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The importance of hoof health in dairy production

Lenka Krpálková[1,2], Victor E. Cabrera[3], Ludmila Zavadilová[4], Miloslava Štípková[1]*

[1]*Department of Cattle Breeding, Institute of Animal Science, Prague-Uhříněves, Czech Republic*
[2]*Department of Agricultural and Manufacturing Engineering, School of Science Technology Engineering and Maths, Institute of Technology Tralee, Clash, Tralee, Co. Kerry, Ireland*
[3]*Department of Dairy Science, University of Wisconsin, Madison, USA*
[4]*Department of Genetics and Breeding of Farm Animals, Institute of Animal Science, Prague Uhříněves, Czech Republic*

**Corresponding author: lenka.krpalkova@centrum.cz*

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Abstract: The objective of this study was to evaluate the association of hoof health on reproduction and production performance, somatic cell count, and longevity in dairy cattle. The data set consisted of records from 19 145 dairy cows at 11 dairy farms in the Czech Republic during years 1998 to 2016. Observations were grouped according to the number of hoof disease (HD) incidence. Each record included a binary variable indicating if HD was observed. The prevalence (% of all cows) observed with HD and its changes according to parity, milk yield, and calving interval were calculated. Great variability among farms was observed. HD detected in the first month of first lactation was associated with 1.5 kg/day lower milk yield and 58 000 cell/ml higher somatic cell count during first lactation. HD detected in the first month of second lactation was associated with 2.6 kg/day lower milk yield and 45 000 cell/ml higher somatic cell count during second lactation. Results from completed lactations showed that observed HD was associated with significantly lower milk yield: 124 kg less during first lactation and 308 kg less during second lactation. Reproductive performance was the poorest in the group with the highest number of HD observations (frequency) within a single lactation (≥ 4). The higher the number of HD frequency per lactation, the greater was the negative association on production and reproductive performance.

Keywords: disease; prevention; reproduction; trimming

Foot health and lameness are major issues in dairy cattle that can cause tremendous economic losses. Prevention, early detection, and prompt treatment can minimize losses, improve recovery, and reduce animal suffering (Osorio 2016). The behaviour of lame cows or cows with foot pathologies as compared to healthy, non-lame cows, has been characterized by longer lying bouts and more total time spent lying (Ito et al. 2010), shorter stride and slower walking speed (Chapinal et al. 2013), lower bite rate while grazing (Walker et al. 2008), and shorter feeding time or faster eating (Norring et al. 2014). Economic losses due to lameness are mostly due to the health issues *per se*, not the treatment costs (Bruijnis et al. 2010). Losses are often subtle. Depending on severity, the following losses components can be identified: body weight loss (Neveux et al. 2016), decreased milk production (Green et al. 2002; Huxley 2013), decreased dry matter intake (Charfeddine and Perez-Cabal 2017), decreased herd longevity (Randall et al. 2016), and impaired reproductive efficiency (Bruijnis et al. 2010). Studies have shown that lame cows are less willing to visit the milking

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units where automatic milking systems are used (Buch et al. 2011). This results in fewer milkings per day, which not only leads to decreased milk yield but may also increase mastitis risk (Adams et al. 2017). Moreover, when cows do not go to the milking unit voluntarily, labour is increased because workers must fetch such cows and bring them to the unit (Borderas et al. 2004). The highest costs classified by cost factor are those due to milk production losses and culling (Ettema and Soren 2006; Bruijnis et al. 2010).

Increasing dairy farmers' awareness regarding foot health and following best practices could reduce the economic consequences while simultaneously could improve animal welfare (Bruijnis et al. 2010). Regular hoof care (hoof trimming, disinfection) may increase the chances of good hoof health, but improper use of footbaths can potentially even do more damage than good (Holzhauer et al. 2008). Ensuring clean and dry conditions underfoot is a major protective factor, reducing lameness due to foul-in-the-foot, interdigital growths, and digital dermatitis while improving claw and heel horn quality and health (Cramer et al. 2009). Correctly trimming a cow's feet can give the claw stability and enable the cow to distribute weight equally across the claw (Adams et al. 2017). Manske et al. (2002) state that at least two claw trimmings per year are necessary, but the optimal frequency of trimming is likely to be determined by factors specific to each farm and animal.

Several areas of dairy farm management relate to bovine lameness. These include nutrition, feeding management, animal behaviour, stress, cow comfort (flooring surfaces etc.), and frequency of hoof trimming (Huxley 2013). Even though nutrition is often cited as the main cause, lameness is a multifactorial problem and all relevant areas should be evaluated (Adams et al. 2017). Hoof quality is even influenced by genetics (type traits of feed and legs) (Novotny et al. 2017). The aim of this study was to evaluate how hoof health affects reproduction, production parameters, somatic cell count (SCC), and longevity in dairy cattle.

MATERIAL AND METHODS

Farms. The data set for this study consisted of herd records from 19 145 dairy cows from 11 dairy farms in the Czech Republic during years 1998–2016. All cows were kept in free-stall barns. Cows were loose-housed indoors the whole year round on all farms. Six farms were equipped with individual lying boxes and used straw bedding in the boxes, five farms were equipped with rubber mats. In all farms there was concrete flooring in the walkways and feeding area. Four farms were equipped with autotandem milking parlour, 3 with carousel parlour, while five had a fishbone type of milking parlour. Frequency of milking was two times per day in all farms. Nine farms divided animals into 3 groups: Fresh cows, Mature lactating cows and Dry cows, and the remaining two farms managed also the fourth group: First lactation heifers in last few years. Three farms had two dry cows groups (Far-off dry cows, Close-up dry cows). Primiparous and multiparous cows were fed total mixed ration (TMR) diets of forage and grain. Composition of diets differed depending on the region, breed, management, and use of feeding company services. Farm records of hoof health, reproductive performance, and production traits were collected monthly via the milk recording system (ICAR 2017).

