Correlations of production factors in automated milking system in a Hungarian dairy farm

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Abstract: Nowadays the use of automated milking systems (AMS) is increasingly popular as a technology that can reduce labor, increase milk production, and maximize profit. This study, which was carried out on a private dairy farm located in West Hungary, aimed to examine the relationship between AMS and production efficiency in lactating cows with herd sizes ranging from 267 to 322 Holstein-Friesian cows in the middle of lactation specifically 165 ± 10 days in milk. The result of this study indicates that on average, an AMS unit milked 49 ± 3 cows daily with each cow being milked 2.7 ± 0.1 times per day and producing a daily milk yield of 32.5 ± 1.3 kg per cow. The data was statistically analyzed using Pearson correlations and multiple linear regression analysis. The study found that daily milk yield was positively correlated with milking frequency ($r = 0.61$, $p < 0.01$) and negatively correlated with failed milkings ($r = -0.34$, $p < 0.01$) but had no correlation with refusals ($p > 0.05$). As we expected, a positive correlation was observed between the amount of concentrate offered in AMS per cow per day and both milk yield ($r = 0.52$, $p < 0.01$) and milking frequency ($r = 0.27$, $p < 0.01$). Finally, the fat content was negatively correlated with daily milk yield ($p < 0.05$) and the amount of concentrate, however, there was no correlation observed for protein content with daily milk yield or the amount of concentrate in the AMS ($p > 0.05$). Detailed knowledge of these factors such as milking frequency and concentrate intake associated with increasing milk yield by using AMS will help guide future recommendations to producers for maximizing milk yield and decreasing the cost on dairy farms.

Key words: milk yield, milking frequency, milking composition, automatic milking system (AMS), concentrate

Introduction

The EU is a significant participant in the global dairy industry, with a substantial share of production for various dairy products. In 2022, it produced about 160 million tonnes of raw milk. The increase in milk yield of dairy cattle coincides with multiple challenges imposed on the cows (Probo et al. 2018). During the past century, the dairy industry has embraced technological advancements to optimize its output and financial gains. There is a strong connection between technological advancements and structural changes in agriculture. The livestock industry's fascination with automation and precision technologies is continuously growing (Cogato et al. 2021). European dairy farms are presently undergoing a phase of transition to acclimate to modern dairy technology. The objective is to enhance various activities, such as management, consulting, physical labor, data collection, and analysis (McKinsey Global Institute, 2017). The persistent shortage of labor and the dairy farmers' aspirations to enhance their quality of life and professionalize their farms have resulted in the continuous evolution and modernization of dairy farming practices. This transformation has progressed from conventional bucket milking systems to tie-stall systems and milking parlors, and more recently, to the implementation of automatic milking systems (AMS). The adoption and proliferation of automated milking systems in European agriculture follow this trend. As of 2020, AMS manufacturers estimated that roughly 50,000 units were operational worldwide (Simões Filho et al. 2020). By 2025, it is projected that 50% of dairy farms in northwestern Europe will be equipped with AMS (Hansen et al. 2019). AMS farms generate significant volumes of data associated with the milking process, cow activity, concentrate feed intake, and rumination time. This data can be utilized to enhance the herd's production level and improve the welfare of the animals (De Koning, 2010). With the growing adoption of robotic milking, numerous studies have investigated the impact of automated milking on various factors. These include milk yield and quality (Lessire et al. 2020), animal behavior, health, and welfare (Piwczyński et al. 2020), herd management (Penry et al. 2018), and labor efficiency (Hansen and Stræte, 2020). Schewe and Stuart (2015) observed that the implementation of AMS has altered the dairy farm's operations and organization, leading to a restructuring of the relationships between farmers, animals, technology, and the environment. The objective of this study was to assess the impact of utilizing an Automatic Milking System on the production efficiency of dairy farms. The study examined various factors such as milk yield, milking frequency, visit time, feed intake, milk composition, and more.

Literature survey

Precision Livestock Farming (PLF) is a novel method of animal husbandry that employs advanced technologies to collect data on every animal within a farm by improving productivity. One of the most significant developments in some countries is the introduction of milking robots, or AMS, which has transformed the daily work of farmers and the relationship between farmers and animals (Hårstad, 2019). By 2020, AMS manufacturers predicted worldwide adoption of 50,000 units (Marcos et al. 2020), dairy farmers are increasingly evolving toward automation of their farms (Boscaro et al. 2015) automatic concentrate dispensers and automatic milking systems (AMS) have been utilized for years, and several manufacturers have introduced automatic feeding systems

(AFS) during the past decade (Unal and Kuraloglu, 2015). The application of this system delivers lower feeding costs, improved breeding performance, and healthy, productive cows (Lencsés et al. 2014). When considering the introduction of milking systems, several factors should be considered, such as the special features of the stable, the extra investment cost of the equipment compared to conventional milking, the potential yield and quality improvement, higher income, indirect effects such as fewer herd diseases, better production parameters, and possible subsidies (Lencsés et al. 2017).

