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Influence of Environmental Temperature on Dairy Herd Performance and Behaviour

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Abstract**—**The objective of this study was to determine the effects of environmental stressors on the performance of lactating dairy cows and discuss some future trends. There exists a relationship between the meteorological data and milk yield prediction accuracy in pasture-based dairy systems. New precision technologies are available and are being developed to improve the sustainability of the dairy industry. Some of these technologies focus on welfare of individual animals on dairy farms. These technologies allow the automatic identification of animal behaviour and health events, greatly increasing overall herd health and yield while reducing animal health inspection demands and long-term animal healthcare costs. The data set consisted of records from 489 dairy cows at two dairy farms and temperature measured from the nearest meteorological weather station in 2018. The effects of temperature on milk production and behaviour of animals were analyzed. The statistical results indicate different effects of temperature on milk yield and behaviour. The "comfort zone" for animals is in the range 10 °C to 20 °C. Dairy cows out of this zone had to decrease or increase their metabolic heat production, and it affected their milk production and behaviour.

Keywords**—**Behaviour, milk yield, temperature, precision technologies.

I. Introduction

CLIMATE change is likely to be one of the main challenges of the current century. In many regions of Europe, the summer period is characterized by climatic conditions that can adversely affect the welfare of farm animals and in particular of dairy cows. It is known that the dairy cow, because it generates a lot of metabolic heat, is sensitive to high environmental temperatures to which it reacts by implementing various physiological responses. These involve reduction of feed intake, reduction of growth rate [1], alteration of gastrointestinal function [2], reduction of reproductive performances [3], changes in the endocrine-metabolic system [1], impairment of immune system [4], and even animal death in extreme cases [3]. Many studies reported that high air temperatures, coupled with high relative humidity, negatively affect milk yield and its composition [1], [5]. In areas such as Ireland, Great Britain and New Zealand, the temperate maritime climate allows for pasture-based dairy systems for the majority of the lactation period. On Irish dairy farms, cows are housed indoors in winter and grazed from early spring to late autumn. This allows for grazed grass to be the primary feed source for Irish dairy cows, where effective grass utilization plays an essential role in the cost efficiency of the Irish dairy industry [6]. Hence, the relationship between meteorological data and milk yield is of particular interest for pasture-based dairy systems, as is its impact on the prediction accuracy of milk production [7].

The most important environmental factor affecting the normal functioning of the farm animal body is temperature. The optimal zone for farm animals is in the range of 10 °C to 20 °C. If the temperature is out of the optimal zone, the animal must decrease or increase its metabolic heat production. In extreme cases, it can affect the normal functioning of the animal's body [8]. In some areas, such as central and south of Europe, heat stress on the lactating cow is one of the greatest production challenges facing dairy farmers [6]. Cattle tend to be more susceptible than sheep to high temperatures, and they are most susceptible when they are producing. The dramatic impact of suboptimal temperature can be found also in very young animals with under-developed heat regulation mechanisms [8].

Dairy cows are homeothermic animals and their body's thermoneutral zone is the range of ambient conditions at which metabolic heat production balances heat loss. Dairy cows experience heat stress when environmental variables such as ambient temperature, humidity, radiation, and air flow combine to exceed above mentioned heat equilibrium [1]. High yielding dairy cows require high metabolic rates to support such yields, and this generates considerable metabolic heat [9]. As metabolic heat production increases, a cow's thermoneutral zone shifts to a lower temperature range [8]. This means that higher yielding dairy cows experience heat stress at lower temperatures than lower yielding cows [9]. In response to heat stress, cows reduce nutrient uptake, reallocate energy to thermoregulation, and experience changes in metabolism and endocrine function [2]. These adjustments can lead to decreases in milk yield and quality of milk [5]. Animals that have a higher core body temperature, all else being equal (e.g., feed intake), are expected to direct a greater proportion of feed energy into metabolic heat production than into productivity, which reduces their production efficiency [1]. It means that dairy cows that convert feed into milk more efficiently produce less heat as a proportion of gross energy

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intake [10] and have lower skin surface temperatures than less efficient cows [11]. This suggests that efficient dairy cows might be less susceptible to thermal stress than less efficient cows due to better body thermoregulation [1].

Finally, pasture grazing of cattle increases economic performance and is regarded as beneficial for cows' health but weather may affect animal behaviour and welfare. Sprinkler and fan cooling offers promise as means of reducing heat stress in cows [1]. However, this may not be practical, or can be only particularly effective in pastoral systems common in Australia, New Zealand and some other countries. Milk production with increasing heat stress varies between animals and is a lowly to moderately heritable trait. Genomic selection can be a supplementary strategy which would have cumulative and permanent effects. It means that heat tolerance should be included in a multitrait selection index, correlations with other production and functional traits and finally net economic effect [12].