Data. Lifetime production was calculated as the aggregated lifetime mean production per lactation (milk yield, percentage of protein and fat in milk). Animals were not of the same age at the start of data collection, and therefore the data set was unbalanced. Number of parity ranged from 1 to 8. Records of individual milk production in lactations lasting 250 days or longer were included into the analysis due to comparison of milk production. Number of removed cows from calculation was 3062 cows with mean of days in milk 132 ± 72 days and average milk production 3300 ± 2100 kg. Level of reproduction was evaluated using subsequent indicators: time at first service (days), services per conception (count of service) and days open (days). Mentioned indicators were routinely recorded during the whole period of research.

The basic characteristics of the variables in the data sets, including the numbers of animals with data in each lactation, are presented in Tables 1–3.

Dairy herd managers merely report whether or not a given animal is or is not affected by such a condition during a given month at the time the milk production is recorded and sampled. Thus, the term might represent any infectious or noninfectious disease of the foot or an injury. Types of hoof diseases (HD) were not distinguished. If HD was continuing from one month to the next, multiple occurrences for a given animal were reported.

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Table 1. Association between the incidence number of hoof disease (HD) during lifetime (all lactations) and production and reproduction parameters

Item	Number of HD observations in lifetime					Mean ± SD
	0	1	2	3	≥ 4	
Observations n	8 339	11 204	4 747	1 935	1 025	
Milk yield (LP) (kg)	8 221 ± 102^{ab}	8 143 ± 99^{c}	8 188 ± 102^{abc}	8 195 ± 107^{abc}	8 264 ± 114^{ab}	9 285 ± 2 206
Protein (LP) (%)	3.33 ± 0.01^{a}	3.32 ± 0.01^{b}	3.31 ± 0.01^{cd}	3.30 ± 0.01^{cd}	3.28 ± 0.01^{e}	3.31 ± 0.24
Fat (LP) (%)	4.05 ± 0.02^{c}	4.04 ± 0.02^{d}	4.04 ± 0.02^{d}	4.06 ± 0.03^{abc}	4.09 ± 0.03^{a}	3.85 ± 0.49
Time at first service (days)	83.76 ± 2.70^{c}	84.86 ± 2.64^{c}	89.33 ± 2.71^{b}	92.39 ± 2.82^{a}	95.18 ± 2.98^{a}	80.94 ± 42.43
Services per conception	2.30 ± 0.11^{c}	2.29 ± 0.11^{c}	2.39 ± 0.11^{b}	2.54 ± 0.12^{a}	2.54 ± 0.12^{a}	2.47 ± 1.73
Days open (days)	144.27 ± 5.66^{c}	145.10 ± 5.55^{c}	155.63 ± 5.68^{b}	167.81 ± 5.92^{a}	174.69 ± 6.26^{a}	144.18 ± 88.69
CI (days)	417.07 ± 5.25^{c}	418.10 ± 5.10^{b}	430.66 ± 5.25^{b}	442.56 ± 5.54^{a}	446.85 ± 5.99^{a}	416.23 ± 83.35
Age at first calving (days)	798.76 ± 4.39^{c}	802.01 ± 4.26^{b}	804.54 ± 4.38^{ab}	806.36 ± 4.60^{a}	803.51 ± 4.92^{ab}	799.80 ± 87.60
Age at culling (days)	2 936 ± 29^{a}	2 891 ± 28^{bc}	2 884 ± 29^{bc}	2 853 ± 30^{d}	2 847 ± 32^{d}	2 209 ± 672
Cows (% of total)	30.6	41.1	17.4	7.1	3.8	–

CI = calving interval, LP = lifetime mean production per lactation, SD = standard deviation
within a row, mean values and SD related to the same independent variable marked with different superscripts differ significantly ($P < 0.05$)

Statistical analysis. Cow records were divided within the data set according to the lifetime number of HD observations (i.e., 0, 1, 2, 3, ≥ 4 per lifetime) (Table 1). Then, records were divided into 4 main groups for the calculation of the influence of HD on selected parameters – all 4 groups were subdivided into 2 groups (healthy cows and cows with HD; Table 2) as follows: group 1 – all cows in first lactation, group 2 – all cows in second lactation, group 3 – all cows with HD observed in first lactation, and group 4 – all cows with HD observed in second lactation (Table 2). In order to evaluate recurrence of HD in second and third lactations, groups 3 and 4 from Table 2 were further subdivided. Group 3 within Table 2 was subdivided as follows: subgroup 5 – HD not observed in second lactation (S5SecondL.healthy), subgroup 6 – HD observed in second lactation (S6SecondL.disease). The sum of animals in subgroups 5 and 6 does not equal the total number of animals in subgroup 2 due to culling of animals for various reasons during lactation 2. Group 4 within Table 2 also was subdivided to create two more subgroups: subgroup 7 – HD not observed in third lactation (S7ThirdL.healthy) and subgroup 8 – HD observed in third lactation (S8ThirdL.disease). The sum of animals in subgroups 7 and 8 does not equal the total number of animals in subgroup 4 due to culling of animals for various reasons during lactation 3. Finally, to evaluate the month of lactation at which HD occurred, cows were divided in Table 3 as follows: groups 1 and 3 – HD not observed in first and second month of lactation, respectively; and groups 2 and 4 – HD observed in first and second month of lactation, respectively.

