Association Between Milk Urea Nitrogen and Fertility in Ohio Dairy Cows

**P. J. Rajala-Schultz, W. J. A. Saville, G. S. Frazer,
and T. E. Wittum**
Department of Veterinary Preventive Medicine,
College of Veterinary Medicine, The Ohio State University,
1900 Coffey Road, Columbus, OH 43210

ABSTRACT

The purpose of this study was to evaluate the association between milk urea nitrogen (MUN) and fertility of dairy cows using field data. The data came from 24 dairy herds belonging to Ohio Dairy Herd Improvement Cooperative Inc. Reproductive data and MUN measurements from cows that calved between June 1998 and May 1999 and that had been bred at least once were included in the study. Survival analysis, using the Cox proportional hazards model, was performed and days from calving to conception or to the end of the study was used as the outcome. Cows that had not been reported pregnant during the study were considered censored. The mean of monthly MUN values of cows before conception (or the end of the study for censored cows) was used to reflect the MUN status of a cow. Animals were categorized into quartiles based on MUN values in these data. Parity, calving season, peak milk yield, number of services, and herd were included in the models as fixed effects.

Cows with MUN levels below 10.0 were 2.4 times more likely and cows with MUN levels between 10.0 and 12.7 mg/dl were 1.4 times more likely to be confirmed pregnant than cows with MUN values above 15.4 mg/dl. Our results indicate that increasing MUN levels appear to be negatively related to dairy cow fertility and are associated with a lower risk of detectable pregnancy at herd checks. They also suggest that the levels of MUN that are adversely associated with fertility might be lower than reported earlier.

(**Key words:** milk urea nitrogen, dairy cows, fertility, survival analysis)

Abbreviation key: BUN = blood urea nitrogen, **MUN** = milk urea nitrogen, **RHA** = rolling herd average.

INTRODUCTION

Protein is an expensive ingredient of dairy cattle feeds and thus overfeeding of protein could be costly to producers. Also, several studies (Canfield et al., 1990; Ferguson and Chalupa, 1989; Sklan and Tinsky, 1993; Wenninger and Distl, 1994) have shown an association between protein nutrition and reproductive performance of dairy cows—feeding excess amounts of protein may be detrimental to the fertility of cows. However, there are other reports (Carroll et al., 1988; Howard et al., 1987) that found no association between the concentration of protein in the diet and reproductive traits.

Urea is an end product of protein metabolism. Excess dietary protein not needed by the cow usually is broken down into ammonia. Ammonia is toxic to animal tissues and therefore is rapidly converted into urea in the liver. This urea is then measurable in both the blood stream and milk. Milk urea levels are highly correlated with serum urea concentrations (Butler et al., 1996; Gustafsson and Palmqvist, 1993). Conversion of ammonia into urea requires energy, and it is protein-fermentable carbohydrate ratio in the rumen—not only the amount of CP ingested—that affects blood and milk urea nitrogen levels (Moore and Varga, 1996; Oltner et al. 1985).

Milk urea nitrogen (**MUN**) can be used as a tool to monitor protein feeding efficiency and dietary protein-energy ratio in dairy cows (Eicher et al., 1999; Hof et al., 1997; Moore and Varga, 1996; Refsdal et al., 1985; Roseler et al., 1993). Several DHIA offer MUN measurements as a service to their clients. When milk samples are taken as a part of regular DHIA testing, sampling involves no extra labor, and it is cheaper than sampling and analyzing blood. Results from MUN measurements can provide valuable information to farmers on the nutritional status and health of their cows.

The majority of studies relating MUN or blood urea nitrogen (**BUN**) levels to fertility of dairy cows have been experimental and have used relatively small

sample sizes (fewer than 100 to 200 animals). The purpose of this study was to use field data and the milk urea measurements from over 1200 cows to evaluate the association between MUN and fertility of dairy cows.

