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Study of the association of atmospheric temperature and relative humidity with bulk tank milk somatic cell count in dairy herds using Generalized additive mixed models

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ABSTRACT

Elevated bulk tank milk somatic cell count (BMSCC) has a negative impact on milk production, milk quality, and animal health. Seasonal increases in herd level somatic cell count (SCC) are commonly associated with elevated environmental temperature and humidity. The Temperature Humidity Index (THI) has been developed to measure general environmental stress in dairy cattle; however, additional work is needed to determine a specific effect of the heat stress index on herd-level SCC. Generalized Additive Model methods were used for a flexible exploration of the relationships between daily temperature, relative humidity, and bulk milk somatic cell count. The data consist of BMSCC and meteorological recordings collected between March 2009 and October 2011 of 10 dairy farms. The results indicate that, an average increase of 0.16% of BMSCC is expected for an increase of 1 °C degree of temperature. A complex relationship was found for relative humidity. For example, increase of 0.099%, 0.037% and 0.020% are expected in correspondence to an increase of relative humidity from 50% to 51%, 80% to 81%; and 90% to 91%, respectively. Using this model, it will be possible to provide evidence-based advice to dairy farmers for the use of THI control charts created on the basis of our statistical model.

1. Introduction

Milk somatic cell count (SCC) of dairy cows is considered an excellent indicator of udder health and milk quality at the individual cow and herd levels. Bulk tank milk somatic cell count (BMSCC) is limited by law in the European Union to a threshold of 400,000 cells/ml, considered as geometric mean of at least one sample per month for three consecutive months. Decreased milk production and value associated with increasing somatic cell count and the regulatory limits for BMSCC make it imperative for dairy farmers to monitor and manage the many factors that influence infection risk and inflammatory response. The losses at the farm level associated with increasing SCC have been extensively reviewed by Fetrow (2000). Changes in fluid milk quality, shelf life, and cheese yield and quality associated with elevated SCC have been well defined by Schällibaum (2001). Subclinical and clinical mastitis reduce dairy farm profit because they reduce milk production (Hagnestam-Nielsen et al., 2009), change milk composition (Ma et al., 2000), and increase therapeutic costs and labor. BMSCC measures are indicative of farm-level prevalence of infected quarters and should be considered a measure of animal welfare because mastitis is a painful disease even in its subclinical stage (Kemp et al., 2008). Improved udder health will lead to improved animal welfare, improved production efficiency, and reduced use of antibiotics (Trevisi et al., 2014).

Season and heat stress are described as risk factors for new intramammary infections (IMI), contributing to an increase in SCC in milk (Gautam et al., 2011; Pusta et al., 2011; Smith et al., 2013; Bertocchi et al., 2014; Lambertz et al., 2014). Stress caused by heat occurs when dairy cows suffer hyperthermia as they fail to maintain thermo-neutrality in environments with high ambient temperature and relative humidity. Evaluation of air temperature alone does not provide an accurate assessment of the effects of the thermal environment on physiology, welfare, health, and productivity in farm animals (Segnalini

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et al., 2011; Hill and Wall, 2015; Nasr and El-Tarabany, 2017). Strong winds, especially in combination with precipitation, amplify the adverse effects of low temperature. Dakić et al. (2006), indicated that cold stress during winter has a considerable influence on the somatic cell count increase in cow milk, but humidity was not considered.

Different approaches have been adopted to quantify heat stress in farm animals, including utilization of the Temperature Humidity Index (THI), which combines measurements of temperature and relative humidity in a single value. This is a practical tool and a standard for many studies and applications in animal biometeorology. The THI proposed in literature are defined as linear combinations of temperature and relative humidity (Akyuz et al., 2010; Crescio et al., 2010; Segnalini et al., 2011). Because different farm animal species differ in their sensitivity to climatic conditions, several formulas that differ in the weight given to the variables have been proposed (Bohmanova et al., 2007). The predictive performances of such formulas have been reported in the literature, thus showing the utility of THI for assessing the effects of heat stress. Nevertheless, the formula's linearity, although convenient, cannot be assumed to hold a priori. Thus a THI based on a more complex formula could be needed. To such end, a preliminary step is necessary to understand the shape of the relationship among BMSCC, temperature and humidity. Whenever THI is provided only as a synthetic measure of heat stress, this prevents showing to the practitioner the role of temperature and relative humidity. To our knowledge, no attempt has been made to investigate the effects of temperature and relative humidity as separate variables, as a first step of THI building.

The aim of our work is to improve the understanding of the effects of temperature and relative humidity on daily BMSCC variations through a multivariable regression modeling approach as described by Harrell (2001).