The MIXED procedure of SAS software (Version 9.2, 2008) was used with the model described in Equation 1, which determines the impact of hoof health on reproduction and production traits during lactations. Tukey's range test was used for comparison of means (Verbeke et al. 2000). The equation included the fixed effects and individuals were considered as random (Z_l).

$$y_{ijklmno} = \mu + H_i + Y_j + S_k + Z_l + A_m + B_n + b(Age_{ijklmn} - Age_{00000}) + e_{ijklmno} \quad (1)$$

where:

$y_{ijklmno}$ = value of dependent variable (listed in Tables 1–3)
μ = overall mean
H_i = effect of the i^{th} herd
Y_j = effect of the j^{th} year of calving (j = years 1998–2017)
S_k = effect of the k^{th} season of calving (k = spring, summer, autumn, winter)
A_m = explanatory variables (effect of the m^{th} category of hoof disease observations, listed in Tables 1–3)
B_n = effect of the n^{th} sire's breed (Holstein = 14 636, Czech Fleckvieh = 3544, Red Holstein = 965)
b = vector of regression coefficients of age at first calving (AFC)
Age_{ijklm} = AFC in days
Age_{00000} = overall mean for AFC
e_{ijklmn} = random error

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Table 2. Effect of incidence of hoof diseases (HD) on production parameters in 1st and 2nd lactation and incidence of HD in subsequent lactations (2nd and 3rd) if detected in previous lactation

	Group 1				Group 2		
HD incidence	NO – subgroup 1	YES – subgroup 2		HD incidence	NO – subgroup 3	YES – subgroup 4	
Code in text	S1allFirstL.healthy	S2allFirstL.disease	Mean ± SD	code in text	S3allSecondL.healthy	S4allSecondL.disease	Mean ± SD
n (cows)	3700	6099		*n* (cows)	2451	4994	
1st Lactation				**2nd lactation**			
Milk yield (kg/lactation)	7575 ± 111	7595 ± 106	8459 ± 1917	milk yield (kg/lactation)	8905 ± 134	8879 ± 125	9834 ± 2218
Protein (%)	3.34 ± 0.01	3.34 ± 0.01	3.34 ± 0.24	protein (%)	3.40 ± 0.01^{a}	3.37 ± 0.01^{b}	3.32 ± 0.24
Fat (%)	4.07 ± 0.03	4.06 ± 0.03	3.87 ± 0.48	fat (%)	3.99 ± 0.03^{a}	3.96 ± 0.03^{b}	3.83 ± 0.50
SCC (× 1000 cell/ml)	106.52 ± 15.07^{b}	117.43 ± 14.31^{a}	145.93 ± 228.57	SCC (× 1000 cell/ml)	134.06 ± 20.53^{b}	158.01 ± 19.18^{a}	203.02 ± 301.41
CI (days)	419.70 ± 4.46^{b}	427.97 ± 3.90^{b}	411.74 ± 89.68	CI (days)	410.91 ± 5.81^{b}	418.08 ± 5.38^{a}	417.83 ± 79.30
Age at first calving (days)	781.46 ± 5.39^{b}	786.45 ± 5.12^{a}	797.51 ± 88.06	age at first calving (days)	796.57 ± 5.40^{b}	803.36 ± 5.05^{a}	798.66 ± 87.71
Age at culling (days)	1832 ± 38^{a}	1780 ± 36^{b}	1857 ± 586	age at culling (days)	2092 ± 37^{a}	2049 ± 34^{b}	2104 ± 536
Trimming (frequency)	0.75 ± 0.04^{a}	0.14 ± 0.04^{b}	1.07 ± 1.05	trimming (frequency)	0.07 ± 0.04^{a}	0.09 ± 0.04^{b}	1.03 ± 1.02
	Group 3				Group 4		
HD incidence in previous 1st lactation: YES				HD incidence in previous 2nd lactation: YES			
HD incidence	NO – subgroup 5	YES – subgroup 6		HD incidence	NO – subgroup 7	YES – subgroup 8	
Code in text	S5SecondL.healthy	S6SecondL.disease	mean ± SD	code in text	S7ThirdL.healthy	S8ThirdL.disease	mean ± SD
n (cows)	783	2142		*n* (cows)	1286	3698	
2nd Lactation				**3rd lactation**			
Milk yield (kg/lactation)	9124 ± 115	9064 ± 106	9834 ± 2218	milk yield (kg/lactation)	8952 ± 149	8888 ± 134	9896 ± 2247
Protein (%)	3.39 ± 0.01^{a}	3.35 ± 0.01^{b}	3.32 ± 0.24	protein (%)	3.35 ± 0.01^{a}	3.33 ± 0.01^{b}	3.28 ± 0.24
Fat (%)	3.94 ± 0.02^{a}	3.88 ± 0.02^{b}	3.83 ± 0.50	fat (%)	3.96 ± 0.03	3.95 ± 0.03	3.85 ± 0.50
SCC (× 1000 cell/ml)	150.58 ± 19.47^{b}	187.83 ± 14.44^{a}	203.02 ± 301.41	SCC (× 1000 cell/ml)	201.69 ± 27.64^{b}	225.87 ± 24.75^{a}	261.45 ± 376.16
CI (days)	403.24 ± 5.29	407.78 ± 4.02	417.83 ± 79.30	CI (days)	405.92 ± 5.08^{b}	415.61 ± 4.08^{a}	421.06 ± 78.34
Age at first calving (days)	792.65 ± 4.79^{b}	804.22 ± 3.55^{a}	798.66 ± 87.71	age at first calving (days)	816.71 ± 5.90	820.29 ± 5.28	801.11 ± 87.38
Age at culling (days)	2086 ± 49^{a}	2041 ± 44^{b}	2104 ± 536	age at culling (days)	2455 ± 39^{a}	2399 ± 35^{b}	2404 ± 490
Trimming (frequency)	0.86 ± 0.04^{a}	0.11 ± 0.03^{b}	1.03 ± 1.02	trimming (frequency)	0.89 ± 0.05^{a}	0.10 ± 0.04^{b}	0.87 ± 0.99

