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Herd-level and territorial-level factors influencing average herd somatic cell count in France in 2005 and 2006

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Mastitis is a multifactorial disease and the most costly dairy production issue. In spite of extensive literature on udder-health risk factors, effects of metabolic diseases, farmers' competencies and livestock farming system on somatic cells count (SCC) are sparsely described. Herd-level or territorial-level factors affecting monthly composite milk weighted mean cow SCC (CMSCC) were analysed with a linear mixed effect model. The average CMSCC was 266 000 cells/ml. Half of the herds had CMSCC $>$ 300 000 cells/ml for 2–6 months a year, and 15% of herds for more than 7 months a year. CMSCC was positively associated with the number of cows, having a beef or fattening herd in addition to the dairy herd, the monthly average days in milk, the yearly age at first calving, the yearly proportion of purchased cows and the yearly culling rate. Moreover, a positive association is reported between CMSCC and the monthly proportion of cows probably with subacute ruminal acidosis (fat percentage minus protein percentage $\leqslant 0{\cdot}30\%$, for Holstein) and negative energy balance (protein to fat ratio $\leqslant 0{\cdot}66$, for Holstein), the yearly average calving interval, having at least one dead cow and the mean monthly temperature. The association was negative for a predominant breed other than Holstein, the monthly milk production, the yearly dry-off period length, the monthly first calving cow proportion, having an autumn calving peak, being a Good Breeding Practices member, the monthly number of days with rain, the altitude and the territorial cattle density. CMSCC varied widely among the 11 dairy production areas. In conclusion, this study showed the average CMSCC for the French dairy cows, compared with international results. Moreover, it quantified the contribution of several factors to CMSCC, in particular metabolic diseases and the farm environment.

Keywords: Composite weighted SCC, herd-level factors, territorial-level factors.

Mastitis is a common multifactorial disease and is the most costly production issue in dairy cows. The major factor influencing BMSCC or composite weighted mean cow SCC (CMSCC) (Valde et al. 2005) is the prevalence of intramammary infections within the herd. A lot of epidemiological studies reported herd-level factors influencing BMSCC: first, milking procedures and general cleanliness (Barnouin et al. 1986; Chassagne et al. 2005; Rodrigues & Ruegg, 2005); second, effects related to the lactation, such as milk production, lactation stage and parity (Berry et al. 2006; Wenz et al. 2007; Green et al. 2008; Madouasse et al. 2010b); third, some structural farm characteristics (herd size) and replacement policy (De Vliegher et al. 2004; Rodrigues et al. 2005; Wenz et al. 2007; Elmoslemany et al. 2010). The influence of these factors on BMSCC are probably indirect, because they impact the prevalence of (sub)clinical mastitis.

In addition to these well known effects, BMSCC or CMSCC also seem to depend on other factors. First, few studies evaluated the direct effect of nutrition or metabolic diseases on BMSCC (Nyman et al. 2008, 2009). Because the effects of metabolic diseases on immunity are extensively reported (Scalia et al. 2006), an association between udder health and negative energy balance or subacute ruminal acidosis can be suspected. Second, farmers' characteristics and competencies were reported to highly influence clinical mastitis (Jansen et al. 2009) and BMSCC (Barkema et al. 1999; Rougoor et al. 1999; Khaitsa et al. 2000; Valeeva et al. 2007). The farmer's perception of BMSCC as a problem has an effect on SCC management, and BMSCC is associated with precise or fast workers (Valeeva et al. 2007). In addition, various combinations of farm activities (dairy, beef or fattening cattle, goats, sheep, poultry and pigs) within one

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*For correspondence; e-mail: d.raboisson@envt.fr farm usually occur in France (Renting et al. 2009); the behaviour of the farmer towards the dairy herd could differ between specialized and non-specialized farmers. Third, some studies showed that BMSCC and CMSCC depend on the geographical areas or on the territorial characteristics of the dairy production (Allore et al. 1997; Norman et al. 2000), but such results are rare. This effect is potentially important in France, because of its large livestock diversity. Dairy cattle are mainly in the north, beef, sheep and goat in the centre and the south and Protected Designation of Origin milk productions in the mountains (a fifth of the agricultural land) (Rouquette & Pflimlin, 1995; Sarzeaud et al. 2008).

