Economic Value of In-Line Milk Analysers for Early Diagnosis and Prevention of Negative Energy Balance in Dairy Cattle

Akvilė Girdauskaitė[1], Samanta Grigė[1], Laima Andrejevaitė[2], Paulius Subačius[2], Karina Džermeikaitė[1], Justina Krištolaitytė[1], Gabija Lembovičiūtė[1], Greta Šertvytytė[1], Rolandas Stankevičius[3], Ramūnas Antanaitis[1]

[1]Large Animal Clinic, Veterinary Academy, Lithuanian University of Health Sciences, Tilžės Str. 18, LT-47181 Kaunas, Lithuania

[2]Brolis Sensor Technology, Molėtų Str. 73, LT-14259 Vilnius, Lithuania

[3]Department of Animal Nutrition, Veterinary Academy, Lithuanian University of Health Sciences, Tilzes Str. 18, LT-47181 Kaunas, Lithuania

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Abstract. *This study aimed to evaluate the economic benefits of using the in-line milk analyser "Brolis HerdLine" (Brolis Sensor Technology, Vilnius, Lithuania) for the early detection of negative energy balance (NEB) and to assess the value of preventive treatment in dairy cows at a high risk of NEB. A total of 52 Holstein cows were selected and paired based on lactation number, days in milk, and fat-to-protein ratio. The pairs were randomly allocated into two treatment groups: Control group (CON, n = 26) and Test group (TE, n = 26). Cows in the TE group received a single 32.4 g monensin (Kexxtone®) controlled-release capsule, while CON cows received no treatment. Milk composition was monitored using the in-line analyser, and energy-corrected milk (ECM) was used to evaluate performance. Over a 200-day period, the TE group produced 9916 kg more ECM than the CON group, resulting in an additional €3056 profit after subtracting treatment costs. On day 20 post-treatment, TE cows showed significantly higher lactose levels (4.64%) than CON cows (P = 0.03). The successful insemination rate was 8.11% higher in the CON group. These results imply that early intervention through the use of an in-line milk analyser to identify cows at a high risk of NEB improves economic performance. The study emphasises how milk analysers can be used to make decisions in real time when managing dairy herds.*

Introduction

For dairy cows, innovative technologies not only improve animal welfare but also boost milk productivity and quality, supporting more economically efficient production (Zarba, 2023). The use of sensors and technology enables the collection of vast amounts of data, which must be analysed using advanced statistical methods to draw meaningful conclusions about animal behaviour, health, and welfare (Džermeikaitė, 2023).

Precision livestock farming using on-farm in-line milk analysers is gaining attention as a method for automating the monitoring of animals. Key milk components, such as fat, protein, and lactose, serve as critical health indicators within animal monitoring systems (Uusitalo, 2021). Using spectroscopic technology, an in-line milk analyser provides detailed insights into milk quality, including parameters such as fat, protein, lactose and temperature, which can indicate issues such as NEB (Antanaitis, 2023).

Energy-corrected milk (ECM) is an essential metric in dairy production, as it adjusts milk yield based on its energy content, offering a more precise evaluation of production relative to energy intake (Cabezas-Garcia, 2021). Studies have identified various factors that influence ECM in dairy cattle, particularly feeding strategies and overall cow performance. Moreover, a statistical analysis of data from Holstein-Friesian cows revealed a negative correlation between the fat-to-protein ratio (FPR) in milk and energy balance, especially during early lactation. This finding highlights the importance of monitoring ECM as an indicator of cows' nutritional status and energy balance (Gohary, 2016).