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Explanation to Table 2
CI = calving interval, SCC = somatic cell count, SD = standard deviation
Group 1 = all cows in 1st lactations: subgroup 1 = HD not observed in 1st lactation (S1allFirstL.healthy), subgroup 2 = HD observed in 1st lactation (S2allFirstL.disease); Group 2 = all cows in 2nd lactations: subgroup 3 = HD not observed in 2nd lactation (S3allSecondL.healthy), subgroup 4 = HD observed in 2nd lactation (S4allSecondL.disease); Group 3 = all cows with HD observed in 1st lactation: subgroup 5 = HD not observed in 2nd lactation (S5SecondL.healthy), subgroup 6 = HD observed in 2nd lactation (S6SecondL.disease). The sum of animals in subgroups 5 and 6 does not equal the total number of animals in subgroup 2 due to culling of animals for various reasons during 2nd lactation; Group 4 = all cows with HD observed in 2nd lactation: subgroup 7 = HD not observed in 3rd lactation (S7ThirdL.healthy), subgroup 8 = HD observed in 3rd lactation (S8ThirdL.disease). The sum of animals in subgroups 7 and 8 does not equal the total number of animals in subgroup 4 due to culling of animals for various reasons during 3rd lactation
^{a,b}within a row, mean values and SD related to the same independent variable marked with different superscripts differ significantly ($P < 0.05$)

The differences between the estimated variables were tested at significance level $P < 0.05$.

RESULTS AND DISCUSSION

Prevalence of hoof disease on dairy farms. Hoof disorders constitute an important problem for intensive dairy operations all over the world (Chapinal et al. 2013). This might be due to loss of natural environment and increased use of modern housing systems with hard flooring surfaces, which facilitate increased spread of contagious diseases as well as greater hoof wear and exposure to wet manure (Cramer et al. 2009). Prevalence (% of cows) and frequency of HD incidence grew with parity (Figure 1) and length of calving interval (CI) (Figure 2). The group of cows with the highest milk yield (> 11 000 kg/cow per year) showed the lowest percentage of cows with HD (61.1%) but the highest frequency of HD observations per animal (1.75; Figure 2). Other initial analysis showed that if HD was observed once in a given Holstein, however, it was more likely to be detected again in that animal than would have been the case for animals in other breeds (i.e., frequency was on average 1.7 in Holsteins compared to 1.4 or less in other evaluated breeds). Cramer et al. (2009) reported that HDs are most prevalent when the feet of cattle are continuously bathed in slurry and they are most common during wet months. Therefore, farmers must heighten their attention to this situation during winter. Across all 11 evaluated dairy farms, the highest percentage and frequency of HD occurred during autumn and winter, which are colder and rainier (Figure 1). Regarding AFC, the lowest HD prevalence and frequency of observation occurred in the middle group calving between days 700–749 (approximately at 23–25 months) (Figure 1). The trend towards selecting larger and higher-producing cows might also contribute to these problems (Cramer et al. 2009). In a study by Krpalkova et al. (2016), however, the effect of herd size *per se* was not associated with the occurrence of hoof disorders. More important were housing conditions and preventive management. In the present study, farm number 4 (Figure 1) had one of the largest dairy herds (5672 cows evaluated in total) and the HD incidence in that herd was less than 50%, the lowest of all studied farms.

A good hoof trimming program is of major importance in preventing hoof disorders (Holzhauer et al. 2008). According to Adams et al. (2017), high-producing dairy cows have faster growth of the hoof horn (due to better nutrition) and greater susceptibility to diseases. At the same time, high-quality herds often are better managed in terms of work organization. Moreover, more frequent hoof checks and subsequent trimming as needed reveals more diseases while they are in an early stage, still easy to treat. While we found that most HD was observed in the first, second, and fifth months of lactation, the percentage of dairy cows having their hooves trimmed was the highest in the 1st, 5th, and 11th months of lactation. It seems probable that more HD was detected due to the higher percentages of cows having their feet trimmed in the 1st and 5th months of lactation (Figure 3). Furthermore, as is evident from Figure 3, the older the cow (higher number of parity), the greater was the incidence of HD. Figure 4 corroborates the fact that various diseases are often interrelated (e.g.,

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Table 3. Associations between the occurrence of hoof disease (HD) in the first 2 months of 1st and 2nd lactations on production and reproduction parameters

