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Farmer Adoption of Precision Livestock Farming in USA: Current and Future

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ABSTRACT

With the improvement of the livelihoods of people in the world and changing dietary habits, it is predicted that livestock products will lead to a 70% increase in demand by 2050. Moreover, there will be a 22% relative change in demand for animal protein on the American continent by 2050. Hence, the best way to overcome the above challenges is to follow a per-animal approach that helps continuously monitor the real-time conditions such as health and welfare, production, reproduction, and environmental impact of individual animals. This technology is termed as Precision Livestock Farming (PLF). A systematic literature review was conducted via PRISMA approach to identify the types of PLF technologies in practice, its uses, opportunities and challenges faced by USA farmers. PLF technologies are extensively practiced in dairy cattle and beef cattle, while the technologies are used considerably in swine and poultry. The widely used PLF technologies include GPS, RS, and sensors, Infrared technologies embedded in equipment and microphones, wireless communication tools, and robots, UAVs, and cameras. Although barriers to adopting PLF exist among the farming community in terms of technology literacy, costs, and infrastructure, privacy, technical complexity, and societal dynamics, and market dynamics, it is possible to overcome the barriers with time through the facilities made available to promote PLF: university contributions, grants and funding schemes, partnerships, and PLF manufacturers' contributions to disseminating such technologies.

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INTRODUCTION

With the improvement of the livelihoods of people in the world and changing dietary habits, it is predicted that livestock products will lead to a 70% increase in demand by 2050 (Berckmans, 2017). According to FAO (2018), there will be a 22% relative change in demand for animal protein on the American continent by 2050. But the number of farmers and farms is decreasing, resulting in increased herd sizes per farm. Larger herds per farm raise serious concerns in feed, fodder, and pasture management, animal and human health and welfare, reproduction and space management, and environmental impact management (Berckmans, 2017).

For example, it is highly possible in outbreaks of zoonoses if the large herds of animals were improperly managed and the farmers were unable to locate such an outbreak well in advance. Further, it is essential to notice, treat, and take relevant preventive measures regarding diseased animals right at the initial stage without leading to an outbreak. If such issues were left unnoticed, entire herds may require culling, causing a significant economic shock to the farmers. Livestock farming records emit 75% of agricultural N_2O, 80% of agricultural CH_4, and more than 90% of atmospheric NH_3 (Sejian et al., 2016; Berckmans, 2017). It is possible to reduce these statistics by achieving animal productivity closer to its' genetic potential where less feed, less water, and less manure is utilized and produced (Berckmans, 2017; FAO, 2018). Further, it is crucial to maintain the farms at their maximum productivity to ensure a profitable financial gain.

Hence, the best way to minimize the adverse impacts of the above is to follow a per-animal approach that helps continuously monitor the real-time conditions such as health and welfare, production, reproduction, and environmental impact of individual animals separately. Such a technology is termed as "Precision Agriculture" and this could be further narrowed into livestock sector with the umbrella term "Precision Livestock Farming (PLF)".

Thus, Precision Livestock Farming is defined as "Intelligent management and care of (individual) animals in livestock farming by continuous automated monitoring/controlling of the production/reproduction, health and welfare of (individual) animals, thereby allowing quick corrections when deviations from normal are monitored" (Bartzanas et al., 2017; Marino et al., 2023).

In order to monitor the above dimensions 24*7, in real time, information communication technologies are embedded into the livestock systems. According to Kleen and Guatteo (2023), current Precision Livestock Farming system comprised of four main elements: sensors, algorithms, applications, and interfaces. These elements enable the combination of livestock farming with real time data capture and analysis, paving the way towards information driven decision making allowing precision in the livestock sector. Figure 1. conceptualizes a model of PLF.