The connection between ketosis and NEB in lactating dairy cows is crucial and complex. During the transition period (three weeks before to three weeks after calving), dairy cows often experience NEB, which can lead to the development of both subclinical and clinical ketosis as the energy demands for milk production exceed dietary intake. This situation causes body fat to be mobilised, leading to increased ketone production and the risk of metabolic disorders like ketosis and fatty liver (Zhang, 2020). Ketosis is considered one of the most common metabolic disorders, which reduces milk yield, impairs reproductive performance and has significant economic losses due to its detrimental effects on milk production, reproductive performance, and overall herd health (Uusitalo, 2021). In Canadian dairy herds, the cost of a single subclinical case is estimated at approximately $203, factoring in increased clinical disease rates, prolonged time to pregnancy, culling,

Corresponding author: akvile.girdauskaite@lsmu.lt

early lactation deaths, and milk production losses (Steeneveld, 2020). Another study has shown that in the Netherlands, the combined annual herd-level costs of ketosis (both clinical and subclinical) are at €3613 for an average farm, rising to €7371 for high-risk farms. These expenses stem from milk production losses, treatment costs, and managing associated conditions such as mastitis and metritis. A dynamic stochastic simulation model further highlighted the economic burden, estimating the total cost of subclinical ketosis at €130 per case per year, with variation depending on factors like parity and disease incidence (Ha, 2023). Factors such as calving season, body condition score at parturition, and calf birth weight significantly influence ketosis severity, aiding in risk prediction and the implementation of preventive strategies (Dubuc, 2010).

Monensin (MON) is widely regarded as one of the most effective agents for preventing ketosis and negative energy balance. Moreover, the monensin capsule is frequently chosen due to its convenient mode of administration. A systematic review by Mammi et al. (2021) revealed that administering monensin as a controlled-release capsule during the transition period significantly improved cow metabolism and health. The treatment enhanced propionate production in the rumen, which supports energy metabolism, and lowered blood BHBA and non-esterified fatty acid levels, indicating a reduced risk of ketosis – a condition commonly associated with NEB in dairy cows (Antanaitis, 2023). Furthermore, the review found that monensin did not adversely affect milk production or composition, demonstrating its potential to maintain energy balance without compromising productivity (Huralska, 2024). Robinson (2020) suggests that monensin supplementation may reduce milk fat yield without significantly affecting milk protein yield.

Although monensin is a widely used antibiotic, it has been associated with negative effects. Monensin can alter the gut microbiome and promote the selection of resistant microbes. Besides, its extensive usage in livestock has sparked worries about the emergence of antibiotic resistance (Lee, 2015). One of the main causes of the worldwide issue of antibiotic resistance is the excessive and improper use of antibiotics in animal production, including cattle farms. Due to their frequent exposure to high doses of antibiotics, cattle may develop and spread germs that are resistant to these drugs (Kasap, 2020). A multifaceted strategy is required to address the issue of antibiotic resistance in cattle farms, which includes limiting the overuse of antibiotics in livestock production and using them sparingly, as well as enacting laws and policies that limit their use as feed additives (Jacobs, 2012).

Based on previous studies showing the link between milk composition, particularly the fat-to-protein ratio and NEB, the use of in-line milk analysers offers a promising method for early detection of metabolic imbalances. These technologies can continuously and non-invasively monitor milk constituents, allowing for earlier identification of cows at risk. Our hypothesis was that by using milk composition data to identify cows at risk of NEB early on, timely intervention would be possible, leading to better economic results. The aim of this study was to evaluate the economic value of an in-line milk analyser for the early detection of NEB in dairy cows, by comparing productivity and economic outcomes between animals monitored and treated early versus those monitored only. After NEB was detected, monensin was used as a standard intervention; this study did not examine its effects on its own.

Materials and methods

Housing conditions of study animals

This investigation adhered to the Lithuanian Law on Animal Welfare and Protection, with study approval number PK012858. The study was conducted in Lithuania (55.819156, 23.773541) over the period from 14th February to 1st July 2023. The dairy cows were housed in free-stall barns equipped with ventilation systems and were fed a total mixed ration (TMR) tailored to meet their physiological requirements year-round. Feeding occurred daily at 06:00 and 18:00, with a typical TMR formulation for high-producing, multiparous cows. The diet included 25% corn silage, 5% alfalfa grass hay, 20% grass silage, 15% sugar beet pulp silage, 30% grain concentrate mash, and 5% mineral mixture. This ration was designed to support or exceed the nutritional demands of a 500-kg Holstein cow producing 37 kg of milk per day. The cows were milked twice daily, at 05:00 and 17:00, using a parlour system. The chemical composition of the TMR was as follows (Table 1).