Stage of lactation	1st Month (1–30 days)		Stage of lactation	2nd Month (31–60 days)		
HD incidence	NO – group 1	YES – group 2	HD incidence	NO – group 3	YES – group 4	Mean ± SD
n (cows)	18 461	3 706	*n* (cows)	20 006	2 161	
1st Lactation (1–30 days)			**1st lactation** (31–60 days)			
Milk yield (kg/day)	25.80 ± 0.32^{a}	24.32 ± 0.38^{b}	milk yield (kg/day)	27.68 ± 0.37^{a}	27.14 ± 0.43^{b}	27.95 ± 6.45
Protein (%)	3.24 ± 0.03	3.20 ± 0.04	protein (%)	3.12 ± 0.02^{a}	3.07 ± 0.02^{b}	3.12 ± 0.56
Fat (%)	4.27 ± 0.06^{b}	4.36 ± 0.07^{a}	fat (%)	3.97 ± 0.04^{b}	4.06 ± 0.05^{a}	4.07 ± 1.00
SCC (× 1000 cell/ml)	196.25 ± 34.54^{b}	254.20 ± 41.01^{a}	SCC (× 1000 cell/ml)	130.85 ± 34.34	145.85 ± 39.72	241.23 ± 683.62
2nd Lactation (1–30 days)			**2nd lactation** (31–60 days)			
Milk yield (kg/day)	36.38 ± 0.69^{a}	33.76 ± 0.73^{b}	milk yield (kg/day)	36.07 ± 0.42^{a}	34.59 ± 0.52^{b}	40.56 ± 8.37
Protein (%)	3.28 ± 0.05^{a}	3.22 ± 0.06^{b}	protein (%)	3.17 ± 0.05^{a}	3.13 ± 0.02^{b}	3.06 ± 0.37
Fat (%)	4.18 ± 0.09^{b}	4.30 ± 0.10^{a}	fat (%)	3.78 ± 0.04^{b}	3.87 ± 0.05^{a}	3.68 ± 0.80
SCC (× 1000 cell/ml)	232.24 ± 61.40^{b}	276.97 ± 65.04^{a}	SCC (× 1000 cell/ml)	250.22 ± 40.11	267.28 ± 49.69	267.83 ± 717.91
1st Completed lactation			**1st completed lactation**			
Milk yield (kg/day)	7 612 ± 106^{a}	7 488 ± 113^{b}	milk yield (1st lactation) (kg)	7 588 ± 106^{a}	7 631 ± 117^{b}	8 459 ± 1 917
Protein (%)	3.34 ± 0.01	3.34 ± 0.01	protein (1st lactation) (%)	3.34 ± 0.01	3.33 ± 0.01	3.34 ± 0.24
Fat (%)	4.06 ± 0.03	4.05 ± 0.03	fat (1st lactation) (%)	4.06 ± 0.03	4.06 ± 0.03	3.87 ± 0.48
SCC (× 1000 cell/ml)	113.38 ± 14.32^{b}	130.88 ± 15.23^{a}	SCC (× 1000 cell/ml)	116.74 ± 14.32	110.01 ± 15.84	145.93 ± 228.57
2nd Completed lactation			**2nd completed lactation**			
Milk yield (2nd lactation) (kg)	8 929 ± 125^{a}	8 621 ± 135^{b}	milk yield (2nd lactation) (kg)	8 906 ± 125^{a}	8 686 ± 141^{b}	9 834 ± 2 218
Protein (2nd lactation) (%)	3.37 ± 0.01	3.37 ± 0.01	protein (2nd lactation) (%)	3.37 ± 0.01	3.36 ± 0.02	3.32 ± 0.24
Fat (2nd lactation) (%)	3.97 ± 0.03	3.95 ± 0.03	fat (2nd lactation) (%)	3.96 ± 0.03	3.99 ± 0.03	3.83 ± 0.50
SCC (× 1000 cell/ml)	153.93 ± 19.23	164.18 ± 20.73	SCC (× 1000 cell/ml)	154.02 ± 19.22	167.21 ± 21.74	203.02 ± 301.41
CI (1st lactation) (days)	426.98 ± 3.92	425.32 ± 4.61	CI (1st lactation) (days)	426.33 ± 3.91	429.56 ± 5.07	411.74 ± 89.68
CI (2nd lactation) (days)	416.92 ± 5.40	418.49 ± 5.93	CI (2nd lactation) (days)	417.28 ± 5.41	416.56 ± 6.20	417.83 ± 79.30
AFC (1st lactation) (days)	785.38 ± 14.88	791.64 ± 9.10	AFC (1st lactation) (days)	784.99 ± 5.12^{b}	792.44 ± 5.66^{a}	797.51 ± 88.06
AFC (2nd lactation) (days)	802.44 ± 5.06	803.86 ± 5.45	AFC (2nd lactation) (days)	802.09 ± 5.05	807.02 ± 5.72	798.66 ± 87.71
Age at culling (1st lactation) (days)	1 792 ± 36^{a}	1 760 ± 39^{b}	age at culling (1st lactation) (days)	1 788 ± 36	1 775 ± 40	1 857 ± 586
Age at culling (2nd lactation) (days)	2 061 ± 34^{a}	2 006 ± 37^{b}	age at culling (2nd lactation) (days)	2 057 ± 34	2 029 ± 39	2 104 ± 536

AFC = age at first calving, CI = calving interval, SCC = somatic cell count, SD = standard deviation

groups 1 and 3 = HD not observed in 1st and 2nd month of lactation, groups 2 and 4 = HD observed in 1st and 2nd month of lactation; within a row, mean values and SD related to the same independent variable with different superscripts differ significantly ($P < 0.05$)