The objective of this study was to evaluate the influence of environmental temperature on milk yield and behaviour of dairy cows and discuss some future trends.

II. Experimental Details

A. Precision of Dairy Technologies

The MooMonitor+ is a health and fertility monitoring system which detects cows in heat and monitors the resting, feeding, rumination, head position and restlessness of each animal 24x7. The system improves farm profitability by decreasing labor requirements on farm, improving reproductive performance and minimizing losses due to missed heats, undiagnosed illnesses and general cow health. Dairymaster's MooMonitor+ is one of the most accurate systems to monitor cows' behaviour, according to two new studies conducted in the US [13] and Ireland [14]. This is the first system validated in both indoor [13] and outdoor [14] systems. Both prove the precision of the Dairymaster MooMonitor+ system. According to [13], it is important to validate all precision dairy technologies (PDT) to understand their precision and accuracy before taking measurements or applying them to cattle management or research. Grinter et al. [13] added that the behaviour-monitoring collar (MooMonitor+, Dairymaster, Co. Kerry, Ireland) performed precisely, with very high correlations for ruminating, feeding, and resting behaviours. MooMonitor + was used in our study to measure rumination and feeding of dairy cows (Table I).

B. Data

The data comprising 43,110 daily milking records of pasture-based cows were collected from two experimental dairy farms within one grazing period (March to October) during the year 2018. One of the farms was situated in Ireland and the second one in Germany. Each daily milking record contained date of milking, milk yield (kg) and a cow identification number. Meteorological data (Table I) were measured from the nearest meteorological weather station (Ireland: Ardfert, Germany: Bremen). Meteorological data consisted of daily rainfall (mm), sunshine hours (hour) and temperature (°C) data. However, we used only temperature data for our analysis. All cows that satisfied the criteria shown in Table I were selected i.e., in total 489 dairy cows.

TABLE I
EVALUATED PARAMETERS

Indicator	Mean ± std	Min	Max
Dairy cows (489 cows)			
DIM (d)	146 ± 77	1	310
Milk yield (kg/d)	25.6 ± 9.1	5.0	54.9
Rumination (min/d)	542 ± 80	201	750
Feeding (min/d)	443 ± 113	69	834
Resting (min/d)	342 ± 82	87	842
Activity (min/d)	112 ± 55	20	300
Meteorological data			
Maxt (°C/d)	17 ± 5	5	32
Mint (°C/d)	8 ± 5	-3	17
Meant (°C/d)	12 ± 5	4	25

DIM = days in milk, Maxt = maximum temperature per day, Mint = minimum temperature per day, Meant – average temperature per day

C. Model

The MIXED procedure of SAS software (Version 9.4) was used with the model described in (1), which determines the impact of temperature on milk yield and feeding behaviour (feeding and rumination). Tukey's range test was used for comparison of means. The equation included the fixed effects and individuals were considered as random (Z_l). Pearson correlations among temperature, milk yield and behaviour variables were calculated using the CORR procedure of SAS.

$$y_{\mathrm{ijklmno}} = \mu + H_i + Y_j + S_k + Z_l + A_m + \mathrm{L}_n + e_{\mathrm{ijklmno}} \quad (1)$$

where $\mathbf{y}_{\mathrm{ijklmn}}$ = value of the dependent variable (milk yield, rumination and resting), $\boldsymbol{\mu}$ = overall mean, $\mathbf{H}_i$ = effect of the i^{th} herd, $\mathbf{Y}_j$ = effect of j^{th} month of lactation, $\mathbf{S}_k$ = effect of k^{th} season of calving (month), $\mathbf{A}_m$ = effect of the m^{th} maximum, minimum or average temperature per day class (Table I & Figs. 1-3), $\mathbf{L}_n$ = effect of the n^{th} lactation, and $\mathbf{e}_{\mathrm{ijklmno}}$ = random error. The differences between the estimated variables were tested at significance level $P < 0.05$. It means that averages of feeding, rumination and milk yield in Figs. 1-3 are corrected of these effects.

III. Results and Discussion

The highest average feeding times were recorded when the average temperature fell below 9 °C (Fig. 1). The difference in feeding time between groups > 16 °C and 9 – 5 °C and groups > 16 °C and < 4 °C was 14 minutes (< 0.05). The milk yield differed around 0.5 kg between these groups (Fig. 1).