Historical evolution of AMS

The number of dairy farms using an automatic milking system (AMS) is increasing rapidly, especially in Northwest Europe (Figure 1). The majority of AMS are in northern Europe (90%) and Canada (9%), with only about 1% located in the United States (de Koning, 2010). Though adoption rates have been slower in the States than in Europe, automatic milking systems seem to be on the rise (Marques et al, 2023).

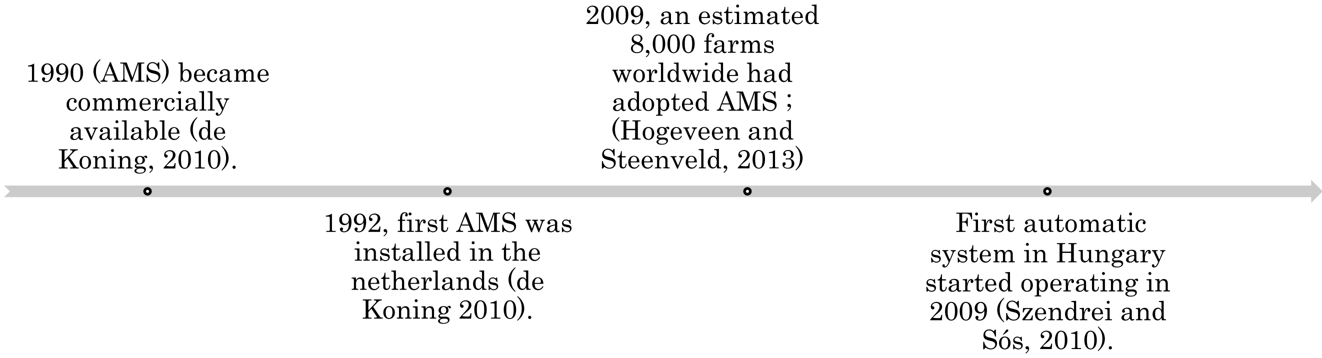

Figure 1. Evolution of AMS

According to Svennersten-Sjaunja and Pettersson (2008), the introduction of an AMS requires not only new milking technology but also a new management system that encompasses cow traffic, feeding, cow behavior, grazing, and milk quality. The use of AMS is most effective on farms with 60-260 cows (Gustavsson, 2010). Table 1 shows the benefits and disadvantages of the AMS.

In an AMS, in the standby position, the rear door is open, and the front door remains closed. When the cows voluntarily (motivated by the supply of concentrate) enter the milking box (de Koning et al. 2004) they will be detected by the infrared entry cell and then identified by their collar. The back door closes, and the computer checks if the cow is ready to milk. If so, she gets her dose of concentrate. Its mass is recorded using sensors located under the robot's cage. The system cleans the udder, milks the cow, and analyses the milk to detect any abnormalities (Freiss, 2009).

Table 1. Pros and cons of the introduction of AMS

Pros	Cons
Reduce the need for hired labour	Expensive cost between $150,000 to $200,000 (Bijl et al. 2007).
An increase in milk production is due to more frequent milking (Svennersten-Sjaunja and Pettersson, 2008).	Behavioural or conformational issues. For example, if a cow has an unfavourable teat position or variations in udder quarter size, cluster attachment may be challenging if teat cup attachment fails. (Bach and Busto, 2005).
Less time is spent on milking, and less need for relief in the cow house (Hansen 2015),	Requires approximately 3 to 4 weeks of intensive labour to achieve a success rate of 80 to 90% of cows voluntarily using the system (Jacobs et al. 2012).
Improve their quality of life and achieve a more flexible working day (Hårstad, 2019).	

Effect of AMS on Animal performance

Milk Yield: Automatic milking systems have the potential to increase milk production by up to 12%, decrease labor by as much as 18%, and simultaneously improve dairy cow welfare by allowing cows to choose when to be milked (Jacobs et al. 2012).

