Herd-level and contextual factors influencing dairy cow mortality in France in 2005 and 2006

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ABSTRACT

Dairy cow mortality causes financial loss and is increasing over time; it indicates suboptimal herd health or welfare. To describe the herd-level and contextual factors affecting cow mortality, the French National Bovine Dataset Identification was used to create dairy, beef, or fattening units within farms, for 2005 and 2006. Mortality rate (MO-RA, outcome variable) and most variables were calculated at the unit level, whereas contextual variables were defined at the municipality level [cattle density, inhabitant density, agricultural land always with grass on overall agricultural land (ALWG/OAL)]. The localization (11 dairy production areas, representative of the farming systems) was also included. The statistical analysis was performed with a probit regression model (MO-RA = 0 or >0) and with a linear model corrected by the Heckman method for bias sample selection. For 2005 and 2006, 3.8 and 3.7 million dairy cow-years, 101,445 and 96,954 dairy units, and 141,677 and 143,424 deaths were recorded, respectively. Over one-third of the units had no dairy cow mortality in 2005 or 2006. Overall MO-RA was 3.7 and 3.8% for 2005 and 2006, respectively. Restricted MO-RA (farms without death excluded) was 5.8% for 2005 and 2006. The correlation of MO-RA among units between the 2 yr was 0.25. The same effects and close estimate values were reported for 2005 and 2006 with both models. Mortality rate was positively associated with the number of cow-years, having a beef unit in addition to a dairy unit, the proportion of purchased cows, the proportion of first-calving cows, the average calving interval, being a Milk Control Program member, inhabitant density, not being in dairy production area Grand-Ouest, and ALWG/OAL. Negative associations were reported for breed other than Holstein, being a Good Breeding Practices member, having a calving peak in autumn, culling rate, and municipal cattle density. This study reports an average mortality rate for the French dairy

cows. It suggests that the farmer's management style highly influences mortality. In addition, farming system has an effect on the mortality. A possible association between municipal intensification of production and decreased mortality was also reported.

Key words: dairy cow mortality, France, herd-level factor, contextual factor

INTRODUCTION

Dairy cow death causes financial loss, including the value of the animals, the cost of their replacement, the loss of milk production, and the extra labor. Moreover, high mortality rates may indicate suboptimal health or welfare (Thomsen et al., 2006). Few studies have focused on dairy cow mortality; most have focused on describing mortality relative to the population characteristics (Gardner et al., 1990; Faye and Perochon, 1995; Menzies et al., 1995; Smith et al., 2000; Thomsen et al., 2004; Miller et al., 2008; Pinedo et al., 2010), on specifying the causes of death (Esslemont and Kossabati, 1997; McConnel et al., 2009, 2010), or on defining the risk factors of dairy cow mortality (Milian-Suazo et al., 1988; Thomsen et al., 2006; McConnel et al., 2008). Moreover, they reported an increase of the death frequency among dairy cows (Thomsen and Houe, 2006). Currently, a comprehensive overview of the natural or normal level of mortality in a dairy herd does not exist, but a review reported that dairy cow mortality rates ranged from 1 to 5% (Thomsen and Houe, 2006).

Cattle are very important in France, with approximately 19 million animals on 300,000 farms, in 2005. They represent 22% of cattle in the European Union (EU, 25 countries). This cattle population consists of approximately 4 million dairy cows (17% of EU dairy cows, ranked second after Germany), 4 million suckler cows (33% of EU beef cows, ranked first), and 12 million replacement and fattening animals (Eurostat, 2005; Sorensen et al., 2006). Moreover, much of Europe's diversity in livestock production can be found in France. The north is mainly focused on dairy cattle, whereas the central and southern regions are predominantly focused on beef, sheep, and goat production.

Received July 19, 2010.

Accepted January 7, 2011.

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Furthermore, one-fifth of French land is at mountain altitude, where beef and Protected Geographical Indication milk production occur (Rouquette and Pflimlin, 1995; Sarzeaud et al., 2008). This territorial diversity of livestock production describes the French breeding systems. At the farm level, various combinations of units exist within one farm, including dairy, beef, and fattening cattle as well as goats, sheep, poultry, or pigs (Renting et al., 2009).

The possible relationship between herd factors and cow mortality was investigated in recent studies (Smith et al., 2000; Thomsen et al., 2006; McConnel et al., 2008). Herd risk factors of cow mortality include structural factors, management practices, and the farmer's management style. A farmer's management style corresponds to his or her attitudes, and previous studies suggest that it should be distinguished from management practices. The farmer could contribute to variations in farm performance, in addition to the management practices (Bigras-Poulin et al., 1985; Tarabla and Dodd, 1990; Beaudreau et al., 1996). Nevertheless, the classification of mortality risk factors into structural factors, management practices, and farmer's management styles is debatable.

The territorial characteristics of cattle production are rarely taken into account in cow mortality studies, even if some effects of the farm location are observed (Gardner et al., 1990; Smith et al., 2000; Stull et al., 2008). Specific and homogeneous risk factors of mortality are observed within a farming system. Including the farming system in an analysis summarizes a global effect that is greater than the sum of specific factors of this area, because farming system includes some nonobserved effects that are difficult or impossible to "trap" into an indicator (Faye, 1992). The way farming is organized depends heavily on the individuals and the organizations involved in it, particularly in relation to strategies and practices used (Ploeg and Renting, 2002).

The data sets used in studies dealing with dairy cow mortality come from the national cattle database or survey systems (Thomsen et al., 2004, 2006; McConnel et al., 2008), milk control programs (Smith et al., 2000; Hare et al., 2006; Thomsen et al., 2006; Dechow and Goodling, 2008; Miller et al., 2008; Pinedo et al., 2010), stratified random samplings based on census (Menzies et al., 1995), local information systems related to ambulatory clinics (Milian-Suazo et al., 1988; Esslemont and Kossabati, 1997), specific questionnaires (Gardner et al., 1990; Faye and Perochon, 1995), or several large herds (McConnel et al., 2009, 2010). Studies excluding the nonmember farms or including only a few herds could have a bias in the estimation of the risk factors. The present study is based on the hypothesis that mor-

tality depends on both herd-level and contextual risk factors. First, it aims to describe cattle mortality in France. Second, it quantifies the weight of some risk factors of mortality, taking into account the farming systems and using a data set including all herds for 2005 and 2006.

