Trakia Journal of Sciences, No 3, pp 272-279, 2025
Available online at:
https://trakia-uni.bg

ISSN 1313-3551 (online) **doi:10.15547/tjs.2025.03.011**

Review

PRECISION SYSTEMS IN DAIRY FARMS RELATED TO MONITORING AND MANAGEMENT OF SOME PRODUCTIVE AND TECHNOLOGICAL INDICATORS - A REVIEW PART 1

E. Mitev*, S. Laleva, Y. Popova

Agricultural Institute, Stara Zagora, Bulgaria

ABSTRACT
The aim of this study is to present up-to-date information on the precision monitoring systems used in modern dairy cattle breeding, related to some productive and technological indicators. Nowadays, more and more data are being collected in practice through various technologically innovative systems. Some of the important benefits of precise monitoring systems include increased efficiency, reduced costs, improved product quality, minimized adverse environmental impacts, improved animal health and welfare. The use of precise technology to record productive, reproductive and health indicators increasingly provides farmers with reliable information. When this information is properly used in the production process, it reduces financial costs and improves the management of large herds. The use of innovative monitoring systems for precision dairy cattle breeding also has its drawbacks and limitations. The state of precision dairy farming in our country is still in its infancy, as there are a large number of dairy cows that are scattered over a wide range of geographical areas. The majority of these dairy animals belong to smaller farms or herds. Some farmers cannot afford such expensive technologies. In addition, most of the herds are composed of different breeds with different production parameters. This creates difficulties in the adoption and introduction of precision dairy farming technology outside the large farms.

Keyword: precision monitoring systems, dairy cattle, productive indicators, technological indicators

INTRODUCTION

Precision dairy monitoring systems are defined as systems that help track the physiological, behavioral, and production performance of individual animals to increase farm efficiency. The focus is not only on the entire herd, but also on each individual animal to develop its maximum potential. Precision dairy farming is considered to be the implementation of technologies to track physiological, behavioural, and production indicators of individual animals with the aim of improving farm management strategies (1). Other authors define precision dairy farming monitoring systems as the application of information technologies to assess the condition of animals and their physiological needs, aimed at improving farm management strategies as well as optimizing its economic, social, and environmental efficiency (2).

***Correspondence to**: *Emil Mitev, Agricultural Institute, 6000 Stara Zagora, Bulgaria. E-mail:emillmitev@gmail.com*

Precision farming involves the use of digital technologies and aims to improve production and reproduction, animal welfare, and facilitate targeted resource use to reduce environmental and human health impacts through precise process control (3). According to the authors, the implementation of precision dairy farming depends on many factors - socio-demographics, farm size, production system, type of animals raised, farming technology, farmer age, country and region, etc.

A number of researchers have defined precision livestock management as the potential use of technology to optimize the individual contribution of animals on a dairy farm. Through an "information for every animal" approach, the farmer can achieve better results in terms of quantity and quality of milk produced for more sustainable dairy farming. According to some, it is the use of technology to measure physiological, behavioural, and production indicators of individual animals to improve management strategies and farm efficiency (4).

Precision dairy farming, with a special emphasis on technologies for individual animal monitoring, aims at environmentally and economically sustainable milk production with guaranteed quality, as well as a high level of consumer and animal protection (5). Precision agriculture is based on information technologies that allow the producer to collect information and data for better decision-making. An important aspect of PMR technologies is the monitoring of health and production and the conversion of monitoring results into useful information for the farmer and the actions to be taken (6).

According to other authors, the concept of precision dairy farming can also be called spatial, computer-assisted animal husbandry; satellite farming; high-tech sustainable agriculture, soil-specific crop management, site-specific agriculture, and precision agriculture (7, 8). Schulze defines the main goals of precision dairy farming as increasing animal productivity, detecting early diseases in individual cows, detecting early health and production problems at the herd level, and minimizing the use of drugs through preventive health measures (9).