Table 1. Chemical composition of TMR

TMR Component	Value
Dry matter (DM)	48.8%
Neutral detergent fibre (NDF)	28.2% of DM
Acid detergent fibre (ADF)	19.8% of DM
Non-fibre carbohydrates (NFC)	38.7% of DM
Crude protein (CP)	15.8% of DM
Net lactation energy	1.6 Mcal/kg

Experimental design

This experiment utilises A/B testing. This method of testing works by splitting sample data into the control (A) and test (B) groups. Cows were selected in pairs so that both animals were in the same lactation, with similar days in milk (DIM) with fat-to-protein ratio values above 1.5 indicating high NEB, and without a noticeable yield drop before or at the time of selection. In total, 52 cows were included because their fat-to-protein ratio was greater than 1.5, which indicates a high risk of NEB. Cows were chosen before there was a discernible decline in milk production, and there were no clinical symptoms of illness at the time of selection. The average DIM in the control and test groups was 45 days (± 5 days), and the average lactation number for both groups was 1.57 (32 cows were primiparous and 20 cows were multiparous). For a given pair, one animal was put in the test group and the other in the control group. In total, 52 animals were selected with 26 animals in each group. On day 1 of the study, cows in the test group received a single 32.4 g monensin controlled-release capsule (Kexxtone®, Elanco GmbH, Cuxhaven, Germany) by using a rumen bolus applicator as treatment while those in the control group were only observed. Monensin was used as a standardised preventive treatment once high-risk cows were identified based on milk composition (specifically elevated fat-to-protein ratio), to model a practical on-farm management response following early NEB detection. The study's objective was to replicate a normal response after analyser-based NEB identification, rather than to assess the precise effects of monensin.

After given time, the two groups were compared to assess the economic benefit of BROLIS sensors. It is worth mentioning that not all animals were selected at the same time; therefore, we measure time not by date but by

days since treatment (DST), which was on average 200 days (± 5 days). In the case of the control group DST refers to the days since the beginning of observation. The various procedures of this group comparison are discussed below.

Measurements

The milk fat and protein measurements were performed with "Brolis HerdLine" in-line milk analysers (Brolis Sensor Technology, Vilnius, Lithuania) installed on each milking point in the farm. The devices are factory calibrated, continuously monitored, and do not require any additional reagents. This creates an environment where animals are not stressed by additional interventions and no milk is lost due to continuous measurements of milk composition. In addition, this method allows for accurate comparison of energy corrected milk among animals.

Each cow had its daily NEB recorded using the "Brolis HerdLine" in-line milk analyser (Brolis Sensor Technology, Vilnius, Lithuania). This advanced system incorporates a GaSb widely tunable external cavity laser-based in-line spectrometer operating within the 2100–2400 nm spectral range. Milk flow was continuously monitored in transmission mode throughout the milking cycle. The molecular absorption spectra obtained were processed to determine the levels of the main milk constituents. The analyser provided continuous milk composition measurements for each cow during every milking session. This compact mini spectroscope was installed on milking stalls or milking robots directly within the milk line and operated without requiring additional reagents or maintenance. Among the measured parameters, the fat-to-protein ratio (FPR) was specifically monitored, providing important insights into the cows' metabolic status, particularly for early detection of NEB.

Methodology

ECM

To assess individual animal's performance, energy corrected milk (ECM) was used. The formula for ECM is as follows:

$$ECM_{kg} = (1 + (fat_a - fat_b) \times k_1 + \\ + (protein_a - protein_b) \times k_2) \times milk\ yield_{kg}$$

Where

- fat_a: "fat animal" (%). This term describes the average fat concentration each day.
- $protein_a$: "protein animal" (%). This term describes the average protein concentration each day.
- fat_b: "fat base" = 3.4%.
- $protein_a$: "protein base" = 3%.
- k_1: fat multiplier = 0.178.
- k_2: protein multiplier = 0.267.
- $milk\ yield_{kg}$: total daily milk yield (kg).

The base values and multipliers for both fat and protein are set by the Lithuanian authority UAB "Pieno Tyrimai".

