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RESEARCH ARTICLE

Effects of Electrical Conductivity, Activity Level, Age and Lactation Number on Milk Yield in Dairy Cows during the Lactation Period

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Abstract

This study aimed to evaluate the relationships between milk yield and variables such as milk electrical conductivity, animal activity, age, and lactation number. The study was based on 2022 data from Holstein cows on a private dairy farm located in the Karapınar district of Konya, Türkiye. Cows were fed a total mixed ration with a roughage-to-concentrate ratio of 55:45 and 17.5% crude protein. Data were obtained from the farm's computerized herd management system, which recorded daily data on milk yield, milk conductivity, and animal activity for each cow. Pearson correlation analysis and one-way analysis of variance (ANOVA) were used to analyze the data. A significant positive correlation was found between milk yield and both age ($r = 0.353$, $P<0.01$) and lactation number ($r = 0.269$, $P<0.01$). However, the correlation between milk conductivity and milk yield was weak and not statistically significant ($r = -0.086$). ANOVA results revealed that milk yield differed significantly among age groups ($P<0.001$), with cows aged 4–5 years producing more milk than younger cows aged 1–3 years. These findings suggest that age and lactation number significantly affect milk yield, whereas milk conductivity and animal activity are not directly related to production. Although these factors may not directly influence milk yield, the results can provide a useful basis for developing herd management strategies that support animal health, economic outcomes, and farm efficiency. Future research involving different breeds or production systems could further validate these findings.

Introduction

Dairy cattle breeding plays a strategic role not only in contributing to global human nutrition but also in the sustainability of agricultural economies. Milk yield is shaped by the interaction of multifaceted factors such as genetic potential, nutritional levels, environmental conditions, and management practices. The genetic structure is associated with production traits like feed intake, body weight, and milk yield, and significant genetic correlations have been reported among these traits (Veerkamp and Brotherstone, 1997). Adequate and balanced provision of the nutrients required during lactation directly impacts the physiological performance of the animals (NRC, 2001). Particularly, heat stress caused by high environmental temperatures can lead to significant losses in milk yield and physiological imbalances in high-producing cows due to increased metabolic heat production (Kadzere *et al*., 2002). Furthermore, recent studies have highlighted the impact of global warming on herd health and productivity, stressing the need for adaptive management strategies to mitigate these effects (Arslan *et al*., 2024; Erzurum, 2024). In this context, it is essential to address these factors with a holistic approach to optimize milk production.

The effects of age and lactation number on milk yield have been widely studied in dairy cattle literature. It has been reported that milk yield peaks during the 3rd and 4th lactation periods, but declines are observed from the 5th lactation onwards (Vijayakumar *et al*., 2017). However, the relationship between age and milk yield is complex, with some studies indicating an increase in yield with age, but a plateau or decline after a certain age (Kerslake *et al*., 2018). These findings emphasize the importance of considering age and lactation number to optimize milk yield.

The relationship between milk electrical conductivity, animal movement, and milk yield has not been clearly established in the literature, and different results have been obtained in various studies. Milk electrical conductivity is generally associated with udder health and is used as an indicator of infections such as mastitis (Norberg, 2005). The relationship between electrical conductivity and yield is uncertain due to the influence of non-mastitis factors such as temperature and milking intervals (Nielen *et al*., 1993). Studies on the relationship between animal movement and milk yield have yielded inconsistent results, as movement data produce inconsistent results due to both metabolic effects of activity increase and differences in measurement methodologies (Chapinal *et al*., 2011). This highlights the complexity of factors affecting milk yield, suggesting that a single biometric parameter may not be sufficient.

Electrical conductivity refers to the measurement of the electrical level between two electrolytes, typically expressed in mS/cm (miliSiemens/santimetre) (Hilerton and Walton, 1991; Johri *et al*., 2023). Milk electrical conductivity began to be used in the 1940s for mastitis evaluation (Davis, 1947). The electrical conductivity of milk is measured and recorded by most automatic milking systems together with data such as milking time and milk yield (Norberg, 2005). Such electronic measurement systems have an important place for precision technology applications (Ordolff, 2001). The desire to increase milk yield in dairy cows has led to an increase in udder problems and mastitis risk (Alaçam *et al*., 1983). Key anions and cations in milk, such as Na+ and Cl-, increase in the presence of intramammary infections (Nielen *et al.,* 1992; Bruckmaier *et al*., 2004; Norberg, 2004). Mastitis causes significant economic losses in terms of reduced milk production and quality, inability to use milk, treatment costs, and culling of cows (Vilas Boas *et al*., 2017; Guimarães *et al*., 2017; Samaraweera *et al*., 2022). The financial burden of mastitis, ranging from $100-228 per cow per year in Turkey, €240 in Germany, and €440 in Canada, has led to increased research in this area (Aghamohammadi *et al.*, 2018; Firth *et al.*, 2019; Sarıözkan, 2019). This impact has prompted the replacement of human observers with automatic milking systems (Inzaghi *et al*., 2021). As a result, a focus has shifted to milk electrical conductivity, a cheaper and more practical method (Mottram *et al*., 2007).