The development of science and technology offers opportunities for further innovation in milk production. The main drivers are genetics and breeding, microchips and nanotechnology, information and communication technologies, etc. Some of the tools for precision dairy cattle breeding can be of importance in dairy farms and in terms of animal welfare.

The aim of this study is to present up-to-date information on the precision monitoring systems used in modern dairy cattle breeding, related to some productive and technological indicators.

Precise monitoring systems related to milking, milk composition and quality

Milking systems that provide data on milk production and quality provide in-depth information both for each cow and for all lactating animals in the herd. Lukas et al. investigated systems that, in addition to milk quantity, also measured milk conductivity (10). Ten days before the diagnosis of an adverse health event, they observed significant changes in milk yield and milk conductivity. It has been shown that the effects of animal diseases on milk production begin 5 days before the diagnosis of these diseases and can last for more than several months after diagnosis (11).

A group of authors found that developing a monitoring system that is able to observe and identify small changes would be very useful in subclinical phases of health problems (12). They believe that the electrical conductivity of milk together with information on milk quantity and flow, number of incomplete milkings, etc. leads to increased detection accuracy and the ability to determine early signs of mastitis.

It has long been known that milk composition, particularly the fat/protein ratio, can be used to determine energy status (13). The milk fat/protein ratio is used as an indicator of negative energy balance (14). The development and use of an automated milk monitoring system has led to a much higher accuracy in measuring and determining energy status compared to the previously used system of collecting samples during monthly milk control (15).

Early detection of mastitis improves treatment efficiency and reduces economic losses in dairy cattle farms. To improve the speed of mastitis detection, a monitoring system called EFMYOLOv3 (Enhanced Fusion MobileNetV3 You Look Only Once v3) based on two-way filtering and enhancement of thermal infrared images (16) was developed. The test results of the system showed an average frame rate of 99 frames per second and an average accuracy of 96.8%, which means that it works with sufficient speed and accuracy.

Precise monitoring systems related to animal body condition

Daily body weight measurements, which are incorporated into modern milking systems or automatic feeders, are used as an indicator for monitoring body condition and energy balance (17). Ultrasound measurement of the thickness of subcutaneous fat in the rear part of the body and around the base of the tail provides additional information compared to some other body condition scoring (BCS) systems (18). Body condition scoring systems are useful as a means of long-term monitoring of energy balance in dairy cows, since the amount of body fat changes slowly relative to the accuracy of the available measurement scale. The authors recommend that body condition score at calving has to be in the range of 3.5 to 4.0, in early lactation from 2.0 to 2.5, and in the dry period – from 3.5 to 4.0.

The traditional body condition scoring method uses visual and palpation techniques, making it relatively subjective, time-consuming, and stressful for the animals in the herd (19). Recently, body condition scoring models based on image analysis and machine learning techniques have been developed and used to assess the body condition of dairy cows (20). Studies have been conducted in which they captured images of cows from behind using network cameras, manually marked key body parts (such as the tail, hooks and pins, and rump), and then determined the amount of fat deposited around the tail using a single-shot multibox detector (21). With this metric, they determined the body condition score of the animal and achieved an accuracy of 98.46%.

Rodrigues-Alvarez et al. propose the use of an automated BCS system using data transfer, achieving accuracy of 82% at a step of 0.25 points and 97% at a step of 0.50 points (22). Other authors have compared the results of the implementation of an automated BCS system and a traditional BCS system and found approximately equal efficiency for both systems, which they believe may discourage farmers from implementing automated BCS systems (23). Studies have been conducted to determine the body condition of Holstein heifers and lactating cows using 3D cameras (24). The results obtained from them indicate that 3D cameras have a good future for commercial use, although the model still requires improvements in lateral and dorsal images. The accuracy of automated BCS determination is improving with the development of technology. There are also some limitations - readiness for network connectivity, difficulty in uploading and downloading data streams from the cloud, updating data, constant connection to an Internet source that provides sufficient streaming power for transmitting and downloading data.