MATERIALS AND METHODS

Data from the French National Bovine Database Identification

The French National Bovine Database Identification (BDNI) was built in 2000 and combined several local databases to enhance French cattle traceability after the bovine spongiform encephalopathy crisis in 1996 and 2000. It is managed by a specific office (Information Systems) of the French Ministry of Agriculture and Fisheries. It contains routine records from farmers and merchants (gathering centers), including data on herds, animals, and the presence of cattle on farms. All animals, farms, farmers, and gathering centers are individually identified. Animal data include identification number, sex, date of birth, farm of birth, breed, and identification of dam and sire (if available), and date of first calving for females. The presence of an animal on a farm is recorded with the date and reason (birth, purchase, or renting) of entrance and the date and reason (death, slaughter, selling, renting) of exit. Data on farms include herd size (after calculation) and location based on the municipality administrative areas ("commune," 36,679 units in France, mean area = 1,550 km²). All farmers breeding at least one animal are required by law to report data to BDNI; 2% of the farms are controlled spontaneously each year, and lack of conformity induces important financial penalties on the Common Agricultural Policies subsidies (Henke and Sardonne, 2003).

Data from the BDNI concerning all cattle were collected using MySQL software (MySQL, version 5.0, Oracle Corp., Redwood City, CA). All animals present at least 1 d during 2005 and 2006 were included in the data set, which represented 5.3 and 5.1 million dairy cows for 2005 and 2006, respectively. For all cows, previous and next (until 2009 included) calvings and calves also were recorded. Years 2005 and 2006 were selected because movement limitations due to the European bluetongue outbreak occurred in 2007 and 2008. Depending on the location and the months, movements of animals were stopped (except to the slaughterhouse) or restricted. If years 2007 and 2008 had been taken into account instead of years 2005 and 2006, the number of cow-years and consequently the mortality rates would probably be biased and misrepresentative.

Other Data Sets

The records from herds on the Milk Control Program (MCP) in France during 2005 and 2006 were provided by France Livestock Genetics (<http://www.france-genetique-elevage.fr/>). The records included lactation number, date of calving, all test-day milk results, and lactation data (length and production) for all lactations with at least 1 d in 2005 or 2006. Farms registered as Good Breeding Practices (GBP, “Charte des bonnes pratiques d’élevage”) members for 2005 and 2006 were provided by the National Breeding Institute (<http://www.inst-elevage.asso.fr/>). The charter of GBP is a voluntary program that includes constraints on identification, sanitary management, feeding and breeding schemes, milk production hygiene, and welfare of cattle (Dockes et al., 2006). The MCP and GBP herds were identified with the same code as BDNI, and were consequently geo-located.

Data on municipalities were provided by the National Statistic and Economic Studies Institute (<http://www.insee.fr>; “Institut national de la statistique et des études économiques”) for the number of inhabitants and the area (km²). The 2000 National Census carried out by the French Ministry of Agriculture and Fisheries and conducted by the Central Service for Survey and Statistical Studies (<http://agreste.agriculture.gouv.fr/>; “Service central des enquêtes et études statistiques”) was used to determine the agricultural land as “always with grass” (ALWG) and the overall agricultural land (OAL) as well as the price of the milk for each dairy production area (DPA) and each month. The DPA were defined according to the Interprofessional National Milk Industry Center scheme (<http://www.cniel.com/>; “Centre National Interprofessionnel de l’Economie Laitière”).

Data Control

Some information was registered in more than one way and the concordance within and between data sets was investigated, according to its plausibility. Some automatic procedures were built to correct errors that were suspected or detected on individuals or groups of animals, as follows. In BDNI, cows >20 yr old or with parities >15 were not included in the study. Entrance and exit reasons were used to determine the origin and future of the animals. The relationship between each birth and the calving of the dam was checked. An entrance for purchase without previous event was considered as an import and was consistent with the identification code of the animal (specific for each country). The slaughterhouse and incineration databases were not available to investigate the concordance of

the information when the exit cause was reported as death or slaughter. When selling was reported by the farmer as the exit cause and the animal was not found on another farm thereafter, the animal was considered as exported (for breeding or slaughterhouse). Moreover, because the transfer between 2 herds was registered in both the exit and entrance herds, the concordance between the dates was investigated and modifications occurred if necessary. Calvings were removed when the interval from the previous calving was <300 d and a live calf was born. If a stillborn calf was recorded, the calving was not removed and it was considered as an abortion. The modifications or deletions made up <0.05% of all individual information.

Because BDNI is a recent global data set, its accuracy has been evaluated. Data were compared with the national agricultural census in 2000 and to the annual structural questionnaires. The number of animals, cows, calvings, and breed proportions were correlated among the 3 data sets (Monniot et al., 2007). The agreement between individual-level BDNI and MCP data was also investigated. All cows registered in a farm in MCP were found in the same farm in BDNI. The calving dates rarely (<0.05%) differed between the 2 data sets, and the BDNI date was then considered. Data of herd-level BDNI and MCP was compared. All MCP herd identification codes were known in BDNI and no significant difference between the number of dairy cows was found. All GBP herd identification codes were also known in BDNI.

BDNI Unit-Level Data Editing

Because the BDNI data record is the animal and the farmer, not the unit, it was necessary to define 3 units: dairy, beef (suckler cows), and fattening (bulls, steers, or veal calves). The units were defined on the first of each month for the 2-yr period. A unit could exist a maximum of 24 times for 1 farm. The animals were considered as cows on the first calving day. Dairy, beef, or fattening units were created when at least 6 dairy cows, beef cows (according to the breed), or fattening animals were present, respectively. This threshold was defined and usually used by the National Breeding Institute and the Central Service for Survey and Statistical Studies of the French Ministry of Agriculture and Fisheries.

In total, 94,839 (85%) dairy units were present 24 times, and 97,435 (87%) dairy units were present at least 11 times a year. The same pattern was reported for the beef units, but less stability was observed for the fattening units (data not shown). Units were then defined for 2005 and 2006 independently when they were present for most of the months of the year. When

a unit was only present 1 or 2 mo of a year it was not considered as a unit for that year, and was deleted. Related cows were excluded from the study. The relationships between the animals and the units were then established according to reciprocal rules of the unit definition. The dairy calves, heifers, and cows were linked to the dairy units.

Variables

Mortality Rate. The mortality rates (**MO-RA**) were calculated for each year and each dairy unit as the total number of dairy cow deaths on the number of cow-years at risk. The number of cow-years equaled the sum of all the days and all the cows of the unit for 1 year divided by 365 d. Only cows after the first calving were taken into account, and no distinction was made between in-milk or dry cows. The calculation of the restricted **MO-RA** excluded the units without mortality.

Dairy Unit Factors. All the unit factors available in the data set were used except if a high correlation with another variable was detected or if the data were lacking for an important proportion of units (**MCP**, for example). The number of cow-years (**NUMB**) was calculated yearly as described for the mortality rate. The predominant breed (**BRD**) was defined as the breed that contributed to more than 75% of the different cows of the unit during the study period. Five groups were determined: Holstein (reference breed), Montbéliarde, Normande, no predominant breed (several dairy breeds within the unit), and other breeds (mainly Abondance, Simmental, Brune, Tarentaise, Pie Rouge des plaines, or crossbred cattle). The farm typology (**TYPO**) was defined yearly with a 3-level categorical factor: dairy (**D**; reference), when no other unit was described in the farm; dairy and beef (**DB**) if dairy and beef units were reported irrespective of fattening units; dairy and fattening (**DF**) if dairy and fattening units but no beef unit were reported.