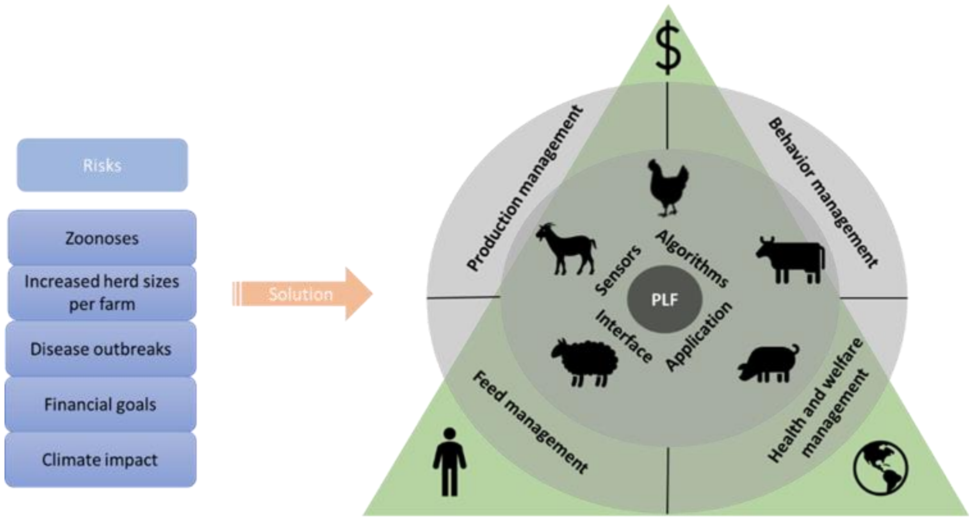

Figure 1. PLF model with its 04 pillars addressing Tripple Bottom Line; People, Planet and Profit

The current review was therefore undertaken to identify the types, potential and benefits of PLF technologies in use and to explore the challenges and opportunities in PLF technologies.

MATERIAL and METHOD

A systematic literature review on Precision Livestock farming was conducted using the PRISMA approach. The first-round of literature was retrieved through a keyword search. It included access to online databases such as Google Scholar, JSTOR, Elsevier, Taylor and Francis and Springer. Moreover, backward referencing was conducted for recently published research articles to identify relevant papers. The literature search was conducted under the themes; Precision Livestock farming types, and benefits, opportunities, and threats. The following list of keywords was used in the literature search (Figure 2).

'Precision Livestock Farming' OR 'Smart livestock farming'
AND
'USA' OR 'benefits' OR 'opportunities' OR 'Challenges' OR

Figure 2. Keyword search for the literature retrieval

The initial literature search resulted in 70 journal papers, conference proceedings and books. The abstracts were reviewed and categorized according to theme relevance. Accordingly, 58 articles were screened for the systematic literature review, removing the duplications, conference proceedings, and irrelevancy. The literature review was conducted under the headings of title, theme, and results using MS Excel software.

RESULTS and DISCUSSION

PLF Technologies in Use and Their Benefits

Various technologies have been developed to facilitate the collection and integration of Big Data, such as Global Positioning Systems, Internet, robots, and automated equipment controlling devices, sensor technologies, microphones, wireless communication tools, and cloud storage facilities (Bartzanas et al., 2017). These advanced tools support collecting health, feed, genetics, and social behavior related data from individual animals and arriving at decisions that can enhance approaching the triple bottom line (People, Planet and Profit) in livestock businesses (Wathes et al., 2008).

According to FAO (2017), world livestock could be classified into 8 broader categories, yet research evidences are mainly available on the use of Precision Livestock Farming technologies in dairy farming, poultry, swine and beef production (Jiang et al., 2023). In dairy, PLF technology is employed especially in developing automated milking systems, detecting diseases, reproduction, and in feeding management (Jiang et al., 2023; Kaur et al., 2023). Beef PLF applications are similar to dairy, but with no applications in milking management (Jiang et al., 2023; Kaur et al., 2023; Pomar and Remus, 2023). In poultry, it is mainly applied to monitor the real-time bird weight, environmental condition regulation, health indicators measurement, and feeding pattern regulation (Jiang et al., 2023; Patel et al., 2022; Pomar and Remus, 2023). Swine PLF technologies are mainly applied across respiratory disease monitoring, behavior detection, and optimizing nutrition to increase productivity (Akinyemi et al., 2023; Garrido et al., 2023; Jiang et al., 2023; Pomar and Remus, 2023; Wutke, 2023).