The highest feeding time and milk yield have been shown to occur when the minimum temperature was between 4 °C and 0 °C (Fig. 2). As it continued to cool (group < 0 °C) feeding time started to be negatively affected. Likewise, milk yield increases in cooler environments – but as it continues to cool below 0 °C milk yield is negatively affected. This may be a survival mechanism, as milk production results in large amount of heat production and reducing milk yield will be beneficial towards maintaining body temperature when body temperature begins to fall [15]. When temperatures fell below the lower critical temperature of the animal, metabolism increased in order to maintain body temperature through increasing the heat produced. However, as the temperature continues to decline, the cow will reach a summit metabolism, or milk production, at which point the cow can no longer maintain body temperature, and hypothermia sets in [3]. The difference between groups > 16 °C and 4 °C – 0 °C was 15 minutes (< 0.05) and between groups 4 °C – 0 °C and < 0 °C was 6 minutes (no significant difference). During periods of cold stress, cows tend to have lower feed intakes, and therefore, must rely on endogenous energy to maintain milk and heat production, which can result in weight loss, leaving the cow weaker [3].

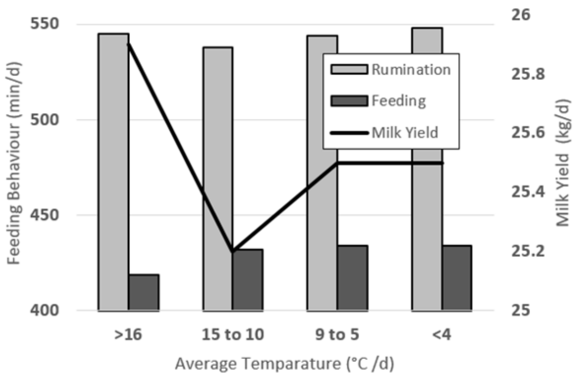

Fig. 1 Analysis of milk yield, rumination and feeding based on groups of average temperature per day

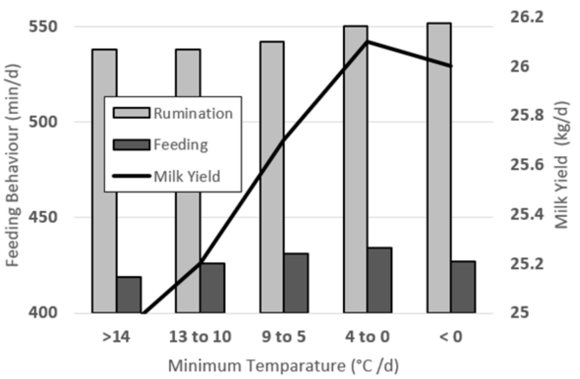

Fig. 2 Analysis of milk yield, rumination and feeding based on groups of minimum temperature per day

The evaluation of maximum temperature (Fig. 3) showed no significant rules in feeding time. Milk yield of dairy cows has risen when maximum temperature increased. However milk yield decreased when the maximum temperature exceeded 25 °C. The lowest feeding time has been found in the same group > 25 °C. This corresponds with a study [3] which also shows that, when air temperature was greater than about 23 °C and relative humidity was greater than 80%, cows began to experience heat-induced depression of feed intake, and lower productivity. Rumination time was found to be positively associated with milk yield in early-lactation dairy cows, across all parities and also showed contemporary effect with feeding time [16]. In our study, the correlation between milk yield and rumination was 0.12. Negative low correlation coefficients (r = -0.05 to -0.1) have been found between temperature and rumination, feeding and resting and between temperature and milk yield. Positive low correlation coefficients (r = 0.12 to 0.14) have been found between temperature and activity.

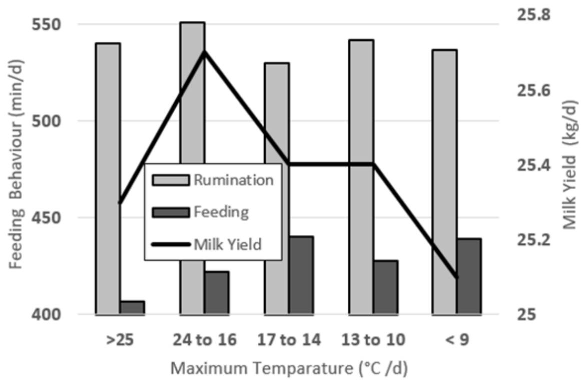

Fig. 3 Analysis of milk yield, rumination and feeding based on groups of maximum temperature per day