Milking frequency: Studies have shown that increasing milking frequency can increase milk production by up to 10.4 % when milking cows three times per day compared to twice Melin et al. 2005. Milking frequency depends on the cows' willingness to voluntarily visit the milking unit continuously during the day (Melin et al. 2005).

Milking intervals: Shorter milking intervals have been shown to increase milk production and reduce somatic cell count (SCC) in dairy cows (Wright et al. 2013).

Compositional Aspects: According to a study by Abeni et al. (2005), the type of milking system does not appear to have an impact on the protein and fat content in milk, nor does it affect the levels of lactose and urea in milk as found by Hopster et al. (2002). Instead, research suggests that the interval length between milkings and variation in milk yield per milking have more of an impact on fat content, as noted by Friggens and Rasmussen (2001). Some evidence exists indicating that levels of Free Fatty Acid (FFA) are increased in milk collected from farms that milk cows with AMS (de Koning and Rodenburg, 2004).

Milk Quality Aspects: Automatic milking units are fitted with sensors that measure milk quality, for instance, somatic cell count (SCC) and electrical conductivity (Jacobs et al. 2012). The milk's electrical conductivity (EC) is a measure of its concentration of anions and cations. Cows that are suffering from mastitis have an increased level of Na+ and Cl concentration in the milk, which increases the EC and can be detected with the robotic milking system (Hovinen and Pyörälä, 2011).

Environment: Recently, robotic milking systems allowed the estimation of methane emissions using towers equipped with fast-response methane sensors and wind speed/direction sensors, combined with atmospheric transport modelling. More specifically, it uses signal processing to detect burping peaks of methane (CH4) released by dairy cows during robotic milking. It reduces environmental pressure by using resources more efficiently. By keeping the animal healthier, less will be out, which will need to be replaced by fewer heifers, thus reducing the ecological footprint (Van Breukelen et al, 2023).

Materials and Methods

Study design

The study was carried out on a private dairy farm located in West Hungary. The farm was characterized by a free-stall system housing 294 lactating cows with concrete floor and surface scrapers for the frequent removal of manure equipped with a ventilation system. There are 6 singles AMS units installed in the barn, all of which are Lely Astronaut A5 models from Lely Industries, based in the Netherlands. The milking robots were purchased from their resources. The prevailing breed was Holstein-Friesian. The original data were collected over 3 months per AMS from October 2022 to January 2023. In total, 49 Holstein cows were milked daily per AMS unit. The days in milk were 165 (mid-lactation) with a total of 9542.3 kg of milk production per herd per day.

Data Collection

The data were collected from the farm management software. Every milking and refusal were registered with the following data: cow ID, date and time of the milking, milk yield (kg) as measured by the milk meters installed on each AMS unit, milk quality, and type of visit. The AMS automatically collected all data and saved it as "log files". These log files included classifications for three types of cow visits: milkings, refusals, and failures. Milkings indicated that the cow was milked normally, refusals indicated that the cow was not permitted to be milked and failures indicated that the milking was not successful. The log files were processed using MS-Excel to calculate various metrics such as mean milk yield (kg/d/cow), milking frequency (n/d), refusal frequency (n/d) and visit frequency (n/d), amount of concentrate offered (kg/cow/day) and milk fat and protein content (% of milk volume) for each day of each feed delivery treatment.

Statistical analysis

A statistical analysis was carried out using Lely T4C and SPSS 12 (IBM Statistical Package for the Social Sciences). Descriptive statistics were calculated for almost all the variables. Results were analysed statistically by Pearson linear correlations at 0.95 and 0.99 probability levels. A single-trait model was used to measure the effect of increasing milk yield per AMS per day. Multiple linear regression data analysis was applied to model the linear relationship between the dependent variable (milk yield) and the independent variables. The model expressed the value of the dependent variable as a linear function of the predictor variables and an error term.

Results and discussion

The study found that the Daily Milk Yield (DMY) at this AMS farm averaged 32.5 ± 1.3 kg/cow/day, consistent with Tse et al. (2018) who reported 32.6 kg/cow/day using the same technology (Table 2).