Comparison among animals

To account for differences in lactations and days in milk among animals, the comparison was calculated based on the distance from the corresponding average ECM curves. First, average farm lactation curves were calculated (Fig. 1). Then the average fat and protein values for each DIM were determined (Fig. 2). By using the formula from **part 2.4.1**, average ECM curves for the farm were derived.

The distance from the corresponding curve was determined for each day that the animal was observed. Then the cumulative difference and the average difference were calculated.

$$difference\ each\ day_{ecm} = ECM_{animal} - ECM_{farm}$$

$$cummulative\ difference = \sum_{dim=min}^{dim=max} daily\ difference_{ecm}$$

$$average\ difference = \frac{cummulative\ difference}{number\ of\ days}$$

To calculate results for the test and control groups, the corresponding animals were summed or averaged (depending on the measure in question). We do not reference days in milk as our base for time calculations but rather divide by the number of days since treatment. This allows for comparison of animals that were treated at very different moments in time.

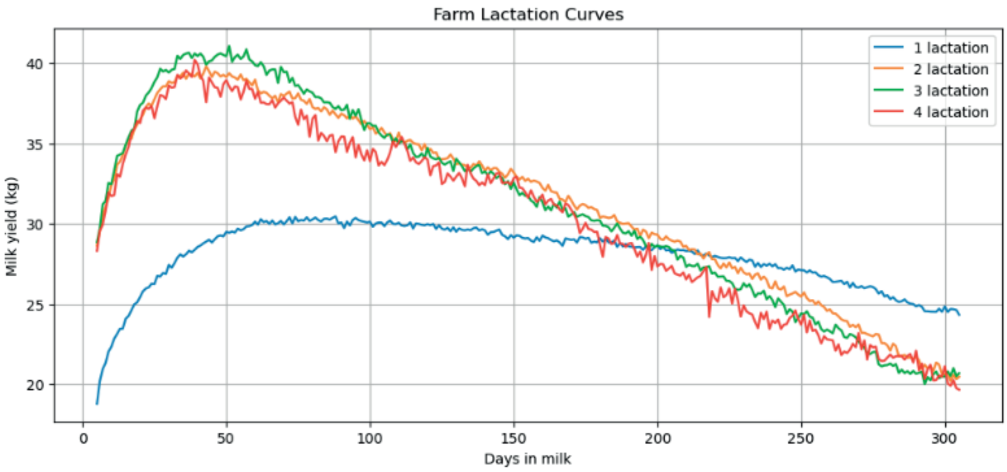

Fig. 1. Farm lactation curves

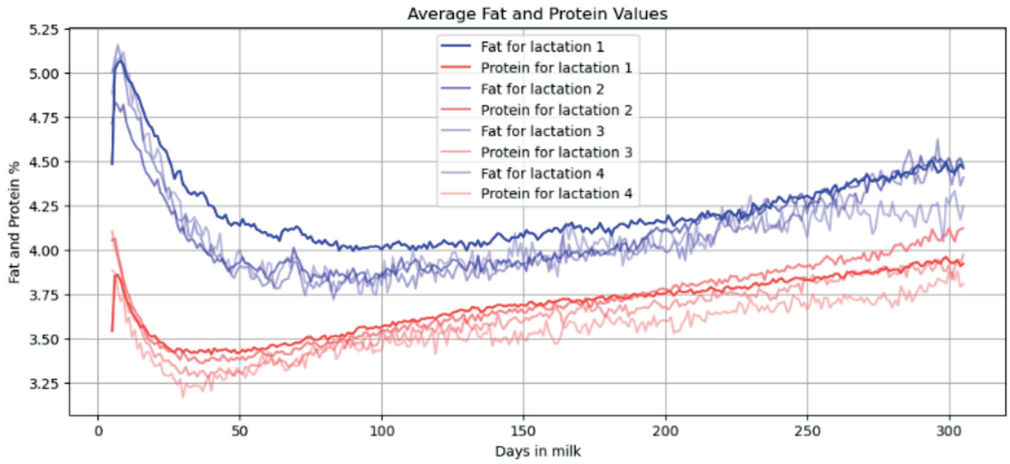

Fig. 2. Average fat and protein values

Economic evaluation

One of the ways to evaluate benefits of treatments is through calculation of profits. For this, we assumed a price of €0.40 per kg of ECM. The average daily difference in terms of money was calculated by multiplying the average daily difference in ECM by the price. In addition, the price of Kexxtone® was set at €35 per bolus. This allowed for the calculation of the payback period for the farmer.