The PLF technology is widely adopted with high accuracy in intensive farming systems, while discussions are available on its adapted practical usability in pasture-based livestock categories too (Aquilani et al., 2022). Overall, the use of PLF technologies benefits farmers and their businesses by increasing animal productivity (lowered stress on animals, enhanced nutrition, and increased genetic capacities), reducing costs (lowered labor requirements, reduced cost of feed, reduced post-harvest losses), and increasing product marketability and market approachability (traceable supply chains).

Available PLF technologies could be classified in to 10 main categories; animal identification, body condition, and behavior, health and welfare, reproduction, pasture and space management, predation, milking and feed management related.

Accordingly, Radio Frequency Identifiers (RFID), boluses, ear tags, and injectable glass tags are used to uniquely identify animals (Awad, 2016). This system of unique identification helps in establishing supply chain transparency, authenticity, and traceability (Ruiz-Garcia & Lunadei, 2011) creating potential for incorporating blockchain technologies along the supply chain nodes. This incorporation will enhance the market price and the demand for the produce. Moreover, the collection of daily records such as medical treatments, growth performance, pedigree, and reproduction performance from each animal is facilitated by these advanced technologies, which aid in arriving at informed decisions (Ruiz-Garcia & Lunadei, 2011).

Numbers on the body weights of the animals could be gathered with Walk-Over-Weigh (WOW) platforms (Brown et al., 2015). The main benefits of this system are its applicability even in pasture-based systems, the need for minimum animal handling, and the possibility of recording data automatically on a computer once combined with a tag reader (González-García et al., 2018). Moreover, farmers can use the calculated weights to identify potential infections that cause changes in animals' body weight (e.g.: nematode infections) (Segerkvist et al., 2020) in taking decisions to open new pasture lands to maintain animal feeding and nutrition (Aquilani et al., 2022) and to locate postpartum anoestrus levels in grazing cattle (Menzies et al., 2017). These crucial conditions may not be possible for a farmer to identify with his naked eye in the initial stages. Hence, such a technology aids in early detection, saving unnecessary future costs.

The body conditions of animals could be easily gathered via 2D and 3D image analysis (Aquilani et al., 2022). Body condition scores and morphometric evaluations support livestock breeding, welfare management, and determining the fitness for slaughtering (Qiao et al., 2021). Automatic drafting systems help farmers easily identify and classify animals according to different dimensions, such as those who have reached the weight of slaughter, females nearing parturition, dry cows, new-born animals, animals that need feed supplements, or animals that need special medical attention (Morgan-Davies et al., 2017). These will reduce the workload of the farmer and the workers, increase the accuracy of the decisions taken, and allow them to delegate their time to other timely matters at the farm.

Farmers can use PLF technologies that measure the internal body temperature (surgically implanted devices, infrared devices, endo-ruminal boluses with temperature sensors) to identify animals entering heat stress (Pezzopane et al., 2018). The combination of environmental parameters and the Thermal-Humidity Index (THI) helps to manage the herds according to pasture characteristics such as tree patterns. Surgically implanted devices can be used to monitor the body temperature of animals who range freely on mountains without the farmer personally handling them (Fuchs et al., 2019). Usually, Unmanned Aerial Vehicles (UAVs) are monitored in the field to capture the temperature data emitted from the sensors, and the same could be used to count livestock through visual analysis. Moreover, the gathered images from the UAV can be used to note down the grazing preferences and group livestock species according to their behaviors and habits (Xu et al., 2020). These functions are difficult to carry out with manual labor without the support of PLF technologies.