MATERIALS AND METHODS

Data

The data came from 24 Holstein herds belonging to the Ohio DHI Cooperative, Inc. The study population was selected to represent Ohio dairy herds with either high or low milk production. High producing herds were defined as herds with rolling herd average (**RHA**) milk production of greater than 10,433 kg (23,000 lbs). Low producing herds were defined as herds with RHA milk production of less than 7258 kg (16,000 lbs). A list of all dairy herds participating in the Ohio DHI that met the definitions of high or low production was obtained in the beginning of the study. Twelve high producing herds and 12 low producing herds were then randomly selected using a random numbers table. Attempts were made to contact the managers of these 24 dairy farms by phone. At the initial contact, the study was described and 12 mo of free MUN testing was offered in return for access to all DHI records for the farm during the period of the study. Alternate dairy farms, selected in the same manner as the original farms, were contacted when any of the original 24 farms refused to participate, or if contact could not be made following repeated attempts. All participants were provided summary information about MUN values and their interpretation at the beginning of the study.

The milk samples for urea measurements were collected by the DHI supervisors during their regular monthly farm visits from June 1998 to May of 1999. All samples in this study were taken during normal milking time, in some herds twice, but in some herds only once a day. If tested twice during a day, the samples were mixed together. Urea measurements were performed at the Ohio DHI laboratory spectrophotometrically by an automated procedure with a Skalar Segmented Flow Analyzer (Skalar Analytical B.V., De Breda, The Netherlands). Cows whose lactations started during the study period were initially included in the study (n = 1728). Information on the pregnancy status of the cows was also collected from the farms by the DHI supervisors, and days open was calculated. The conception date was recorded as the last breeding before pregnancy was confirmed. In the majority of cases, data on the number of times cows had been serviced had also been recorded. Data were checked for illogical values; for example, for some cows, pregnancy was recorded to have been confirmed within the first 2 wk after calving, but those were considered data entry errors. Consequently, all cows less than 35 DIM were considered to be open, and they were also recorded not to have been bred.

The mean of the monthly MUN levels for each cow before the conception date or the end of the study (in case a cow had not been confirmed pregnant) was used in the study. The cows were categorized into four quartiles based on the urea values in these data: less than 10.0, between 10.0 and 12.7, between 12.7 and 15.4, and greater or equal to 15.4 mg/dl. Thus, one fourth of the cows fell into each MUN category. The data were also analyzed separately for the high and low producing herds, using cutoff points for the MUN categories based on the data originating from the two production groups.

For the analysis, parity had three levels: 1, 2, and 3 or higher. Calving season had four classes: winter (December to February), spring (March to May), summer (June to August), and fall (September to November). For number of services, all cows that had been bred more than six times were recorded to have six services. The peak milk yield for each cow was also included in the models. Herd was included in all models as a fixed effect to account for the varying management and feeding regimens.

Statistical Analysis

Survival analysis, using the Cox proportional hazards model in SAS (SAS Institute Inc., 1994), was performed to study the association between MUN and fertility of dairy cows. The outcome variable was days from calving to conception, or to the end of the study, or to the last test day from which data were available for a cow. Only cows that had been bred at least once (n = 1249) were considered at risk for conception and pregnancy and were thus included in the analysis. If a cow was confirmed to be pregnant during the study period, she was coded to have experienced the event of interest (i.e., she had conceived and conception was assumed to have occurred at the last breeding). If a cow was not reported pregnant, she was considered censored. A cow could have been censored if she had been bred, but had not conceived or had suffered embryonic loss prior to confirmation of the pregnancy. If her pregnancy status was simply unknown at the end of the study period, she was also censored. Survival analysis allows the inclusion of data from cows that did not experience the event of interest during the study period (did not conceive or had not been reported pregnant), and thus the loss of information due to incomplete records can be minimized.