Electrical conductivity is also influenced by factors such as lactation number, udder lobe, milking intervals, milk composition, estrus, and nutritional levels (Nielen *et al*., 1992; Norberg, 2005; Špauskas *et al*., 2006). Prolonged milking intervals increase conductivity, while increased milk fat reduces it (Atasever and Erdem, 2008). Furthermore, it has been reported that conductivity values in front udder lobes are lower than those in rear udder lobes (Cavero *et al*., 2006).

In a healthy cow, the electrical conductivity of milk at 25°C ranges from 4-5.5 mS/cm, values up to 6.1 mS/cm are considered normal, and values above 6.2 mS/cm are considered abnormal (Nielen *et al*., 1992; Špauskas *et al*., 2006; Çelik, 2020). However, it has been noted that milk with conductivity above 6.2 mS/cm is not always indicative of mastitis, as the value of colostrum may exceed 6.2 mS/cm (Çelik, 2020). High-temperature milk (38°C) has been shown to increase electrical conductivity levels (Norberg, 2005). Furthermore, when electrical conductivity exceeds 6.5 mS/cm, and the difference between udder lobes exceeds 1 mS/cm, it indicates the likelihood of disease (Janzekovic *et al*., 2009). An increase in conductivity by 1 mS/cm corresponds to a 0.88 kg/day decrease in milk yield (Nielen *et al*., 1993).

The aim of this study is to investigate the effects of factors such as age, lactation number, animal movement, and milk electrical conductivity on milk yield, as well as their interactions, using the 2022 data from a dairy cattle farm in Konya province. The study aims to provide new insights on how these factors can be managed to enhance productivity in dairy farming.

Materials and Methods

This study was carried out at a private dairy cattle farm in the Karapınar district of Konya province. The material of the study consisted of the 2022 lactation period data obtained from the computer-based herd management program for 170 Holstein cows of different ages at the farm. The dataset included individual records of milk yield, age, lactation number, milk conductivity, and animal movement for all animals. All animals included in the study were subjected to the same feeding and management protocol. The cows were housed in modern free-stall barns and fed twice daily, in the morning and evening, ad libitum with a total mixed ration (TMR) diet. Access to clean drinking water was provided continuously through automatic float-controlled waterers.

The composition of the ration used in the feeding included wheat straw, dry alfalfa, alfalfa silage, corn silage, barley, canola, carrots, urea, molasses, yeast, vitamin-mineral premix, salt, marble powder, bypass fat, toxin binder, and concentrated milk feed. The ration was formulated according to NRC (2001), with a roughage/concentrate ratio of 55%/45% and a protein level of 17.5%.

There were no restrictions based on age and lactation number for the animals included in the study. The age distribution varied from 1 to 9 years. Lactation numbers ranged from the 1st to the 7th lactation. Milk yield, milk conductivity, and animal movement data were measured and recorded daily via transponders attached to the animals and the computerised milking system. These data were periodically transferred to the farm management software for analysis. In the study, 65 cows underwent two milkings per day, and 105 cows were milked three times daily. The sample size for statistical analysis was determined after excluding any outlier data.

Statistical analyses

In this study, the relationships between milk yield and age, lactation number, milk conductivity, and animal movement were investigated using correlation and variance analysis. The data were analyzed using IBM Corp. (2012) SPSS Statistics software (v.21). The normality of the data was tested using the Shapiro-Wilk test. Data that did not show normal distribution were excluded from the study. For data that followed a normal distribution, the relationships between milk yield and age, lactation number, milk conductivity, and animal movement were determined using Pearson's correlation coefficient (r). Differences in milk yield among groups were evaluated using one-way analysis of variance (ANOVA). Statistical significance of the differences between groups was tested using the Duncan test. Statistical significance was considered at $P < 0.05$.

Ethical approval for the study was granted by the Ethics Committee of the Experimental Animal Production and Research Center (SUVDAMEK), Faculty of Veterinary Medicine, Selcuk University (Decision No: 2025/99).

