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Symposium Review
Midwest Branch/Forages and Pastures Symposium

Precision technologies to improve dairy grazing systems*

B. J. Heins,[1]† G. M. Pereira,[2] and K. T. Sharpe[1]

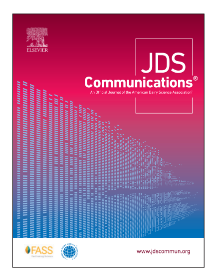
Graphical Abstract

Summary

Grazing dairy farmers may benefit from using on-farm precision technologies. However, the adoption of technology on grazing dairy farms is a challenge because of the lack of research-based information that addresses the accuracy and profitability of using technologies. In the future, pasture-based dairy farms are likely to rely on digital and automation technologies to improve animal health, reproduction, and well-being monitoring, pasture management, and labor productivity. Wearable animal technologies, remote sensing such as satellite imagery, unmanned aerial vehicles, virtual fencing, and automated animal herding, as well as ground-based sensing and automation, will provide potential solutions.

Highlights

- Grazing farmers may improve animal welfare, increase farm efficiency, and reduce costs with precision technologies.
- Adoption of precision technologies remains a challenge.
- Pasture-based dairy farms may rely on virtual fencing, drones to detect animal health issues and forage availability, and autonomous vehicles to move cattle and detect weeds on pasture.



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Precision technologies to improve dairy grazing systems*

B. J. Heins,[1]† G. M. Pereira,[2] and K. T. Sharpe[1]

Abstract: Pasture-based dairy herds continue to grow around the world as demand increases for sustainable farming practices. Grazing dairy farmers may benefit from the utilization of precision dairy technologies because these technologies have the potential to improve animal welfare, increase farm efficiency, and reduce costs. Precision dairy technologies have provided novel information about activity, rumination, and grazing behavior of various breeds in pasture-based systems. Previous research with wearable technologies has indicated that rumination, eating, and no activity have moderate to high correlations (r = 0.65 to 0.88) with visual observation; however, activity may be difficult to record in grazing herds. However, many grazing dairy farmers around the world are using activity monitors with generally positive success. Grazing is a complex behavior to define because cows may walk to an area and stop to eat or continuously walk and take bites of grass from the pasture. Wearable technologies can detect whether a cow is grazing with reasonable accuracy. However, the challenge is to determine pasture intake as bite rate and bite size because these can vary as the pasture is grazed to a low residual height. Nevertheless, grazing behavior data collected with wearable technologies was highly correlated (r = 0.92 to 0.95) with visual observations. Grazing is a behavior that should continue to be explored, especially with precision dairy technologies. As healthy and productive pastures are integral to grazing systems, accurate forage biomass measurements can improve efficiency and production of pastured dairy cows. However, few farms use technology to determine forage availability. Therefore, using dairy technologies to monitor forage dry matter from pasture may provide a potential benefit for grazing-based dairy farms. Current satellite technology with the normalized difference vegetation index and electronic rising plate meters may provide new technologies for farms to monitor forage biomass and fine-tune grazing within pastures. In the future, pasture-based dairy farms may rely on virtual fencing, drones to detect animal health issues and forage availability, and autonomous vehicles to move cattle and to detect weeds on pasture.

The number of pasture-based, including organic, dairy herds continues to increase in the United States as there is continued demand for grass-fed and sustainable farming practices (USDA, 2022). Sustainable farming practices may be realized with confinement dairy herds; however, the increased expense of dairy farming has caused farmers to adopt different management styles within their dairy herds. Animal welfare and cow comfort must be a priority within pasture-based dairy herds; however, unlike in confinement herds, cattle are not always within eyesight of employees. Therefore, precision dairy technologies (**PDT**) allow for cattle to be monitored continuously without constant human observation. Monitoring daily behaviors such as feeding, ruminating, resting, or lying, and active time can aid in understanding animal health and productivity. Farmers who want to increase overall production efficiency should consider implementing PDT, as decision making may improve and labor costs tend to decrease (Bikker et al., 2014).