The Cox model is semiparametric; the effects of the covariates on the event times (in this study, time to conception or to the end of the study) are of parametric form, but the underlying survivor function (distribution of event times) need not to be specified. The proportional hazards model describes a hazard of some event (in this study, conception) for an individual i at any time t and it can be written as a product of two factors: a baseline hazard function $\lambda_0(t)$, that is left unspecified (except that it cannot be negative) and a linear function of a set of k fixed covariates $(x_1 - x_k)$, which is then exponentiated (Allison, 1995):

$$H_i(t) = \lambda_0(t) \exp \beta_1 x_{i1} + .. + \beta_k x_{ik}$$

The mean of monthly MUN values for each cow from calving up to the time of conception or to the end of the study was used in the modeling to reflect her MUN status during the study. Some cows had only one measurement, and the maximum number of MUN measurements for a cow during the study period was 12.

A full model with all the explanatory variables was fitted first, and the least significant variable was dropped based on the change in the –2 log likelihoods between a reduced and a full model so that all the variables in the model were significant at $P < 0.05$ level. However, even if only one level of an indicator variable for the categorical variables (MUN categories, parity, season of calving, herds) was significant, all of them were kept in the model. Models were run for the entire data, and also separately for data from the low producing and the high producing herds. After the final model was found, the fit of the model was checked by plotting the deviance residuals (Allison, 1995). Potential outliers were deleted and the analysis with the final model was performed again, with consequent examinations. Also, the assumption of proportional hazards for covariates included in the final model was checked by plotting the estimated survival functions for different strata of those variables. If the proportional hazards assumption holds for a covariate, the stratum-by-stratum plots should lie approximately parallel to one another when plotted on the same graph (Allison, 1995).

One of the assumptions associated with survival analysis is that censoring is noninformative, i.e., the censoring mechanism carries no prognostic information about the probability of experiencing the event (conception/confirmed pregnancy). However, there is no statistical test for informative versus noninformative censoring. Thus, to evaluate the validity of the assumption, sensitivity analysis was performed with the final model (Allison, 1995). First, all censored cows were assumed to be pregnant at the time of censoring,

Table 1. Descriptive statistics for the 24 study herds enrolled in Ohio DHIA.

	All herds	Low producing herds	High producing herds
No. of cows	1728	654	1074
Milk yield (kg), RHA[1]	8883	6850	10,916
Milk protein (kg), RHA	287	220	353
Milk fat (kg), RHA	327	257	399
MUN, mg/dl[2]	12.6	11.1	13.6

[1]Rolling herd average at the beginning of the study.

[2]Mean of monthly milk urea nitrogen values of individual cows for the period from calving to conception or the end of the study.

i.e., in this case no observations were censored (scenario 1). In the other scenario, all censored cases were assumed to have been censored at the longest time observed in these data (scenario 2).

RESULTS

The descriptive statistics for these data are presented in Table 1. The mean of RHA milk production in these data was 8883 kg (19,583 lbs), it was 10,916 kg (24,066 lbs) in the high producing herds and 6850 kg (15,101 lbs) in the low producing herds. The average herd size was 90 cows; the high producing herds had on average 112 cows, and the low producing herds had 69 cows. We had data from 1728 cows calving between June 1998 and May 1999 with information on their parity, calving dates, and monthly milk urea measurements. Of the study population, 1074 cows were in the high producing herds, and 654 cows were in the low producing herds. One thousand two hundred forty-nine of these cows had been bred at least once and had information on the number of times they had been serviced.

The mean MUN across the herds in these data was 12.6 (with standard deviation of 4.0 mg/dl). It was 13.6 mg/dl in the high producing herds and 11.1 mg/dl in the low producing herds. The mean days from calving to conception (pregnant cows only) was 124 d, it was 123 d for cows in the high producing herds and 125 d for cows in the low producing herds. Of the study population, 70.7% of the cows were confirmed pregnant during the study, and 29.3% of the cows were censored. The mean MUN value for cows confirmed pregnant during the study period was 12.3 and for the censored cows it was 13.2 mg/dl.