The purchase of cows from other farms (**PU-COW**) was calculated yearly as the number of purchased cows on the number of cow-years. It was then transformed into a categorical factor: no purchase, low purchase, or high purchase. The threshold used to distinguish low from high purchase levels were 27 and 19% for 2005 and 2006, respectively. These values were the 75% quartile of the purchased cow proportion for 2005 and 2006, respectively. The yearly proportion of primiparous cows (**PR-PR**) was the number of first-calving cows on the overall number of calvings in the year. The culling rate (**CU-RA**) was the number of sold cows on the number of cow-years, irrespective of the in-milk or dry status and of the reasons for the removal; dead cows were not included in the culling rate. The average calving

interval (**ACI**, d) was calculated yearly. The monthly calving percentage represented the percentage of the annual calvings that occurred in this month. An autumn calving peak (**ACP**) was defined by (1) 2 successive months with a monthly calving percentage above 10%, (2) a monthly calving percentage >25% for 1 of these 2 mo, and (3) the first of the 2 mo between July and November (inclusive). This variable aimed to capture the sensitivity of farmers to produce milk during the best-paid period of the year. Milk Control Program member (**MCP-Mb**) and GBP member (**GBP-Mb**) were defined once for the 2-yr period. The average parity and the average age of the cows were calculated too, but they were not retained as explanatory variable in the models because of their high correlation with **PR-PR** ($r > 0.7$).

Contextual Factors. Three explanatory quantitative variables were calculated for each municipality: the cattle density [**CA-DE**, livestock units (**LU**)/km²], the inhabitant density (**IN-DE**, number/km²), and the proportion of agricultural land always with grass within the overall agricultural land (**ALWG/OAL**, %). Cattle density was expressed in **LU**, as suggested by a previous study (Sarzeaud et al., 2008). Livestock unit was the number of animal-years corrected by the age and breed of the animals with specific coefficients: 1, 0.85, 0.8, 0.9, 0.6, 0.32, and 0.44 for dairy cows, beef cows, all other females over 24 mo of age, all males over 24 mo of age, cattle between 12 and 24 mo of age, females under 12 mo of age, and males under 12 mo of age, respectively. For instance, a dairy cow present for 100 d in a year accounted for 0.27 cow-years ($1 \times 100/365$) and a beef cow present 200 d in a year for 0.46 cow-years ($0.85 \times 200/365$).

Dairy Production Areas. Eleven DPA were used to characterize the French territories (Figure 1). These areas were determined according to the industrial organization of the milk collection, but they overlap approximately with the French breeding systems (Rouquette and Pflimlin, 1995; Sarzeaud et al., 2008).

Statistical Analysis

Data was analyzed using R (version 2.10.1, 2009–12–14, The R Foundation for Statistical Computing, Vienna, Austria). A *t*-test was performed to compare the values of variables for 2005 and 2006. Moreover, 2 models were used in the study. First, the probability of having at least 1 death, (probability of having mortality, **PR-MO**), was analyzed by using a probit regression. Second, a linear regression using the Heckman correction and involving the previous probit regression results was done on **MO-RA** (the Heckman model). The 2 models were applied separately for 2005 and 2006.

Heckman Correction. The R package “sampleSelection” (Toomet and Henningsen, 2008) was used for the 2-stage Heckman method (Heckman, 1979). Mortality rate was categorized into 2 levels (MO-RA = 0.0% or MO-RA >0.0%) and named Ca-MO-RA. In addition, MO-RA was transformed according to the following formula to become Ln-MO-RA, with a normal distribution:

$$\text{Ln-MO-RA} = \text{Ln}[\text{MO-RA}/(1 - \text{MO-RA})].$$

The Heckman correction offers a way of correcting for nonrandomly selected samples that can lead to erroneous conclusions and poor policy. It involves a normality assumption and provides a test for biased sample selection and a formula for bias-corrected models.

The Heckman correction took place in 2 stages. First, a probit regression model focused on the probability of having at least 1 death (Ca-MO-RA = 1) [1]. The estimation of the model yield's results was used to predict the probability of mortality for each unit. In the second stage, a linear regression model was corrected for self-selection by incorporating a transformation of these predicted individual probabilities (the inverse Mill's ratio; **IMR**) as an additional explanatory variable [2] (Heckman, 1979). The equations used were:

$$\text{Prob}(\text{Ca-MO-RA} = 1 \mid \mathbf{Z}) = \Phi(\mathbf{Z}\gamma), \quad [1]$$

where $\mathbf{Z}$ was a vector of explanatory variables, γ was a vector of unknown parameters, and Φ was the cumulative distribution function of the standard normal distribution.

$$\begin{aligned} E[\text{Ln-MO-RA} \mid X, \text{Ca-MO-RA} = 1] = \\ X\beta + \rho\sigma_u \lambda(Z\gamma), \end{aligned} \quad [2]$$

where E was a conditional expectation of mortality rate (if not null), ρ was the correlation between unobserved determinants of propensity to die and unobserved determinants of overall mortality risk u , X was a vector of explanatory variables, β was the estimator of the variables, σ_u was the standard deviation of u , and λ was the IMR.

Definitive Models. The initial probit model was

$$\begin{aligned} \text{Probit}(\text{Ca-MO-RA}) = \mu + \text{NUMB} + \text{BRD} \\ + \text{TYPO} + \text{PU-COW} + \text{PR-PR} + \text{CU-RA} \\ + \text{ACP} + \text{ACI} + \text{MCP-Mb} + \text{GBP-Mb} \\ + \text{CA-DE} + \text{IN-DE} + \text{DPA} + \varepsilon, \end{aligned}$$

Figure 1. Definition of the dairy production areas (DPA). Numbers refers to DPA: 1 = Grand-Ouest; 2 = Normandie; 3 = Nord; 4 = Est; 5 = Centre; 6 = Poitou; 7 = Massif Central; 8 = Rhône-Alpes; 9 = Sud-Ouest; 10 = Franche-Comté; 11 = Savoies.

where μ was the intercept value and ε was the residuals. The variables DPA or ALWG/OAL were used alternatively. Nonsignificant explanatory variables of the previous models for 2005 and 2006 were removed and the definitive model became

$$\begin{aligned} \text{Probit}(\text{Ca-MO-RA}) = \mu + \text{NUMB} + \text{BRD} \\ + \text{PU-COW} + \text{PR-PR} + \text{CU-RA} + \text{ACP} + \text{ACI} \\ + \text{MCP-Mb} + \text{GBP-Mb} + \text{DPA} + \varepsilon, \text{ [model 1]} \end{aligned}$$

Model 1 became model 1' when ALWG/OAL replaced DPA.