The hypothesis of this study was that French CMSCC depends on several herd-level factors, including metabolic diseases and farmers' competencies, as well as some territorial risk factors, regarding the livestock farming system. This study aimed to describe CMSCC in France and, secondly, it quantified the weight of selected herd-level and territorial-level risk factors on CMSCC.

Materials and Methods

Datasets

Several datasets reporting animal or farm data were used to calculate dairy herd-level and farm environmental indicators. All data were geo-located at the municipal level. There are 3600 municipalities in France, with a mean area of 15 km^2.

The detailed characteristics of the National Bovine Identification Database (NBID) was previously described (Raboisson et al. 2011). Briefly, NBID contains routine records on individual data of farms and animals. The number of dairy cows identified for at least one day was 5·3 and 5·1 million and the number of cow-years was 3·8 and 3·7 million for 2005 and 2006, respectively. Animals were sorted and associated to a dairy, beef (suckler cows) and fattening (bulls, steers or veal calves) herd within each farm. The records from French herds in the Milk Control Programme (MCP) during 2005 and 2006 included lactational and test-day records for the 4294 million cows with at least one control in 2005 or 2006. The other datasets used were previously described (Raboisson et al. 2011). Briefly, they included the farms registered as following the charter of Good Breeding Practices member, the municipal agricultural land as 'always with grass' (named grassland) and the municipal overall agricultural land (named overall land). Protected Designation of Origin areas were provided from the National Institute for Quality (www.inao.gouv.fr). Data related to weather conditions were provided by Météo-France (www.meteofrance.fr).

Variables

The variables were calculated at the dairy herd level, for each month or year (2005, 2006) from the databases. Calculations made from NBID (breed, typology, primiparous proportion, culling rate, age at first calving, calving interval) were previously described in detail (Raboisson et al. 2011). The variables calculated from the MCP data included all the lactating animals present in the farm on the days of the controls.

CMSCC is the herd arithmetical mean of all individual SCC weighted by each cow's 24-h milk production for one test-day, as previously suggested (Valde et al. 2005).

Three 'structural' variables were included: herd size (average number of cows for all test-days of the year), predominant breed and farm typology (Dairy; Dairy and Beef; Dairy and Fattening). The lactation characteristics were defined using the test-day mean milk production of the herd and the test-day average days in milk. The average length of the dry-off period was calculated yearly. Several variables accounted for the farm replacement policy: monthly proportion of primiparous cows, monthly average age at first calving, yearly culling rate (irrespectively of the reasons for the removal) and yearly purchase of cows from other farms (No purchase, Low purchase or High purchase). The thresholds used to distinguish Low and High classes was the 75% quartile of the purchase percentage (27 and 19%, for 2005 and 2006, respectively).

For each test-day, cows were considered to have a negative energy balance (NEB) when their milk protein-to-fat ratio was $\leqslant 0{\cdot}66$ (Duffield et al. 1997). They were considered to have subacute ruminal acidosis (SARA) when their fat percentage minus protein percentage was $\leqslant 0{\cdot}30\%$ (including fat percentage <protein percentage). When the predominant breed was not Holstein, the thresholds were corrected proportionally to the mean milk and fat protein percentages of each breed (rule of three; Holstein with 3·2% and 4·1% of protein and fat). Three classes were built for monthly SARA and NEB: Low risk (percentage = 0% at one test-day), Moderate risk and High risk. The threshold used to distinguish Moderate and High classes was 10 and 25%, for NEB and SARA, respectively, as suggested by the distribution of the values.