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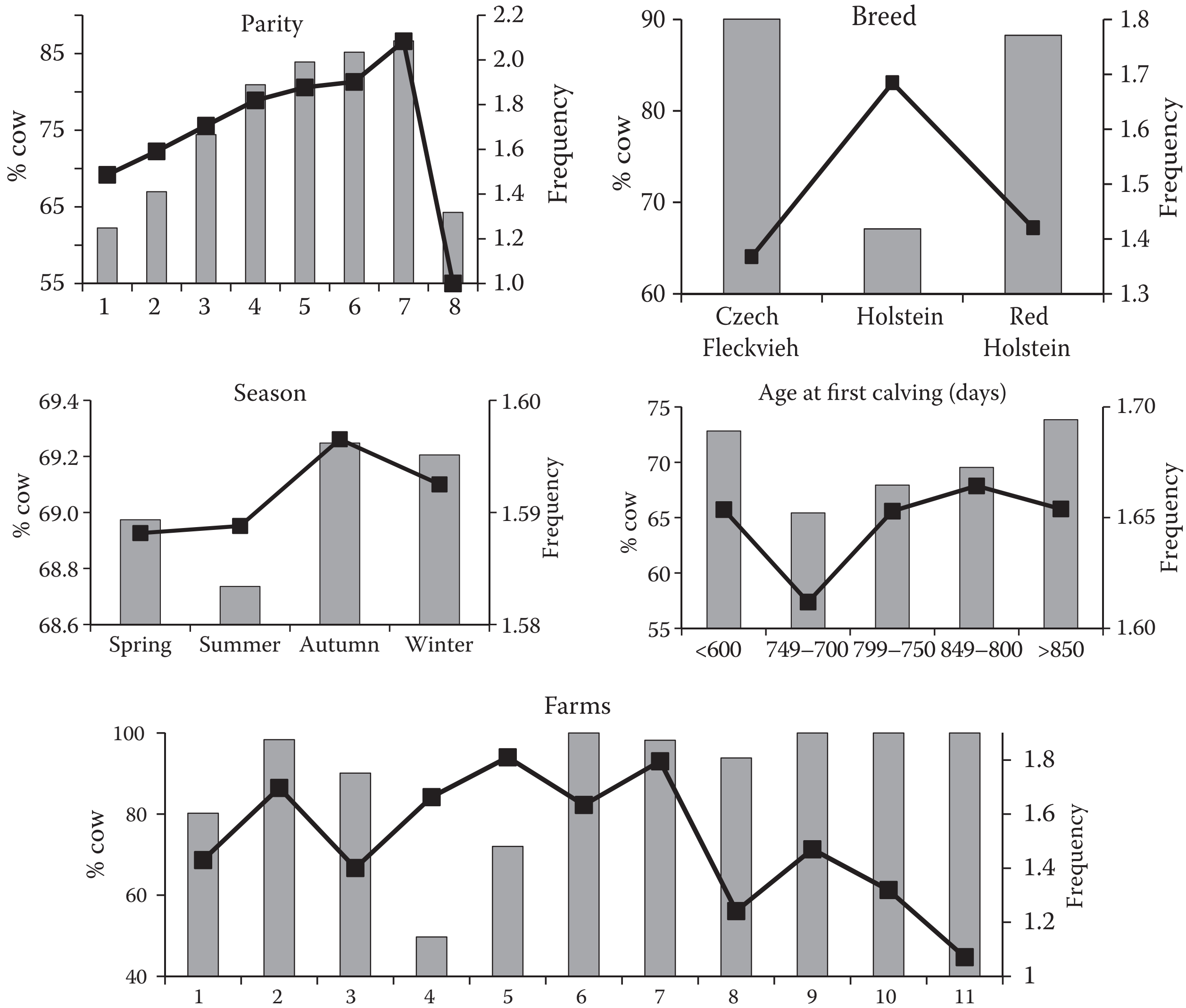

Figure 1. Prevalence of hoof disease observations according to parity, breed, season, age at first calving and farms (1998–2016, 11 farms), bars illustrate percentages and lines illustrate frequency

% cow = percentage of cows in dairy herd with observed hoof disease according to parity, breed, season, age at first calving (days) and farms, frequency = average number of hoof disease observations according to parity, breed, season, age at first calving (days) and farms

HD and mammary gland disease). SCC increased with cow age (lactation number). The fat content in milk decreased below 3.5% approximately at days 120–150 of lactation. The main trimming (preventive treatment) of hooves should be performed during the days open and in the period of 100–130 days of lactation. Problematic cows (detected HD, movement disorders) should be checked every 60 to 90 days (Chapinal et al. 2013). Although most authors agree that dairy herds need at least 2 claw trimmings per year (Ettema and Soren 2006), the optimal frequency of claw trimming is likely to be determined by factors specific to each farm and each animal (Manske et al. 2002).

Association of the number of HD during lactations and production and reproduction parameters. Lameness in dairy cows has been demonstrated to be associated with significant impacts on performance, such as reduced milk yield and increased culling risk (Green et al. 2002; Krpalkova et al. 2016). Examining the numbers of HD observations (Table 1), we found that the highest milk yields – 8221 kg and 8264 kg, respectively, were found in the group with no observed HD and in those with the highest number of HD observations (≥ 4). The highest protein content in milk was found in the group with no observed HD (3.33%; $P < 0.05$). Fat content exhibited the opposite relationship, being the highest (4.09%;

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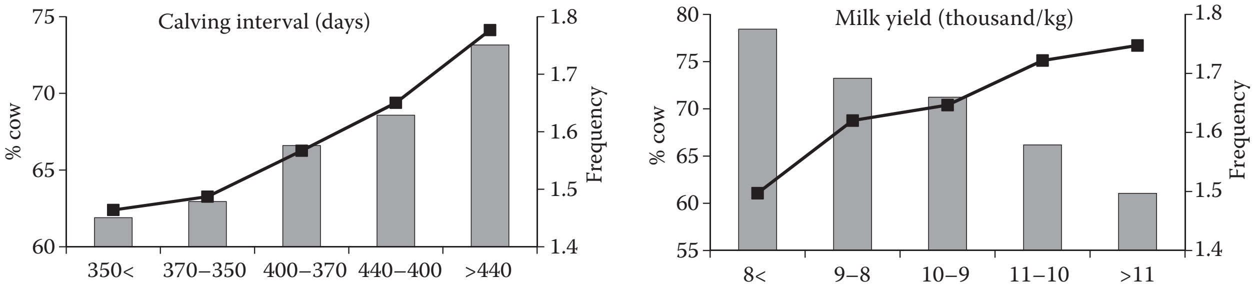

Figure 2. Prevalence of hoof disease observations according to annual milk yield and length of calving interval (1998–2016, 11 farms), bars illustrate percentages and lines illustrate frequency

% cow = percentage of cows in dairy herd with observed hoof disease according to calving interval (days) and milk yield (thousand/kg), frequency = average number of hoof disease observations according to calving interval (days) and milk yield (thousand/kg)

$P < 0.05$) in the group with the highest number of HD observations (≥ 4). The lowest age at culling was found in the group of cows with more than 3 HD observations per lactation (Table 1).