The goals of PDT for dairy grazing systems include increased animal performance through enhanced milk production, increased fertility, improved animal health, reduced transition disorders, reduced lameness, and increased utilization of pasture through improved grazing patterns and behavior of cattle. Labor productivity is a key driver of technology adoption. Precision dairy technologies for grazing dairies has received a lot of attention because of advances in continuous monitoring of animal behavior and health of cattle on pasture, robotics, computer vision, and machine learning techniques. This review summarizes the current research and status of precision technologies for grazing dairy herds with wearable technologies, forage measurements, and grazing management, and autonomous and unmanned vehicles for use on pastured dairy farms. By no means is this review meant to cover the depth and breadth of PDT for grazing dairy herds. Table 1 shows precision technologies (wearable sensors, autonomous vehicles, and virtual fencing) that are available to grazing dairy farmers.

More than 50 wearable technologies have been developed and marketed for dairy cattle (Lee and Seo, 2021). Many technologies are worn by the cow and may be reused, whereas some are placed inside of the cow and may not be reused. Cow behavior data such as changes in activity, eating time, ruminating time, lying time, and standing time may be continuously collected by the PDT. Once data are processed through algorithms, the data can be categorized into specific behaviors or health and estrus alerts. The data can then be viewed on a computer system or on a website, and some companies have applications for mobile devices (Pereira et al., 2018). There is a need to improve welfare, efficiency, and management monitoring behaviors such as feeding, rumination, lying, and standing time and to study grazing patterns as well as to determine how heat stress can affect cattle on pasture. However, the dairy market is saturated with wearable precision technologies and farmers may be confused as to which wearable technology to use on farm. This

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Table 1. Precision technologies (wearable sensors, autonomous vehicle, and virtual fencing) that are available to dairy grazing farmers

Device	Behavior measurement	Attachment location	Manufacturer information	Reference
CowManager	Rumination, eating, activity	Ear tag	CowManager B.V., Harmelen, the Netherlands https://www.cowmanager.com/en-us/	Bikker et al., 2014; Pereira et al., 2018; Sharpe et al., 2021
RumiWatch	Rumination, eating, drinking, grazing bites, rumination chews, standing, lying, walking	Noseband sensor + pedometer	ITIN + HOCH GmbH, Fütterungstechnik, Liestal, Switzerland https://www.rumiwatch.com/	Werner et al., 2018; Pereira et al., 2020b, 2021; Raynor et al., 2021
SCR Heatime Pro+	Activity, rumination, panting	Collar or ear-tag	SCR Engineers Ltd., Netanya, Israel https://www.allflex.global/livestock-monitoring/	Elischer et al., 2013; Pereira et al., 2020a; Minegishi et al., 2019; Pereira and Heins, 2019; Sjostrom et al., 2016
SmaXtec	Activity, rumination, body temperature, pH	Reticulum bolus	Animal Care GmbH, Graz, Austria https://smaxtec.com/en/	Sharpe et al., 2021
AfiCollar and AfiAct II pedometer	Activity, rumination, grazing,	Collar and pedometer	Afimilk Ltd., Israel www.afimilk.com/	Iqbal et al., 2021
Smartbow	Activity, rumination, grazing, location	Ear tag	Smartbow GmbH, Weibern, Austria https://www.smartbow.com	Pereira et al., 2020b
CowBot	Autonomous vehicle	Pasture	Morris, MN https://wcroc.cfans.umn.edu/research/renewable-energy	Maini et al., 2022
Unmanned ground vehicle	Autonomous vehicle; cow herding	Pasture	https://www.sydney.edu.au/science/our-research/research-areas/life-and-environmental-sciences/livestock-welfare-group.html	Clark et al., 2014
Nofence	Virtual fence, activity	Pasture	Nofence, Batnfjordsøra, Norway https://www.nofence.no/en	Aaser et al., 2022; Hamidi et al., 2022
eShepherd	Virtual fence, activity	Pasture	Agersens, Melbourne, Victoria, Australia https://am.gallagher.com/en-US/new-products/eShepherd	Colusso et al., 2021
Halter	Virtual fence, activity	Pasture	Halter, Auckland, New Zealand https://halterhq.com/	
Vence	Virtual fence, activity	Pasture	Vence Corp., San Diego, CA http://vence.io	
PaddockTrac	Pasture biomass	Pasture	University of Missouri Dairy Extension https://grazingwedge.missouri.edu/	
C-Dax	Pasture biomass	Pasture	C-Dax Agricultural Solutions, Palmerston, New Zealand https://www.c-dax.com/measure-pasture-meter	Rennie et al., 2009
Pasture Reader	Pasture biomass	Pasture	Naroaka Enterprises, Narracan, Victoria, Australia http://pasturereader.com.au/	
Pasture.io	Pasture biomass	Pasture and satellite imagery	Pasture.io, Hobart, Tasmania, Australia https://pasture.io/	
SPACE	Pasture biomass	Pasture and satellite imagery	LIC, Hamilton, New Zealand https://www.lic.co.nz/products-and-services/space/	

review provides brief information on wearable technologies that are available to grazing dairy farmers in the United States.