Farmers' competencies were included through variables related to the general farming management, as suggested by a previous study (Valeeva et al. 2007). The yearly average calving interval was used as an indicator of the reproduction management efficiency on the farm. The presence of an 'autumn calving peak' was defined when at least 35% of the annual calvings occurred in a 3-month period that was between July and November. This variable aims to detect the sensitivity of farmers to produce milk during the best paid period of the year. Because one-third of farms had no mortality each year, the annual mortality was a categorical variable defined by 'No dairy cow death' or 'Having at least one dairy cow death'. Being a Good Breeding Practices member was defined once for the 2-year period.

Two territorial factors used in the present study were previously described [(Raboisson et al. 2011): cattle density (expressed in livestock unit/km^2 (Sarzeaud et al. 2008)] and the grass on land (grassland on overall land) ratio. Moreover,

Fig. 1. Definition of the dairy production areas (DPA). Numbers refer to dairy production areas (see key in Table 5).

the municipal monthly mean temperature, wind, relative humidity, quantity of rain and number of days with rain and frost per month were included. The 11 dairy production areas (Fig. 1) used to characterize the French territories (Raboisson et al., 2011) overlap approximately the French breeding systems (Rouquette & Pflimlin, 1995; Sarzeaud et al. 2008).

Statistical analysis

Data were analysed using R (version 2.10.1). A linear mixed effect model was used to explain monthly CMSCC, with the farm as random variable (package nlme). CMSCC was ln-transformed, because it suited a non-normal distribution. Estimates reported are expressed in % change of CMSCC (UCLA, 2012).

All variables including month were included in the model, except the following ones. The variables 'parity' and 'cow age' were excluded, because of their high correlation with primiparous proportion and age at first calving ($r > 0{\cdot}7$). Because the grass on land ratio was strongly correlated with the dairy production areas and altitude ($r = 0{\cdot}65$), it was not included. Moreover, the effects of month or weather were included alternatively, because of the correlation among these variables. The altitude was neither correlated with temperature ($r = -0{\cdot}18$), nor with the number of rainy days ($r = -0{\cdot}30$), and all 3 remained in the models. Only the mean temperature and the number of days with rain were included in the model, because of the high correlations with the other weather variables. Because of the large variations of altitude within the areas, both remained in the model. All the possible two-factor interactions were included (one by one) in the model with all the main effects. Depending on the coefficient of the interaction and on the AIC of the model, the interaction can be removed from the model, even if significant: it was interpreted as a significant interaction without any biological importance.

Results

Descriptive analysis of CMSCC

Monthly CMSCC and percentage of herds above 250 000, 300 000 and 400 000 cells/ml were very close between the 2 years (Table 1). The correlations of CMSCC between 2 successive months were 0·55–0·57 for months from January to July and 0·49–0·52 for months from July to December. The within-farm correlations of CMSCC between the same months of 2005 and 2006 were 0·33–0·35, but raw data show the same monthly distribution among areas (Fig. 2). Percentages of cows and herds in MCP and average CMSCC varied widely among dairy production areas (Table 2). No significant difference ($P > 0{\cdot}05$, *t*-test and χ^2 tests) was observed for continuous and categorical variables between 2005 and 2006 (Tables 3 & 4). The correlations between proportion of cows with SARA or NEB for the whole lactation and the first 4 months were 0·84 for SARA and 0·86 for NEB.

Regression analysis

The results of the model are expressed in CMSCC change (Table 5). For instance, a 10 cow increase is associated with an 3·3% CMSCC increase: if the initial value of CMSCC is 300 000 cells/ml, the expected CMSCC after an 10 cow increase is 309 900 cells/ml (300 000 × 1·033) (UCLA, 2012).

Among the effects reported, a 10% increase of the cow proportion at risk for NEB and SARA is associated with a 1–2% CMSCC increase (SARA) and a 3–6% CMSCC increase (NEB) (Table 5). CMSCC was also positively associated with the average calving interval and having at least one dairy cow death this year, although association was negative for having a calving peak in autumn and being a Good Breeding member. For the territorial variables, the cattle density and the altitude were negatively associated with CMSCC, but association was positive for temperature. All area but area 11 were positively associated with CMSCC, compared with area 1 (Table 5).