Observation period

The observation period refers to the duration over which individual cows were monitored following inclusion in the study, specifically to evaluate daily milk composition, FPR, and ECM values. For cows in the test group, this period began immediately after monensin administration; for the control group, it began on the same relative day of selection. The average monitoring duration was approximately 200 days (± 5 days), which was used for the evaluation of ECM production and economic outcomes. Milk composition parameters — including lactose, fat, protein, and FPR — were analysed at selected time points over a 180-day period (days 10, 20, 30, 60, 90, 120, 150, and 180). All 52 cows (26 in each group) were part of the final analysis and stayed in the study until the end of the observation period.

Statistical analysis

The statistical software SPSS 26.0 (SPSS Inc., Chicago, IL, USA) was used to conduct the analysis. Using the Shapiro-Wilk test, the data distribution normality was evaluated. Calculated descriptive statistics were displayed as means ± standard deviation.

For normally distributed variables, independent samples t-tests were used to compare the control and test groups. In cases where the normalcy assumptions were not fulfilled, the Mann-Whitney U test was utilised. Using two-way repeated measures ANOVA, repeated measurements at various time points were examined.

Differences were considered statistically significant at $P < 0.05$. Treatment costs and group-level ECM differences were used to calculate economic outcomes (such as cumulative profit and payback period), which were then confirmed using descriptive production data.

Results and discussion

By comparing the productivity and profitability results of early-treated cows based on milk composition with untreated controls, this study sought to evaluate the financial impact of using an in-line milk analyser for early detection of NEB in dairy cows.

Monetary

The results suggest that there is a significant difference among the test and control groups in terms of ECM. The summary is available in Table 2.

Table 2. ECM difference between test and control groups

Measure	Difference between test and control group cows
Average daily difference (per cow)	2.35 kg of ECM
	€0.95
Average cumulative difference (per cow) after 200 days	470 kg ECM
	€190

Since not all animals stayed in the experiment for the full 200 days (as mentioned in section 2.4.5), the actual cumulative difference between the two groups is 9916 kg of ECM (or in monetary terms €3966). The farm spent €910 on monensin boluses and thus had €3056 in profit. From an economic perspective, the treatment saved €3056 when comparing the test and control groups. By offering many advantages, especially in the early detection of ketosis, financial benefits, and the resolution of problems associated with negative energy balance in dairy cows, "Brolis Herd line" in-line milk analyser have completely transformed the dairy industry. Continuous health monitoring of individual cows has been made possible, which is essential for early identification of metabolic diseases like ketosis. Real-time monitoring of milk composition and other health indicators is one of in-line milk sensors many noteworthy benefits. For example, the regular analysis of milk components made possible by the use of near-infrared spectroscopic sensors in in-line milk sensors allows for the early detection of ketosis and other health problems without interfering with the cows' daily routines (Jacobs, 2012). This ability is especially crucial because, if left untreated, ketosis can result in serious health issues and financial losses. Timely interventions made possible by early diagnosis can greatly increase recovery rates and lower the number of severe cases requiring prolonged treatment (John, 2016).

Advanced milk analysers that continuously measure the fat-protein ratio in milk offer many advantages for dairy farms, especially when it comes to improving animal health, milk production, and farm management in general. In order to make well-informed management decisions, real-time analysis of milk composition is made possible by the integration of technologies like in-line milk analysers. In dairy cattle, the problem of negative energy balance (NEB) is crucial, especially during the transition period. Ketosis and other metabolic diseases are more likely to occur in cows with NEB. In-line milk sensors can help mitigate NEB by allowing for more frequent milking, which can encourage higher feed intake and better energy balance (Bovo, 2021). In-line milk sensors can help cows optimise their feeding habits and enhance their overall energy utilisation by giving them the choice to be milked whenever it is most convenient for them. This will lower the risk of NEB and its related complications (Verde, 2023). Furthermore, herd health management can greatly benefit from the information gathered from in-line sensors about the health and behaviour of individual cows. This information can help farmers further improve productivity and animal welfare if they choose feeding plans and health treatments that are suited to the individual requirements of each cow (Ma, 2016).

