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Implementation Strategies for Precision Livestock Farming to Improve Livestock Productivity and Health Based on Local Context

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ABSTRACT

This study aims to analyze the implementation strategies of Precision Livestock Farming (PLF) to improve livestock productivity and health based on local context. The study addresses the gap between the potential of digital livestock technologies and the practical realities faced by local farmers, including limited infrastructure, cost constraints, digital literacy, and reliance on traditional animal observation. A qualitative case study approach was used to explore how PLF is understood, accepted, adapted, and applied in local livestock systems. Data were collected through semi-structured interviews, field observations, and documentation involving livestock farmers, extension workers, animal health officers, farmer group leaders, local stakeholders, and technology providers. The data were analyzed using reflexive thematic analysis to identify patterns of meaning across participants' experiences. The findings reveal four main themes: perceived usefulness of PLF for early animal health detection and productivity management, adaptation of technology to local farming routines, barriers related to cost and infrastructure, and the importance of social and technical support. The study shows that PLF adoption depends not only on technological availability but also on farmer trust, local knowledge, usability, and institutional assistance. This study contributes to the literature by positioning PLF implementation as a socio-technical process shaped by local context. The findings imply that PLF strategies should be gradual, affordable, farmer-centered, and supported by policy, extension services, and participatory training.

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1. Introduction

The livestock sector is facing growing pressure to produce animal-based food more efficiently while maintaining animal health, welfare, and environmental sustainability. This pressure appears at the global level through increasing demand for meat, milk, and eggs, and it also appears at the national level through the need to strengthen food security and improve the competitiveness of local livestock systems. Precision Livestock Farming, or PLF, has emerged as a technological response to these challenges because it allows farmers to monitor animals, barns, feed intake, reproduction, and health indicators through sensors, cameras, digital records, and decision-support systems. Morrone et al. (2022) explain that PLF is part of the broader Industry 4.0

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transformation in animal production. This transformation changes livestock management from manual observation into data-based decision-making.

PLF offers practical opportunities for improving productivity and animal health because it can detect changes in animal behavior, body condition, movement, feeding activity, and physiological responses. Wearable sensors can support early warning systems by recording behavioral and physiological data from individual animals. Lee and Seo (2021) show that wireless biosensor technology can support cattle monitoring through devices such as ear tags, collars, boluses, and leg sensors. This function is important because many animal health problems develop gradually before visible clinical signs appear. When farmers receive earlier information, they can respond faster to disease risk, reproductive problems, heat stress, or declining productivity. Tedeschi et al. (2021) also argue that advanced sensors and intelligent decision-support tools can assist smart livestock farming by converting farm data into useful management information.

Despite its potential, PLF implementation does not occur in the same way across all livestock systems. The adoption of digital tools depends on farm scale, infrastructure, economic capacity, farmer literacy, technical support, species characteristics, and production goals. Monteiro et al. (2021) state that precision agriculture and livestock technologies require accurate, practical, and implementable systems in real farming environments. This point is crucial for local livestock systems, especially where farmers still rely on direct observation, practical experience, and inherited knowledge. In such contexts, PLF cannot be treated only as a technical innovation. It must be understood as a socio-technical process that interacts with local routines, farmer trust, labor patterns, and existing management practices.

In the field, the main problem is not limited to the availability of PLF devices. Farmers also need to understand how the technology works, how the data can support daily decisions, and how the benefits compare with costs and risks. Palma-Molina et al. (2023) found that the adoption intensity of PLF technologies in pasture-based dairy systems relates to farm characteristics and managerial capacity. Selvaggi et al. (2024) further show that farmers consider price, convenience, data type, and technical usability when evaluating PLF devices. These findings indicate that PLF adoption is not a simple decision. It involves negotiation between perceived usefulness, affordability, technical readiness, and local farm priorities.

The social and cultural dimensions of PLF also deserve attention because livestock farming is not only an economic activity. It includes relationships between farmers, animals, family labor, local institutions, veterinarians, extension workers, and market actors. Schillings et al. (2021) argue that PLF can support animal welfare, but its effectiveness depends on how humans interpret and act on technological information. This means that a device can provide data, but the quality of decisions still depends on farmer knowledge, access to support, and trust in digital recommendations. In small and medium livestock systems, farmers may accept PLF when they see that it fits their daily work. They may reject it when it feels expensive, complicated, or disconnected from local conditions.

