

SMART AND EFFICIENT MANAGEMENT OF REPRODUCTIVE PERFORMANCE ON DAIRY FARMS

Amalia-Gianina Strateanu, Mariana Sandu*

Center for Studies and Research for AgroForestry Biodiversity "Acad. David Davidescu", Romanian Academy, 13,

Calea 13 September, 5th district, Bucharest, Romania. *E-mail: marianasandu47@gmail.com

ORCID number: Amalia-Gianina Strateanu – 0000-0003-0340-5444; Mariana Sandu - 0000-0003-3704-5758

Abstract

Reproductive efficiency is essential for the profitability of dairy farms. The key to profitability and sustainability lies in herd management and operational efficiency. From an economic standpoint, poor management leads to increased involuntary culling (removal of cows from the farm) and longer calving intervals, directly resulting in a reduction in the number of calves born and in the total amount of milk produced over the cow's productive life. To determine the intelligent and efficient management of reproductive performance on dairy farms, research was conducted at the SC Agro Chirea SRL farm in the village of Rusănești, Rusănești commune, Olt County, with an average herd size of 581 Holstein-Friesian cows, a breed specialized for milk production, during the analyzed period (January 1, 2023 – June 20, 2025). To evaluate the reproductive efficiency and performance of cows used for milk production, the study analyzes the following reproductive indices as key parameters: age at first calving, average calving interval, service interval, insemination rate, and pregnancy rate.

Keywords: SMART management; reproductive indices; reproductive performance; performance indicators

1. INTRODUCTION

The growing global demand for animal-based products, combined with consumer concerns about the environment and animal welfare, requires dairy farms to improve their efficiency and adopt sustainable practices. In the current context of animal husbandry in Romania, it is essential to focus on implementing innovative technologies and sustainable practices to ensure a prosperous future. Businesses in the animal husbandry sector go hand in hand with adaptability, investment in modern infrastructure, and continuous training. Through the efficient use of resources, precision livestock farming, and support for sustainable initiatives, we can create a resilient and competitive system [1].

1.1. Technological solutions in Precision Livestock Farming

In addition to genetics, reproductive performance efficiency is a key factor in ensuring the profitability of a dairy farm. Smart reproductive management, achieved by increasing the use of technology on farms, directly results in fewer health issues among cows and improved cow comfort. In recent decades, the dairy industry and technology developers have created innovative solutions and systems for smart dairy farms by implementing new technologies used in precision livestock farming [4]. These technologies create complex ecosystems for collecting farm data, enabling timely managerial decision-making. From the perspective of reproductive efficiency, these technologies used in precision livestock farming can be divided into several main categories based on their role:

- **activity sensors** – a cow in heat changes her behavior. Thus, the sensors monitor movement by detecting the animal's agitation and the number of steps taken [9]. Additionally, the sensors can identify the "leaping" behavior specific to the moment when the cow accepts

mating, with an accuracy far exceeding human observational ability (over 90–95%). These sensors detect the onset of estrus, which leads to an increase in conception rates and a reduction in the interval between calvings. Additionally, some sensors can trigger alarms regarding the onset of calving, enabling real-time assistance if the medical situation requires it;

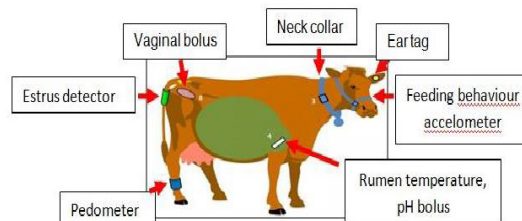


Figure 1. Locations of various sensors used for data collection in a dairy animal [8]

- **automated milking systems** – even though the initial investment for this type of system is high, the added value comes from reduced labor costs and increased milk production [6]. Thus, a routine activity that consumes financial and human resources is transformed into a decision-support system, with direct results based on the collected data, which helps extend the cows' productive lifespan (ensuring the cow's health and well-being by monitoring health, movement, and feed) and in producing high-quality milk (by analyzing the milk collected prior to processing and preservation).