Precise monitoring systems related to feed intake and feeding behaviour

Feeding behaviour and dry matter intake, especially in the week before calving, may indicate that cows are at risk of metritis (25), left displaced abomasum (26) and even dystocia (27). This would help to suggest and implement supportive measures to reduce the risk of various diseases. It has been suggested that cows with a large drop in dry matter intake immediately before calving may be at risk of metabolic diseases such as fatty liver and/or ketosis (28).

Changes in animal behaviour can indicate disease as well as the risk of disease (29). Therefore, early warning control measurements, such as individual measurements of dry matter intake, feeding behaviour (30) and locomotion activity, should also be performed in the period immediately before calving. If dairy cows are not fed a balanced diet during this period, serious health disorders such as ketosis, acute and chronic lameness, etc., will subsequently occur (31).

Feed intake is a major factor influencing lactation in dairy cows, and atypical feeding behaviour may signal a health disorder. This makes changes in feeding behaviour in dairy cows an indicator that should be studied and monitored continuously. In many different research studies, various visual analysis devices and training through intelligent systems have been applied to track feeding behaviour in cows (32).

Kuan et al. developed an embedded image system to automatically monitor the feeding time of individual dairy cows (33). A similar real-time image analysis system was developed to monitor the behavior of dairy cows (34). Different classifiers based on a specific model were used to analyze the images. The results of the application of this system show 92% accuracy in determining the standing and feeding behavior of the animals. Yu et al. presented a behavioral monitoring model (35). The model detects the feeding behavior of cows photographed from the front, reporting low accuracy and sensitivity of the algorithm used in extensive outdoor farming.

Other authors propose an online-based algorithm for the recognition of jaw movements using sound, the main advantage of this method being low computational costs (36). According to Li et al. the technique of combining the collected sound data with algorithms can be used to determine the feeding behavior of dairy cows, taking into account that feeding movements (biting, chewing and chewing-biting), types of feed (alfalfa, fescue) and pitch of the sound significantly affect the amplitude and duration of the sounds (37). Although sound sensors have good applicability in monitoring feeding behavior, they are significantly affected by noise, due to the complex technological processes and the movement of many units and machines in larger farms. There are different methods for monitoring feeding behavior, based on sensors that are fixed in different places - on the head, ear, neck, lower jaw, etc. They identify feeding behavior by distinguishing the movements and postures taken by the cows (38, 39). A sensor developed to identify rumen movements eliminates initial pressure, and in combination with commonly used data processing algorithms and time-domain feature extraction methods, shows a recognition accuracy of 0.966 (40).

Near-infrared spectroscopy is a rapid and accurate analytical technique used to collect information on the chemical and physical composition of raw materials, materials, manure and milk and shows good potential in predicting the chemical composition of forages (41). Piccioli-Cappelli et al. evaluated the effect of using a precision feeding system based on a near-infrared scanner on metabolic conditions and milk yield in lactating dairy cows (42). The system performed real-time analysis of dry matter and each feed ingredient. The authors found that using this system avoided dry matter loss and resulted in higher efficiency of forage protein absorption.

Other authors calibrated a near-infrared spectroscopy system to predict quality parameters such as dry matter and crude protein in freshly cut grass (43). According to the authors, this system gives results with a high degree of reliability for dry matter and a lower degree of reliability for crude protein content.

Precise monitoring systems related to animal hygiene requirements and compliance with animal welfare rules

Continuous monitoring of dairy cow activities provides valuable information for both ethology researchers and precision animal breeding tool developers.

Meunier et al. conducted an in-depth study in dairy cow barns (44). They segmented the barn into clearly defined zones associated with a specific cow activity (e.g., resting), and then used a real-time location system to automatically translate the cow's position information into a specific behavioural action. The authors tested a system that could identify major activities (resting, locomotion, feeding, etc.) by focusing on integrating image analysis techniques to visualize and analyze the dataset, both to validate the data and to enrich the information extracted. The algorithm, developed using freely available tools, confirmed the system's ability to identify major cow activities (excluding drinking behaviour) with excellent sensitivity (almost 80%). According to the authors, improving such precise systems will undoubtedly be of benefit to specialists developing various devices and indicators to ensure optimal health and welfare of animals, which will bring practical benefits to the veterinary specialist or the farmer raising dairy cows.