The HR-LD Tag (Allflex Livestock Intelligence, Merck Animal Health, Merck and Co. Inc.) is worn on a strap around the neck of cattle. As of 2023, the tags are marketed as eSense Flex Tag and the cSense Flex Tag with Heatime Pro+ software. Elischer et al. (2013) validated the SCR HD-LD tag with Holstein cows in a pasture-based robotic milking herd and reported a moderate correlation (r = 0.61) between activity recorded by the tag compared with visual observations. Several studies have evaluated the applicability of the SCR system under grazing conditions, and authors reported the technology may not perform as well under grazing conditions as confinement conditions (Kamphuis et al., 2012); however, the system may improve estrus detection in grazing dairy herds.

Pereira et al. (2020a) evaluated estrus detection of the SCR system by utilizing subsequent calving as the gold standard. During the summer breeding season when cattle are on pasture, the SCR system was less sensitive for estrus detection compared with the winter breeding season when cows were in confinement. Minegishi et al. (2019) reported that 96% of estrus events showed increased activity and 82% showed decreased rumination in a grazing dairy herd. However, the accuracy of the SCR system suffered during the grazing period. Holstein and crossbred dairy cows from an organic grazing and low-input conventional grazing herd were evaluated for activity and rumination (Pereira and Heins, 2019). Results from this study suggest that activity and rumination were different between breeds in grazing dairy herds.

There have been advances in algorithm development with the SCR Heatime system over the last 10 yr with data sets from pasture-grazed herds. However, there are not many recent published studies, and these technologies need to perform as well as manual methods of detecting estrus in grazing systems, so development for pasture-based herds must continue.

The CowManager sensor (Agis Automatisering BV) is an ear-tag sensor which includes an accelerometer that records ear and head movements and classifies them into ruminating, eating, resting, and active behaviors. The sensor has been previously validated by accurately detecting ear and head movements compared with visual observation in a confinement herd in the Netherlands (Bikker et al., 2014).

Pereira et al. (2018) was the first study to validate the CowManager sensor on pasture. The study used 24 crossbred cows, and the experiment was conducted at the University of Minnesota West Central Research and Outreach Center during the summer of 2016. For total recorded time, the ear-tag sensor determined that grazing cows spent 19.1% of the day ruminating, 51.9% eating, 11.9% not active, and 21.1% active. Visual observations were compared with sensor data and correlations were rumination, r = 0.72; eating, r = 0.88; not active, r = 0.65; and active, r = 0.20. The study suggested that the CowManager sensor accurately monitored rumination and eating behavior of grazing dairy cattle. However, algorithms need to be improved for active behaviors because grazing behavior is difficult to define. Furthermore, grazing dairy cattle in a solar shading system were evaluated for behaviors with the CowManager sensor. During the grazing season, dairy cows spent 7 min/h with high activity, 6 min/h with activity, 21 min/h eating, 18 min/h ruminating, and 8 min/h with no activity (Sharpe et al., 2021).

The primary reason for purchase of wearable technologies by pasture-based dairy farmers around the world is to collect activity data for heat detection. Since the introduction of these technologies, pasture-based dairy farming improvements have been made to the detection algorithms to account for the larger variation in daily activity from walking distance from pastures. However, relationships have been determined between these sensor data and pasture intake or pasture residuals, which are the key grazing data farmers are seeking.

Smartbow is an ear-tag sensor (Smartbow GmbH) with an accelerometer can monitor estrus detection and rumination by acceleration data from ear and head movements, as well as monitor rumination and real-time location of cattle. Pereira et al. (2020b) validated a grazing algorithm developed for the Smartbow system at the University of Minnesota grazing dairy and at the Teagasc, Animal & Grassland Research and Innovation Centre in Moorepark, Fermoy, Co. Cork, Ireland. To validate the ear-attached accelerometer grazing algorithm, the RumiWatch System was used (Pereira et al., 2021). The ear-attached accelerometer and halter system were compared for number of grazing minutes per hour. For total recorded time, the percentages of time recorded for the ear-attached accelerometer for grazing and nongrazing were 40.7% and 59.3%, respectively. The correlation of grazing behavior was 0.96 in the Minnesota herd and 0.92 for the Irish herd for the ear-attached accelerometer and halter system. The results suggest that the ear-attached accelerometer accurately monitored grazing behavior in a pasture-based system (Pereira et al., 2020b).