The Heckman model was

$$\begin{aligned} \text{LM}(\text{Ln-MO-RA}) = \mu + \text{NUMB} + \text{BRD} + \text{UNIT} \\ + \text{PU-COW} + \text{PR-PR} + \text{CU-RA} + \text{ACP} \\ + \text{ACI} + \text{MCP-Mb} + \text{GBP-Mb} + \text{CA-DE} \\ + \text{IN-DE} + \text{DPA} + \text{IMR} + \varepsilon. \text{ [model 2]} \end{aligned}$$

In model 2', ALWG/OAL was used instead of DPA.

All possible 2-factor interactions were included (one by one) in the model with all of the main effects. The degree of interaction of the statistically significant ($P < 0.05$) interactions was evaluated by comparison of

Table 1. Mortality characteristics of French dairy cows and herds in 2005 and 2006

Characteristic	2005	2006
Number of different cows ¹ ($\times 1,000$)	5,300	5,100
Number of cow-years ($\times 1,000$)	3,828	3,753
Deaths, n		
Overall	141,677	143,424
0–30 d after calving, n (%)	49,780 (35.1)	48,680 (33.9)
0–100 d after calving, n (%)	78,345 (55.2)	77,625 (54.1)
First lactation, n (%)	39,627 (27.9)	39,109 (27.2)
Second lactation, n (%)	25,562 (18.0)	26,344 (18.6)
Individual relative risk of death compared with cows in lactation ≥ 3		
Cows in first lactation	0.75*	0.74*
Cows in second lactation	0.63*	0.63*
Units without mortality, n (%)	37,128 (36.6)	33,997 (35.1)
Units with mortality		
All, n (%)	64,317 (63.4)	62,957 (64.9)
With 1 death, n (%)	29,161 (28.7)	27,599 (28.4)
With 2 deaths, n (%)	16,776 (16.5)	16,354 (17.1)
With 3 deaths, n (%)	8,609 (8.4)	8,637 (8.9)
Mortality rate (MO-RA), %		
Minimum	0	0
Maximum	88.5	98.4
Mean	3.7	3.8
SE	4.4	4.5
Median	2.8	2.9
Restricted mortality rate, % (MO-RA = 0 excluded)		
Minimum	0.6	0.5
Maximum	88.5	98.4
Mean	5.8	5.8
SE	4.4	4.4
Median	4.6	4.6

¹The number of different cows was higher than the number of cow-years because some cows stayed in the herd for less than a whole year.

* $P < 0.05$.

the estimate weight for the different combinations of interactions in question. If the differences between the estimate values were small for different levels of interactions, it was interpreted as a significant interaction without any biological importance. The interaction was then removed from the model.

The original estimate (Est) values of the Heckman models were transformed into Es-MO-RA according to the following formula, to allow a direct interpretation of the effect relative to the mean value of MO-RA (0.5):

$$\text{Es-MO-RA} = [\text{Exp}(\text{Est}) / (1 + \text{Exp}(\text{Est}))].$$

Then, the estimates of the probit models and Es-MO-RA were transformed into mortality change and expressed in percentage of change when quantitative variables changed by 1 unit or compared with reference for categorical variables.

RESULTS

Descriptive Analysis of Mortality

As shown in Table 1, 3.8 and 3.7 million cow-years were registered in 101,445 and 96,954 units for 2005 and 2006, respectively. The number of different cows

was higher than the number of cow-years, because some cows stayed in the herd for less than an entire year. More than 140,000 dairy cows died in France in 2005 and 2006, and more than one-third of the units had no dairy cow mortality in 2005 or 2006 (Table 1). The units with 1 to 3 deaths/yr represent half of the units. The correlation between the number of cow-years and the number of deaths (0 excluded) was 0.44 for both 2005 and 2006. The overall MO-RA and restricted MO-RA were not different ($P > 0.05$) between 2005 and 2006.

When the units with animals in both 2005 and 2006 were considered (6,034 and 1,543 units excluded for 2005 and 2006, respectively), 44,936 (47.1%) units had at least one dead cow in 2005 and 2006, and 16,316 (17.1%) units had no cow mortality in either 2005 or 2006. Moreover, 16,686 (17.5%) and 17,473 (18.3%) units had cow mortality only in 2005 or 2006, respectively. The correlation of MO-RA between 2005 and 2006 was 0.25; it was 0.38 if calculated on the 44,936 units with mortality in both 2005 and 2006. The number of deaths per month was between 9,609 and 14,285 cows (Figure 2) and its correlation with the number of calvings per month was 0.34. Over one-third of the deaths occurred in the first month after calving and more than half of the deaths within 100 d after calving (Table 1).

Table 2. Descriptive statistics of continuous variables in 2005 and 2006

Item	Year	Minimum	Maximum	Mean	SE	Median
Cow-years, n	2005	5.1	404.2	37.7	20.3	34.4
	2006	5.1	421.1	38.7	20.7	35.2
First-calving cow proportion, %	2005	0.0	100	28.6	12.7	30.0
	2006	0.0	100	28.0	12.9	29.4
Culling rate, %	2005	0.0	100	21.3	13.6	20
	2006	0.0	100	21.6	14.4	20
Average calving interval, d	2005	244	1,565	416	43	408
	2006	237	1,799	417	43	409
Cattle density, livestock units/km ²		0.01	3.18	0.55	0.35	0.51
Inhabitant density, n/km ²		0.01	31.21	0.64	1.05	0.38
Agricultural land always in grass/overall agricultural land, %		0.01	1	0.55	0.25	0.53

In 2005, 31.0 and 24.0% of the 3,614,501 calvings occurred in first and second lactations, respectively. Respective proportions for 2006 were 30.5 and 24.1% of the 3,493,500 calvings. Around 27 and 18% of the cows died in their first and second lactations, respectively. Compared with parities ≥ 3 , the relative risk of death was around 0.75 (0.74–0.76) and 0.63 (0.62–0.64) for first and second parity, respectively ($P < 0.05$; Table 1). The descriptive statistics for quantitative and categorical variables are reported in Table 2 and Table 3, respectively. In Table 3, the overall number of units per category and the number of units with mortality per category represent the distribution of units among categories within the probit and Heckman models, respectively.

The distribution of units and cows was heterogeneous among DPA. Thirty and 15% of the dairy units or cows were in DPA 1 and 2, respectively; DPA 4, 5, and 11 accounted for less than 5% of French dairy units or cows each, and all other DPA for 5 to 10% each (Table 3). No differences ($P > 0.05$) were observed on NUMB, PR-PR, CU-RA, and ACI values between 2005 and 2006.