The results from the survival analysis are presented in Table 2. The assumption of proportional hazards was checked visually for covariates in the final model by plotting the estimated survival functions for different strata of the covariates, and no serious violations

Table 2. Risk ratios (RR) and their 95% confidence intervals (CI) of the covariates for conception from the survival analysis models for 1249 Ohio dairy cows which had been bred at least once during the study period.[1]

Covariate	All herds[2]		Low producers[2]		High producers[2]	
	RR (95% CI)					
MUN[2], mg/dl						
Lowest quartile	2.4	(1.8–3.3)	2.5	(1.6–4.1)	2.3	(1.6–3.1)
2nd lowest	1.4	(1.1–1.8)	1.1	(0.7–1.7)	1.5	(1.1–1.9)
2nd highest	1.2	(0.9–1.4)	1.1	(0.8–1.7)	1.1	(0.9–1.4)
Highest	1		1		1	
Parity						
1	1.1	(0.9–1.3)	0.8	(0.6–1.1)	1.2	(0.9–1.5)
2	1.1	(1.0–1.2)	1.2	(1.0–1.4)	1.2	(1.1–1.3)
≥3	1		1		1	
Peak milk yield[3]	1.08	(1.03–1.13)	1.05	(0.98–1.13)	1.05	(1.00–1.11)
No. of services[4]	0.41	(0.38–0.44)	0.46	(0.39–0.54)	0.37	(0.34–0.40)
Calving season						
Fall	1.6	(1.4–1.9)	1.8	(1.3–2.5)	1.5	(1.2–1.8)
Winter	1.7	(1.4–2.0)	2.5	(1.8–3.6)	1.4	(1.1–1.7)
Spring	2.0	(1.6–2.6)	4.2	(2.5–7.1)	1.4	(1.1–1.9)
Summer	1		1		1	

[1]Herd was included in the models, but risk ratios for individual herds are not shown.

[2]Mean milk urea nitrogen (MUN) values of cows in the data set were 10.0, 12.7, and 15.4 mg/dl; the cutoff values for the quartiles in low producing herds were 8.0, 10.9, and 13.6 mg/dl; the cutoff values for the quartiles in high producing herds were 11.1, 13.5, and 15.9 mg/dl.

[3]Peak milk yield in 4.54 kg (10 lb) increments; e.g., an increase of 4.54 kg in peak yield increased the risk of being confirmed pregnant by 8% in all herds.

[4]With every additional service, the risk of conception was only 41, 46, or 37% of that at the previous breeding in all, low or high producing herds, respectively.

of the assumption were observed. The fit of the model was also checked and potential outliers were detected with deviance residual plots, and some observations were omitted based on this visual inspection (1% of all observations). The parameter estimates for the covariates did not change due to the omissions.

Herd was included in the model as a fixed effect to account for the different management factors and feeding regimens, but risk ratios for individual herds are not shown (Table 2). As expected, herd had a very significant effect on the results. Some study herds used both artificial insemination and a bull, and some predominantly used a bull for breeding. We had data on the number of services from 1249 cows, which had all been bred at least once. The number of times a cow had been bred was most likely missing for cows that had been bred by natural service. A model without the variable "the number of services" was also run; however, the coefficients of all the other variables in the model changed considerably when compared with the model that included it. Therefore, we concluded that the number of services was a confounder and should be included in the model. With every additional breeding, the risk of conception was only 41% from that at the previous service (RR = 0.41 for all herds, Table 2).

High MUN values were associated with a lower risk of being confirmed pregnant. Cows with mean MUN values below 10.0 mg/dl before conception or the end of the study were 2.4 times more likely to have been confirmed pregnant than cows with MUN values above 15.4 mg/dl ($P < 0.0001$). Cows with MUN values between 10.0 and 12.7 or between 12.7 and 15.4 mg/dl were 1.4 ($P < 0.01$) and 1.2 ($P > 0.05$) times more likely to be confirmed pregnant, respectively, than cows with the mean of monthly milk urea concentrations above 15.4 mg/dl (Table 2).