The smaXtec bolus (smaXtec Animal Care GmbH) is a bolus that is placed in the reticulum of the cow and measures activity, internal body temperature, rumination, and drinking behavior, and can detect SARA and feeding issues with a pH bolus. Sharpe et al. (2021) reported that the smaXtec bolus can be used for determining heat stress of grazing dairy cattle. Internal temperature, drinking bouts identified by temperature change, and activity together may useful indicators of heat stress in grazing dairy cattle.

Satellite photography is growing in popularity to measure forage biomass on grazing dairy farms and is likely better than photography. Weekly data will provide availability of satellite images and weather conditions that should allow for a suitable image of farms. Evaluation of forage biomass measurements will aid farmers in understanding the availability of cool-season grasses for cattle grazing. Furthermore, the use of satellite technology will reduce the amount of time that farmers must spend on determining forage biomass of their pastures. (Gargiulo et al., 2020). On a grazing dairy farm in Camden, Australia, normalized difference vegetation index (**NDVI**) from satellite images had a moderate to high correlation (0.74 to 0.94) with forage biomass estimated using the electronic rising plate meter (Gargiulo et al., 2020).

Newer satellite technology that can incorporate weather data and may be tailored to individual farms is available to automate measurement of pasture forage biomass. Pasture.io (http://pasture.io) assists in automation of grazing records and can track a farm's individual performance with satellite-enhanced forage biomass prediction. For a 100-ha farm, the cost for Pasture.io would be about US$150 per month. Furthermore, LIC in Hamilton, New Zealand, also provides pasture data from satellite imagery for grazing dairy farmers. The SPACE service (https://www.lic.co.nz/products-and-services/space/) provides satellite images, pasture cover data on all paddocks, a detailed grazing wedge, and estimated DM per hectare to farmers that can save time and money for grazing dairy farmers.

Satellite imagery for pasture measurement is a significant opportunity for farmers. However, the images need to be provided at least weekly without complications arising from poor weather and cloudy conditions. Some issues with commercially available satellite services are that cloud cover may limit the frequency of useful images, and may cause saturation of the NDVI image at high levels of pasture biomass. Alternative methods to calculate the forage biomass of pastures may provide more advantages for farmers to determine grazing management of pastures.

PaddockTrac (https://grazingwedge.missouri.edu/) is currently under development and brings a new and improved method to measure forage biomass of pastures that include multispecies grazing of grasses and forbs. This Bluetooth-enabled sensor is mounted on a vehicle and can measure 50 forage height readings per second. Once a week, farmers drive through pastures and measure forage cover and growth rates to create a grazing wedge. Currently, PaddockTrac data are being collected for a multitude of forage and legume species, because earlier work has been only completed with perennial ryegrass. There are research gaps that need to be evaluated before this system is ready for farmer use. One of the key issues is developing an equation that will accurately convert forage height to forage DM. Furthermore, data will have to be collected from various pasture environments, as well as focusing on pasture species beyond perennial ryegrass. Multi-species sward issues need to be researched because forage biomass may be more difficult with multi-species compared with monoculture pastures.

Similar methods are available such as the Pasture Reader (http://pasturereader.com.au/) and C-Dax pasture meter (Rennie et al., 2009; https://www.c-dax.com/measure). The C-Dax pasture meter is commonly used in New Zealand, and research has concluded that the C-Dax has limitations in prediction of forage biomass in kikuyu-based pastures in the Northland region of New Zealand. However, most pastures in New Zealand are perennial ryegrass and white clover, and the C-Dax pasture meter has similar accuracy to a rising plate meter (Murphy et al., 2021). Furthermore, the C-Dax can record more information than a rising plate meter or people, with less labor. Currently, the C-Dax is not used extensively by North American or European grazing dairy farmers.