When the threshold used to define a unit (>5 cow-years) was increased to 10 or 15 cow-years, the proportions of herds, cows, and deaths excluded were 4, 1, and 1% for the 10 cow-years threshold and 10, 3, and 3% for the 15 cow-years threshold, respectively. Proportions of units with or without mortality and of units with 1, 2, or 3 deaths were not affected by the thresholds used (5, 10, or 15 cow-years). Mortality rate and restricted MO-RA were 3.7 and 5.8% for the 10 cow-years threshold and 3.6 and 5.4% for the 15 cow-years threshold, respectively.

Regression Analysis

The same effects ($P < 0.05$) and very close estimate values were reported for 2005 and 2006 in the model 1 (probit; Table 4). The variables NUMB, PR-PR, ACI, PU-COW, and MCP-Mb were positively associated (P

< 0.05) with PR-MO (model 1), whereas the association was negative ($P < 0.05$) for CU-RA, BRD (no Holstein), ACP, and GBP-Mb. Being in a DPA other than DPA 1 (Grand-Ouest) increased MO-PR for all DPA ($P < 0.05$), except for DPA 11 (decreased MO-PR; $P < 0.001$). The effects for DPA 10 (2005) and DPA 5 (2006) were not significant.

For model 2 (Heckman), all the explanatory variables were associated ($P < 0.05$) with MO-RA in 2005 and 2006, except TYPO (DF compared with D) and CA-DE ($P > 0.05$; Table 4). The signs (positive or negative) of all effects are the same between models 1 and 2. Moreover, TYPO (DB compared with D) and IN-DE were positively associated ($P < 0.001$) with MO-RA (model 2). The inverse Mill's ratio had an effect ($P < 0.001$) in 2005 and 2006.

The same effects ($P < 0.05$) with very close estimate values were observed in models 1' and 2' compared with models 1 and 2 (data not shown), except for CA-DE (model 2', $P < 0.05$). The mortality changes for an increase of 10 LU of CA-DE were -12.1 and -10.2% for 2005 and 2006, respectively ($P < 0.05$). The variable

Figure 2. Number of calvings and deaths by month of study.

Table 3. Descriptive statistics of categorical variables in 2005 and 2006

Complete name and abbreviation	Category	Overall number of units per category ¹		Number of units with mortality per category ²	
		2005	2006	2005	2006
Predominant breed (BRD)	Holstein	57,496	55,041	40,948	40,013
	Montbéliarde	16,034	15,408	8,297	8,258
	Normande	9,024	8,470	4,442	4,347
	No predominant	16,170	15,402	9,534	9,224
	Other breeds	2,721	2,633	1,109	1,118
Farm typology (TYPO)	Dairy	48,220	45,507	26,252	28,280
	Dairy and beef	17,625	17,313	10,988	11,106
	Dairy and fattening	35,624	34,144	24,093	23,574
Purchased cow proportion (PU-COW)	No purchase	75,585	71,571	46,746	45,241
	Low purchase	23,386	21,157	15,937	14,862
	High purchase	2,474	4,226	1,647	2,857
Milk Control Program member (MCP-Mb)	No	38,941	36,196	20,642	19,843
	Yes	62,504	60,758	43,688	43,117
Good Breeding Practices member (GBP-Mb)	No	39,090	35,353	22,043	20,474
	Yes	62,355	61,601	42,287	42,486
Autumn calving peak (ACP)	No	79,116	76,090	50,394	49,672
	Yes	22,329	20,864	13,936	13,288
Dairy production area (DPA)	1 (Grand-Ouest)	31,662	30,263	20,424	19,994
	2 (Normandie)	14,400	13,701	9,377	9,240
	3 (Nord)	9,348	8,899	6,319	6,158
	4 (Est)	8,130	7,828	5,927	5,913
	5 (Centre)	1,697	1,597	1,179	1,099
	6 (Poitou)	2,905	2,755	2,072	1,980
	7 (Massif Central)	8,628	8,320	5,090	4,839
	8 (Rhône-Alpes)	7,617	7,204	4,190	3,982
	9 (Sud-Ouest)	9,442	9,010	5,859	5,721
	10 (Franche-Comté)	5,226	5,077	2,786	2,913
	11 (Savoie)	2,390	2,316	1,007	1,121

¹Distribution of units among categories within the probit model.²Distribution of units among categories within the Heckman model.

ALWG/OAL was not associated with PR-MO (model 1'; $P > 0.05$), but it was associated with MO-RA (model 2', $P < 0.001$) for 2005 and 2006. The mortality changes for a 10% increase in ALWG/OAL were +9.1 and +12.3% for 2005 and 2006, respectively.

Most of the significant interactions were considered biologically irrelevant because their effects on MO-RA were very small. The interactions involving NUMB and BRD were the most important interactions. Their inclusion in the Heckman model induced small variations of mortality changes for NUMB and BRD and no modifications of the P -values. After the inclusion of these interactions, the multiple R^2 values were 0.26 and 0.25 (model 2) and 0.25 and 0.24 (model 2') for 2005 and 2006, respectively.

DISCUSSION

Data Sets

Milk Control Program and Survey Systems are reported to represent 80 to 90% of the dairy cows and herds (Thomsen et al., 2006; McConnel et al., 2008). In this study, MCP represented approximately 60% of

the herds and cows and 85% of the milk produced. The present study was based on BDNI and included all animals and farms with at least 6 dairy cows. Few studies on dairy cow mortality have used exhaustive data sets (Thomsen et al., 2004). Membership in MCP was associated with an increased MO-RA in all models of the present study, suggesting an overestimation of MO-RA in studies based on MCP data sets. Moreover, several data sets were restricted to the Holstein breed (Milian-Suazo et al., 1988; Esslemont and Kossaibati, 1997), which could induce a bias of the MO-RA evaluation, as suggested by the association of BRD and MO-RA in the present study.