In addition to UAVs, technology has advanced into using GPS (Global Positioning Systems) collars with GSM (Global System for Mobile Communication) to prevent livestock theft by detecting animals that move outside the virtual perimeter (Tangorra et al., 2013). According to Carlson, (2023), livestock theft is a serious issue in the USA, with 4000 head of livestock reported missing between 2017 and 2022 in Wyoming, while 454, 177, 74, and 71 cattle went missing in 2023 in Nebraska, Montana, North Dakota, and South Dakota, respectively. GPS with accelerometers is also available for detecting animal activity features such as lying, walking, feeding, ruminating, resting, and grazing (Anderson et al., 2012). Predation is another serious concern, as discussed in USDA (2024). Predation of livestock by coyotes, wolves, foxes and mountain lions is a rising issue both in the West and the East of USA. As a mitigation response to this, GPS trackers could be used in developing predator-Prey models specific to a farm or to a region.

Remote Sensing (RS) technology is used to estimate grass production and grass quality. Further, it is combined with virtual fencing technology to design rotational grazing management systems. Decisions on the right stocking rate and optimized pasture efficiency are also achieved through remote sensing technology (Wachendorf et al., 2018). This contributes to reducing the labor costs of ranching. Virtual fencing could be coupled with a GPS tracker-mounted collar to delineate boundaries in pasture where livestock can graze (Rutter, 2017).

As a basic pillar in PLF technology, reproduction is also supported and has contributed to increasing its efficiency through technologies such as pedometers, accelerometers, GPS combined collars, and RFIDs (Brassel et al., 2018). Such tools aid in minimizing calving losses and help in the early detection of calving. Furthermore, RFID technology is used to determine ewe-lamb pairs, which helps ensure the pedigree of the offspring. This reduces the extensive labor and manual work that needs to be done in determining pedigree, parturition, and oestrus (Calcante et al., 2014). The timely detection of oestrus helps in either timely artificial insemination of animals or increasing the conception chances through natural mating, reducing the chance of missing the next milking cycle from the cattle.

Milking livestock is another labor-intensive task, and it is practically impossible to run a farm in an economically viable state if manual labor is hired for milking thousands of dairy cows twice a day. Hence, PLF technologies such as automated milking machines, parlors, and robots have been in popular use, reducing the labor requirement, increasing the milk yield, and ultimately raising the lifestyles of dairy animals (Halachmi et al., 2019). Automated feeding systems and sensors control the amount of feed provided as well as support tailoring the nutrients and feed composition for individual animals's requirements. This personalized approach enhances the productivity of the farm at large (Zuidhof, 2020).

Table 1 summarizes the identified PLF technologies applied in all four rearing systems (extensive, grazing, pasture and outdoor) across the four main livestock categories (poultry, dairy, swine and beef production).

Table 1. Identified PLF technologies in livestock

Purpose	Type of technology	Use
Animal identification	• RFID • Boluses • Ear tags • Injectable glass tags	• Gather daily records of animals • Track and monitor livestock
Body weight calculation	• Walk-Over-Weight (WOW)	• Calculate growth rate • Decision on pasture management
Body condition	• 2D and 3D image analysis • Automatic drafting gates	• Estimate body condition scores, Body Weight, morphometric evaluations • To classify animal categories
Temperature regulation	• Thermal Humidity Index calculation • Surgical implanted devices, IR devices, endo-ruminal boluses with temperature sensors	• Identify animals entering heat stress
Animal location	• Aerial Unmanned vehicles (UAVs) • GPS collar with GSM • GPS with accelerometer	• To count animals • Identify grazing preferences of animals • Prevent animal theft • Maintain animal health
Pasture evaluation and grazing management	• Remote Sensing • Sensor technologies such as optical, synthetic aperture sensors, light detection and ranging sensors, Pressure sensors, Acoustic sensors • Virtual fencing	• Estimate grass quality • Sustainable herd management • Rotational grazing management
Animal behavior, grazing intake	• Global Positioning Systems (GPS)	• Grazing behavior preference • Spatial distribution of animals and preferred grazing sites
Animal welfare	• Accelerometers • Sound sensors	• Detect lameness and other general behaviors