The AIC value of the model was lower when the weather variables replaced the variable month, even if difference was low (AIC = 1 536 000 and 1 548 000, respectively). Removing the variables altitude and weather from the model induced important changes for the coefficient of areas 4, 7 and 10 (CMSCC change were − 2, − 2, − 1·5%, respectively), but not for the coefficients of other variables.

All significant interactions were considered as non-biologically relevant, according to the coefficients and the AIC.

Table 1. Characteristics of French monthly composite milk weighted mean cow somatic cell count (Mo-CMSCC)† in 2005 and 2006

		2005		2006	
Mo-CMSCC, cells/ml × 10^{-3}	Mean	266		266	
	SE	163		166	
	Median	229		229	
Number of herds	Overall	61 965		59 759	
	With ⩽ 6 test days a year	935	(1·5%)	980	(1·6%)
	With 7–9 test days a year	7210	(11·6%)	7732	(12·9%)
	With ⩾ 10 test days a year	53 820	(86·8%)	51 047	(85·5%)
Number of herds with Mo-CMSCC > 300 000 cells/ml	In 0 month	11 528	(18·6%)	9984	(16·7%)
	In 1 month	10 297	(16·6%)	10 357	(17·3%)
	In 2–6 months	30 762	(49·6%)	30 176	(50·5%)
	In 7–12 months	9378	(15·2%)	9242	(15·5%)

† CMSCC was the herd arithmetic means of all individual SCC weighted by each cow's 24-h milk production for each test-day

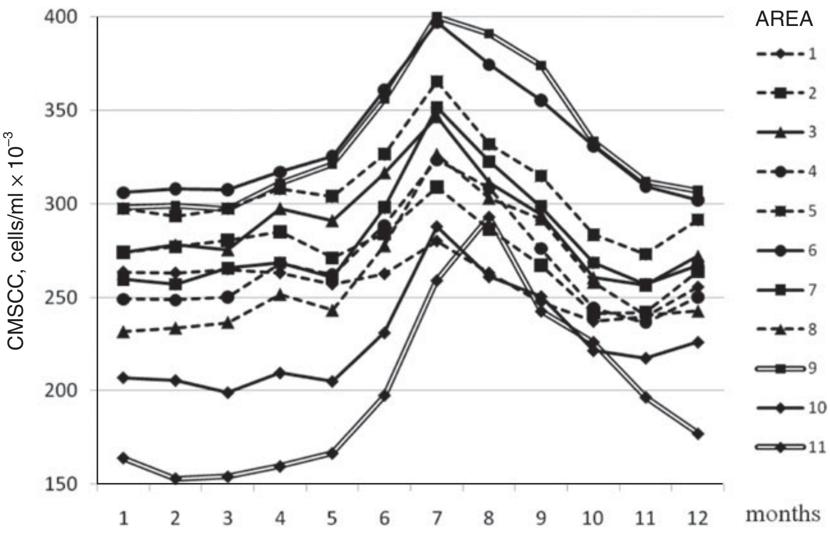

Fig. 2. Monthly composite milk weighted mean cow somatic cell count (CMSCC) per dairy production area (DPA) and per month. The values of each month, indicated by the month number, is the 2005 and 2006 mean CMSCC value.

Discussion

Datasets and CMSCC

French MCP represented 61, 57 and 85% of the herds, cows and milk produced, respectively. MCP is reported to represent 40–90% of the dairy cows and herds, depending on countries (Lukas et al. 2005). In spite of differences among dairy production areas (Table 2), present results seem to represent well the French situation and probably also the udder health in other countries.

The use of CMSCC in this study allowed investigation of the udder health situation of the herds and taking into account the issues relative to the BMSCC. A high correlation (0·78) among prevalence of high SCC and CMSCC is reported (Lievaart et al. 2007). In small herds (mean herd size = 15 cows), CMSCC is highly correlated with both BMSCC ($r = 0·77$) and with the percentage of individual cow milk samples > 200 000 cells/ml ($r = 0·72$) (Valde et al. 2005). Nevertheless, differences between CMSCC and BMSCC are reported to vary from 10 000 to 182 000 cells/ml in larger herds, depending on at least the milk withheld from the bulk tank (Lievaart et al. 2009).