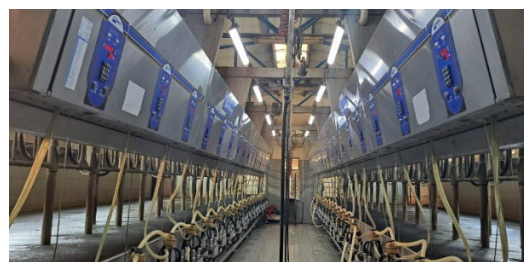


Figure 2. Automatic milking parlor



Figure 3. Collection of a milk sample for quality testing directly in the milking parlor to determine the percentage of protein, fat, bacteria, and somatic cells.

Sensors integrated into milking systems provide real-time data on each individual animal, reducing animal stress during milking and shortening milking time. They also provide direct insights into milk quality control and milk production volume. Milk analyzers test parameters such as pH, protein, fat, lactose, and conductivity (an indicator of mastitis);

- **The Internet of Things (IoT)** makes it possible to transform raw data into breeding success. On a farm that uses IoT, each individual animal becomes a data node connected to a global network, thereby improving the performance of the breeding process. This enables real-time connectivity and monitoring (24/7), allowing for constant communication between devices, and triggers instant alerts at the peak of estrus, synchronizing the entire veterinary team with the same data. In order to confirm a reproductive event on the farm, it is necessary to combine data from different sources, integrating multiple data sets through simultaneous analysis and cross-validation. So-called "silent estrus" can be detected, ensuring that these animals are inseminated on time. Reproductive efficiency is determined not only by gestation itself, but also by bringing it to a successful conclusion and restarting a new cycle after calving, using transition period monitoring. Following a proper analysis of the data collected and stored in the cloud, it is possible to identify fertility trends and compare the farm's reproductive performance relative to the global or regional average, using anonymized databases;

- **broadband technologies** transmit large data streams generated by precision livestock management, but require a stable, high-speed internet connection, providing real-time alerts regarding the optimal window for insemination. Broadband provides high-resolution video monitoring, access to cloud computing, and predictive analytics to compare a cow's current data with her lifetime history against global fertility models. In the event of a difficult calving, the farmer can utilize telemedicine and remote assistance from veterinarians;

- **data analysis** is the final step, but also the most important one, where data collected by sensors and transmitted via broadband is transformed into managerial decisions, thereby eliminating human error. Reproductive efficiency enhances data analysis by identifying the optimal insemination window, enabling early detection of fertility issues, monitoring pregnancy rates and embryonic losses, evaluating performance by batch and genetics, and reducing the service interval (the time between calving and conception).

Data management errors and a lack of consistency in data interpretation can lead to a decline in reproductive performance efficiency due to inseminations at inappropriate times. Activity sensors and automated milking systems collect the data, the Internet of Things and broadband technologies transmit it, and data analysis interprets it to enable informed decision-making [10].

1.2. Key aspects of reproductive performance and performance indicators

Effective management of reproductive performance is the key factor in the profitability of a dairy farm, determining the sustainability of the entire business. It is not merely a matter of producing one calf per year, but rather about how technology and the data collected and analyzed can eliminate downtime in the cow's production cycle. Reproductive performance represents an animal's ability to conceive, carry, and raise offspring, impacting herd replacement and milk production - essential for animal profitability and genetic progress.

Key reproductive performance indicators include heat detection rate (target > 60–70% of the total herd), age at first calving (influences lifetime productivity), - calving interval (the period between successive births, ideally between 380 and 400 days, with targets that minimize "open days"), pregnancy rate (calculated as the percentage of eligible cows that become pregnant every 21 days; a rate above 20–25% indicates a high-performing farm), and conception rate (the number of pregnant cows out of the total number inseminated).

Factors influencing reproductive performance:

- Management [7] is not merely an administrative task, but a precision-based process that directly links animal health to business profitability;
- Nutrition: An appropriate diet, particularly protein intake, has a significant impact on fertility.
- Environment: Heat stress can drastically reduce fertility, leading to lower conception rates and higher abortion rates.
- Health: A cow cannot achieve good reproductive performance unless she has impeccable metabolic and digestive health. In addition, maintaining uterine health and vaccination programs are absolutely necessary.

2. MATERIALS AND METHODS

The research was conducted at the Agro-Chirea farm, which had an average herd size of 581 Holstein-Friesian cows, a breed specialized in milk production, during the period from January 1, 2023, to June 20, 2025.