This surpasses the average milk yield of 28 kg/d reported by Nixon et al. (2009). The observed milking frequency of 2.7 ± 0.1 per cow per day exceeds Gygax et al. (2007) range of 2.38 to 2.56, and Bach et al. (2009) reported values for free (1.7 to 2.2) and forced (2.4 to 2.5) cow traffic. However, Madsen et al. (2010) noted 2.96 milkings per cow per day, suggesting potential for increased throughput. The high milking frequency may result from the smaller herd size (49 ± 3 cows) compared to Dussault's (2001) recommended range of 60 to 70 cows per AMS. Increasing herd size should be carefully managed to maintain optimal conditions. The concentrate offered per cow per day averaged 6 ± 0.1 kg, aligning with Rodenburg and Kelton (2001), who reported between 1.8 and 7.7 kg. Unsuccessful milkings were infrequent (0.1 ± 0) compared to refusal or rejection (2 ± 0.5), comprising only 3.7% of total milkings. Fat and protein content averaged 3.4 ± 0.2% and 3.3 ± 0.1%, respectively, like Bach et al. (2007) protein levels but slightly lower than their fat content.

Table 2. Descriptive statistics of the production and operation variables for the automatic milking system (AMS) in West Hungary (n =100)

Variable	Mean	Minimum	Maximum	SD [1]
Days in Milk (DIM)	165	149	181	10
Total Cows milked (n[2])	294	267	322	16
Cows per milking unit (AMS) (n)	49	45	54	3
Total Milk Yield (kg/per herd/day)	9542.3	8463.1	11050.7	535
Daily Milk yield per cow per day (kg)	32.5	28.9	36.0	1.3
Milking frequency per cow per day (n)	2.7	2.3	3.0	0.1
Refusals frequency per cow per day (n)	2	0.9	3.4	0.5
Unsuccessful frequency per cow per day (n)	0.1	0	0.2	0
Separated Milk per herd per day (kg)	251.6	81.8	602.3	110.9
Fat content (%)	3.4	3.1	3.7	0.2
Protein content (%)	3.3	3.2	3.5	0.1
Total cc intake (kg/herd/day)	1566.2 4	1171	1767	65.56
Average concentrate offered per cow per day (kg)	6.0	5.8	6.4	0.1
Rest of cc per AMS (kg)	0.6	0.4	1.1	0.1

[1]= Standard deviation; [2]= Number

Correlation between milking, failure frequency, and milk production

The study found a strong positive correlation between daily milk yield (DMY) and milking frequency ($r = 0.61$, $p < 0.01$) (Table 3). Using a single-trait model (Model 1), the R2 value for DMY as a function of milking frequency was 0.37, indicating some information gained (Table 4). In contrast, a multivariate linear model (Model 5) with a forward stepwise method yielded a higher R2 value (0.72), identifying significant predictors of DMY including milking frequency, concentrate intake, total feed intake, failed milkings, refusals, fat, and ruminating minute (Table 5).

Increasing milking frequency typically leads to a proportional rise in milk production, as supported by Melin et al. (2005), who noted a 2% to 12% increase when frequency increased from two to three times a day. However, Gygax et al. (2007) found no impact on milk yield when the milking frequency was increased in AMS cows with flavoured feed. Automated milking's primary advantage lies in adjusting milking frequency based on physiological state and milk production. Numerous studies, such as Knight et al. (1998), justified that milk secretion rate directly correlates with milking frequency due to mechanisms governing local milk secretion control.

A negative correlation was found between daily milk yield (DMY) and failed milking frequency ($r = -0.34$, $p < 0.01$) (Table 3). Unsuccessful milking can decrease milk yield and increase the risk of udder health issues, negatively impacting production. The primary cause of unsuccessful milking was failed teat cup attachments (72.4%). Failure to redirect a cow for subsequent milking after an unsuccessful attempt can result in production losses and compromise dairy welfare. Daily milk yield was not correlated with refusal frequency ($p > 0.05$). However, a negative correlation was observed between total milk yield and refusal frequency ($r = -0.29$, $p < 0.01$) (Table 3). An increase in refusal frequency leads to decreased milk production per AMS per herd per day.

Additionally, a strong positive correlation between milking and refusal frequency was found ($r = 0.67$, $p<0.01$). Furthermore, our study revealed a positive correlation between total milk yield and herd size (number of cows) ($r = 0.61$, $P < 0.01$). As the number of cows per robot increased, milking frequency and daily milk yield tended to decrease ($p < 0.05$), consistent with findings by Castro et al. (2012).

Table 3. Linear correlations between production variables of lactating cows on Automated Milking Systems (Pearson correlation, n=100).