MO-RA Calculation

The mortality rate was calculated as the number of deaths per cow-years, as suggested by previous studies (Gardner et al., 1990; Faye and Perochon, 1995; Esslemont and Kossaibati, 1997; Miller et al., 2008). Other studies used mortality risk (mortality per cow lactation; Thomsen et al., 2004), sometimes restricted to the first 100 d of lactation (Thomsen et al., 2006). Lactational mortality risk as a measure of mortality

Table 4. Mortality change with the probit and Heckman models for dairy production areas¹

Item	Category	Mortality change (%)			
		2005		2006	
		Model 1 (Probit)	Model 2 (Heckman)	Model 1 (Probit)	Model 2 (Heckman)
Intercept		−149***	−49.8***	−149***	−49.8***
Number of cow-years ² (NUMB)		25.0***	2.0***	25.0***	2.0***
Predominant breed (BRD)	Holstein	Reference	Reference	Reference	Reference
	Montbéliarde	−37.5***	−12.5***	−36.3***	−13.5***
	Normande	−44.9***	−15.7***	−46.6***	−16.3***
	No predominant	−19.9***	−6.2***	−22.4***	−7.3***
	Other breeds	−58.4***	−20.4***	−56.9***	−19.3***
Farm typology (TYPO)	Dairy	Removed ³	Reference	Removed	Reference
	Dairy and beef		8.0***		8.0***
	Dairy and fattening		−15.0		0.1
Purchased cow proportion (PU-COW)	No purchase	Reference	Reference	Reference	Reference
	Low purchase	22.6***	8.2***	21.8***	7.5***
	High purchase	44.7***	17.6***	33.8***	13.0***
First-calving cow proportion ⁴ (PR-PR), %		3.0***	1.0***	3.0***	1.0***
Culling rate ⁴ (CU-RA), %		−6.0***	−2.0***	−5.0***	−2.0***
Average calving interval ⁵ (ACI), d		2.0***	1.0***	2.0***	1.0***
Autumn calving peak (ACP)	No	Reference	Reference	Reference	Reference
	Yes	−6.9***	−2.7***	−7.9***	−3.1***
Milk Control Program member (MCP-Mb)	No	Reference	Reference	Reference	Reference
	Yes	10.6***	2.5***	8.3***	1.4***
Good Breeding Practices member (GBP-Mb)	No	Reference	Reference	Reference	Reference
	Yes	−7.1***	−3.6***	−6.1***	−3.7***
Cattle density ⁶ (CA-DE), LU/km ²		Removed	3.1	Removed	−3.0
Inhabitant density ⁷ (IN-DE), n/km ²		Removed	2.1***	Removed	3.2***
Dairy production area (DPA)	1 (Grand-Ouest)	Reference	Reference	Reference	Reference
	2 (Normandie)	13.7***	6.8***	16.2***	6.4***
	3 (Nord)	10.1***	4.7***	8.5***	4.4***
	4 (Est)	22.9***	9.9***	27.9***	10.3***
	5 (Centre)	8.6*	5.1***	0.8	2.7***
	6 (Poitou)	12.0***	5.3***	9.9***	4.9***
	7 (Massif Central)	19.7***	8.6***	13.5***	6.2***
	8 (Rhône-Alpes)	16.3***	7.7***	11.8***	6.0***
	9 (Sud-Ouest)	10.7***	5.4***	12.3***	5.7***
	10 (Franche-Comté)	2.5	0.9*	10.6***	3.9***
	11 (Savoie)	−13.5***	−4.1***	−9.7**	−2.6***
Inverse Mill's ratio			38.4***		37.8***
Adjusted R ²			0.249		0.234

¹The results are expressed in mortality change (%). For instance, an increase in herd size of 10 cows was associated with a +25% change in the probability of mortality and a mortality rate change of +2.0% in 2005. Further, using Montbéliarde rather than Holstein as the predominant breed in the herd was associated with a −37.5% change in the probability of mortality, and a mortality rate change of −12.5%, in 2005.

²For an increase in herd size of 10 cows.

³The effect was removed from the model (see Materials and Methods).

⁴For an increase of 10%.

⁵For an increase of 10 d.

⁶For an increase of 10 livestock units (LU).

⁷For an increase of 10 inhabitants.

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

was recommended because it prevents bias related to the calving distribution in the data set (Thomsen and Houe, 2006). However, calculating the mortality risk on the first 100 d of lactation would have excluded half of the dairy cow deaths in the current study. In the present study, approximately 35 and 55% of the deaths were registered during the first 30 and 100 d of lactation, respectively. This observation agrees with other studies that found a high proportion of deaths

during the first 15 to 30 d of lactation (Milian-Suazo et al., 1988; Faye and Perochon, 1995; Menzies et al., 1995; Thomsen et al., 2004; Miller et al., 2008). The correlation between the monthly number of deaths and calvings remained low ($r = 0.34$).

MO-RA Values

The average MO-RA among French dairy cows (3.7 and 3.8% in 2005 and 2006, respectively) was higher

than those reported in studies published in the 1990s but lower than or in agreement with recent studies. The annual mortality rates were 2% among 43 Californian dairy herds (Gardner et al., 1990), 1.6% for 1,069 dairy herds in Northern Ireland (Menzies et al., 1995), 0.96% among 47 herds in Brittany, France (Faye and Perochon, 1995), 1.6% in 50 English Holstein-Friesian herds (Esslemont and Kossaibati, 1997), and 1% among 249 herds in Ireland (Leonard et al., 2001). The mortality per cow-lactation was 1.2% among 34 herds in New York State (Milian-Suazo et al., 1988), and the risk of mortality during the first 100 d of lactation was 2.5% (Thomsen et al., 2006). Recent studies tend to report higher mortality rates. The annualized mortality rate among 3 million lactations was 6.6% for the 2001 to 2006 period (Pinedo et al., 2010), and it was 5.7% among US cows in 2007 (USDA, 2007).

Mortality rate has tended to increase for the last several years. The mortality risk among Danish dairy cows was approximately 2% in 1990, 3.5% in 1999, and 5% in 2005 (Thomsen et al., 2004; Thomsen and Sorensen, 2009). For US dairy cows, it was 3.8% in 1996, 4.8% in 2002, and 5.7% in 2007 (USDA, 2007). The increased mortality in Danish herds was caused in part by an increased number of killed cows, with a lower threshold for euthanasia in 2006 compared with the previous 5 to 10 yr (Thomsen and Sorensen, 2008). In France, a clinical veterinary inspection has been performed at slaughterhouses on all animals since 2000, and a financial subsidy for euthanasia costs was given by the government from 2000 to 2004. Some of the cows that are currently euthanized on the farm would probably have been sent to slaughter before the bovine spongiform encephalopathy crisis.

In this study, a dead or slaughtered cow was registered by the farmer but no control was made with the slaughterhouse or incineration databases at the animal level. A misestimation of the mortality rate due to errors in exit reason was not likely to occur. No difference was shown between BDNI and incineration data sets when compared at the national level (Monniot et al., 2007).

MO-RA Variations

The ranges of MO-RA were very important among herds, with minimum values at 0% and maximal values close to 100% (Table 1). Units without cow mortality were not rare, suggesting the distinction between the units with or without mortality. Approximately 1 of 3 units had no cow mortality. This is in accordance with the few studies reporting a percentage of farms without mortality: 31% among 47 herds in Brittany (Faye and Perochon, 1995), 18.2% for 1,069 dairy herds in

Northern Ireland (Menzies et al., 1995), and 26.9% for 6,839 Danish dairy herds (Thomsen et al., 2006). The maximum mortality rate among herds was very high in the present study. However, few herds had similarly high rates as suggested by the 90th percentile, which is around MO-RA equal to 10% for both years.