For first lactation, we observed that production parameters (milk yield, milk components) did not change significantly when HD was observed (Table 2). Mean SCC was, however, significantly higher in the group where HD was observed, and the same was true for length of AFC and CI (all $P < 0.05$). S5SecondL.healthy (subgroup 5, HD not observed) and S6SecondL.diseases (subgroup 6, HD observed) showed the impact of observed disease in first lactation on the subsequent lactation. The HD observed also in second lactation was associated with lower milk yield and lower content of milk components (although this was significant only for components and not milk yield). Mean SCC was significantly higher in the group with observed HD (S6SecondL.diseases) ($P < 0.05$). Trimming frequency in that same subgroup was found to be the lowest and was characterized by almost no trimming at all. A comparison of all cows in second lactation (Table 2, subgroups 3 (S3allcows.FirstL.healthy) and 4 (S4allcows.SecondL.healthy)) showed similar results to those for subgroups S5SecondL.healthy and 6 S6SecondL.diseases, but less statistically significant.

The mean parameters for cows with observed HD in second and also in third lactation (S8ThirdL.disease) were similar to those for S7ThirdL.healthy. Statistically significant differences between subgroup S8ThirdL.disease and S7ThirdL.healthy were observed for (lower) percentage of protein in milk, (higher) SCC, (longer) CI, (lower) trimming frequency, and (lower) age at culling ($P < 0.05$; Table 2).

Huxley (2013) summarized that milk losses attributed to sole ulcer and white line diseases were of 1.5 and 0.8 kg/day, respectively, resulting in total losses over the course of a lactation of 574 and 369 kg, respectively. A study by Green et al. (2002) indicated that the total loss in milk yield during a 305-day lactation was approximately 360 kg and the losses estimated 5 months before and after hoof problems were detected around 2 kg/day. Milk losses of 1.5–2.8 kg/day (Rajala-Schultz et al. 1999), 1.5 kg/day (Warnick et al. 2001), and 1.47–2.66 kg/day (Charfedine and Perez-Cabal 2017) have been observed within 2 weeks from determination of an HD diagnosis. Our study showed similar results (Table 3). The HD observed in the first month of first lactation was associated with 1.5 kg/day lower mean milk yield ($P < 0.05$) and 58 000 cell/ml higher mean SCC ($P < 0.05$). The same group 2 in lactation 1 also had higher mean fat in milk ($P < 0.05$). The occurrence of HD in second lactation within the first month of lactation resulted in more clear impacts, as it was associated with 2.6 kg/day lower mean milk yield ($P < 0.05$) and 45 000 cell/ml higher mean SCC ($P < 0.05$). Group 2 in lactation 2 also had higher mean percentage fat in milk ($P < 0.05$) and lower mean percentage protein ($P < 0.05$). Results from completed lactations for group 2 showed 124 kg lower milk yield ($P < 0.05$) in first lactation and 308 kg lower yield in second lactation ($P < 0.05$). Age at culling was also affected, and in group 2 it was significantly higher by 32 and 55 days in both first and second lactations, respectively ($P < 0.05$).

The second month of lactation showed similar results as did the first month, but the differences between groups were smaller. Observed HD (group 4)

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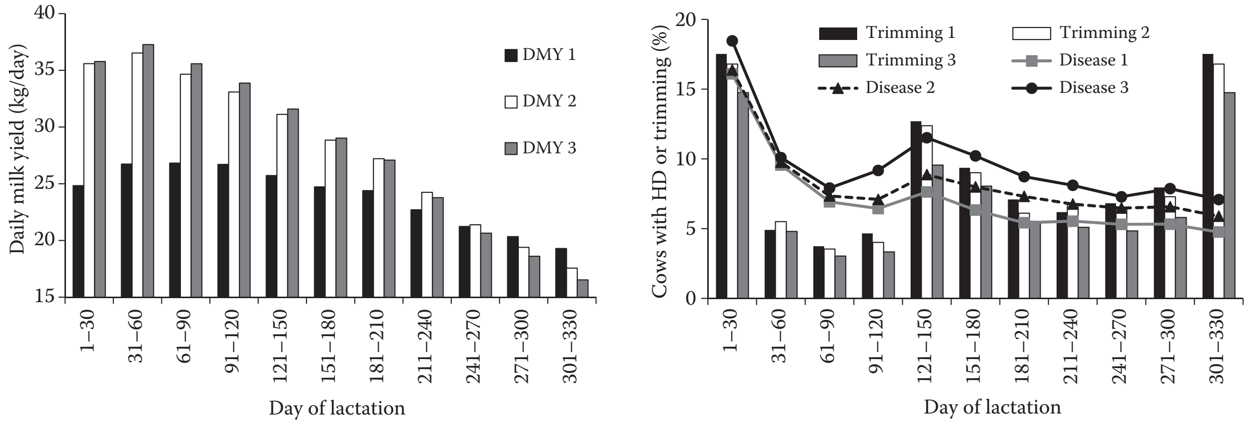

Figure 3. Milk yield (kg/day), hoof disease (HD) occurrences and trimming in the first 3 lactations according to days in milk (1998–2016, 11 farms)

DMY = daily milk yield in first three lactations (first part, bars), trimming = % of trimming in the first three lactations (second part, bars), disease = % of hoof disease incidence in the first three lactations (second part, lines)

in the second month was associated with 0.54 kg/day lower mean milk yield ($P < 0.05$) in first lactation and 1.5 kg/day lower milk yield ($P < 0.05$) in second lactation. For the completed lactations, this resulted in 43 kg lower mean production in first lactation ($P < 0.05$) and 220 kg lower production in second lactation ($P < 0.05$).

Green et al. (2002) and Borderas et al. (2004) also found a negative effect on milk quality in case of observed HD (higher SCC in milk). According to Warnick et al. (2001), cows with feet problems commonly may also have – at the same or at a later time – mastitis, reproduction or other health issues. Krpalkova et al. (2016) pointed out that high culling rate due to movement disorders reduces the culling for other reasons. Dairy cows leave the herd for a variety of reasons, which are very often manifested together.