Parameters	DIM	Nc	TMY	DMY	MF	Refusals	Unsuccess Jul	Separated milk	Total CC intake	CC in AMS	Rest of CC	Fat	Protein	Rumination
Days in milk	1	-0.29**	-0.37**	-0.13	- 0.1	0.31**	-0.06	0.16	-0.32**	-0.1	0.09	-0.59**	-0.37**	-0.01
Number of cows		1	0.61**	-0.32**	-0.39**	-0.49**	0.24*	-0.11	0.45**	-0.58**	0.20*	0.70**	0.25*	0.014
TMY (kg/herd/d)			1	0.55**	0.16	-0.29**	-0.08	-0.01	0.81**	-0.07	-0.16	0.46**	0.30**	0.11
DMY (kg/cow/d)				1	0.61**	0.18	-0.34**	-0.004	0.45**	0.52**	-0.43**	-0.20*	0.09	0.12
Milking frequency (n/d)					1	0.67**	-0.23*	-0.07	0.49**	0.27**	-0.81**	-0.25*	-0.13	-0.01
Refusals (n/d)						1	-0.22*	0.02	0.04	0.16	-0.53**	-0.45**	-0.27**	-0.03
Unsuccessful (n/d)							1	-0.24*	-0.06	-0.14	0.13	0.04	-0.1	0.13
Separated milk (kg/d)								1	-0.22*	-0.05	0.20*	-0.12	0.17	-0.22*
Total cc intake (kg/herd/d)									1	-0.135	-.514**	0.38**	0.19	0.01
CC offered in AMS (kg /cow/d)										1	-0.014	-0.34**	0.07	0.105
Rest of cc (kg)											1	0.174	0.14	0.135
Fat (%)												1	0.25*	0.04
Protein (%)													1	-0.35**
Rumination (min)														

*= Correlation is significant at the 0.05 level (2-tailed); **= Correlation is significant at the 0.01 level (2-tailed).
DMI: Days in Milk, NC: Number of cows, TMY: Total Milk yield, DMY: Daily Milk yield, MF: Milking frequency, CC: Concentrate, n: number, d: day

Table 4. Single-trait model and multiple regression analysis output using the forward stepwise method (dependent variable: daily milk yield)

Model	R	R^2	Adjusted R^2	Std. error of the estimate	Change statistics					Durbin-Watson
					R^2 change	F change	df1	df2	Sig. F change	
1	0.61[a]	0.37	0.37	0.91615	0.374	58.636	1	98	0.000	
2	0.72[b]	0.51	0.50	0.81371	0.137	27.229	1	97	0.000	
3	0.78[c]	0.60	0.59	0.73615	0.093	22.517	1	96	0.000	
4	0.80[d]	0.64	0.63	0.70445	0.037	9.833	1	95	0.002	
5	0.82[e]	0.67	0.66	0.67472	0.033	9.557	1	94	0.003	
6	0.84[f]	0.71	0.69	0.63902	0.037	11.795	1	93	0.001	
7	0.85[g]	0.72	0.70	0.62830	0.013	4.203	1	92	0.043	1.394

a. Predictors: (Constant). Milking frequency.
b. Predictors: (Constant). Milking frequency. Average total concentrate intake.
c. Predictors: (Constant). Milking frequency. Average total concentrate intake.
d. Predictors: (Constant). Milking frequency. Average total concentrate intake. Unsuccessful.
e. Predictors: (Constant). Milking frequency. Average total concentrate intake. Unsuccessful. Refusals.
f. Predictors: (Constant). Milking frequency. Average total concentrate intake. Unsuccessful. Refusals. Fat.
g. Predictors: (Constant). Milking frequency. Average total concentrate intake. Unsuccessful. Refusals. Fat. Chewing.
h. Dependent Variable: average daily milk yield.

Table 5. Single-trait model and multiple regression analysis output using the forward stepwise method (dependent variable: total milk yield)

Model	R	R^2	Adjusted R^2	Std. error of the estimate	Change statistics					Durbin-Watson
					R^2 change	F change	df1	df2	Sig. F change	
1	0.81[a]	0.66	0.66	235	0.660	190.044	1	98	0.000	
2	0.87[b]	0.76	0.75	199	0.099	40.021	1	97	0.000	
3	0.88[c]	0.78	0.77	192	0.018	7.922	1	96	0.006	
4	0.89[d]	0.79	0.78	189	0.010	4.608	1	95	0.034	1.275

a. Predictors: (Constant). Total concentrate intake (robot).
b. Predictors: (Constant). Total concentrate intake (robot). Failures.
c. Predictors: (Constant). Total concentrate intake (robot). Failures. Rest of concentrate.
d. Predictors: (Constant). Total concentrate intake (robot). Failures. Rest of concentrate. Unsuccessful.
e. Dependent Variable: total milk yield.