The process of transforming raw data into management decisions follows a well-established workflow. The working material consists of a constant stream of data (Big Data).

The primary data was collected from the farm and interpreted using specific formulas for calculating reproductive indices.

The cow activity monitoring system at Agro Chirea Farm uses monitoring collars, which are easy to install and use. As a result, cows are inseminated more quickly and accurately, directly leading to maximized herd profitability and time savings. The insemination schedule is carried out within the window indicated by the software.

3. RESULTS AND DISCUSSIONS

Reproductive indices are key parameters used to assess reproductive efficiency and performance in dairy cattle. These indices enable farmers and veterinarians to evaluate fertility levels across all herds, making it easier to identify potential reproductive problems and assess the effectiveness of interventions designed to improve fertility rates.

3.1. Age at First Calving

The age at first calving is of particular importance, as animals at this age should weigh 60–70% of their adult body weight; however, there is significant variability in this figure, which depends on rearing practices, management, and breed. In terms of age at first calving, heifers can be classified into several categories: early maturing (under 22 months), standard (between 22 and 25 months), and late maturing.

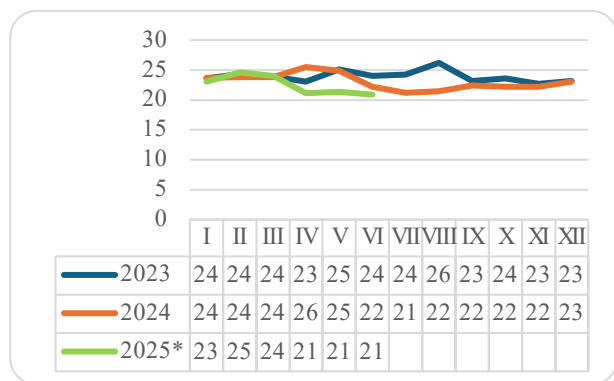


Figure 4. Dynamics of the *first calving age*

Note: *For the year 2025, the first semester was considered

Table 1 Dynamics of the age at first calving within the herd for the period under review

	2023	2024	2025
Average $\bar{x}$	23.92	23.04	22.51
Standard deviation S	0.96	1.32	1.59
Coefficient of variation cv%	4.02	5.76	7.09

For the herd analyzed, the age at first calving was:

- in 2023, an average ($\bar{x}$) of 23.92, with a standard deviation (S) of 0.96 and a coefficient of variation (CV%) of 4.02;

- in 2024, an average ($\bar{x}$) of 23.04, with a standard deviation (S) of 1.32 and a coefficient of variation (CV%) of 5.76;

- in 2025 (first 6 months only), average ($\bar{x}$) of 22.51, with a standard deviation (S) of 1.59 and a coefficient of variation (CV%) of 7.09.

The age at first calving has steadily decreased each year, from 23.92 months in 2023 to 22.51 months in 2025. This may indicate a trend toward improved reproductive management. Although the average is decreasing, variability is increasing, meaning that differences between individuals are becoming greater. In 2025, the coefficient of variation is 7.09%, compared to just 4.02% in 2023. This may suggest a lack of uniformity in the application of breeding practices or greater genetic diversity within the population.

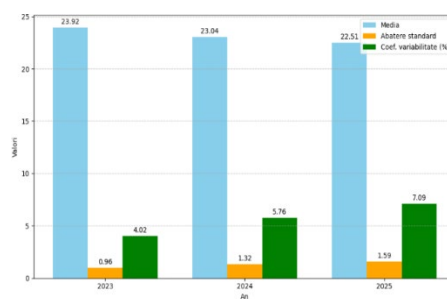


Figure 5. Comparison of the average, standard deviation, and coefficient of variation for age at first calving

The literature specifies an ideal age for first calving of 22–25 months, which can even reach 30 months.

Based on the data analysis, the age at first calving for the farm's breeding herd falls within the category of animals that are highly suitable for breeding [2], [3].

3.2. Average interval between calvings

The calving interval, also known as the average interval between calvings, is calculated only for cows that have calved at least twice [5].

It is expressed as an absolute figure and indicates the regularity of reproduction, as well as the fact that high-milk-producing cows do not come into heat immediately after calving, unlike low-milk-producing cows.