Monthly CMSCC mean and median were close to the lowest penalties threshold of BMSCC (250 000 cells/ml) and important standard deviations were reported. The limits of comparison with other studies come from the variations among the calculation methods (in particular between CMSCC and BMSCC), among the thresholds for penalties and premiums and among the data collection dates. Reported mean herd SCC varied from 140 000 to 340 000 cells/ml in studies carried out in the 1990s in USA, Ontario, New Zealand or Norway (Schukken et al. 1992; Sargeant et al. 1998; Norman et al. 2000; McDougall, 2003; Valde et al. 2005). Taken altogether, this suggests an

Table 2. Characteristics of dairy production areas

	Number of dairy herds and cows in MCP per DPA† in 2005, $\times 10^{-3}$		CMSCC‡, $\times 10^{-3}$ cells/ml		Mean altitude, m		Grass on land ratio,%		Percentage of units in a PDO§ area	Cattle density, LU¶/km^2	
Name	Units	Cows	2005	2006	Mean	SD	Mean	SD		Mean	SD
Overall	60·6 (61%)	2209 (57%)	266	266	292	280	0·52	0·24	34%	0·57	0·35
1 (Grand-Ouest)	22·5 (75%)	796 (64%)	255	257	97	52	0·45	0·12	0%	0·67	0·29
2 (Normandie)	8·0 (56%)	320 (53%)	271	270	127	67	0·55	0·18	87%	0·80	0·38
3 (Nord)	5·1 (55%)	191 (53%)	285	285	120	60	0·33	0·23	13%	0·61	0·42
4 (Est)	5·1 (63%)	209 (59%)	262	260	300	116	0·44	0·24	59%	0·43	0·35
5 (Centre)	1·1 (69%)	48 (67%)	308	297	158	48	0·22	0·15	3%	0·19	0·14
6 (Poitou)	1·9 (67%)	81 (66%)	327	325	136	90	0·39	0·26	0%	0·36	0·25
7 (Massif Central)	3·4 (40%)	108 (40%)	271	274	807	241	0·86	0·12	73%	0·50	0·23
8 (Rhône-Alpes)	4·3 (56%)	131 (57%)	252	255	573	301	0·66	0·21	18%	0·40	0·25
9 (Sud-Ouest)	5·2 (56%)	169 (57%)	322	321	373	265	0·53	0·27	31%	0·36	0·24
10 (Franche-Conté)	3·5 (67%)	114 (59%)	219	222	545	261	0·79	0·21	100%	0·42	0·25
11 (Savoie)	1·2 (55%)	41 (50%)	189	190	991	509	0·88	0·14	100%	0·32	0·24

† Percentages are expressed relative to the overall number of units and to the number of cow-years within dairy production areas (MCP, milk control programme; DPA, dairy production area)

‡ CMSCC (composite milk weighted mean cow somatic cell count) were the herd arithmetic means of all individual SCC weighted by each cow's 24-h milk production, for all test-days of the year

§ PDO: protected designation of origin

¶ Livestock units

Table 3. Descriptive statistics of continuous variables in 2005 (because 2005 and 2006 results are very close, only 2005 results are reported)

	Mean	SD
Number of cows	35·8	15·7
Test-day milk production, l	23·7	4·8
Average days in milk, d	183	43
Length of dry-off period, d	68·2	17·3
First calving cow proportion,%	33·7	8·5
Age at first calving, months	32·3	4·1
Culling rate,%	21·9	10·9
Average calving interval, d	411	30·3
Average temperature, °C	10·7	6·1
Monthly number of days with rain	17·3	5·7
Altitude, m	256	281
Cattle density, LU/km^2	0·57	0·35
Grass on land ratio,%	0·52	0·24

average CMSCC of the French dairy cows that is within the range reported for other countries.