Heckman Correction and IMR

The Heckman method corrects for selection bias. This study aimed to estimate factors associated with cow mortality. However, the descriptive statistics showed a large number of units without mortality and important variations of MO-RA among the units with mortality. A logistic regression based on mortality or no mortality would not have taken into account the difference between the units with low or high mortality rates. Regressing MO-RA for only units with mortality did not allow observation of the equation for the population as a whole (units without mortality were excluded). The IMR is the ratio of the probability density function over the cumulative distribution function of a distribution; it took into account the fact that a herd was with or without mortality.

In this study, the effects of the IMR were highly significant for all models with very low *P*-values and high estimate values. This suggests that MO-RA value and being in the category “with mortality” were not independent. Some nonobserved effects related to the classification of a unit in the category “with mortality” had a positive effect on the MO-RA value of this unit. Moreover, the use of the Heckman model increased the R^2 compared with a previous linear model (data not shown). This suggests the usefulness of this model and the pertinence of the explanatory variables used in the present study.

Effect of Herd Size on MO-RA

An increase in the herd size of 10 cows was associated with a PR-MO change of 25% and with a MO-RA change of 2%, in both 2005 and 2006. Mortality has been reported to increase with herd size in several studies (Smith et al., 2000; Thomsen et al., 2006; McConnel et al., 2008; Pinedo et al., 2010), even if the relation was not found in others (Batra et al., 1971). Increased mechanization, less personal attention, and greater levels of physiologic stress could explain the higher mortality rates in large compared with small herds. Furthermore, average milk production and concentrate consumption could also be involved (Nørgaard et al., 1999). The variations among studies could come from the average herd size; it was dramatically higher in US studies (small herds were defined as <100 cows) com-

pared with this study (Smith et al., 2000; McConnel et al., 2008) and intermediate in a Danish study (median = 67 and interquartile range = 48 cows; Thomsen et al., 2006).

Effect of Breed on MO-RA

The effects of breed on both PR-MO and MO-RA were high, with a change up to 20% of the MO-RA. This is in accordance with higher MO-RA for Holstein compared with Jersey, Red dairy, or other breeds (Thomsen et al., 2006). In the present study, the effect of BRD on MO-RA could partially originate from the milk yield differences among breeds. Regression of mortality on lactation milk yield was established to equal +0.37 to 0.47%/1,000 kg, depending on the breed (Miller et al., 2008). The 2005 French average milk production was 8,500, 6,500, 5,900, 6,700, 6,600, 5,300, 5,100, and 4,100 kg of milk for Holstein, Montbéliarde, Normande, Pie Rouge des plaines, Brune, Simmental, Abondance, and Tarentaise, respectively. The within-herd differences among breeds were small in a US study when milk yields were included in the model (Miller et al., 2008).

Effect of Having a Beef Cow Unit on Dairy Cow MO-RA

Having a beef cow unit increased dairy cow mortality. To our knowledge, this effect has not been reported previously. Three main explanatory hypotheses can be formulated. First, the management of 2 units could lead to less attention for the dairy cows compared with farms with only 1 unit. Second, biosecurity measures are probably less efficient and more difficult to achieve when several units are present within the same farm. This is particularly true when the 2 herds are not strictly separated as is often the case in France. Third, the farmers without another cattle unit could have better management acumen for dairy production than the other farmers. Further investigations focusing on farms with several units or including analysis per DPA are needed to confirm these hypotheses.

Effect of Purchasing Cows on MO-RA

Purchasing cows induced a +5 to +15% change in MO-RA and a +20 to +40% change in PR-MO, compared with the units without purchase. The effect was higher when the proportion of purchased cows was high compared with moderate. This is in agreement with previous results on Danish herds (Thomsen et al., 2006). Perhaps the purchased cows failed to adapt successfully to their new environment or they were exposed

to new infectious agents. Alternatively, the increased mortality could come from the nonpurchased cows, if they were exposed to new infectious agents from the purchased cows. It is difficult for farmers to respect the quarantine delay if cows are producing milk at entrance. This study did not investigate the effects of purchasing calves, heifers, or animals for other units of the farms, which could indirectly lead to an increased risk for infectious diseases.

Effect of Primiparous Percentage on MO-RA

At the animal level, primiparous cows were less likely to die compared with the other cows, but at the herd level, a 10% increase of PR-PR was associated with a +1 to +3% change in MO-RA or PR-MO. This animal-level effect is in agreement with previous studies. The mortality risk was higher for parity ≥ 3 compared with cows in the first and second parity in Danish herds, and death frequency increased linearly with parity for US cows (Thomsen et al., 2004; Miller et al., 2008; Pinedo et al., 2010). The increase of MO-RA with PR-PR at the herd level could come from an indirect effect of having many primiparous cows, such as modifications of herd management (nutrition, care of the animals) or decreased attention for multiparous cows. Reluctance to treat and a lower threshold for euthanasia of multiparous cows may occur when many primiparous cows are available for replacement.

Effect of Culling Rate on MO-RA

The CU-RA effect is in agreement with a US study based on 953 dairy units. An early lactation culling rate between 2 and 20% was associated with a decreased MO-RA compared with a culling rate under 2% (McConnel et al., 2008). Culling rate and mortality were negatively associated in a study of 2,054 US herds (Pinedo et al., 2010). In the present study, CU-RA did not include dead cows in the numerator in spite of the advice of previous studies (Fetrow et al., 2006), because the number of deaths was included in the outcome variable. The correlations between CU-RA and PR-PR were low ($r = 0.11$ and 0.08 for 2005 and 2006, respectively), leading to the inclusion of these 2 explanatory variables in the models. This low correlation also suggests variations in dairy herd size between 2005 and 2006.

Effect of ACI and ACP on MO-RA

The positive association between ACI and MO-RA was previously reported (McConnel et al., 2008). An autumn calving peak is motivated by the higher price

of the milk and the lower feeding costs (with grass availability) in autumn. The association between mortality, ACI, and ACP could be explained by certain general management factors. A high level of management is needed to achieve a low ACI and to gather calvings over a few months. A beneficial effect of this level of management on MO-RA is likely to occur. The influence of the management style on milk production, disease, and culling has been described previously (Bigras-Poulin et al., 1985; Tarabla and Dodd, 1990; Beaudeau et al., 1996). Management style represents farmers' socio-psychological characteristics and attitudes toward a situation. It refers to the fact that 2 farmers are not likely to make the same decision regarding a cow with similar individual characteristics in a given herd (Bigras-Poulin et al., 1985; Tarabla and Dodd, 1990).