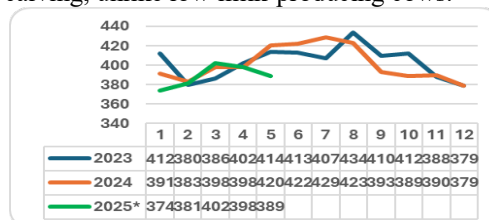


Figure 6. Dynamics of the *interval between calvings*

Note: *For 2025, only the first 5 months were considered

Table 2 Dynamics of the interval between calvings within the herd for the period under review

	2023	2024	2025
Average $\bar{x}$	403.08	401.25	388.8
Standard deviation S	16.591	17.38	11.60
Coefficient of variation cv%	4.11	4.33	2.98

For the herd analyzed, the calving interval was as follows:

- in 2023, the average ($\bar{x}$) was 403.08 days, with a standard deviation (S) of 16.59 and a coefficient of variation (CV%) of 4.11;

- in 2024, an average ($\bar{x}$) of 401.25, with a standard deviation (S) of 17.38 and a coefficient of variation (CV%) of 4.33;

- in 2025 (first 5 months only), with an average ($\bar{x}$) of 388.8, a standard deviation (S) of 11.60, and a coefficient of variation (CV%) of 2.98.

The average interval between calvings decreased from 403.08 days in 2023 to 388.80 days in 2025. This indicates an improvement in reproductive efficiency because of more rigorous reproductive management

The standard deviation decreased significantly in 2025 (from 17.38 to 11.60), suggesting greater uniformity among individuals and increased stability in reproductive performance.

The coefficient of variation decreased from 4.33% in 2024 to 2.98% in 2025, confirming greater consistency in calving intervals.

For the first half of 2025, the observed trends reflect an optimization of the reproductive process (intervals between calvings are shorter and more uniform, which may lead to increased productivity and lower costs per unit of product.

The literature indicates that the ideal interval between calvings is approximately 365 days (one year), which allows for efficient lactation and a new pregnancy without compromising the animal's health. In reality, this interval is often exceeded, with a range varying between 430 and 501 days. The service period is the factor that most influences this interval.

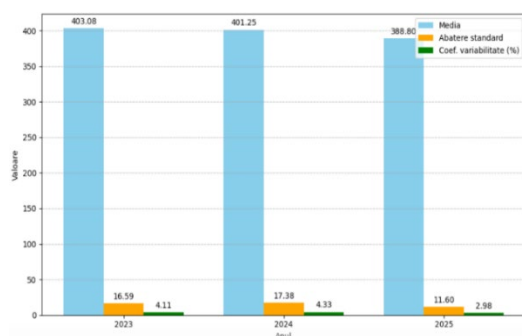


Figure 7. Comparison of the average, standard deviation, and coefficient of variation of the average interval between calvings

At the Agro Chirea farm, it was found that the interval between calvings in all years studied falls below the minimum limit specified in the literature, with a difference of ± 26.92 days in 2023, ± 28.75 days in 2024, and ± 41.2 days in the first 5 months of 2025. Based on the analyzed data, the interval between calvings for the studied population falls within the normal range for the breed, with animals raised in an intensive system.

3.3. Service Period

The Service Period refers to the interval between calving and the onset of a new pregnancy; in other words, this parameter indicates how quickly a cow can return to breeding within a maximum of 3 months, in line with the "year and calf" objective. In the literature, the ideal Service Period is less than 90 days. At the Agro-Chirea farm, management has achieved an average of 64 days, indicating that the farm's animals have no calving issues.

3.4. Insemination Rate

The insemination rate varies depending on environmental factors and animal-specific factors, such as insemination technique, accurate assessment of the optimal time for insemination, animal production, and their physiological condition. This index is essential for evaluating reproductive performance on a dairy farm, as it directly influences productivity and profitability.