Effect of the concentrate supply in the AMS on production efficiency

Total milk yield per herd per day exhibited a strong positive correlation ($r = 0.81$, $p < 0.01$) with total feed intake of concentrate (Table 3). Additionally, our study found a positive correlation between the amount of concentrate offered in the AMS per cow per day and both daily milk yield (DMY) per cow per day and milking frequency (MF) ($r = 0.52$, $r = 0.27$, $p < 0.01$). Conversely, the amount of remaining concentrate in the robot was negatively correlated with both DMY and MF ($r = -0.43$, $r = -0.81$, $p < 0.01$). Henriksen et al. (2018) noted increased milk yield with higher concentrate allocation, and Menajovsky et al. (2018) observed a tendency for increased milk yield.

Our findings align with previous research, showing that cows receiving a low concentrate amount and not fetched were milked 2.4 ± 0.1 times per day, while those receiving a high concentrate amount and not fetched were milked 2.7 ± 0.1 times per day, consistent with Bach et al. (2007). However, Halachmi et al. (2005) found no difference in milking attendance comparing different daily concentrate allowances at the AMS. Despite the common practice of feeding large quantities of concentrate, controlled studies suggest increasing concentrate quantity in the AMS doesn't necessarily improve visits or milk yield (Bach et al. 2007; Hare et al. 2018). In line with findings from Bach et al. (2007), no significant correlations were observed between refusal frequency and concentrate offered in the AMS ($p > 0.05$). However, negative correlations were identified between total milk yield/total concentrate intake and days in milk ($r = -0.37$; $r = -0.32$, $p < 0.01$) respectively, indicating that increased days in milk resulted in decreased milk production and concentrate intake. This may be explained by the high persistence of the robotic herd, and this could be the object of further investigation. Interestingly, days in milk exhibited a positive correlation with refusal frequency ($r = 0.31$, $p < 0.01$), as shown in Table 4.

Correlations between milk composition, milk yield, and feed intake

Examining milk production and cow traits (see Table 2), we found significant negative correlations between fat content and daily milk yield (DMY) ($r = -0.20$, $p < 0.05$), as well as between fat content and milking frequency ($r = -0.25$, $p < 0.05$). Fat percentage increases as milk yield decreases, likely due to energy allocation for body temperature maintenance. Additionally, a negative correlation was observed between fat content and AMS concentrate quantity ($r = -0.34$, $p < 0.01$), indicating a decrease in milk fat with increased concentration. However, protein content showed no significant correlations with DMY, milking frequency, or AMS concentrate quantity ($p > 0.05$) (see Table 3). Fat and protein content were negatively correlated with days in milk (DIM) ($r = -0.59$; $r = -0.37$, $p < 0.01$), respectively, while separated or poor-quality milk was negatively correlated with failed milking ($r = -0.23$, $p < 0.05$).

Conclusions

Milkings frequency was usually considered as an indicator of robot performance and researchers focused on ways to optimize it. It showed wide variability and positive correlation ($p < 0.01$) with daily milk yield. Consequently, with this increase in milking frequency, the average milk yield per cow per day would increase. In contrast, a negative correlation was observed between DMY and failed frequency ($p < 0.01$).

Daily milk yield per cow and milking frequency were positively correlated with the amount of concentrate offered in AMS per cow per day ($p < 0.01$).

Fat content did negatively correlate with daily milk yield. Milking frequency and amount of concentrate offered in automated milking systems ($p< 0.05$).

For protein content no correlations were observed with daily milk yield, milking frequency as well as the amount of concentrate in the AMS ($p > 0.05$).

Detailed knowledge of these factors such as milking frequency and concentrate intake associated with increasing milk yield by using AMS will help guide future recommendations to producers for maximizing milk yield and decreasing the cost on dairy farms.

Continuously monitoring and adjusting the concentrate offering based on individual cow requirements can help maximize milk yield and optimize cow nutrition.

An integrated approach to milk quality: While the focus of the study was on milk yield and composition, a comprehensive approach to milk quality is essential. Additional research and monitoring can be conducted to evaluate other quality parameters such as somatic cell count, bacterial count, electrical conductivity, and other milk components that may impact overall milk quality. AMS can maximize milk production, improve milk composition, ensure overall herd health and welfare, and decrease the cost of dairy farms.

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