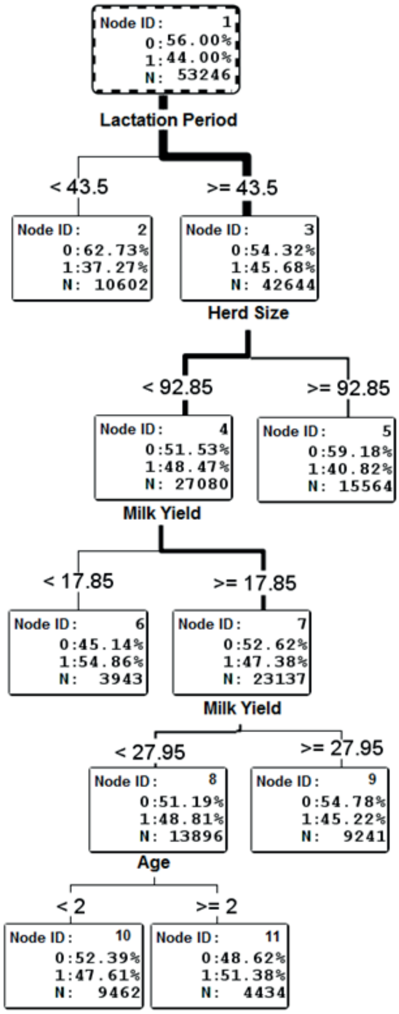

Fig. 1. Decision tree for first insemination success.

reproductive performance depends on many factors connected with reproductive management; however, they underlined that postponing the first insemination may prove beneficial for breeders. Based on the analysis of classification trees Caraviello *et al.* [2006] showed that factors associated with the living environment (type of floor in the barn) and herd management (hoof trimming, insemination method, duration of the voluntary waiting period) are crucial to the first insemination success. Ghiasi *et al.* [2015] demonstrated that first insemination success depends more on factors such as age of cows (number of calvings), age at calving, the herd from which the animal originated, year of calving, and season (month) of the first insemination rather than the standard lactation milk yield of the cows.

The first insemination success of approximately 44% cows observed in the present study is consistent with the figures obtained by other authors [Ferguson and Skidmore 2013, Ghiasi *et al*. 2015]. Miller *et al.* [2001] reported age/number of calvings as a factor significantly ($P \le 0.01$) affecting the non-return rate. König *et al.* [2006] concluded that conception at the first insemination is less likely in primiparous rather than for multiparous cows, due to the energy balance which is more difficult to maintain. In turn, Miller *et al*. [2001] noted insemination success to decrease with the increasing number of calvings, attributing it to the milk yield that increases with age.

Our findings, which show that first insemination success decreases with an increasing daily milk yield, support the widespread opinion on the declining fertility of high-yielding cows [Piccardi *et al.* 2013, Smith et al. 2014]. A factor predisposing high-producing cows to reduced fertility is their increased ability to mobilise energy reserves, mainly from the adipose tissue [Bisinotto et al. 2012; Roy *et al.* 2011, Strucken *et al.* 2012], but in some cases also from the muscle tissue [Strucken et al. 2012] as well as the increased utilisation of amino acids, minerals and vitamins [Bisinotto *et al*. 2012] during the critical, initial period of lactation. The excessive emaciation of animals may result in metabolic changes that lead to a deterioration in reproductive parameters, resulting from functional changes in the reproductive system and reflected in lower conception rates and an increased likelihood of pregnancy loss [Green *et al.* 2012, Stratman *et al.* 2016]. Řehák *et al*. [2009] observed first insemination success to fall by as much as 10% when comparing cows producing 29.5-37.2 kg/day with those yielding more than 37.2 kg FPCM (fat-protein corrected milk).

The very low (26.9%) first insemination success in the cows with a daily milk yield >40 kg coming from herds producing ≤7000 kg of milk may be due to a weak adaptation of these herds to the high production potential and high nutrient requirements of these cows, which are difficult to meet. The supplied nutrients are used first for maintenance and production of milk [Drackley and Cardoso 2014, Zebeli *et al*. 2015].

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A lower number of cows per herd had a favourable effect on first insemination success (Tab. 1). The first insemination success in very small herds (≤20 cows) and small herds (21-50 cows) was higher when compared to large herds (50-200 cows) and very large herds (>200 cows). With the increase in the number of cows per herd from ≤20 to >200, success of first insemination was decreased by 7%. El-Tarabany and El-Tarabany [2015] demonstrated that keeping a large number of animals under one roof may adversely affect climatic conditions inside buildings. Particularly during periods of high temperatures and when animal cooling systems are not sufficiently efficient, this may lead to poorer reproductive performance.

The analysis of a simple model of the decision tree for first insemination success made it possible to evaluate both the effect of daily milk yield and factors such as lactation period during first insemination, herd size, daily milk yield, age of cows These results agree with those reported by Řehák *et al*. [2009], who showed that in terms of first insemination success, it is more favourable (by 10%) to perform the first insemination at least two months after calving when the milk yield of the cows is below 37.2 kg of FPCM.

Ferguson and Skidmore [2013], based on studies conducted in best American herds in terms of fertility, showed that reproductive performance depends on many factors linked with reproductive management; however, they underlined that postponing the first insemination may prove beneficial for the breeders.

Based on the analysis of classification trees, Caraviello *et al*. [2006] showed that the factors associated with the living environment (type of floor in the barn) and herd management (hoof trimming, insemination method, duration of the voluntary waiting period) are crucial to the first insemination success. In turn, Ghiasi *et al*. [2015] demonstrated that first insemination success depends more on such factors as age of cows (number of calvings), age at calving, herd from which the animal originated, year of calving, and season (month) of first insemination rather than on the standard lactation milk yield of the cows.

The criteria calculated for the quality of models based on the classification tree technique as well as chi^2 showed that similar factors were responsible for the insemination success in cows (lactation period, number of cows per herd, age of cows, herd production level). At the same time, the applied methods confirmed that the determinants of fertility in cows are highly complex. This complexity may be well explained using the classification tree technique.

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