The lack of validation of research and the high cost of technology for pasture measurements may provide future challenges for farmers to adopt these technologies. The topography of pasture, size of paddocks, species of grass used for grazing, and timing of grazing may be disadvantages to provide precise pasture measurements through satellite technology. The high cost of technology coupled with measurement errors caused by multi-species grass pasture, high labor cost, and reduced precision of pasture forage biomass have resulted in low adoption rates of these technologies for farmers. Therefore, validation of these technologies along with an improved algorithm are essential for farmers to accept these technologies for use on farm. The cost of technology will be the driving force as to whether farmers use this technology or not in the future.

Grazing farmers can be engaged in an annual battle to control weeds in their pastures. Current weed control methods using herbicides have been very effective; however, there may be unintentional and harmful consequences to air, land, water, and wildlife.

The Cowbot is an autonomous mower being developed to control weeds in pastures at the University of Minnesota West Central Research and Outreach Center in Morris, Minnesota (Maini et al., 2022). The Cowbot uses the Global Positioning System (**GPS**) for navigation, with a GPS receiver on the Cowbot and a GPS receiver on a tripod in the pasture. Weeds are variable in a pasture in terms of density and distribution, which may provide challenges for the Cowbot. First, the perimeter of the pasture to be mowed must be defined by entering GPS coordinates of the corner of the pasture. A control system then determines a path to mow the grazed area that includes turning around in the pasture when the Cowbot reaches the boundaries. Future research will explore the ability to detect specific weeds and determine robustness and safety of the Cowbot. Furthermore, the Cowbot may be used in a dual-purpose manner to mow weeds, as well as herd and move cows from pasture to a milking parlor. The Cowbot could be converted to a solar-rechargeable system with batteries to reduce the carbon footprint of pasture-based dairy production systems, instead of using fossil fuels to power mowers for pasture clipping.

While moving cows from pasture to milking parlor is novel for the Cowbot, researchers in Australia reported that grazing dairy cows adapted quickly to an unmanned ground vehicle (Clark et al., 2014). Advancements in automation technology for herding cows reduced time farmers spend on repetitive tasks, such as herding cows to and from the milking parlor. The future of automated herding techniques may be promising if the unmanned vehicles can also provide information on pasture forage biomass, nutritive quality of forage in pasture, soil moisture, soil carbon dynamics, and soil fertility measurements to reduce the environmental impact of grazing.

Cattle are routinely contained with electric fencing of numerous forms within grazing dairy farms. Virtual fencing is an encouraging future technology to implement with grazing dairy cattle because it has the potential to allow for remote improved pasture utilization, and reduced labor (McSweeney et al., 2020; Colusso et al., 2021). Virtual fencing provides for boundaries for cattle without using a physical barrier. In a review by Umstatter (2011), virtual fencing has been shown to contain animals within a defined pasture or to separate cattle using a moving fence or as a herding device. This review discussed the advantages and challenges of virtual fencing, and encourages researchers and professionals to continue to improve upon them until there is a marketable product that can be readily used by dairy farmers.

Nofence virtual fencing technology (Nofence AS) consists of a solar-powered GPS collar for cattle that uses a digital boundary in the pasture. The collar on the cattle relies on GPS technology and communicates with an easy-to-use app for farmers. The cost of a collar is approximately US$75. Aaser et al. (2022) used virtual fencing with a GPS collar to track animals and to provide electric stimuli to animals when they approached the boundary of the virtual fence. The authors reported that the virtual fence was highly successful in keeping cattle within the virtual paddock, and cattle did not express any adverse behavior to the virtual fence from electric stimuli. Recently, Hamidi et al. (2022) investigated animal welfare impacts of cattle with the acoustic signals from the Nofence collars and reported that cattle were not negatively affected by the virtual fencing system. Langworthy et al. (2021) demonstrated that virtual fencing can contain grazing cattle within the boundaries of a pasture, and in a similar study, Verdon et al. (2021) concluded there were no adverse behavioral events associated with implementing virtual fencing for grazing dairy cattle.

A study in Australia evaluated neckbands for cows (eShepherd, Agersens Pty Ltd.) that produced a warning audio signal and electrical pulse for virtual fencing systems (Colusso et al., 2021). The authors concluded that cows may be contained from fresh pasture forage for 24 h with virtual fencing.