Claw disorders also have adverse effects on fertility in dairy cows (Hultgren et al. 2004). Lame cows have longer intervals from calving to first service and from calving to conception (Hernandez et al. 2001) and thus require more inseminations to become pregnant (Buch et al. 2011). Melendez et al. (2003) reported that cows with claw problems showed lower first-service conception rates (17.5% vs 42.6% in control cows) and higher incidence of ovarian cysts. Our study showed similar results in

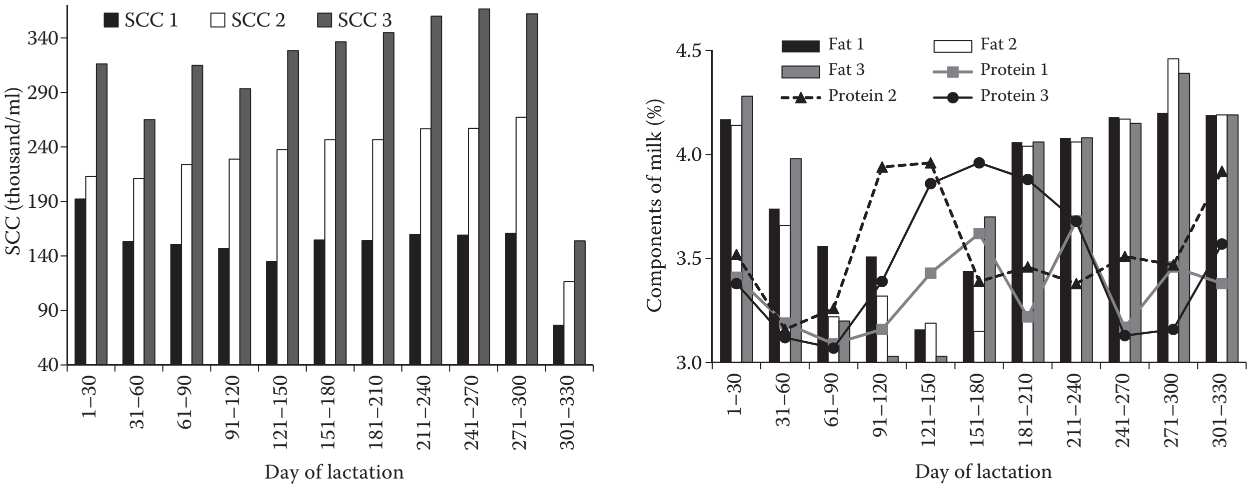

Figure 4. Somatic cell count during the first 3 lactations in relation to milk components according to days in milk (1998–2016, 11 farms)

SCC = somatic cell count (first part, bars) in 1st, 2nd and 3rd lactations, protein = % protein in milk (second part, lines) in 1st, 2nd and 3rd lactations, fat = % fat in milk (second part, bars) in 1st, 2nd and 3rd lactations

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association with reproduction parameters (Table 1). Reproduction parameters were poorest in the group with the highest number of HD observations (≥ 4). HD group (≥ 4) showed longer mean time from calving to first service (95 days vs 84 in HD group (0), $P < 0.05$), greater number of services per conception (95 days vs 84 in HD group (0), $P < 0.05$), longer days open (175 days vs 144 in HD group (0), $P < 0.05$) and longer CI (446 days vs 417 in HD group (0), $P < 0.05$). Age at first calving (Table 1) was the shortest in the group with no observed HD (group (0): 799 days; $P < 0.05$), and age at culling was the highest in the group with no observed HD (group (0): 2936 days; $P < 0.05$). The lowest HD prevalence and frequency were found in the middle group wherein AFC ranged from 23.0 to 24.5 months (Figure 1). According to Krpalkova et al. (2014), AFC under 24.5 months can lead to a decline in fertility and high per-cow depreciation costs. For other diseases, such as mastitis, it has been shown that disease occurring in primiparous affects lifetime performance. For example, an increase in somatic cell count in primiparous in early lactation negatively influences lifetime milk yield (Archer et al. 2013). This relationship may also exist for lameness, but this has not yet been fully studied (Randall et al. 2016). According to Wilhelm et al. (2017), the body condition before calving, as represented by backfat thickness and which is associated with the "fat pillow" in the hooves, plays an important role in noninfectious claw disorders. Changes in energy metabolism postpartum are associated with claw health, especially in the first 2 months of lactation. In our study, fat content in milk within the HD-observed group was significantly higher in the second month of first and second lactations (Table 3). The fat content in milk was growing from the sixth month (Figure 4), and the fifth month was the last with relatively heightened incidence of HD (Figure 3). The correlation coefficients for milk yield in the first, second, and third lactations and observed HD were −0.21, −0.17, and −0.15 ($P < 0.01$), respectively. Notable correlations were found between fat content in milk in the first, second, and third lactations and HD observation (0.15, 0.08, 0.07 ($P < 0.01$)). The correlation coefficients between HD observation and reproduction parameters were low, not exceeding 0.09. The correlation coefficients between SCC and incidence of HD in the first three lactations were very low ($P < 0.05$).

CONCLUSION

This study demonstrates that hoof disorders have an important association on production and reproductive performance in cows, confirming previous observations that HD reduces milk production, milk quality, and herd longevity while impairing reproductive efficiency. The percentage of cows observed with HD and its frequency per cow grow with parity, level of milk yield, and length of CI. This study demonstrates substantial variation among farms. The majority of HD were observed in autumn and winter and in the first, second, and fifth month of lactation. The numbers of these observations were influenced by the higher frequency of hoof trimming within this period. Greater number of HD observations within a single lactation (frequency) was associated with greater impairment of production and reproductive performance. This finding implies that farmers might underestimate the benefits of taking action earlier and that, if they were to do so in a timely and more thorough manner, they could reduce the economic consequences of HD while also improving animal welfare. A good program for hoof trimming including preventive measures is of major importance in preventing hoof disorders. Because HD encompasses traits with low heritability, good herd management and prevention are particularly important for reducing the percentage of animals culled as a consequence of HD.

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