The mean CMSCC values of a country must be interpreted in relation with the local thresholds for penalties and exclusion, which vary widely among countries. It is 750 000 cells/ml for USA, 500 000 cells/ml for Canada and 400 000 cells/ml for most European countries (2 consecutive trimestrial geometric mean BMSCC >400 000 cells/ml; Directive 92/46/EEC), Australia and New Zealand (Norman et al. 2000). Moreover, SCC tended to decrease across time: for instance, BMSCC was 345 000 and 250 000 cells/ml in Ontario in 1986–1987 and 1994–1995, respectively (Sargeant et al. 1998).

Effects of farm structures, lactation characteristics and replacement policy on CMSCC

The positive association of herd size and CMSCC was in accordance with previous results (Skrzypek et al. 2004; Valde et al. 2005), but in disagreement with others (Fenlon et al. 1995; Norman et al. 2000). To our knowledge, the effects of the predominant breed and of specialization into dairy production on CMSCC or BMSCC were not previously reported. Among the hypotheses proposed, the specialized farmers could give more attention for the dairy cows and had better management acumen for the dairy production and better biosecurity measures. From the authors' personal observations, in France, dairy and beef or fattening herds of the same farm are often not strictly separated.

The negative association of CMSCC and the milk production was in accordance with previous results and probably results from a dilution effect (Emanuelson & Funke, 1991; Fenlon et al. 1995; Wenz et al. 2007).

The 5·6% decrease of CMSCC for each 10% increase of primiparous cow percentage is in agreement with the decreased odds ratio of having high SCC in early lactation for primiparous cows compared with cows in parity >5 (Green et al. 2008). In the present study, the culling rate and CMSCC were positively associated, although no significant association between culling-whatever the reason for the culling-and BMSCC was found in previous studies (Fenlon et al. 1995; Wenz et al. 2007). The present study cannot distinguish culling as a consequence of high CMSCC or to decrease CMSCC in the future.

Purchasing cows induced a +7% change of CMSCC, compared with the herds without purchasing. The estimators

Table 4. Descriptive statistics of categorical variables in 2005 (because 2005 and 2006 results are very close, only 2005 results are reported

Name	Classes	Number
Predominant breed	Holstein	40 951
	Montbéliarde	8291
	Normande	4166
	No predominant	7162
	Other breeds	1209
Farm typology	Dairy	28 938
	Dairy and beef	8559
	Dairy and fattening	24 282
Purchased cow proportion	No purchase	47 012
	Low purchase	13 697
	High purchase	1070
Cow proportion at risk for negative energy balance†	Low risk	148 823
	Average risk	289 901
	High risk	197 438
Cow proportion at risk for subacute ruminal acidosis †	Low risk	60 799
	Average risk	403 906
	High risk	171 457
Autumn calving peak	No	46 347
	Yes	15 432
Death	No dairy cow death	18 522
	At least one dairy cow death	43 257
Good Breeding Practices member	No	12 649
	Yes	49 130

† Results refers to the number of farm-controls

were of the same order of magnitude between Low-Purchase and High-Purchase, suggesting an effect related to ‘at least one cow bought’/‘no cow bought’. The effect of ‘any cattle brought onto unit’ was not associated with BMSCC in a study based on 1031 US dairies (Wenz et al. 2007). Newly introduced cows must face modifications of their environment and of the milking practices, increasing their risk for mastitis. Purchasing cows also increases the risk of introducing infection from another herd. It can concern both pathogens directly related to udder health or other pathogens. The involvement of other pathogens was suggested by the positive association between purchasing replacement animals (before calving) and BMSCC (Fenlon et al. 1995). Purchasing could also be the consequence of a high culling because of high CMSCC, but a low yearly association between culling and purchasing was described ($r < 0{\cdot}1$).