2. Materials and methods

2.1. Data

Data were collected from thirteen dairy farms (identified with capital letters from A to M) and two weather stations located in the Lombardia region (in northwest Italy) for 30 months (3th March 2009 until 3th October 2011). Twelve herds were from the province of Bergamo and 1 from the province of Cremona (Fig. 1). The farms were included according to the following criteria:

1. minimum number of 50 lactating cows per herd;
2. herds in a limited geographic area, which allowed weekly bulk tank sample collection in 3 h;
3. farmers' attitude to reliably perform the bulk tank sampling; and
4. two years of continuous data collection.

The last point was related to the availability and reliability of the collected data. According to this criterion, three dairy farms (F, J and M) were excluded from the analysis.

Herd descriptors are summarized in Table 1. Bulk tank milk samples were taken daily from 3 March 2009 to 3 October 2011. Milk samples were taken at the end of the morning milking session after milk was cooled; samples were stored in bronopol at a temperature of + 2 °− + 4 °C for a maximum of seven days. Samples were brought every week to the laboratory of Dipartimento di Scienze Veterinarie per la Salute, la Produzione Animale e la Sicurezza Alimentare and analyzed for SCC using a Bentley Somacount 150™ (Bentley Instruments, Chaska, MN). Daily mean temperature and relative humidity were registered by meteorological control units of the Agenzia Regionale per la Protezione dell'Ambiente (ARPA) at Capralba (Cremona) and Osio Sotto (Bergamo) (Fig. 1). ARPA is the regional official agency which monitors the various components of the environment including climate, air and water quality, soil characterization, and environmental noise level. Data were labelled by ARPA as complete and reliable, complete but

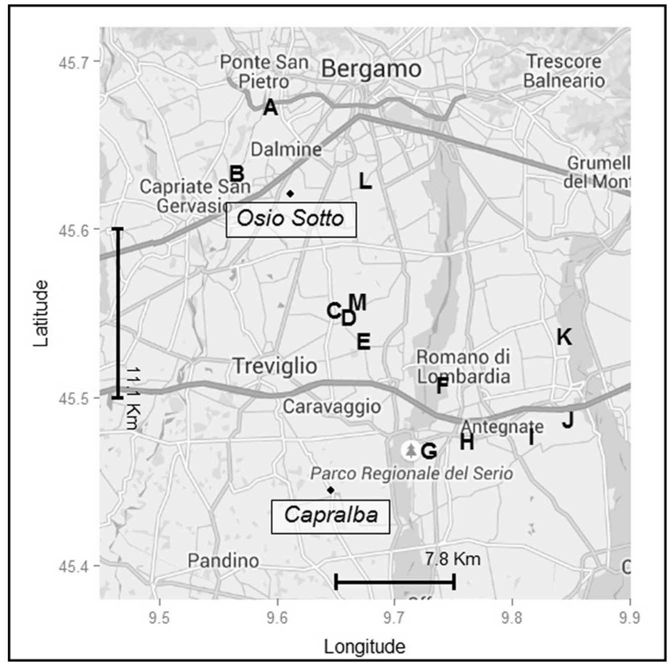

Fig. 1. Map of dairy herds (letters: A–L) and meteorological control units (Osio Sotto, Capralba).

unreliable, or not present. Only complete and reliable data were used. Using the latitude and longitude of dairy herds in conjunction with meteorological control units, we could calculate mean distance from herds to Capralba (15.3 Km) and to Osio Sotto (12.4 Km).

To fully exploit the potential information of the daily recorded data, the problem of missing information and the different sources of error must be taken into account. To ease these issues and to produce robust model, only the data from herds that have been observed for at least two years (10 herds) were used. Furthermore, data recorded from November 2010 and from January 2011 were excluded, because temperature or relative humidity data were missing. The available data consisted of 6682 records of daily BMSCC collected at 10 farms in the period between 21 March 2009 and 03 October 2011, in addition to the corresponding records of temperature and humidity from two control units.

2.2. Statistical analysis

The response variable of the model was daily BMSCC count. To approximate the normal distribution, the natural logarithm of BMSCC divided by 1000 cells/ml was used (Ali and Shook, 1980). For example, values of 300,000 and 400,000 cells/ml correspond to ln(BMSCC) = 5.70 and 5.99, respectively. The main covariates were the average of the daily mean temperatures in degrees Celsius (T) and the percent relative humidity (H) recorded by the two control units on the day of bulk tank milk sample. The deviation from the overall means (14.58 °C for temperature, 70.98% for relative humidity) was entered for each variable in the model.

Other covariates were included to account for the main sources of variability in the response: the natural logarithm of previous day BMSCC (divided by 1000 cells/ml) was included to “explain” the short-term variations in the response variable. Herds were specified as random effect to account for the correlation among measures of BMSCC within each herd. The seasonal component was highly correlated with the temperature data and was consequently omitted because of collinearity issues.

All the analyses were performed using the software package R