Results and Discussion

The descriptive statistics for the dairy cows evaluated in this study are presented in Table 1. The average age of the cows was 3 years, with an average lactation number of 2, a daily average step count of 115 steps, an average milk yield of 10.836 kg throughout the lactation period, and an average milk electrical conductivity of 6.5 mS/cm. Additionally, the incidence of mastitis cases confirmed by the farm's veterinarian was calculated as 9.38%. In the study by Dağ and Zülkadir (2024), milk electrical conductivity was reported to be lower than in this study (6.12±0.097 mS/cm).

The findings of the study reveal the relationships between milk yield and age, lactation order, animal movement and milk conductivity (Table 2). It was observed that these findings were largely consistent with previous studies, but presented some new findings. According to the results of the correlation analysis, a positive and significant relationship was found between age and milk yield ($r = 0.353$, $P<0.01$). Particularly, cows aged between 4 and 5 years exhibited higher milk yields (Table 3). This finding

Table 1. Descriptive statistics of the traits in the dairy cows used in the study (n=170).

Variables	Mean	Std. Error	Minimum	Maximum	Std. Deviation
Age (years)	3.14	0.10	1	9	1.31
Lactation number	1.95	0.85	1	7	1.10
Activity (steps/day)	114.69	2.56	61	334	33.42
MEC (mS/cm)	6.5	0.09	4.5	10.5	1.13
Lactation milk yield (kg)	10836.04	202.36	4642	19759	2630.70

Abbreviations: MEC (mS/cm); milk electrical conductivity (miliSiemens/santimetre).

Table 2. Correlations among dependent variables in the dairy cows used in the study (n=170).

Variables	Age	Lactation number	Activity	MEC	Lactation milk yield
Age	1				
Lactation number	.914**	1			
Activity	-.115	-.116	1		
MEC	.164*	.055	-.032	1	
Lactation milk yield	.353**	.269**	-.085	-.086	1

*Correlation is significant *P* <0.05 level

**Correlation is very significant *P* <0.01 level.

Abbreviations: MEC; milk electrical conductivity.

indicates that age has a significant impact on milk yield, which is a commonly emphasized factor in the literature. Wilmink (1987) similarly reported a noticeable increase in milk yield as age increased. Physiological changes that occur with age (e.g., more developed udders and more mature metabolic systems) are thought to positively affect milk yield. Moreover, the cows in this age group have a longer capacity for milk production, which is important for producers to optimize efficiency.

Another finding from the analysis was that there is a positive and significant relationship between age and milk electrical conductivity ($r = 0.164$, $P < 0.05$). Timurkan (2004) found no difference in electrical conductivity values of animals from the same breed, with values exceeding 5.6 mS/cm, and noted that electrical conductivity increased with age. However, Özdemir and Kaymaz (2013) found that the lactation period, age, and mammary lobe differences did not significantly affect electrical conductivity. Sheldrake *et al*. (1983) reported that as lactation number increases, there is a corresponding rise in milk conductivity and somatic cell count, which may be associated with intramammary infections such as mastitis. Similarly, Inzaghi *et al.* (2021) observed that differences in electrical conductivity between udder quarters become more evident after the third lactation, possibly due to a history of mastitis in older cows. When evaluated together, these findings suggest that the variations in milk conductivity observed with increasing lactation number may be linked to previous udder infections.

The effects of lactation number on milk yield are a debated topic in the literature. In this study, a positive relationship was found between lactation number and milk yield ($r = 0.269$, $P<0.01$). An increase in milk yield was observed as lactation number progressed. This finding is consistent with some studies (Özçelik and Arpacık, 2000; Erzurum and Kayar, 2024). As lactation progresses, cows are expected to become more mature and produce milk more efficiently. However, some studies have reported a decrease in milk yield after the 3rd to 5th lactations (Tekerli *et al*., 2000; Ekşi and Kurt, 2021). The absence of a decrease in milk yield after the 4th lactation in this study suggests that herd management and feeding strategies may influence this result. Bayrakdar *et al*. (2024) reported that lactation number affected electrical conductivity, daily milk yield, and milking duration, and similar to the present study, older cows had higher conductivity and milk yield.