Effects of metabolic diseases on CMSCC

Studies dealing with the relationship between energy balance and milk composition suggest an association of NEB and fat percentage increase, protein percentage decrease, and protein-to-fat ratio decrease (Duffield et al. 1997; de Vries & Veerkamp, 2000; Heuer et al. 2001). Differences among the conclusions of these studies did not allow the defining of a consensual best tool among these three indicators of NEB.

Lactation stage and season were reported to influence protein-to-fat ratio, in particular when large datasets were used (Madouasse et al. 2010a). The potential effects of breed, lactation stage, season (through month or weather) and diets (through month, weather and dairy production areas) were taken into account in the models. Moreover, a high correlation is reported among the indicators calculated for the whole lactation or the first 4 months. Taken altogether, this suggests using protein-to-fat ratio as NEB indicator in the present large database study, even if its accuracy remains difficult to define.

The sensitivity and specificity to detect subclinical ketosis were 58 and 69% with a test-day protein-to-fat ratio threshold of 0·75 (Duffield et al. 1997). Because a high specificity was looked for to analyse the relationship between NEB and CMSCC, the threshold used was 0·66 (sensitivity and specificity reported were 20 and 85%, respectively).

SARA is known to induce a milk fat depression, with no or low milk protein depression (Kleen et al. 2003; Oetzel, 2004; Enjalbert et al. 2008), suggesting its association with the test-day protein and fat percentages difference. Nevertheless, the sensitivity and specificity of milk composition tools to test SARA were not known (Raboisson & Schelcher, 2008).

This study clearly shows the positive association between the SARA and NEB indicators and CMSCC, with an increased change (twice higher) from the Moderate risk class to the High risk class. SCC at first test-day of the lactation was positively associated with the non-esterified fatty acid (NEFA) concentration before calving and with the difference of the NEFA concentration before and after calving, whereas the association with the beta-hydroxybutyric acid (BHBA) concentration before calving was negative (Nyman et al. 2008). This is in agreement with the present results when considering the direct relationship of NEFA on immune cells (Lacetera et al. 2004; Scalia et al. 2006) and the potential origin of BHBA from the rumen (Oetzel, 2004). To our knowledge, the relationship between SARA and CMSCC has not been reported previously.

Effects of dairy farmers' competencies on CMSCC

Farmers' motivations to improve mastitis management referred to monetary factors (premium-penalties oriented motivations and basic economic motivations) and to non-monetary factors as efficient (well-organized) farming (Valeeva et al. 2007). In the present study, the calving interval, the autumnal calving peak and having at least one dairy cow dead this year were included in the models to indicate the farmers' management skills. A high level of management skill was needed to achieve a low herd-calving interval, to gather calvings to a few months and to have no cow death. A beneficial effect of this level of general

Table 5. Variables associated with a monthly composite milk weighted mean cow somatic cell count (CMSCC) change. Results are expressed in CMSCC change (%). For instance, a 10-cow herd-size increase is associated with an 3·3% CMSCC increase: if the initial value of CMSCC is 300 000 cells/ml, the expected CMSCC after a 10-cow increase is 309 900 cells/ml (300 000 × 1·033)

		CMSCC change
Intercept		510***
Number of cows†		3·3***
Predominant breed	Holstein	reference
	Montbéliarde	−18***
	Normande	−6***
	No predominant	−4***
	Other breeds	−24***
Farm typology	Dairy	reference
	Dairy and beef	4·7 ***
	Dairy and fattening	1·4***
Monthly milk production, l‡		−2·3***
Monthly average days in milk, d§		0·3***
Yearly length of dry-off period, d§		−0·4***
Monthly first calving cow proportion,%¶		−5·6***
Yearly age at first calving, months		1·0***
Yearly culling rate,%¶		0·7***
Average temperature, °C		+0·5***
Monthly number of days with rain		−0·2***
Purchased cow proportion	No purchase	reference
	Low purchase	7·1***
	High purchase	6·7***
Cow proportion at risk for negative energy balance	Low risk	reference
	Moderate risk	3·0***
	High risk	6·3***
Cow proportion at risk for subacute ruminal acidosis	Low risk	reference
	Moderate risk	1·1***
	High risk	2·2***
Average calving interval, d§		2·2***
Autumn calving peak	No	reference
	Yes	−1·5***
Cow mortality (per year)	No dairy cow death	reference
	At least one dairy cow death	4·4***
Good Breeding Practices member	No	reference
	Yes	−9·4***
Cattle density, livestock units/km‡		−7·3***
Altitude, 100 m		−2·1***
Dairy production area	1 (Grand-Ouest)	reference
	2 (Normandie)	3·5***
	3 (Nord)	9·3***
	4 (Est)	2·2***
	5 (Centre)	12·2***
	6 (Poitou)	11·3***
	7 (Massif Central)	12·6***
	8 (Rhône-Alpes)	9·5***
	9 (Sud-Ouest)	14·8***
	10 (Franche-Conté)	6·9***
	11 (Savoie)	−13·8***