A. Future Trends

The world of dairy farming is complex and changing fast. Dairy sector economics needs knowledge from many different angles and sources [17]. The way animals are raised on farms has changed greatly over the past century, including a growth in farm size and increased technology [17]. The main characteristics of an ideal dairy system identified by the respondents in [18] were related to animal welfare from two perspectives: consideration for the quality of life of the animals, based on ethical arguments and the consequences of animal care on the quality of milk. However the target of every business is to achieve profit. Relatively little attention has been paid in the economics literature to the effects of meteorological conditions on milk production. Meteorological variables can be expected to affect milk production through their impact on the productivity of cows and the production of foodstuff. Rather than including meteorological variables as inputs in the milk production process, they propose a production function where these variables affect the productivity of cows and the production of forage, thereby indirectly affecting milk production [19]. Dairy producers worldwide often encounter difficult decisions on a daily basis [17]. New technologies are available and are being developed to help the dairy industry improve the welfare of individual animals on dairy farms. This rapid shift appears to be the trend for the future. Using new technologies and proper data analysis, it is possible to identify weaknesses in management and improve the welfare of individual animals and profit in dairy farms. Prediction of milk production and creating algorithm based on behavioural alerts and weather will represent a new approach in evaluation.

The tools based on the new technology – animal relationship are the key to achieving high welfare, and subsequently, more profitable management on dairy farms. The technological improvement of farms made it possible to produce vast amounts of permanent data streams. However, the system of the farm should be able to collect, integrate, manage, and analyze on-farm and off-farm data in real-time for relevant actions [20]. Accurate milk production forecasts will be useful for providing farm management decision support for improving herd management, energy utilization and economic prediction [19]. Improved management practices are of particular importance in the current volatile milk pricing environment across European member states post milking quotas. Therefore, accurate milk production forecasts have become increasingly important and could provide farmers with information related to: farm thermal cooling loads, plant capacity sizing, optimizing plant configurations and cash flow planning [7]. Additionally, highly accurate milk production figures could be used to help determine important factors on dairy farms such as cooling loads, water utilization, economic performance and energy consumption [19]. Due to practical constraints, it is difficult to adopt a holistic approach for milk yield forecasting where detailed inputs such as grass growth, feed intake, body condition and the level of the emitted pollutants are utilized [7]. Detailed farm management and cow body condition records are rarely accessible on commercial dairy farms. However, milking records such as milk yield, milking date and number of cows milked are readily available. Accurately predicting grass growth and cow level supplementary feed intake is very challenging and thus, this information is currently unavailable on commercial dairy farms [7].

Precision Livestock Farming (PLF) can be defined as real-time monitoring technologies aimed at managing the temporal variability of the smallest manageable production unit, known as the ‘per animal approach’. With intense advancements in Artificial Intelligence (AI), there has arisen an array of opportunities for sensor technology to become even more useful in monitoring the needs and behaviour of every animal and also allow robotics to interact with animals safely. Applications include the automatic monitoring of cattle by intelligent camera surveillance technology, and the automation of tasks such as herding, milking, feeding and bedding. This indicates that the automated device could be used to accurately and objectively measure body condition of cows with little effort [21]. Further, automatically recorded longitudinal sensor measurements (i.e., behavioural activity traits) could be a proper alternative for cow phenotyping in extensive grassland systems, providing an accurate data basis for genetic evaluations [9]. Finally, some of the “smart farm decision technologies” will be able to substitute actual farm management and will learn as it goes by applying complex machine learning approaches and exploiting the interdependencies of the complex integrated biological, physical, technological, environmental and informational dimensions of dairy farm systems. The methods of AI will be used to predict more accurately the outcome of various management options and also evaluate the achievement and sustainability of farmers’ targets [20]. Resilience and sustainability are keywords for the future of the sector. This can be achieved with innovation, as a way to reconcile the need for farmers to earn a decent living, consumer demand for affordable and quality dairy products, and environmental/ animal health requirements [18].

IV. Conclusion

In this study, the effects of temperature to milk production and behaviour of animals were tested. The statistical results indicate different effects of weather factors on milk yield and behaviour. The highest feeding time and milk yield was found to occur when the minimum temperature was between 4 °C and 0 °C. However milk yield decreased when the minimum temperature was less than 0 °C. On the other end of the temperature scale, the milk yield of dairy cows was found to rise when maximum temperature increased. However milk yield decreased when the maximum temperature exceeded 25 °C. Animals out of the “comfort zone” must decrease or increase metabolic heat production, and at more extreme temperatures, even this process becomes insufficient to maintain normal functioning and milk production. The significance of mentioned loss depends on the susceptibility of each cow to extreme temperature, i.e. genotype and overall condition of cow are important. For future milk production forecasting models based on machine learning and AI techniques, it will be useful to include genotype, body condition score, behaviour and weather parameters.

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