In New Zealand, a new technology of solar-powered collars for virtual fencing for cows is being offered to farmers. The Halter system (https://halterhq.com/) is a GPS-enabled collar that will monitor the health of cows, as well as provide sound and vibration signals to the cows for virtual fencing. The system provides an audio signal if a cow has moved outside of the virtual fence boundary, and if a cow ignores the signal, a low-energy pulse is delivered to the cow through the collar to guide the cow back within the boundary of the fence. Furthermore, the Halter system uses an app on a smartphone to assist the farmer in herd movements with the virtual fence and monitor animal health. These new technologies that integrate solar power are very practical and save labor for farmers because they reduce the maintenance of precision battery technology. The opportunity for significant labor saving would be in daily herding of cows and establishing temporary fences for pasture allocation.

Virtual fencing is an excellent example of precision technology that will address challenges for grazing dairy farmers. This technology must operate well on farms and meet consumer expectations of animal welfare. Potential opportunities and barriers to adoption before the first commercial application on a dairy farm are summarized by Brier et al. (2020) and are relevant to farmers considering investment in virtual fencing. Brier et al. (2020) reported that the benefits of virtual fencing include environmental improvement, increased feed efficiency, the ability to graze areas that have been unavailable to graze, and labor savings.

For virtual fencing to be used by grazing farmers, one can assume that the technology must be economically feasible, must be easy and convenient for farmers to use, and must reduce labor costs. Further research should explore social herd dynamics, animal welfare, and DMI of pasture forage from various pasture systems around the world as well as the consumer perception of virtual fencing systems.

Among several robotic systems, the use of unmanned aerial vehicles (**UAV**) may be used to monitor animals in a pasture-based herd. The cost of operating a UAV with appropriate sensors is relatively high. In many countries around the world, UAV may only fly within the line of sight of the operator, which makes farm-scale measurements very labor intensive. The UAV may be used to locate and check animals in a pasture (Mufford et al., 2019), and research has shown that infrared temperature sensors can determine the temperature of the animal through use of UAV. Unmanned aerial vehicles offer a noninvasive and practical approach to studying physiological (respiration rate) and behavioral (standing behavior) indicators of heat stress and can be used as an effective tool for measuring heat stress indicators of cattle in large-scale feedlot and pasture operations (Mufford et al., 2022). In the future, grazing dairy farmers could use small multi-copter UAV to monitor animal behavior and health, which could lead to early disease detection. Drone spraying of cattle with insecticides or essential oils to control fly pressure may provide advantages for farmers because drones can spray cows in remote locations and would reduce any spray drift effects on humans. Continuous monitoring and individual animal inspection will potentially improve animal health through automatic and routine UAV-based monitoring and inspection activities.

Precision technologies for grazing dairy farms should aid in decision support for farmers, improve animal health and performance, and increase production efficiency. However, there are challenges that come with any new technology including costs of the technology, familiarization of new software, willingness to implement technology, interpretation of the data and subsequent actions to take with cattle, and lack of technical service.

By no means is this review meant to cover the depth and breadth of precision technologies for grazing dairy herds. However, within this short review, there is promise for future technologies for grazing farmers that will increase animal health, determine pasture forage biomass and related soil characteristics, move cows with unmanned vehicles, and contain cattle with virtual fences, all while improving labor efficiency and productivity and profitability of grazing dairy farms. However, additional long-term studies are needed to determine the adoption of these technologies by grazing dairy farmers.

The adoption of precision technology by grazing dairy farms will only increase if more precise and practical technologies are developed and improved related to current available technologies. The cost and benefit to the farm and labor need to be considered when implementing these technologies on farms. These new technologies need to reduce or remove labor, be easy to use and implement, and have adequate support and training from companies to promote these technologies for farms.

Precision dairy technologies for grazing dairy farms have provided novel information about activity, rumination, and grazing behavior of various breeds. They have the potential to maximize profit of a grazing dairy herd when integrated into the whole grazing farm, which includes a self-feeder, robotic milker, feed pusher, wearable technologies, pasture management technologies, and virtual fencing, among numerous other technologies. However, dairy farms need to integrate all available data from precision technologies to aid in quick decision making. By no means does all technology fit all grazing farms. In the future, farmers need more information from researchers and industry professionals to help in implementing new precision technologies on their grazing dairy farm.

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Notes

B. J. Heins https://orcid.org/0000-0003-2186-9082

G. M. Pereira https://orcid.org/0000-0002-2955-0749

K. T. Sharpe https://orcid.org/0000-0002-3955-6562

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