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Modeling heat stress under different environmental conditions

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ABSTRACT

Renewed interest in heat stress effects on livestock productivity derives from climate change, which is expected to increase temperatures and the frequency of extreme weather events. This study aimed at evaluating the effect of temperature and humidity on milk production in highly selected dairy cattle populations across 3 European regions differing in climate and production systems to detect differences and similarities that can be used to optimize heat stress (HS) effect modeling. Milk, fat, and protein test day data from official milk recording for 1999 to 2010 in 4 Holstein populations located in the Walloon Region of Belgium (BEL), Luxembourg (LUX), Slovenia (SLO), and Southern Spain (SPA) were merged with temperature and humidity data provided by the state meteorological agencies. After merging, the number of test day records/cows per trait ranged from 686,726/49,655 in SLO to 1,982,047/136,746 in BEL. Values for the daily average and maximum temperature and humidity index (THI_{avg} and THI_{max}) ranges for THI_{avg}/THI_{max} were largest in SLO (22–74/28–84) and shortest in SPA (39–76/46–83). Change point techniques were used to determine comfort thresholds, which differed across traits and climatic regions. Milk yield showed an inverted U-shaped pattern of response across the THI scale with a HS threshold around 73 THI_{max} units. For fat and protein, thresholds were lower than for milk yield and were shifted around 6 THI units toward larger values in SPA compared with the other countries. Fat showed lower HS thresholds than protein traits in all countries. The traditional broken line model was compared with quadratic and cubic fits of the pattern of response in production to increasing heat loads. A cubic polynomial model allowing for individual variation in patterns of response and THI_{avg} as heat load measure showed the best statistical features. Higher/lower producing animals showed less/more persistent production (quantity and quality) across the THI scale. The estimated correlations between comfort and THI_{avg} values of 70 (which represents the upper end of the THI_{avg} scale in BEL-LUX) were lower for BEL-LUX (0.70–0.80) than for SPA (0.83–0.85). Overall, animals producing in the more temperate climates and semi-extensive grazing systems of BEL and LUX showed HS at lower heat loads and more re-ranking across the THI scale than animals producing in the warmer climate and intensive indoor system of SPA.
Key words: Holstein cattle, heat stress model, climate change

INTRODUCTION

Heat stress (**HS**) effects on lactating cows have been widely studied because of the economic importance of the associated losses (St Pierre et al., 2003). However, optimization of the models that describe those effects has been paid much less attention. The model that has been traditionally used to describe the animal's productive response to increasing heat loads, the so-called broken line (**BL**) model, assumes that production remains constant within a thermoneutral region, where no response to increasing temperatures is observed and that, after the breaking point marking the start of HS, production decreases linearly (Misztal, 1999; Kadzere et al., 2002). However, this pattern may be too simplistic under the complex process that regulates milk production. Under the BL model, a value for the breaking point or comfort threshold of 72 for the most frequently temperature and humidity index (**THI**) used in cattle (NRC, 1971) is widely accepted (see, e.g., review by Zimbelman et al., 2009). However, patterns of animal response may differ across climatic conditions, production systems, or both. For example, in temperate regions, as opposed to warm areas, animals do not go through acclimation periods of gradual

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increase of heat loads during late spring and summer, but normally suffer the effects of high temperatures in sudden heat waves that do not last for long periods. In recent studies dealing with Holstein cattle in Central Europe, low THI thresholds for milk yield, at values of 60 in the German Holstein (Gorniak et al., 2014; Lambertz et al., 2014) and 62 in the Holstein population of Luxembourg (Hammami et al., 2013) have been found. In the Mediterranean region, Carabaño et al. (2014) found thresholds for milk, fat, and protein yields at 73, 59, and 62, respectively, for Holstein cattle in Southern Spain but using daily average temperatures instead of maximum values as in the previous studies. These results contrast with the results observed by Bernabucci et al. (2014) with Italian Holsteins who found THI thresholds at values of 73 to 76 for milk yield, 71 to 73 for fat and protein yields, and 65 to 71 for protein percentage. These different results point at differences in HS thresholds across climates, but they could also be associated with differences in the statistical models and methods used in each study. Moreover, Ravagnolo et al. (2000) found that for THI indices based on daily maximum temperature and minimum relative humidity, this combination of daily values showed a slightly superior goodness of fit than other combinations under the hot and humid conditions of Georgia (United States), but this superiority has not been tested under other environmental conditions.

Alternative functions to the BL model to describe the pattern of response in milk production to increasing heat loads can also be considered. Recently, several authors have used polynomial functions, which provide more flexible patterns than the BL model, to fit milk production response to increasing heat loads (Brügemann et al., 2011; Hammami et al., 2013; Carabaño et al., 2014). Little research has been done as to what polynomial degree should be used and whether the same type of function is optimal under different environmental conditions.

Apart from the average or population response to increases in heat load, estimation of individual deviations from the average response are the target for management and genetic selection of cows. The pattern of individual deviations is expected to be determined by differences in the HS threshold and the magnitude of the negative effect of HS among cows. Estimation of individual thresholds under BL models has been proven to be cumbersome (Sánchez et al., 2009) because of the complexity of the needed models. Again, polynomial functions have been used to describe individual deviations to avoid these drawbacks (Brügemann et al., 2011; Hammami et al., 2013; Carabaño et al., 2014).

The objective of this study was to explore average and individual patterns of response of milk production performance to HS under different climatic conditions and production systems, represented by 3 regions in Europe. Using a unified methodological framework to compare results across environmental conditions will allow identification of differences in heat stress effects due to differences in environmental conditions and not to the methods, as when comparing results from different studies. Different models varying from the traditional BL model to polynomial approximations and relying in different indices to measure heat load are used to predict response of milk production traits to increasing heat loads in each climate.

MATERIALS AND METHODS

Productive and Weather Data

Milk, fat, and protein test-day records came from official milk recording programs, for 1999 to 2010 inclusive, in 4 Holstein populations located in the Walloon Region of Belgium (**BEL**), Luxembourg (**LUX**), Slovenia (**SLO**) and in 2 regions with the hottest temperatures in Southern Spain (**SPA**). Data were provided by the corresponding breed associations, Walloon Breeding Association (**AWE**), Convis Herdbuch Service Elevage et Génétique, Agricultural Institute of Slovenia and the Confederation of Associations of Spanish Friesian (**CONAFE**), respectively. The associations furnished 1,982,047, 994,927, 686,726, and 1,589,563 test-day records collected from 136,746, 59,040, 49,655, and 105,223 cows in BEL, LUX, SLO, and SPA, respectively.

Those populations were chosen because they represent a comprehensive range of environments in terms of meteorology and production systems across Europe. According to the Köppen-Geiger climate classification (Peel et al., 2007), BEL and LUX have a temperate maritime climate, Cfb. Slovenia, despite its small size, has a moderate continental climate with several subtypes in areas where Holstein cows are raised, which suits Cfb, Cfa, and Dfb classes in the Köppen-Geiger system. For SPA, Andalusia has several sub-types of Mediterranean climate and Castile La Mancha, a continentalized Mediterranean climate, responding to Csa and Bsk classes of the Köppen-Geiger system. Production systems vary between semi-intensive grazing systems in BEL and LUX, mainly indoor semi-intensive to intensive production in SLO, and intensive indoor production in SPA.

Weather records were provided by the corresponding meteorological state agencies, Belgian Crop Growth Monitoring System consortium (B-CGMS), Administration des Services Techniques (ASTA), Slovenian Environment Agency (ARSO), and the Spanish Me-