† For an increase in herd size of 10 cows
‡ For an increase of 1000 l
§ for an increase of 10 d
¶ for an increase of 10%
*$P<0·05$; **$P<0·01$; ***$P<0·001$; NA, not available

management on CMSCC was likely to occur. Previous studies suggested taking into account variables related to the farmers' attitudes, and not to the farmers' behaviour, to evaluate farmers' characteristics (Barkema et al. 1998; Rougoor et al. 1999; Khaitsa et al. 2000; Jansen et al. 2009). For instance, low BMSCC was reported to be associated with 'clean and accurate' farmers, compared with 'quick and dirty' (Barkema et al. 1999).

The effect of being a Good Breeding Practices member appears to be high when considered in the light of the limited conditions relative to membership (Dockes et al. 2006). Maybe a selection bias occurred, with the most informed and competent farmers that would tend to become Good Breeding Practices member.

Effects of farm environmental factors on CMSCC

Municipal cattle density was an indicator of the local farming system intensification level. Increased cattle density was associated with a decreased CMSCC and was previously associated with decreased mortality (Raboisson et al. 2011).

The environment of the farm and its localization among dairy production areas had important and various effects on CMSCC.

The positive association of the mean temperature and CMSCC is in agreement with previous studies reporting higher BMSCC in southern compared with northern regions of USA (Allore et al. 1997; Norman et al. 2000; Oleggini et al. 2001; Wenz et al. 2007). The negative association of altitude and CMSCC is not related to the lower temperature in the mountains, because the temperature was included within the model and because the correlation among altitude and temperature was low. The effect of the number of days with rain remains unexplained.

If altitude and weather variables were excluded from the model, areas 2, 4, 7, 10, 11 were negatively associated with CMSCC. These 5 areas include at least half of the herds in a Protected Designation of Origin (PDO) area (Table 2), whereas the other areas had less than half of the herds in a PDO area. Some, but not all of these 5 areas are in the mountains (Table 2). PDO goods are produced, processed and prepared in a given geographical area. They are related to specific farm structural factors and management practices and they refer to specifications and a recognized know-how. PDO are also collective tools to promote the products in association with high milk price; the specific payment scheme concerns SCC and bacteria count thresholds among other specifications. This context probably impacts SCC management. A direct evaluation of being in a PDO area would need specific analysis and was not done here.

With the altitude and weather variables in the model, the effect of each DPA was still significant. The coefficients of the areas represented specific and homogeneous risk factors relative to the farming system which were not included in the other effects. The effect of area or farming system summarized a global effect that is over the sum of the specific factors of this area (Ploeg & Renting, 2002). For instance, the very hot weather of area 9 in summer could explain the highest association of this area and CMSCC, compared with other areas.

Conclusions

This study shows the average CMSCC for the French dairy cows and the impact of several herd-level risk factors on CMSCC. An association between metabolic disorders and udder health was established. Farmers' competencies, general farm management and farmers' specialization into dairy production also appeared as key factors concerning the udder health. Including territorial considerations in SCC studies also seems of high importance.

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