Separate analyses were performed for the low and high producing herds, using the cutoff points applicable to their own strata. The cutoff points for quartiles in the low producing herds were lower (8.0, 10.9, and 13.6 mg/dl) and in the high producing herds they were higher (11.1, 13.5, and 15.9 mg/dl) than in the entire data set. Effects of the covariates appeared similar to the ones obtained from the "all herds" model. In the low producing herds, cows in the lowest MUN quartile were 2.5 times more likely to be confirmed pregnant than the cows with the highest MUN values, whereas the respective risk ratio in high producing herds was 2.3. In low producing herds, the hazard of being confirmed pregnant for cows in the other MUN categories did not significantly differ from that of cows with the

highest MUN values. In the high producing herds, cows in the second lowest quartile were also more likely to have been confirmed pregnant than cows with the highest MUN values (RR = 1.5, Table 2.).

The peak milk yield had a statistically significant effect in the model with data from all herds. With increasing milk yield, the risk of being confirmed pregnant increased slightly (RR = 1.08 for 4.54 kg (10 lb) increase in peak yield, i.e., with 4.54-kg increase in the peak milk yield the probability of being confirmed pregnant increased by 8%). The trend was the same in both the low and the high producing herds; however, milk yield did not significantly affect the risk of pregnancy in the low producing herds ($P > 0.05$), and it had a borderline significance ($P < 0.058$) in the high producing herds. In general, as the peak milk yield increased, MUN levels increased, i.e., the peak milk yield was highest for the cows in the highest MUN quartile and lowest for the cows in the lowest MUN quartile.

The age (parity) of a cow did not have a great effect on days open and conception; cows in parity 2 were 1.1 times more likely to be confirmed pregnant than cows that had calved three or more times ($P < 0.01$), but the hazard of pregnancy between first- and third-parity cows did not differ significantly. Calving season, on the other hand, was significantly associated with the hazard of conception. Cows calving during summer were least likely to have been confirmed pregnant during the study period and cows calving in fall, winter, and spring were 1.6, 1.7, and 2.0 times more likely to have been confirmed pregnant ($P < 0.0001$), respectively, than were cows that calved during the summer. Also, calving season appeared to have a greater effect on pregnancy rate in the low than in the high producing herds (Table 2).

Sensitivity analysis. Sensitivity analysis was performed to check the assumption of noninformative censoring with the final model (results not shown). For the lowest MUN category, the risk ratios from both scenarios of the sensitivity analysis were lower than in the original model (RR = 2.4 in the final model, 2.1 in scenario 1, and 1.9 in scenario 2). However, in all cases the 95% confidence intervals overlapped, indicating that the differences were not significant. Otherwise, the original final model estimates fell in between the estimates from the two extreme scenarios. Only the effects of calving season on the hazard of being confirmed pregnant changed meaningfully between the original model and the scenarios from the sensitivity analysis. In scenario 1 (with all censored cows assumed to have conceived at the time of censoring), the effects of calving season were similar, but much more pronounced than originally (e.g., cows calving in the

spring were 4.6 times more likely to conceive than cows calving in the summer), but in scenario 2 (all censored cows assumed to have been censored much later) calving season had almost an opposite effect than in the original model: in this case, cows calving in the spring had the lowest and cows calving in the fall had the highest hazard of conception (results not shown).

DISCUSSION

Ohio DHI uses an automated Skalar Segmented Flow Analyzer for MUN analysis. In that system, MUN concentration is measured spectrophotometrically at 520 nm. The precision and repeatability of this method has been observed to be good (Miller, 2000). However, there may be diurnal variation in the MUN values, as well as some variation depending on the time of feeding and the time of milking with respect to sample collection (Butler et al., 1996; Gustafsson and Palmqvist, 1993; Moore and Varga, 1996). All samples in this study were taken during normal milking time; however, the exact time of the day of sampling was not known for individual herds, and it might have also varied within a herd from test day to test day. We chose to use the mean of the monthly MUN measurements during the beginning of a lactation prior to conception to reflect the MUN status of a cow, instead of using any single value available for a cow. We believe that the average MUN value for a cow better reflects the true status of a cow and also smooths out possible variation due to the time of sampling.