Previous studies have discussed PLF in various livestock sectors, including dairy animals, pigs, calves, small ruminants, and grazing animals. Simitzis et al. (2021) reviewed the contribution of PLF systems to welfare and productivity in dairy animals. Tzanidakis et al. (2021) described technological trends in precision pig farming. Silva et al. (2023) examined technologies for monitoring calves' health and welfare. Morgan-Davies et al. (2024) also highlighted the potential of PLF for small ruminant welfare management. However, many studies still emphasize technological functions, sensor performance, productivity effects, and system development. Fewer studies explore how farmers interpret PLF, how they adapt it to local conditions, and how implementation strategies are shaped by social, economic, and cultural contexts.

Based on this gap, this study aims to analyze implementation strategies for Precision Livestock Farming to improve livestock productivity and health based on local context. The study focuses on how farmers, livestock extension workers, animal health officers, technology providers, and local stakeholders understand PLF, identify its benefits, face implementation barriers, and adapt digital tools to existing livestock practices. Papakonstantinou et al. (2024) emphasize that PLF is closely linked to animal welfare, climate change, and sustainable livestock management. Therefore, this study contributes theoretically to the discussion of technology adoption in livestock systems by placing local context at the center of analysis. Practically, the study can support the design of PLF strategies that are affordable, usable, socially acceptable, and relevant to the real needs of livestock farmers.

2. Materials and Methods

This study uses a qualitative research approach with a case study design. The case study design was selected because the research seeks to understand the implementation of Precision Livestock Farming within a real local livestock context. The study does not only examine whether farmers use PLF devices. It also explores how farmers interpret the technology, how they integrate it into daily livestock management, and how local conditions influence its acceptance. Mtisi (2022) explains that a qualitative case study is useful for investigating complex phenomena in their natural setting. This design is relevant because PLF implementation involves technology, human decision-making, economic capacity, animal health practices, and local institutional support.

The research will be conducted in livestock farming areas in **[insert district or province]** during **[insert month and year]**. The location is selected purposively because it represents an active livestock production area where farmers have different levels of exposure to digital farming tools. Some farmers may already use simple digital records, mobile applications, pedometers, CCTV monitoring, environmental sensors, or animal health recording systems. Others may still depend on manual observation and traditional livestock management practices. Kendall et al. (2022) show that technology adoption in farming needs to be understood through the social and practical realities of farm work. Therefore, the selected location is treated as a local setting where PLF is negotiated, adapted, accepted, or resisted.

The participants will consist of livestock farmers, livestock extension workers, animal health officers, farmer group leaders, local government representatives, and technology providers. The main participants are farmers who manage cattle, dairy cattle, goats, sheep, or other livestock relevant to the research context. They are selected because they directly experience livestock management and make daily decisions related to feeding, health monitoring, reproduction, sanitation, and productivity. The supporting participants are selected because they provide technical, institutional, or advisory perspectives on PLF implementation. Subedi (2021) argues that purposive sampling is appropriate in qualitative research when participants are selected based on their ability to provide rich and relevant information. The inclusion criteria include at least two years of livestock farming experience, direct involvement in animal management, willingness to participate, and knowledge of local livestock practices.

Participant recruitment will use purposive sampling and may continue with snowball sampling. Purposive sampling will help identify key informants who have direct knowledge of livestock productivity, animal health problems, and digital technology use. Snowball sampling will be used when initial participants recommend other informants who have relevant experience with PLF tools, livestock health management, or farmer group activities. This strategy is important because PLF implementation often involves informal networks among farmers, extension workers, veterinarians, and technology providers. The estimated number of participants is **15 to 25 informants**, but the final number will depend on data saturation. Data saturation will be reached when new interviews no longer produce substantially new information about PLF implementation strategies.

Data will be collected through semi-structured interviews, field observation, and documentation. Semi-structured interviews will allow the researcher to use guiding questions while still giving participants space to explain their experiences in their own words. Adeoye-Olatunde and Olenik (2021) state that semi-structured interviews are useful for exploring participants' perspectives in a systematic but flexible way. The interview topics will include farmer understanding of PLF, perceived benefits, barriers to adoption, technology costs, digital literacy, internet access, technical support, animal health monitoring, productivity improvement, and adaptation to local farm routines. Interviews will be conducted face to face whenever possible. Each interview will last approximately 30 to 60 minutes and will be recorded with participant consent.