In response to the challenges of climate change, Bonora et al. developed and tested innovative procedures for comprehensively analyzing the relationship between milk production and climatic conditions during the hot season, with the aim of supporting livestock farm management and developing preventive scenarios (45). The specific objective of the study is to define and formulate a model that provides forecasts based on integrated milking data and parameters quantifying environmental conditions (temperature and humidity) measured by local sensor networks and adjusted for expected changes in climatic conditions. Heat stress is a serious problem that threatens the welfare and productivity of dairy cows during the summer season. The problem is becoming more serious due to the ongoing trend of increasing average and peak temperatures. To address this problem, various systems and devices are used on dairy farms to monitor and control the temperature-humidity index, animal behaviour, and other production parameters (46). Scientific research in this direction has laid the foundation for the development, calibration, validation, and testing of numerical models that quantify individual responses to heat stress conditions. A model was developed to analyze the relationship between milk production, animal behaviour, and environmental parameters based on previous data. Cows in this experiment were identified according to their response to heat conditions and accordingly distributed into three classes of heat stress sensitivity within a herd. The authors then linked these attributes to various phenotypic parameters collected by precision animal breeding devices used on the farm. Thus, the study provides a model for assessing the consequences of heat stress on individual animals.

Global Positioning System (GPS)

In recent decades, the use of GPS collars for animals, including lactating dairy cows, has been widely used. This allows recording and collection of detailed information about the location of dairy cows over long periods of time. This provides a better understanding of the habits and reasons for the spatial distribution of cows (47). Furthermore, given the historical price of electronic technologies, it is very likely that with appropriate investment in research and development, we will have cost-effective herd information systems that will allow us to see where and how all our animals are and what they are doing at any time (48). A precise identification system for Friesian cattle based on a robotic drone is being developed (49). They evaluated the performance of the components offline and also online through real field tests by flying at low altitudes over farms. According to the authors, the presented system is a proof-of-concept and a successful step towards autonomous biometric identification of individual animals from the air.

Precise monitoring systems in the dairy sector – advantages and benefits

The dairy sector is in transition but is on an upward trend in terms of the number of high-yielding cows. The number of dairy cattle with good genetic potential is increasing. Precision dairy farming technologies allow dairy farmers to make timely and informed decisions, which some authors argue leads to better productivity and profitability (50).

Often, by the time an animal shows clinical signs of stress and disease, it is already too late for preventive action. The appearance of noticeable clinical symptoms is usually preceded by physiological responses that are not visible to the human eye (e.g. changes in temperature and heart rate). The availability and use of precise monitoring systems allows the dairy farm manager to intervene earlier and take adequate preventive action. Currently, more and more data are being collected in practice through various technologically innovative systems. Some of the important benefits of precise monitoring systems include increased efficiency, reduced costs, improved product quality, minimized adverse environmental impacts, improved animal health and welfare (1). The use of precise technology to record productive, reproductive and health indicators increasingly provides farmers with reliable information. When this information is properly used in the production process, it reduces financial costs and improves the management of large herds (1, 51, 52).

Integrated, computerized information systems are essential for interpreting the large amounts of data generated by precision dairy farming technologies (1). This information can be incorporated into systems designed to facilitate decision-making for problems that require data collection from multiple sources. The same authors report that by identifying changes in physiological parameters, the farm manager can intervene earlier, whereas in the absence of precision technologies, decisions for each cow would be based almost entirely on the judgment and experience of the farmer (1, 52). Therefore, timely and correct decisions for individual animals or groups of animals based on data from precision monitoring technologies lead to positive outcomes (53).