The cutoff points for the MUN categories were based on the quartiles from these data, with mean value of 12.6 mg/dl (median of 12.7 mg/dl). Moore and Varga (1996) reported that acceptable MUN levels based on automated milk testing may range from 10 to 14 mg/dl. The MUN values were lower in lower producing herds (mean of 11.1 mg/dl) than in higher producing herds (mean of 13.6 mg/dl), and variation in low producing herds was larger (standard deviation of 4.6 vs. 3.3 mg/dl, respectively). The difference in overall MUN levels between herds with different production levels most likely reflects the management and feeding in these herds. Herds with high RHA milk yield have a high level of management and are most likely feeding their cows efficiently. When MUN levels become lower, there is a greater potential for a deficient protein feeding and lost production. And, as mentioned earlier, MUN levels also depend on the protein-fermentable carbohydrate balance in the rumen, not only on the amount of CP in the diet.

We observed that with higher MUN levels, the risk of being confirmed pregnant decreased. Several other

studies have also reported that high urea levels in blood and milk may be associated with reduced reproductive efficiency. However, in general, the reported levels of MUN related to reduced fertility have been much higher than in our study. Butler et al. (1996) reported that concentrations of MUN and BUN greater than 19 mg/dl were associated with decreased pregnancy rates. The mean MUN concentration in their study (samples collected from 155 first parity cows on the day of AI, at least 60 d after calving) was, however, 22.3 ± 4 mg/dl, which is much higher than in our study and what has generally been reported as acceptable (10 to 14 mg/dl, Moore and Varga, 1996; 10 to 16 mg/dl, Jonker et al., 1998). Also, Ferguson and Chalupa (1989) reported that BUN concentration exceeding 20 mg/dl was associated with reduced conception rates in lactating cows. In the study of Larson et al. (1997), cows with MUN concentrations greater than 21 mg/dl were more likely to return to estrus on d 21, and as MUN values increased, cows were reported to be marginally less likely to become pregnant.

In our study, cows with MUN concentrations higher than 15.4 mg/dl were less likely to have been confirmed pregnant than cows with MUN levels less than 15.4 mg/dl. In fact, cows with MUN levels less than 10 mg/dl before conception were 2.4 times more likely to be pregnant than cows with MUN levels over 15.4 mg/dl. Ferguson et al. (1993) reported that conception rate decreased with a serum urea nitrogen of 14.9 mg/dl using likelihood ratio tests, but that dichotomized tests suggest that the decrease does not occur until serum urea nitrogen is >20 mg/dl. We categorized cows into four groups based on their MUN levels and thus were able to see the effects in more detail. In many of the other above-mentioned studies, cows were only divided into two groups based on their MUN or BUN levels. That may partially explain why the negative association between elevated MUN and fertility has only been observed at relatively high levels.

The term "conception" in the context of this study may not be the most appropriate, because strictly speaking, we do not know how many of the cows conceived. We only know how many of them were confirmed and reported pregnant based on pregnancy checks by a veterinarian. A cow could have conceived, but experienced an early embryonic loss. However, the practical consequence is indisputable: the cow is open at the pregnancy check. Elrod and Butler (1993) and Elrod et al. (1993) reported that increased dietary protein decreased uterine pH during the luteal phase, which may play a role in reduced fertility. Larson et al. (1997) suggested that high MUN concentrations at breeding may be associated with fertilization failure

or very early embryonic losses before maternal recognition of pregnancy.

The interdependence of milk yield and fertilty has been under a lot of discussion, and many studies point to a negative association while some have found no or a positive association. Dhaliwal et al. (1996) reported that high yielding cows had consistently lower reproductive performance than low yielding cows. Cows with increased peak milk production had significantly longer calving-to-first estrus and calving-to-conception intervals as well as lower conception rates than average producing cows in the study of Kinsel and Etherington (1998). In our study, the effect of milk yield on fertility was also statistically significant; however, with 4.54 kg (10 lb) increase in the peak milk yield, the probability of being confirmed pregnant actually increased by 8% (RR = 1.08). This observed positive association could be a reflection of the fact that high yielding cows in a herd are often bred more times and are given more opportunities for conception than are low yielding cows. In fact, Eicker et al. (1996) showed that cumulative 60-d milk yield had only a minimal effect on conception, but in their study, the highest yielders were nearly 30% more likely to be inseminated than were the lowest yielders. Emanuelson and Oltenacu (1998) observed positive association between increasing herd milk production level and fertility, which observation also could be attributed to better management in high producing herds.