Table 3 Insemination rate, period 01/01–06/20/2025

Lactation Days	Insemination Rate (IR)		
	Available	Inseminated	%
0-48	0	0	
49-69	6	6	100,0
70-90	609	552	90,6
91-111	321	180	56,1
112-132	243	172	70,8
133-153	178	120	67,4
154-174	132	92	69,7
175-195	96	59	61,5
196-216	69	52	75,4
217-237	52	39	75,0
238-258	43	26	60,5
259-279	34	24	70,6
280-300	29	13	44,8
301-321	23	11	47,8
322-342	17	11	64,7
343-363	13	6	46,1
364-384	8	6	75,0
> 384	9	6	66,7
	1882	1375	73,1%

3.5. Gestation rate

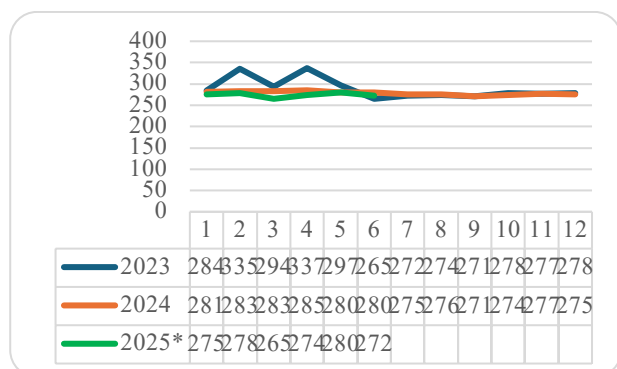
The gestation period averages 283 days, or approximately 9 and a half months. This period may vary slightly depending on breed, individual cow factors, and environmental conditions. An optimal combination of proper nutrition, appropriate care, careful monitoring, and disease prevention contributes to a high gestation rate and efficient reproduction in dairy cows.

Table 4 Gestation rate, period from January 1 to June 20, 2025

Lactation Days	Pregnancy rate (PR)			
	Available	Pregnant	%	95%
0-48	0	0		
49-69	6	2	33,3	0-71
70-90	608	267	43,9	40-48
91-111	318	70	22,0	17-27
112-132	243	68	28,0	22-34
133-153	178	54	30,3	23-37
154-174	132	32	24,2	17-31
175-195	96	22	23,2	15-31
196-216	69	18	26,1	16-36
217-237	52	7	13,5	4-22
238-258	43	6	14,3	4-24
259-279	34	10	29,4	14-44
280-300	29	6	20,7	6-36
301-321	23	6	26,1	8-44
322-342	17	2	11,8	0-27
343-363	13	4	30,8	6-56
364-384	8	0	0,0	
> 384	9	3	33,3	2-64
	1878	577	30,8%	

3.6. Gestation Period

Gestation Period - gestation is defined as the period from fertilization to parturition.

**Figure 8. Dynamics of the Gestation Period**

Note: *For the year 2025, the first semester was considered

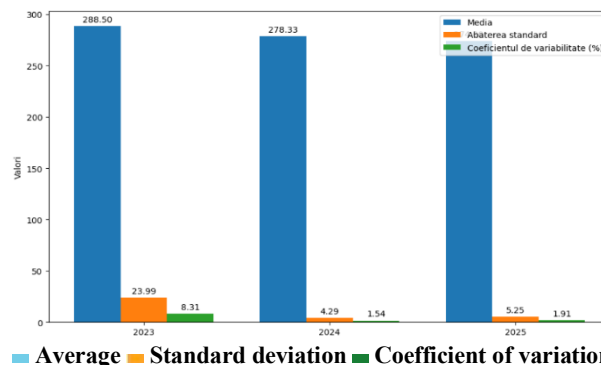
Table 5 Dynamics of the gestation period within the herd for the period under review

	2023	2024	2025
Average $\bar{x}$	288,50	278,33	274,00
Standard deviation S	23,99	4,29	5,25
Coefficient of variation cv%	8,31	1,54	1,91

For the herd analyzed, the gestation period was as follows:

- in 2023, the average ($\bar{x}$) was 288.50 days, with a standard deviation (S) of 23.99 and a coefficient of variation (CV%) of 8.31;
- in 2024: an average ($\bar{x}$) of 278.33 days, with a standard deviation (S) of 4.29 and a coefficient of variation (CV%) of 1.54;
- in 2025 (first semester) average ($\bar{x}$) of 274.00 days, with a standard deviation (S) of 5.25 and a coefficient of variation (CV%) of 1.91.