Precision monitoring systems in dairy farming contribute to improving animal welfare, while providing solutions to global challenges, driven by the increasing demand for animal products to ensure global food security (54). Precision monitoring systems enable both individualized care for individual animals and information for dairy farm management. The development and application of digital technologies are crucial for the sustainable intensification of dairy farming in the coming years, to maximize the benefits of precision monitoring systems.

As technological advances continue, farmers are now able to measure and analyze a vast array of metrics for an individual animal or herd, something that was previously not possible or time-consuming.

Disadvantages and limitations of using precision monitoring systems in dairy farming

The use of innovative monitoring systems for precision dairy cattle breeding also has its drawbacks and limitations.

The information obtained from precision dairy technologies is only useful if it is interpreted and used effectively in decision-making.

Due to the high cost of new precision systems, farmers do not adopt them and do not introduce them into the production process, as they are not sure about the return on investment.

There is a lack of information exchange and demonstration of successful precision solutions between farms of similar size and productivity. Such technologies are adopted by younger and well-educated farmers, who also manage larger enterprises and achieve higher profits.

The equipment used in monitoring systems is very complex and requires quality technical support. Working with it requires continuous improvement of farmers' qualifications in order to work successfully with it.

Errors may occur when transferring data or increasing the duration of processing results with the relevant software program.

There is a lack of validated research results on the effects of implementing these systems, high capital investment and high operating costs. Furthermore, they are applicable to a limited spatial area.

CONCLUSION

The state of precision dairy farming in our country is still in its infancy, as there are a large number of dairy cows that are scattered over a wide range of geographical areas. The majority of these dairy animals belong to smaller farms or herds. Some farmers cannot afford such expensive technologies. In addition, most of the herds are composed of different breeds with different production parameters. This creates difficulties in the adoption and introduction of precision dairy farming technology outside the large farms in the country that raise high-yielding dairy breeds.

ABBREVIATIONS

BCS - Body Condition Scoring
GPS - Global Positioning System

REFERENCES

1. Bewley, J. M. Precision dairy farming: Advanced analysis solutions for future profitability, In: First North American Conference on Precision Dairy Management, Toronto, Canada, 2–5 March, 2010.
2. Eastwood, C.; D. Chapman; Paine, M. Precision dairy farming-taking the microscope to dairy farm management. *Recent research trends in veterinary science and animal husbandry*, Volume 10, Published By: AkiNik Publications, ISBN: 978-93-91538-06-4, 172, 2004.
3. Popova, Y.; Laleva, S.; Oblakova, M.; Ivanov, N.; Slavov, I.; Dimova, N. Precision livestock farming: essence and application in large and small ruminants. Review. *Bulgarian Journal of Animal Husbandry*, *61* (2), 54-63, 2024. (BG).
4. DAHD. Annual Report 2018-19. Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture and Farmers Welfare, GOI, New Delhi, 2019
5. Spilke J.; Fahr R. Decision support under the conditions of automatic milking systems using mixed linear models as part of a precision dairy farming concept. *In EFITA Conference*, Debrecen, Hungary, 780-785, 2003.
6. Hogeveen, H. The value of precision dairy farming: Going beyond labor savings. Conference on Precision Dairy Farming held at Hyatt Regency, Lexington, KY during May 30–June1, pp. 112, 2017.
7. Mandal, D.; Ghosh, SK. Precision farming - The emerging concept of agriculture for today and tomorrow, *Current Science*, *79*:1644-1647, 2000.
8. Singh, A.K.; Chopra, U.K. Geo-informatics applications in agriculture. New India Publishing Agency, New Delhi, 325, 2007.
9. Schulze, C.; Spilke, J.; Lehner, J. Data modeling for precision dairy farming within the competitive field of operational and analytical tasks. *Computers and Electronics in Agriculture*, *59*:39-55, 2007.
10. Lukas, J.M.; Reneau, J.K.; Wallace, R.; Hawkins, D.; Munoz-Zanzi, C. A novel method of analyzing daily milk production and electrical conductivity to predict disease onset. *Journal of Dairy Science*, *92*: 5964-5976, 2009.
11. Bareille, N.; Beaudeau, F.; Billon, S.; Robert, A.; Faverdin, P. Effects of health dis-orders on feed intake and milk production in dairy cows. *Livestock Production Science*, *83*:53-62, 2003.
12. Khatun, M.; Clark, C.; Lyons, N.; Thomson, P.; Kerrisk, K.; Garcia, S. Early detection of clinical mastitis from electrical conductivity data in an automatic milking system. *Animal Production Science*, 57:1226-1232, 2017.
13. Grieve, D.G.; Korver, S.; Rijpkema, Y.S.; Hof, G. Relationship between milk composition and some nutritional parameters in early lactation. *Livestock Production Science*, *14*:239-254, 1986.
14. Heuer, C.; Van Straalen, W.M.; Schukken, Y.H.; Dirkzwager, A.; Noordhuizen, J.