Economically, in-line milk sensors can boost milk production and boost dairy farmers' profits. According to studies, cows milked with in-line milk sensors can yield a lot more milk than those milked the old-fashioned way. For instance, increasing the number of milkings from two to three times a day can increase milk yields by 6% to 25% over the course of full lactations (John, 2016). Since more milk means more sales, dairy producers will directly benefit from this increase in milk yield. Furthermore, in-line milk sensors lower labour expenses related to conventional milking techniques, enabling farmers to more effectively allocate resources (Mecitoglu, 2016).

In this study, cows at a higher risk for NEB were given 32.4 g (Kexxtone®) of monensin. The biggest advantage of Kexxtone® is that it is a continuous-release drug, which means it does not require a lot of veterinary time per cow. Monensin, an ionophore antibiotic, has been extensively studied for its economic and health benefits in dairy cattle, particularly in enhancing milk yield and improving overall animal health. It has been demonstrated that the veterinary medication monensin significantly improves animal health and farm economics, especially in dairy cattle. Monensin is primarily used to prevent ketosis, a metabolic condition that can negatively affect a cow's ability to produce milk and general health. According to research, treating cows with monensin can significantly increase their average daily milk production. This rise is explained by the drug's beneficial effects on the animal's physiological functions, which raise productivity throughout the cow's life cycle (Tan, 2020). Monensin modifies the rumen's microbial population, promoting the development of bacteria that generate propionic acid, a precursor to glucose synthesis that is essential for lactating cows' energy metabolism (Msellati, 2012).

This has significant ramifications because dairy farmers are more profitable when milk yields are higher, which makes monensin an effective tool for dairy management.

Many scientific studies have been conducted, proving that this medication individually affects the milk yield and health status of cows. In previous studies, we have already found that the administration of monensin significantly increases milk production, with increases ranging from 0.8 kg to as much as 2.8 kg per day (Santos, 2019). Furthermore, another study highlighted that monensin could enhance milk yield by 4.0% compared with control diets, demonstrating its potential to improve economic returns for dairy farmers. The increased milk yield brought on by monensin supplementation has significant economic ramifications. For dairy operations, higher milk production is directly correlated with higher revenue. For instance, a dairy farm with 100 cows might produce an extra 100 kg of milk every day if monensin causes an average increase of 1 kg of milk per cow per day. This financial benefit underscores the importance of monensin as a cost-effective strategy for enhancing dairy farm profitability (Kasap, 2020).

Milk composition difference between test and control groups

Table 3 presents a comparative analysis of key milk composition parameters (lactose, fat, protein, and fat-to-protein ratio) and milk yield between the control group and the test group over a 180-day period. The goal was to evaluate potential differences in milk quality and production efficiency between the two groups.

The only statistically significant difference was in lactose content at 20 days ($P < 0.05$), where the test group showed higher lactose levels (4.29%) compared with the control group. No significant changes were observed in milk yield, fat, protein, or fat-to-protein ratio, indicating that the treatment did not drastically impact these parameters. Monensin is known to reduce the percentage of milk fat and protein, but data on the amount of lactose and its changes in milk are lacking. For example, large-scale studies have reported that monensin has no significant effect on selected components such as lactose, protein, and fat (Kazama, 2010). Overall, it seems that monensin has an indirect impact on the amount of lactose in milk. Studies directly related to changes in lactose are still lacking, so more research is needed to clearly identify and confirm these effects.

This study has a number of advantages: it utilises in-line sensors for milk analysis, offering a non-invasive method to assess dairy cow metabolic status, enhancing animal welfare. It also allows for the early detection of ketosis, which could enhance the management of herd health. Data recorded with in-line sensors allows for the integration of milk composition data with health indicators, helping to create comprehensive health monitoring systems. However, the study also has disadvantages. To confirm these findings, larger cow groups would be beneficial for future studies. The milk fat-to-protein ratio could also be affected by environmental factors, such as heat stress or other environmental factors. Therefore, future studies should consider these actions when evaluating study results.