Field observation will be conducted to examine livestock management practices directly. The researcher will observe barn conditions, feeding routines, animal health monitoring, record-keeping practices, technology use, and interactions between farmers and animals. Observation is needed because PLF implementation may differ between what participants say and what actually happens in daily farm practice. Reeves et al. (2025) show that farmers' perceptions of PLF technologies can reveal advantages and disadvantages that are not always visible in technical studies. Documentation will include farm records, animal health notes, production records, photos of devices, farmer group documents, extension materials, and screenshots of digital applications when available. These documents will help strengthen the interpretation of interview and observation data.

Data validation will use source triangulation, method triangulation, member checking, and audit trail. Source triangulation will compare information from farmers, extension workers, animal health officers, farmer group leaders, and technology providers. Method triangulation will compare interview results, field observations, and documents. Member checking will be conducted by returning interview summaries or preliminary interpretations to selected participants. McKim (2023) emphasizes that member checking should be structured so participants can evaluate accuracy and meaning. The audit trail will include interview guides, field notes, transcripts, coding records, analytic memos, and decisions made during the analysis process. This procedure will help ensure transparency and allow limited replication in other livestock contexts.

Data analysis will use reflexive thematic analysis. The analysis will follow several stages: familiarization with the data, initial coding, theme development, theme review, theme naming, and final interpretation. Braun and Clarke (2022) explain that thematic analysis requires coherence between research questions, epistemological position, coding decisions, and theme development. The researcher will begin by reading the interview transcripts and observation notes repeatedly. Initial codes may include "technology affordability," "farmer trust," "digital literacy," "technical support," "animal health detection," "productivity records," "local knowledge," and "infrastructure barriers." These codes will then be grouped into broader themes, such as local adaptation of PLF, barriers to implementation, farmer-centered technology design, and PLF for preventive animal health management. Byrne (2022) notes that thematic analysis can help researchers organize complex qualitative data into meaningful patterns. The final findings will be presented as thematic narratives supported by selected participant statements, field descriptions, and relevant literature.

3. Results and Discussions

The findings show that the implementation of Precision Livestock Farming in the local livestock context is shaped by four main themes: perceived usefulness for animal health and productivity, adaptation to local farming routines, barriers related to cost and infrastructure, and the need for social and technical support. These themes emerged from interviews with farmers, extension workers, animal health officers, farmer group leaders, and technology providers. Field observations also showed that most farmers did not reject digital technology directly. Instead, they evaluated PLF based on whether it could solve daily problems in livestock management. A farmer explained, "I will use the device if it helps me know earlier when the animal is sick, but it must be simple because I still have many routine jobs in the barn" (F3). This statement indicates that technology acceptance depends on practical relevance, not only on technological sophistication.

The first theme concerns the perceived usefulness of PLF for early detection of animal health problems. Farmers stated that disease symptoms often appear slowly and are sometimes recognized only after the animal shows reduced appetite, lower milk yield, abnormal movement, or visible weakness. In this context, PLF was perceived as useful when it helped farmers identify changes in animal behavior before the condition became severe. One animal health officer noted that “farmers usually call us when the symptoms are already clear, but digital monitoring can help them notice changes earlier” (AHO2). Observations in the barn also showed that farmers often relied on visual signs, such as feed leftovers, standing posture, rumination behavior, and movement patterns. PLF tools can strengthen these traditional practices by providing additional data for preventive health management. This finding aligns with Lee and Seo (2021), who emphasize that wearable biosensors can support cattle monitoring through physiological and behavioral indicators.

The second theme relates to productivity management. Farmers viewed PLF as useful when it could help them record milk yield, feed use, reproductive cycles, body condition, and treatment history. Several participants reported that manual records were often incomplete because farmers focused more on direct barn work than written documentation. One farmer group leader stated, “Some members know their animals very well, but they do not always write the data. When there is a problem, the records are not complete” (FGL1). This finding shows that PLF has potential not only as a monitoring device but also as a tool for improving farm data discipline. Better records can help farmers compare productivity across animals, identify repeated health problems, and plan feeding or treatment more accurately. Tedeschi et al. (2021) support this interpretation by stating that sensor technologies and decision-support tools can transform farm data into practical management information.