Prediction of energy balance in high yielding dairy cows with test-day information. *Journal of Dairy Science*, *84*:471-481, 2001.

15. Friggens, N.C.; Ridder, C.; Lovendahl, P. On the use of milk composition measures to predict the energy balance of dairy cows, *Journal of Dairy Science*, *90*:5453-67, 2007.
16. Zhang, X.; Kang, X.; Feng, N.; Liu, G. Automatic recognition of dairy cow mastitis from thermal images by a deep learning detector, *Computers and Electronics in Agriculture, 178*, 105754, 2020.
17. Meijer, R. The use of precision dairy farming in feeding and nutrition. First North American Conference on Precision Dairy Management, Toronto, Canada, 2010.
18. Schroder, U.J.; Staufenbil, R. Invited Review: Method to determine body fat reserves in the dairy cow with special regard to ultra-sonographic measurement of backfat thickness, *Journal of Dairy Science, 89*:1-14, 2006.
19. Azzaro, G.; Caccamo, M.; Ferguson, J.D.; Battiato, S.; Farinella, G.M.; Guarnera, G.C.; Puglisi, G.; Petriglieri, R.; Licitra, G. Objective estimation of body condition score by modeling cow body shape from digital images. *Journal of Dairy Science*, *94*:2126–2137, 2011.
20. Kojima, T.; Oishi, K.; Aoki, N.; Matsubara, Y.; Uete, T.; Fukushima, Y.; Inoue, G.; Sato, S.; Shiraishi, T.; Hirooka, H.; Estimation of beef cow body condition score: A machine learning approach using three-dimensional image data and a simple approach with heart girth measurements. *Livestock Science*, *256*, 104816, 2022.
21. Huang, X.; Hu, Z.; Wang, X.; Yang, X.; Zhang, J.; Shi, D. An improved single shot multibox detector method applied in body condition score for dairy cows. *Animals, 9(7)*, 470, 2019.
22. Rodriguez Alvarez, J.; Arroqui, M.; Mangudo, P.; Toloza, J.; Jatip, D.; Rodriguez, J.M.; Teyseyre, A.; Sanz, C.; Zunino, A.; Machado, C. Estimating body condition score in dairy cows from depth images using convolutional neural networks, transfer learning and model ensembling techniques. Agronomy 9(2), 90, 2019.
23. Mullins, I.L.; Truman, C.M.; Campler, M.R.; Bewley, J.M.; Costa, J.H. Validation of a commercial automated body condition scoring system on a commercial dairy farm. *Animals 9(2)*, 287, 2019.
24. Martins, B.M.; Mendes, A.L.C.; Silva, L.F.; Moreira, T.R.; Costa, J.H.C.; Rotta, P.P.; Chizzotti, M.L.; Marcondes, M.I. Estimating body weight, body condition score, and type traits in dairy cows using three dimensional cameras and manual body measurements. *Livestock Science*, 236, 104054, 2020.
25. Huzzey, J.M.; Veira, D.M.; Weary, D.M.; Von Keyserlingk, M.A.G. Prepartum behavior and dry matter intake identify dairy cows at risk for metritis, *Journal of Dairy Science*, *90*:3220-3233, 2007.
26. LeBlanc, S.J.; Leslie, K.E.; Duffield, T.F. Metabolic predictors of displaced abomasum in dairy cattle, *Journal of Dairy Science*, *88*:159-170, 2005.
27. Proudfoot, K.L.; Huzzey, J.M.; von Keyserlingk, M.A.G. The effect of dystocia on the dry matter intake and behavior of Holstein cows, *Journal of dairy Science, 92*:4937-4944, 2009.
28. Grummer, R.R. Impact of changes in organic nutrient metabolism on feeding the transition dairy cow, *Journal of Animal Science, 73*:2820-2833, 1995.
29. Weary, D.M.; Huzzey, J.M.; Von Keyserlingk, M.A.G. Using behaviour to predict and identify ill health in animals, *Journal of Animal Science*, *87*:770-77, DOI: 10.2527/jas.2008-12972, 2009.
30. Urton, G.; Von Keyserlingk, M.A.G.; Weary, D.M. Feeding behaviour identifies dairy cows at risk for metritis, *Journal of Dairy Science*, *88*:2843-49, 2005.
31. Gonzalez, I.; Tolkamp, B.; Coffey, M.; Ferret, A. Changes in feeding behaviour as possible indicators for the automatic monitoring of health disorders in dairy cows, *Journal of Dairy Science*, *91*(3):1017-1028, 2008.
32. Liu, N.; Qi, A.; Xiaoping, Y. A. Review on information technologies applicable to precision dairy farming: Focus on behavior, health monitoring, and the precise feeding of dairy cows. *Agriculture*, *13 (10)* 1858, 2023.
33. Kuan, C.Y.; Tsai, Y.C.; Hsu, J.T.; Ding, S.T.; Te Lin, T. An imaging system based on deep learning for monitoring the feeding behavior of dairy cows, In Proceedings of the 2019 ASABE *Annual International Meeting*, Boston, MA, USA, 7–10 July 2019.
34. Achour, B.; Belkadi, M.; Filali, I.; Laghrouche, M.; Lahdir, M. Image analysis for individual identification and feeding behaviour monitoring of dairy cows based on convolutional neural networks (CNN). *Biosystem Engineering*, *198*, 31–49, 2020.