		• Identify respiratory pathologies in swine (Marx et al., 2003) • To calculate the feed intake by broilers (Carolin et al., 2017)
Reproduction monitoring • Oestrus • Parturition • Pedigree • Incubation of eggs	• Pedometers • Accelerometers • GPS embedded collar • RFID technology • sensors	• Herd management • Detect the calving and calving time • Real time monitor the egg shell temperature and weight loss of eggs to improve hatching results (Berckmans, 2017)
Predation	• GPS tracker	• To identify predator prone areas
Milking management	• Automatic milking machines/parlors/ robots	• To carry out milking with minimum human intervention
Feed management	• Feed sensors • Automated feeding systems	• Tailor the nutrition requirement • Control the amount of feed

Though several categories of PLF technologies and tools are available and are in commercial use in different livestock sectors worldwide, literature records the commercialization and availability of the following PLF technologies in the USA (Table 2). But Graff et al. (2021) states that farmer adoption of these digital technologies has yet to be studied and tracked on a national level in the USA. Thus, exact statistics on the farmer's adoption of these smart technologies are unavailable (McFadden, 2023). According to the survey conducted by Michigan State University on nationwide swine farmer awareness of PLF, it was found that the majority (63%) of farmers have never used PLF technologies on their farms, but 57% of the farmers are intending to adopt PLF technologies at their sow farms (Akinyemi and Siegford, 2023). According to Rowe et al. (2019), poultry-based PLF research is primarily produced in the USA, but the commercialization and adoption of such technologies are still in their primary state. PLF technologies are widely in practice among farmers with regard to dairy; specifically in dairy cattle (Chandra Rai and Bhateshwar 2023) and also in beef cattle farming (Penn State Extension, 2023).

Table 2. Available commercialized and adopted PLF technologies in USA

Livestock species	PLF tool/technology	Purpose	Reference
Dairy cattle	GPS, accelerometer Wide frequency inward microphone Three axis accelerometers/Pedometers Wearable sensors/ neck collars	Virtual fencing Monitoring animal activity Pasture management Track the forage intake and grazing behavior Detect oestrus	Aquilani et al. (2022) Chelotti et al. (2016) Pereira et al. (2018) Penn State Extension (2023)
Beef cattle	GPS	Monitoring behavior	Anderson et al. (2012)
Cattle/Sheep/Goat	Microphone Automatic milking parlors/robots	Identifying feeding habits through jaw movements Automatic milking	Navon et al. (2013)
Livestock	UAV/drones/satellite tracking/GNSS technology RFID ear tags/RFID antenna	Optimize farmland management Livestock monitoring Geo referencing	McFadden (2023)
Swine	Electronic sow feeders Water drinkers Pressure plates Weighing scales Video monitoring cameras Automated data entering tablets Cough monitors	Automated feeding and water intake Detect lameness Body weight Monitor behavior Respiratory issue detection	Akinyemi and Siegford (2023)
Poultry (Broilers and laying hens)	Environmental and wearable sensors and cameras Thickness and crack sensors for eggs	Measure environmental parameters Individual animal identification and tracking movements	Rowe et al. (2019)

Is PLF For Every Farm? Challenges Faced By U.S. Farmers in Adopting PLF

The adoption of Precision Livestock Farming (PLF) technologies in the USA confronts several significant challenges for the farming community. The challenges derived from the literature could be grouped into six categories related to cost, infrastructure, privacy, technical complexities, societal barriers, and market dynamics.

A noteworthy issue is infrastructure and connectivity, specifically in areas where existing Wi-Fi networks, cellular connectivity, and power sources have to be upgraded to link with real-time data collection and integration (Banhazi et al., 2012; Akinyemi et al., 2023). Poor internet connectivity hinders the crucial real-time data collection and analysis for PLF.

High initial costs are also another barrier. Farmers have to bear significant costs in purchasing sensors, automated systems (GPS trackers, robots), and data management tools that are unaffordable or incompatible for small or medium-scale farms (Russell and Bewley, 2013; Vlaicu et al., 2024). Additionally, data management (collection, storage, and handling), data security, and privacy issues such as fears of data misuse or security breaches repel farmers from adopting these technologies (Akinyemi et al., 2023). Deficiencies in technical expertise are also another barrier to PLF adoption at farms because the implementation and maintenance of PLF systems require specialized knowledge and training, which can overwhelm the farmers (Kaur et al., 2023).