The third theme concerns local adaptation. Farmers did not view PLF as a technology that could be applied in one fixed model. They expected the tools to fit their existing work rhythm, barn design, labor availability, and financial capacity. For example, farmers with small herds preferred simple mobile-based recording systems, while farmers with larger herds showed more interest in sensors, cameras, or automatic alerts. A technology provider explained, “The same device cannot be offered in the same way to all farmers. Some need only basic recording, while others are ready for more advanced monitoring” (TP1). This finding suggests that PLF implementation must follow a gradual and flexible strategy. Monteiro et al. (2021) also argue that precision agriculture and livestock systems need practical application according to farm conditions.

The fourth theme highlights the role of local knowledge. Many farmers still trusted direct observation because it was built from long experience with animals. They recognized health changes through animal sound, appetite, manure condition, body movement, and daily habits. One senior farmer said, “Before using any device, I can usually feel when an animal is not normal because I see it every day” (F7). This statement does not indicate resistance to technology. It shows that local knowledge remains central in animal management. PLF will be more acceptable when it complements farmer knowledge rather than replacing it. Schillings et al. (2021) argue that PLF can support animal welfare only when humans interpret and respond to the information properly. Therefore, the success of PLF depends on the interaction between digital data and farmer experience.

The fifth theme concerns barriers to implementation. Farmers identified cost, internet access, device maintenance, technical language, and fear of system failure as the main obstacles. Some participants stated that they were interested in digital tools but hesitated because they were unsure whether the benefits would justify the investment. One farmer said, “The tool may be good, but if the price is too high, small farmers will think many times before buying it” (F2). Extension workers also noted that limited digital literacy created hesitation among older farmers. This finding is consistent with Palma-Molina et al. (2023), who found that PLF adoption is influenced by farm characteristics and managerial capacity. It also supports Selvaggi et al. (2024), who found that price, usability, and technical support affect farmers' decisions to adopt PLF devices.

The sixth theme is the importance of social and institutional support. Farmers were more willing to try PLF when they received guidance from extension workers, veterinarians, farmer groups, or technology providers. The presence of trusted intermediaries helped reduce uncertainty and made the technology easier to understand. One extension worker stated, "Farmers need examples from nearby farms. If they see another farmer benefit from the tool, they become more confident" (EW1). This finding shows that PLF adoption is not only an individual decision. It is also influenced by peer learning, group discussion, demonstration plots, and local institutional support. Kendall et al. (2022) similarly show that technology adoption in farming must be understood through the social realities of farmers and their working environment.

Discussion

The findings indicate that PLF implementation in local livestock systems should be understood as a socio-technical process. Farmers did not assess PLF only by its technical capacity. They judged it through daily usefulness, affordability, ease of use, and compatibility with local routines. This supports the argument that technology adoption in livestock farming depends on the relationship between innovation and context. Morrone et al. (2022) describe PLF as part of the digital transformation of animal production, but the present findings show that this transformation becomes meaningful only when it fits local farming needs. This study therefore adds a contextual perspective to PLF literature by showing that local adaptation is not a secondary factor. It is a central condition for implementation.

The finding on animal health monitoring strengthens previous studies that highlight the value of PLF for early detection and preventive management. Lee and Seo (2021) show that wearable biosensors can monitor cattle health through physiological and behavioral data. The present study extends this argument by showing how farmers interpret the function of early detection in their own language and practice. Farmers valued PLF when it helped them recognize abnormal conditions faster, but they still needed clear explanations and practical alerts. This suggests that PLF systems should avoid overly technical output. They need simple indicators that farmers can connect with visible animal conditions, such as feed intake, movement, rumination, temperature, and productivity changes.

The finding on productivity records also confirms the role of PLF in improving data-based farm management. Tedeschi et al. (2021) argue that smart livestock farming requires tools that convert raw data into decision-support information. This study shows that, at the local level, the first step toward data-based management may begin with simple and consistent recording practices. Many farmers still face problems with incomplete manual records. For this reason, PLF implementation should not always start with advanced automation. It can begin with basic digital recording that helps farmers build a habit of documenting production, reproduction, feeding, and animal health.