35. Yu, Z.; Liu, Y.; Yu, S.; Wang, R.; Song, Z.; Yan, Y.; Tian, F. Automatic detection method of dairy cow feeding behaviour based on YOLO improved model and edge computing. *Sensors, 22,* 3271, 2022.
36. Chelotti, J.O.; Vanrell, S.R.; Rau, L.S.M.; Galli, J.R.; Rufiner, H.L. An online method for estimating grazing and rumination bouts using acoustic signals in grazing cattle, *Computers and Electronics in Agriculture, 173,* 105443, 2020.
37. Li, G.; Xiong, Y.; Du, Q.; Shi, Z.; Gates, R.S. Classifying ingestive behavior of dairy cows via automatic sound recognition, Sensors, 21, 5231, 2021.
38. Rayas-Amor, A.A.; Morales-Almaráz, E.; Licona-Velázquez, G.; Vieyra-Alberto, R.; García-Martínez, A.; Martínez-García, C.G.; Cruz-Monterrosa, R.G.; la Lama, G.C.M.-D. Triaxial accelerometers for recording grazing and ruminating time in dairy cows: An alternative to visual observations. *Journal of Veterinary Behavior, 20,* 102–108, 2017.
39. Chapa, J.M.; Maschat, K.; Iwersen, M.; Baumgartner, J.; Drillich, M. Accelerometer systems as tools for health and welfare assessment in cattle and pigs—A review. *Behavioural Processes, 181,* 104262, 2020.
40. Chen, G.; Li, C.; Guo, Y.; Shu, H.; Cao, Z.; Xu, B. Recognition of cattle's feeding behaviors using noseband pressure sensor with machine learning. *Frontiers in Veterinary Science, 9,* 822621, 2022.
41. Evangelista, C.; Basiricò, L.; Bernabucci, U. An overview on the use of near infrared spectroscopy (NIRS) on farms for the management of dairy cows. *Agriculture 11,* 296, 2021.
42. Piccioli-Cappelli, F.; Calegari, F.; Calamari, L.; Bani, P.; Minuti, A. Application of a NIR device for precision feeding in dairy farms: Effect on metabolic conditions and milk production. *Italian Journal of Animal Science, 18,* 754–765, 2019.
43. Murphy, D.J.; O'Brien, B.; O'Donovan, M.; Condon, T.; Murphy, M.D. A near infrared spectroscopy calibration for the prediction of fresh grass quality on Irish pastures. *Information Processing in Agriculture, 9,* (2)243–253, 2022.
44. Meunier, B.; Pradel, P.; Sloth, K. H.; Cirié, C.; Delval, E.; Mialon, M. M.; Veissier, I., Image analysis to refine measurements of dairy cow behaviour from a real-time location system. *Biosystem Engineering, 173,* 32–44, 2018.