Table 3. Comparison of milk composition and yield between control and test groups 0, 10, 20, 30, 60, 90, 120, 150, 180 days after Kexxtone administration

Variable	Time Point (days)	Control Mean	Test Mean	T Statistic	P Value
Lactose (%)	10	4.41	4.5	–1.27	0.2
Lactose (%)	20	4.44	4.64	–2.13	0.03*
Lactose (%)	30	4.52	4.52	0.02	0.98
Lactose (%)	60	4.48	4.55	–0.82	0.41
Lactose (%)	90	4.5	4.57	–1.04	0.31
Lactose (%)	120	4.46	4.49	–0.39	0.7
Lactose (%)	150	4.49	4.53	–0.61	0.55
Lactose (%)	180	4.47	4.51	–0.58	0.57
Milk yield (kg/d)	10	27.22	28.93	–0.73	0.46
Milk yield (kg/d)	20	30.94	31.63	–0.26	0.78
Milk yield (kg/d)	30	30.3	30.38	–0.03	0.97
Milk yield (kg/d)	60	31.12	31.55	–0.29	0.77
Milk yield (kg/d)	90	30.74	31.26	–0.36	0.72
Milk yield (kg/d)	120	29.88	30.55	–0.42	0.68
Milk yield (kg/d)	150	29.67	30.34	–0.43	0.67

Table 3 cont.

Variable	Time Point (days)	Control Mean	Test Mean	T Statistic	P Value
Milk yield (kg/d)	180	29.35	30.01	–0.45	0.66
Fat (%)	10	4.66	4.42	0.82	0.41
Fat (%)	20	4.42	4.29	0.59	0.55
Fat (%)	30	4.67	4.24	1.28	0.2
Fat (%)	60	4.6	4.31	1.1	0.27
Fat (%)	90	4.55	4.33	0.94	0.35
Fat (%)	120	4.52	4.35	0.81	0.42
Fat (%)	150	4.47	4.36	0.67	0.51
Fat (%)	180	4.45	4.34	0.63	0.53
Protein (%)	10	3.41	3.29	1.05	0.29
Protein (%)	20	3.33	3.33	0.02	0.98
Protein (%)	30	3.44	3.31	1.09	0.27
Protein (%)	60	3.38	3.3	0.86	0.39
Protein (%)	90	3.36	3.28	0.89	0.38
Protein (%)	120	3.32	3.26	0.65	0.52
Protein (%)	150	3.3	3.25	0.58	0.56
Protein (%)	180	3.28	3.24	0.53	0.6
Fat-to-protein ratio	10	1.39	1.34	0.5	0.61
Fat-to-protein ratio	20	1.33	1.29	0.76	0.45
Fat-to-protein ratio	30	1.36	1.29	0.66	0.5
Fat-to-protein ratio	60	1.36	1.31	0.57	0.57
Fat-to-protein ratio	90	1.35	1.32	0.41	0.68
Fat-to-protein ratio	120	1.36	1.33	0.43	0.67
Fat-to-protein ratio	150	1.35	1.32	0.45	0.66
Fat-to-protein ratio	180	1.36	1.33	0.44	0.66

* – statistically significant

Conclusions

Our findings show distinct advantages in relation to the study's objective, which was to assess the economic worth of an in-line milk analyser for the early identification and avoidance of negative energy balance (NEB) in dairy cattle. In comparison with the control group, cows of the test group produced 9916 kg more milk overall and made €3056 more money after 200 days of treatment. Twenty days following the administration of Kexxtone (monensin 32.4 g), the test group also displayed a higher lactose content (4.29%).

According to these results, cows at risk of NEB can be promptly identified by using an in-line milk analyser to monitor the fat-to-protein ratio. The standardised monensin intervention used in the analyser-supported management approach enhanced milk performance and financial results. Although monensin is used as a preventive measure, its effects on its own were not assessed. Rather, this study highlights the importance of in-line milk analysers as tools for decision-making in the early detection of metabolic risk in contemporary dairy herd management.

This study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee (the study approval number is PK016965. 6 June 2017).

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