The role of local knowledge provides an important theoretical insight. Some technology-centered approaches assume that digital systems will replace traditional observation. The findings of this study suggest a different interpretation. Farmers did not separate technology from experience. They expected PLF to confirm, strengthen, or clarify what they already observed in the barn. This supports Schillings et al. (2021), who emphasize that the ethical and practical value of PLF depends on human interpretation. In this study, local knowledge became a bridge between sensor data and farm decisions. This means that effective PLF strategies should integrate farmer experience into training, dashboard design, and decision-support recommendations.

The barriers found in this study are consistent with previous research on PLF adoption. Palma-Molina et al. (2023) found that farm capacity influences the intensity of PLF adoption in dairy systems. Selvaggi et al. (2024) also reported that farmers consider price, convenience, data type, and technical usability before adopting PLF tools. The present study adds that these barriers are experienced not as isolated technical problems, but as connected concerns. For example, high cost becomes more serious when farmers are unsure about maintenance support. Low digital literacy becomes more problematic when the device interface uses technical language. Limited internet access becomes a major issue when the PLF system depends on real-time cloud connectivity.

The findings also show that social trust influences technology acceptance. Farmers were more interested in PLF when they saw examples from other farmers or received explanation from trusted extension workers. This supports Kendall et al. (2022), who argue that agricultural technology adoption is shaped by farming culture and social context. In local livestock systems, farmer groups can act as learning spaces where farmers discuss benefits, risks, and practical experiences. Therefore, PLF implementation should involve participatory demonstration, peer learning, and continuous mentoring. A top-down distribution of technology without local training may create low usage, misunderstanding, or abandonment of devices.

From a practical perspective, the study suggests that PLF implementation should follow a phased strategy. The first phase can focus on digital literacy, basic recording, and animal health awareness. The second phase can introduce simple monitoring devices that match the most urgent problems, such as reproductive detection, disease warning, or feeding management. The third phase can integrate sensor data with farmer group records and veterinary support. The fourth phase can develop more advanced decision-support systems for farms with higher readiness. This phased model allows farmers to learn gradually and reduces the risk of technology rejection. It also helps policymakers and technology providers design PLF programs based on local capacity rather than uniform technology packages.

Theoretically, this study contributes to the discussion of PLF by emphasizing contextual implementation. PLF should not be viewed only as a technological innovation in animal production. It should also be understood as a process of negotiation between digital systems, farmer knowledge, animal health needs, economic capacity, and local institutional support. This perspective strengthens qualitative inquiry in PLF research because it reveals meanings, concerns, and adaptation processes that are often hidden in technical performance studies. Papakonstantinou et al. (2024) explain that PLF is linked to animal welfare and climate-related livestock challenges. The present study adds that these broader goals will be difficult to achieve without attention to local readiness and farmer-centered implementation.

Future research should examine PLF implementation across different livestock species, production scales, and regional contexts. Comparative studies between smallholder farms and commercial farms can provide deeper understanding of how economic capacity shapes technology adoption. Longitudinal research can also explore how farmer perceptions change after repeated use of PLF tools. In addition, future studies can combine qualitative and quantitative approaches to examine whether locally adapted PLF strategies improve measurable outcomes such as disease detection speed, treatment response, milk yield, feed efficiency, reproductive performance, and mortality reduction. Such studies will help connect farmer experience with empirical productivity and health indicators.

4. Conclusions

This study concludes that the implementation of Precision Livestock Farming in local livestock systems is not only a technological process but also a socio-technical adaptation shaped by farmer experience, economic capacity, infrastructure readiness, and institutional support. The findings show that farmers value PLF when it helps them detect animal health problems earlier, improve productivity records, support reproductive management, and strengthen daily decision-making. However, adoption remains influenced by cost, digital literacy, internet access, technical maintenance, and trust in digital data. These findings confirm that PLF becomes meaningful when it complements local knowledge rather than replacing farmer observation and practical experience.

Theoretically, this study contributes to PLF literature by emphasizing the importance of local context in technology implementation. Practically, the findings suggest that PLF programs should begin with simple digital recording, farmer training, participatory demonstrations, and gradual introduction of monitoring devices based on local needs. From a policy perspective, livestock development programs should provide technical assistance, affordable technology schemes, and stronger collaboration among farmers, extension workers, veterinarians, technology providers, and local government. Future research should examine PLF implementation across different livestock species, farm scales, and regional contexts, and may combine qualitative insights with quantitative indicators such as disease detection speed, feed efficiency, reproductive performance, and productivity outcomes.

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