45. Bonora, F.; Pastell, M.; Benni, S.; Tassinari, P.; Torreggiani, D., ICT monitoring and mathematical modelling of dairy cows performances in hot climate conditions: a study case in Po valley (Italy), Agricultural Engineering International: The CIGR e-journal, Special issue: Animal Housing in Hot Climate, pp.12, 2018.
46. Benni, S.; Pastell, M.; Bonora, F.; Tassinari, P.; Torreggiani, D., A generalised additive model to characterise dairy cows' responses to heat stress. *Animal, 14,* 418–424, 2020.
47. Laca, E.A. Precision livestock production: tools and concepts. *Revista Brasileira de Zootecnia. 38*:123-32, 2009.
48. Rathod, P.; Dixit, S. Precision dairy farming: Opportunities and challenges for India. Indian *Journal of Animal Science. 90*(8):1083-1094, 2020.
49. Andrew, W.; Greatwood, C.; Burghardt, T. Fusing animal biometrics with autonomous robotics: Drone-based search and individual id of friesian cattle. In Proceedings of the IEEE/CVF *Winter Conference on Applications of Computer Vision Workshops, Snowmass Village,* CO, USA, 2–5 March 38–43, 2022.
50. Van Asseldonk, M.A.P.M.; Huirne, R.B.M.; Dijkhuizen, A.A.; Beulens, A.J.M.; Udink ten Cate, A.J. Information needs and information technology on dairy farms. *Computers and Electronics in Agriculture 22*(2–3): 97–107, 1999.
51. Eastwood, C.; Chapman, D.; Paine, M. Networks of practice for construction of agricultural decision support systems: Case studies of precision dairy farms in Australia. *Agricultural Systems, 108*:10-18, 2012.
52. Eastwood, C.; Jago, J.; Edwards, J.; Burke, J. Getting the most out of advanced farm management technologies: Roles of technology suppliers and dairy industry organizations in supporting precision dairy farmers, *Animal Production Science, 56*:1752-60, 2015.
53. Parsons, C.H.; Vasconcelos, J.T.; Swingle, R.S.; Defoor, P.J.; Nunnery, G.A.; Salyer, G.B.; Galyean, M.L., Effects of wet corn gluten feed and roughage levels on performance, carcass characteristics, and feeding behavior of feedlot cattle, *Journal of Animal Science, 85* (11): 3079-3089, 2007.
54. Kaur, U.; Malacco, V.M.R.; Bai, H.; Price, T.P.; Datta, A.; Xin, L.; Sen, S.; Nawrocki, R.A.; Chiu, G.; Sundaram, S.; Min, B.; Daniels, K.M.; White, R.R.; Donkin, S.S.; Brito, L.F.; Voyles, R.M. Invited review: integration of technologies and systems for precision animal agriculture—a case study on precision dairy farming, *Journal of Animal Science, 101,* skad206, 2023.