Effect of Being an MCP or GBP Member on MO-RA

The best farmers with high levels of management and good farm performances generally have a higher probability of joining MCP or GBP compared with other farmers (Bourgier, 1980). If this occurred, the estimates of MCP-Mb or GBP-Mb would be biased and would include confounding effects linked to MCP-Mb and GBP-Mb. This would induce differences between the residuals of the models for the members or the non-members units. Because no difference (mean and SE) was found (data not shown), the interpretation of the estimate values was allowed. Being an association member was previously considered a socio-demographic characteristic of the farmers (Beaudeau et al., 1996).

A lower MO-RA (or PR-MO) was expected for MCP-Mb because these farmers were expected to give more attention to the cows and to have better practices and a higher mean genetic value. However, MCP-Mb and MO-RA (or PR-MO) were positively associated. Certain confounding effects of milk yield could occur, because milk yield was suspected to be higher in farms with MCP compared with farms without MCP. The association between the herd-average milk yields and MO-RA is not clear, with a positive relationship (Dechow and Goodling, 2008; Miller et al., 2008), a negative relationship (Smith et al., 2000; Thomsen et al., 2006), or no relationship (Batra et al., 1971) having been described previously. Membership in GBP was associated with an average -5% change in MO-RA and PR-MO. This effect appears to be high when compared with the limited conditions relative to membership (Dockes et al., 2006). The effect of organic compared with conventional production on MO-RA was of the same order (Thomsen et al., 2006).

Effect of IN-DE on MO-RA

Inhabitant density had a positive effect on MO-RA. This could originate from the difficulties of farming in periurban lands (Jarrige, 2004; Vianey et al., 2006). High mortality risk could be the result of specific practices and particular farming strategies in relation to local population claims. This suggests that local inhabitant characteristics should be considered when evaluating farm performance.

Effect of ALWG/OAL and CA-DE on MO-RA

The variables ALWG/OAL and CA-DE were relative to all productions, including cattle, small ruminants, and cereal crop. The calculation of ALWG/OAL at the administrative level instead of at the farm level limited its accuracy. Yet, all the dairy farms within a municipality were likely to have values of the same order, and the municipal ALWG/OAL values ranged from 0 to 100%. Variables ALWG/OAL and CA-DE can be considered indicators of the intensification level of the local farming system. The association between CA-DE and ALWG/OAL with MO-RA suggests that some indicators of the farming systems should be considered within mortality analyses. Nevertheless, the associations reported must be taken with caution and attempts to define more accurate and pertinent indicators should be made.

Effect of DPA on MO-RA

The localization of the unit among DPA had an important effect on MO-RA and MO-PR changes. This is in agreement with the effect of the states in a US study (Smith et al., 2000) or with the U-shaped relationship between cow mortality and monthly average temperature (Stull et al., 2008). Dairy production area was an efficient way to trap effects that cannot be investigated with specific indicators. Important variations in weather and altitude between DPA were observed. Because the DPA overlap the French breeding systems and because the structural characteristics of the DPA differ strongly, an analysis of mortality at this geographical level should be useful.

Risk Factors and Causes of Mortality

Some explanatory variables used in previous studies were not included here because data were not available. For instance, housing systems have an important effect on mortality but were not explored within this study (Thomsen et al., 2006). Preventive health measures such as vaccination or the number of curative

treatments were not included either. The coefficient of determination of the model would probably be higher if these kinds of explanatory variables had been taken into account.

Pathologic causes of death were defined in recent studies (Faye and Perochon, 1995; Esslemont and Kos-saibati, 1997; Thomsen et al., 2004; Watson et al., 2008; McConnell et al., 2009, 2010). Even if the cause of the death cannot be determined by the risk factors, some relationships were reported (McConnell et al., 2010). For instance, death during early lactation is related to the risk factor “negative energy balance,” and the risk factor “failure of disease recognition” is linked to death with infectious components. This suggests that some risk factors give insight into the cause of death.

Mortality as Sporadic Phenomenon or Within-Herd Interdependent Phenomenon

Only around 25% of the variability of the data was explained by the Heckman models. This low value, the low correlation between MO-RA of 2005 and 2006, and the high number of units with few deaths per year are in agreement with the sporadic characteristics of dairy cow mortality. In another study dealing with the cow mortality among US herds enrolled in DHI, the total coefficient of determination of the model was only 8.4%, with year, month, parity, lactation stage, and breed as explanatory variables (Miller et al., 2008).

Contrarily, deaths within a herd seemed to be interdependent as suggested by the significant effect of the IMR values in the Heckman models. This is consistent with the number of units having many deaths as well as the moderate correlation between the number of cow-years and the number of deaths. The positive value of the IMR estimate suggests that having at least one death (MO-RA >0) would be a risk factor to have a high MO-RA. In other words, having one death would be a risk factor to have other deaths, and having no death would be a “protective factor” relative to having one death. This is consistent with the fact that mortality depends on risk factors, which generally concern several animals over a long period.

Risk Factors of MO-RA

This study shows that having no mortality or very low mortality rates are close situations in the field. Most of the explanatory variables significant in both the probit and Heckman models were the same. The results confirm that having mortality compared with having no mortality and being at a high mortality level compared with a low level were caused by essentially the same factors. In spite of low R^2 and low correlation of MO-

RA between 2005 and 2006, this study clearly shows that the same factors influenced dairy cow mortality in both years and that the weight of each effect was close for 2005 and 2006. Even if the units with mortality or without mortality were not the same in 2005 and 2006, and even if the units with low or high mortality differed between 2005 and 2006, the same herd-level factors were involved in the mortality variation. This strongly suggests that MO-RA is the result of several herd-level and contextual factors that can be considered as risk factors for mortality at the farm level.

CONCLUSIONS

This study shows an average mortality rate for French dairy cows. Several herd-level risk factors have an effect on dairy cow mortality. Among them, the association between farms specializing in dairy production and lower MO-RA suggests better management skills in specialized farmers. The study also confirms the influence of the farmers' management style on the mortality. The association between the contextual factors and mortality shows the usefulness of including territorial considerations in mortality studies. The farming system has its own effect on mortality, probably taking into account some nonobserved effects. The relationship between municipal farming intensification and decreased mortality must be considered with extreme caution. Improving the understanding of mortality requires the calculation of accurate and discerning herd-level and contextual indicators. Moreover, a national survey of the annual mortality of dairy cows with data sets including all dairy herds would be useful.

ACKNOWLEDGMENTS

The authors thank Pascal Deriu (Information Systems, French Ministry of Agriculture, Paris, France) for the data disposal; Roland Chartier, Philippe Lemenager, Mathieu Lenivet, Benoit Garcia, Cedric Gendre, and Marc Roze (INRA, Toulouse, France) for data management support; Elise Maigne, Pierre Cantelaube (INRA, Toulouse, France), and Didier Concordet (Statistics Unit, Toulouse University, France) for statistical support; and Steven Hunt and Glen Almond (Population Health and Pathobiology, North Carolina State University, Raleigh) for English reviewing.

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