In the high producing herds, the MUN levels were higher than in the low producing herds. However, in both production groups cows in the lowest MUN quartile were more than twice as likely to be pregnant than the cows in the highest MUN category, suggesting the negative association of increasing MUN levels and fertility, regardless of the herd production level. In addition, in the high producing herds, also cows in the second lowest MUN category were significantly more likely to be confirmed pregnant than cows with the highest MUN values.

We defined all cows as open and not to have been bred if less than 35 DIM. This was a conservative choice, since few cows would have already been bred or pregnant by that time. On the other hand, a standard voluntary waiting period is 50 to 60 d. Our data indicated that the MUN values between different months of lactation did not vary much, during the first month of lactation MUN concentrations were slightly lower than later in lactation (unpublished data). This has also been reported by others (Eicher et al., 1999; Jonker et al., 1998; Moore and Varga, 1996). Thus, cows that might have conceived before 35 DIM, probably had relatively low MUN levels and this would only imply that the hazard of being confirmed pregnant

would have been even higher for cows with the lowest MUN levels. However, the number of such cows is assumed to be low enough not to meaningfully change our estimates.

The number of times a cow had been bred had a significant effect on the results. We observed that with each additional breeding, the probability of a cow conceiving was only approximately 40% of that at the previous service. When the number of services was not included in the model, the effects of MUN levels were much greater. This could be explained by a drop in conception rate with later cycles and repeated services, since these groups contain a higher percentage of subfertile cows.

The results from the sensitivity analysis indicated that the assumption of noninformative censoring was not seriously violated with respect to our main interest, the association of MUN levels with fertility. In other words, the censoring mechanism carried no prognostic information about the probability of conception of cows in this case, i.e., censored cows were at no higher or lower risk of being confirmed pregnant than the noncensored cows. The association between MUN levels and pregnancy was very similar between the scenarios of the sensitivity analysis and the original situation.

The effects of calving season, however, changed considerably between the original model and the extreme scenarios of the sensitivity analysis. Cows calving in summer had the lowest hazard of conception in the original situation, probably because their first breeding coincided with the hottest time of the year in Ohio. It has been reported that follicular growth and development and luteolytic mechanisms are compromised by heat stress (Wilson et al., 1998) and that heat stress before, after and on the day of breeding is associated with low 90-d nonreturn rate (al-Katanani et al. 1999). Our observation about the seasonal effects on conception agree with the results of Dransfield et al. (1998) who also reported conception rates to vary between seasons in their study. In the high producing group, however, the change in season had less of an effect on the likelihood of pregnancy compared with the low producing herds.

When all cows were assumed to have conceived at the time of censoring, risk ratios for cows calving during any other season than summer were higher than in the original scenario (e.g., cows calving in spring were 4.6 times more likely to conceive than cows calving in summer in this scenario, whereas the respective risk ratio was 2.0 in the original situation). Cows calving in the spring (from March to May) were in the study for a maximum of 3 mo, because the study period ended at the end of May. Thus, it seems logical that the risk ratio increased when all these cows were assumed to have conceived at the time of censoring, i.e., at the end of the study, which was within 3 mo of calving.

We did not have information on any possible diseases that the cows might have experienced during the study. Several periparturient disorders (e.g., dystocia, retained placenta, and metritis) have been associated with reduced fertility (Eicker, 1996). However, it could be assumed that these diseases would have been distributed evenly among all cows regardless of their MUN levels and we believe that they would not meaningfully change our results.

In conclusion, the results of this study indicate that increasing MUN levels appear to be negatively associated with fertility of dairy cows and thus decrease the hazard of being confirmed pregnant. The results also suggest that the range for MUN levels with respect to optimal fertility might be lower than has been reported earlier.

ACKNOWLEDGMENTS

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