Also, many PLF tools operate independently and lack interoperability, thus requiring special knowledge to interpret the analyzed data before generating business intelligence; hence, the collected data may not be flexible enough to be used right away by the farmer (Russell & Bewley, 2013). Moreover, this consumes exceptionally high, skilled labor in removing bad data and inaccurate records, which in turn adds up as a cost factor for the farmer (Browns et al., 2015). Hence, farmers may have better alternatives that are easier to accomplish manually, that could fit with their pattern of work, and have a better cost-to-benefit ratio (Browns et al., 2015).

Resistance to change is a societal barrier, with traditional farming practices being deeply ingrained and farmers often hesitant to adopt new methods (Kleen and Guatteo, 2023). Economic and market factors also play a crucial role, as fluctuating market prices and economic uncertainties may negatively impact the propensity to invest in PLF technologies since the return-on-investment time is significant (Abobatta, 2022).

How and Why PLF Is Possible Among U.S. Farmers? Opportunities

Although barriers still exist limiting the farmers' adoption of PLF technologies in the USA, the following opportunities facilitate the rate of adoption of such technologies.

Various federal and state programs provide grants, low interest scheme loans and subsidies so that PLF technologies are made affordable for the farmers. Such grants are provided by USDA (USDA (2024)) to purchase machinery and equipment etc. Moreover, technology transfers with farmers are carried out under the USDA program of Precision Agriculture in Animal Production (Precision Agriculture in Animal Production | NIFA,2024).

The extension services and guidance provided by universities through the organizing of training programs, workshops, and on-site demonstrations help broaden the farmers' knowledge and the mindset towards PLF (e.g., Penn State Extension, Iowa State University, Michigan State University, etc.). Furthermore, the universities apply for competitive grants and conduct timely research and surveys that help generate knowledge regarding PLF that supports speedier dissemination of PLF technologies among the USA farming community (e.g., Akinyemi and Siegford, 2023). Webinars and short courses (UT Precision Livestock Farming, 2022), online programs, farmer conferences, and industry conferences are organized in collaboration with universities and industry stakeholders to strengthen and communicate the PLF information (e.g., National Hog Farmer, 2022). Private sector partnerships with technology companies help farmers access the newest PLF technologies. Also, often, these services are provided as a bundle that helps farmers adapt to and adopt these smart technologies. The manufacturers and suppliers of PLF technologies provide technical support and/or installation support for these smart tools, and even workshops, on-site visits, online help desks, and user manuals are made accessible to the farmers. Farmer cooperatives and farmer networks facilitate the sharing of experiences and best practices.

CONCLUSION

Precision Livestock Farming (PLF) intends to address the enhancement of production, reproduction, human and animal health and welfare, and the environmental impact caused by livestock farming while focusing on the Triple Bottom Line. The main livestock sectors where PLF technologies are in practice in the USA include dairy cattle, beef cattle, poultry (Broilers and egg laying hen) and swine, goats, and sheep. Of these sectors, PLF technologies are extensively practiced in dairy cattle and beef cattle, while the technologies are used considerably in swine and poultry. The widely used PLF technologies across these livestock sectors include GPS, RS, and sensors, infrared technologies embedded in equipment and microphones, wireless communication tools, and robots, UAVs, and cameras. However, certain evidence is available regarding the farmer's adoption of PLF technologies in livestock sectors such as cattle and swine, but there is no nationwide data available regarding the farmer's adoption of such technologies in the livestock sector at large. Hence further studies are required to fill the gap of knowledge in the discipline. Although barriers to adopting PLF exist among the farming community in terms of technology literacy, costs, and infrastructure, privacy, technical complexity, and societal dynamics, and market dynamics, it is possible to overcome the barriers with time through the facilities made available to promote PLF: university contributions, grants and funding schemes, partnerships, and PLF manufacturers' contributions to disseminating such technologies.

Conflict of Interest

The author has declared that there are no competing interests.

Author Contribution

Entire review paper was planned, designed and executed by the author herself.

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