The relationship between animal movement and milk yield has not been clearly established in the literature. In this study, no statistically significant relationship was found between animal movement and milk yield ($P > 0.05$), and it was observed that animal movement had no direct effect on milk yield (Table 3). Results regarding the relationship between animal movement and milk yield in the literature may be contradictory. Some studies have reported a positive relationship between cow mobility and milk yield. For example, a study by Adamczyk *et al.* (2011) found a significant relationship between cows' 24-hour walking activity and milk yield. This study showed that more active cows had higher milk yields. However, in this presented study, no direct relationship between animal movement and milk yield was found. This could suggest that environmental factors may influence the cows' behavior, but these changes do not necessarily reflect in milk yield. Additionally, the mobility of animals could increase their stress levels, which could negatively affect milk yield. Therefore, further in-depth and long-term studies are needed to better understand the relationship between animal movement and productivity.

In this study, a weak and statistically insignificant relationship was found between milk conductivity and milk yield ($r = -0.086$). This suggests that there is no direct connection between milk conductivity and milk yield. Many studies have focused on the early detection of mastitis and udder health parameters rather than the direct relationship between electrical conductivity and milk yield (Hamann and Zecconi, 1998; Norberg *et al.,* 2004; Goodling *et al*., 2000; Rogers, 2002; Tatlısu and Zulkadir, 2024). Vilas Boas *et al.* (2017) reported a positive relationship between somatic cell count and electrical conductivity in dairy Zebu cows (Dairy Gyr), noting that somatic cell count increased for values between 4.81-5.00 mS/cm and that these values could indicate mastitis formation in dairy cows. In contrast, Kurt and Kaygısız (2024) found no significant difference in electrical conductivity among Red Holstein, Black Holstein, and Simmental breeds, and concluded that electrical conductivity cannot be used to detect mastitis. Another study by Timurkan (2014) also reported that there was no correlation between California Mastitis Test (CMT) results and electrical conductivity values.

The results of variance analysis showed that significant differences in milk yield were observed in age groups, with the 4-5 years and older groups having significantly higher milk yields compared to the 1-3 years group (12047-12301 kg; 10300 kg; $P<0.001$). Similarly, analyses based on lactation number showed that as lactation number increased, milk yield also increased. Milk conductivity and animal movement did not have significant effects on milk yield, in line with the correlation analyses (Table 3).

The findings also reveal the impact of environmental and management factors on milk yield. For example, environmental factors such as temperature and humidity can affect milk yield in cows. Additionally, herd management practices and feeding strategies can enhance milk yield in cows, particularly during lactation, which may explain the increases in milk yield observed in this study.

Table 3. Effects of fixed factors on lactation milk yield in dairy cows (Mean ± SE).

Fixed effects	N	Lactation Milk Yield (kg) Mean ± SE	*P*- value
Age (years)			
1 - 3	123	10300.919 ± 218.621 [b]	**0.000**
4 - 5	35	12047.500 ± 340.144 [a]	
≥6	12	12301.229 ± 1211.171[a]	
Lactation number			
1	72	9727.542 ± 260.940 [b]	**0.000**
2	56	11512.625 ± 323.467 [a]	
≥3	42	11814.191 ± 450.974 [a]	
Activity (steps/day)			
≤100	67	10808.060 ± 312.314	0.097
101 - 126	57	11009.421 ± 326.752	
126 - 151	24	11561.375 ± 583.497	
≥150	22	9680.727 ± 611.380	
MEC (mS/cm)			
4 - 5.6	33	10776.667 ± 522.027	0.989
5.6 - 6.2	42	10834.714 ± 412.747	
≥6.2	95	10857.242 ± 258.173	

Note. Different superscript letters (a, b) within a column indicate significant differences (P <0.05).

Conclusion

This study examined the relationships between milk yield and factors such as age, lactation number, animal movement, and milk conductivity. The findings indicate that age and lactation number have significant effects on milk yield. In particular, cows aged between 4 and 5 years were observed to produce higher milk yields. However, the results also show that milk conductivity and animal movement are not directly associated with milk yield. Nevertheless, although these factors do not have a direct impact on yield, they may serve as valuable tools for herd management and the development of producer strategies. In this context, implementing specialized care and feeding programs for cows aged 4–5 years could help optimize milk production. The lack of a direct relationship between milk conductivity and animal movement with milk yield suggests that these parameters should primarily be used for health monitoring purposes. Further studies involving different breeds and larger sample sizes are recommended to reassess the relationship between these parameters and milk yield. Additionally, the effects of animal welfare and environmental factors on milk production should be explored in more detail.

Conflict of Interest

The authors declare that there are no conflicts of interest related to this publication. No financial support that could have influenced the outcome of the study has been received. The manuscript has been read and approved by all listed authors, and there are no individuals who meet the authorship criteria but are not included.

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