In terms of the average gestation period, it can be observed that 2023 had a longer average gestation period. Furthermore, in 2023 there was a very large variation (nearly 24 days), suggesting a lack of uniformity and the possibility that external or internal factors influenced the gestation period. In 2024 and the first quarter of 2025, gestation duration shows consistency, with a shorter and more uniform gestation period, which is a good sign for reproductive stability. The coefficient of variation was high (CV = 8.31%) in 2023, indicating uneven gestations, while in 2024 and the first half of 2025, gestations were very uniform (CV below 2%).

**Figure 9. Comparison of the average, standard deviation, and coefficient of variation for gestation period**

According to the literature, the average gestation period for dairy cows is 285 days. Calving between the 240th and 311th day is not considered abnormal. In general, Holstein cows have a slightly shorter gestation period.

4. CONCLUSIONS

✓ The digital transformation of dairy farms in Romania has significant potential to improve efficiency, productivity, sustainability, and food safety.

The implementation of advanced technologies on dairy farms influences animal reproduction management, with a direct impact on increasing the quality and quantity of production, improving the genetic quality of livestock, and, last but not least, enhancing the economic profitability of the farms.

✓ The use of real-time data is crucial for making informed decisions that impact the health and productivity of the farm's livestock.

The software's analytics dashboard offers a suite of tools, including a cattle growth chart, dairy herd management, and detailed reports on the entire herd as well as individual animals. These tools allow farmers to track performance trends, efficiently manage breeding cycles, and maintain comprehensive health records, ensuring that every decision is supported by accurate and timely information.

✓ Automated dairy farming is the way of the future, with no negative impact on the economy, the environment, or the health of the cows.

These smart, automated technologies allow farmers to get the most out of every cow.

The socio-economic importance of raising cattle, and dairy cows in particular, is widely recognized; integrated data from dairy animal records will lay the foundation for the traceability of animal-based foods.

✓ The raw data were collected from the farm and analyzed using specific formulas for calculating reproductive indices.

- *age at first calving*: 2023, average 23.92, with a standard deviation of 0.96 and a coefficient of variation of 4.02; 2024, average 23.04, with a standard deviation of 1.32 and a coefficient of variation of 5.76; 2025 (first 6 months): average of 22.51, with a standard deviation of 1.59 and a coefficient of variation of 7.09. The age at first calving has decreased steadily each year, from 23.92 months in 2023 to 22.51 months in 2025;

- *Interval between calvings*: 2023, average of 403.08, with a standard deviation of 16.59 and a coefficient of variation of 4.11; 2024, average of 401.25, with a standard deviation of 17.38 and a coefficient of variation of 4.33; 2025 (first 5 months only) averaged 388.8 days with a standard deviation of 11.60 and a coefficient of variation of 2.98. The average interval between calvings decreased from 403.08 days in 2023 to 388.80 days in 2025. This indicates an improvement in reproductive efficiency because of more rigorous reproductive management. It is noted that the interval between calvings in all years studied falls below the minimum limit specified in the literature, with a difference of ± 26.92 days in 2023, ± 28.75 days in 2024, and ± 41.2 days in the first 5 months of 2025;

- *gestation period*: 2023, averaging 288.50 days, with a standard deviation of 23.99 and a coefficient of variation of 8.31; 2024, averaging 278.33 days, with a standard deviation of 4.29 and a coefficient of variation of 1.54; 2025 (first semester): 274.00 days, with a standard deviation of 5.25 and a coefficient of variation of 1.91. In terms of the average gestation period, it can be observed that 2023 has a longer average gestation duration. Furthermore, in 2023, a very large variation (nearly 24 days) was recorded, suggesting a lack of uniformity and the possibility of external or internal factors influencing the duration of gestation. In 2024 and the first half of 2025, gestation duration shows consistency, with a shorter and more uniform gestation period, which is a good sign for reproductive stability. The coefficient of variation was high ($CV = 8.31\%$) in 2023, indicating uneven gestations, while in 2024 and the first half of the year, gestations were very uniform (CV below 2%).

✓ Implementing an integrated approach to digital transformation on these dairy farms results in:

- *improved efficiency* - automation of tasks, reduced waste, and improved decision-making;

- *increased productivity* - monitoring animal health, optimizing milk production, and improving milk quality;

- *increased resilience* - risk management, reduced antibiotic use, adaptation to climate change, and emergency preparedness;

- maximization of reproductive potential for each animal.

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