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Sustainable Natural Feed Optimization and Low-Cost Automated Feeding Systems for Small-Scale Dairy Farms in Sri Lanka

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Abstract **— Small-scale dairy farming is an important contributor to Sri Lanka's agricultural sector, yet productivity and sustainability are limited by inefficient feeding practices, dependence on expensive commercial feed, and limited access to modern technologies. This paper proposes** CattleCare**, an integrated framework that combines a web-based advisory platform with a low-cost automated feed dispensing system to support sustainable feed management for smallholder dairy farmers. A field survey conducted across 16 dairy farms between March and June 2026 collected data from approximately 60 cattle representing indigenous and crossbred dairy breeds. The platform analyzes existing feeding practices and generates customized feeding recommendations based on cattle characteristics, milk production, environmental conditions, and locally available feed resources. The framework is designed to interface with a low-cost automated feed dispensing system for accurate feed allocation, with field validation planned under real farm conditions. By promoting the use of locally available fodder, agricultural by-products, and affordable digital technologies, the proposed framework supports circular agricultural practices while reducing reliance on imported concentrate feeds. Preliminary field observations demonstrate the practical potential of the proposed framework for supporting structured feed management; however, long-term effects on milk productivity, feed efficiency, and environmental performance require further validation.**

Keywords **— Sustainable dairy farming; natural feed optimization; precision livestock farming; automated feed dispensing; environmental sustainability; smart agriculture; digital advisory systems; circular agriculture; feed efficiency; low-cost automation; agricultural by-products; climate-resilient livestock systems; Sri Lanka.**

I. INTRODUCTION

Sustainable livestock production has become increasingly important due to growing concerns about environmental conservation, efficient resource utilization, and waste reduction [1], [2]. In Sri Lanka, small-scale dairy farming plays a vital role in rural livelihoods and national milk production. However, many farmers continue to rely on commercially manufactured cattle feeds, which increase production costs, plastic packaging waste, and the environmental footprint of dairy farming, while locally available grasses, agricultural by-products, and surplus fruits remain underutilized [3], [4].

Sri Lanka has abundant sustainable feed resources, including Guinea grass, CO-3 Hybrid Napier grass, *Gliricidia sepium*, *Leucaena leucocephala*, maize fodder, rice straw, coconut poonac, soybean meal, and mineral supplements. Agricultural by-products and fruit residues such as banana, mango, jackfruit, and pineapple can also be utilized as supplementary feed, reducing agricultural waste, dependence on commercial feeds, and promoting circular agricultural practices [5], [6].

Despite the availability of these resources, small-scale farmers lack practical decision-support tools for optimizing feed according to cattle breed, production stage, milk yield, and environmental conditions. Existing dairy management systems mainly focus on record management and provide limited support for sustainable feed optimization using locally available resources [7], [8].

To address these challenges, this paper proposes **CattleCare**, a web-based dairy management and sustainable feed optimization platform integrated with a low-cost automated feed dispensing framework. The platform compares existing feeding practices with standard nutritional requirements and generates customized feeding recommendations using locally available feed resources. By promoting sustainable feed utilization and reducing dependence on commercially packaged feeds, the proposed framework supports environmentally responsible dairy

farming, minimizes agricultural and plastic waste, and contributes to a circular agricultural economy in Sri Lanka.

Therefore, this study investigates the applicability of a localized digital decision-support approach for sustainable feed management in small-scale dairy farming. The study combines field-level information on cattle and feeding practices with the CattleCare web platform to identify feed gaps and generate resource oriented feeding recommendations. The study also proposes integration with a low-cost automated feed dispensing system. The primary contribution is the integration of localized feed-gap analysis, sustainable feed recommendations, and digital farm management within a smallholder-oriented framework.

II. LIMITATIONS OF EXISTING WORK

A. Local Research Studies

Recent studies conducted in Sri Lanka have focused on improving dairy cattle nutrition, milk productivity, and farm management through the utilization of locally available feed resources [3], [9]. Research has demonstrated that balanced feeding practices and the use of forage crops such as Guinea grass, CO-3 Hybrid Napier grass, *Gliricidia sepium*, *Leucaena leucocephala*, rice straw, and coconut poonac can improve milk production while reducing feed costs [9], [10]. Other studies have evaluated Total Mixed Ration (TMR), nutritional supplementation, and dairy herd management to enhance animal health and productivity.

From a sustainability perspective, these studies emphasize the importance of utilizing locally available feed resources and agricultural residues to reduce dependence on imported commercial feed [5]. However, most local research remains experimental and does not provide farmers with a digital platform capable of comparing existing feeding practices with nutritional standards or recommending sustainable feed alternatives based on individual cattle requirements.

B. International Research Studies

International research has demonstrated considerable progress in precision livestock farming through the Internet of Things (IoT), artificial intelligence, machine learning, cloud computing, and automated feeding systems [11], [12]. Commercial dairy management platforms such as Afimilk, DairyComp 305, and Uniform-Ag provide advanced herd monitoring, milk recording, health management, and production analysis [11], [13]. Similarly, several countries including New Zealand, India, Kenya, and European nations have introduced smart dairy technologies that improve feeding efficiency, disease monitoring, and farm productivity [12], [14].

Recent international studies have also highlighted the importance of sustainable livestock production by promoting precision feeding, efficient water utilization, greenhouse gas reduction, and improved resource management [1], [2]. Nevertheless, these technologies are generally designed for commercial dairy farms with sufficient financial resources and advanced digital infrastructure, limiting their applicability to small-scale farming systems.

C. Limitations of Existing Dairy Management Systems

Although existing dairy management systems provide valuable support for herd management, milk recording, breeding, and disease monitoring, several limitations reduce their suitability for small-scale dairy farmers in Sri Lanka [11], [13].

Most commercial platforms require expensive hardware, software subscriptions, reliable internet connectivity, and trained personnel, making them difficult to adopt in rural communities. Their interfaces are often designed for commercial dairy enterprises and require a level of digital literacy that many small-scale farmers may not possess [13].

Another significant limitation is the lack of localized feed optimization. Existing applications rarely incorporate Sri Lankan feeding standards or recommend locally available feed resources, resulting in greater dependence on commercially manufactured concentrate feeds and higher production costs [5], [9].

From an environmental sustainability perspective, most existing systems provide limited support for circular agricultural practices, agricultural by-product utilization, feed waste reduction, or livestock waste management for renewable energy generation [1], [16].These limitations indicate a need for further development and evaluation of affordable, sustainable, and farmer-friendly decision-support platforms for small-scale dairy farming.

TABLE I. FEATURE COMPARISON OF EXISTING DAIRY MANAGEMENT SYSTEMS WITH THE PROPOSED CATTLECARE PLATFORM

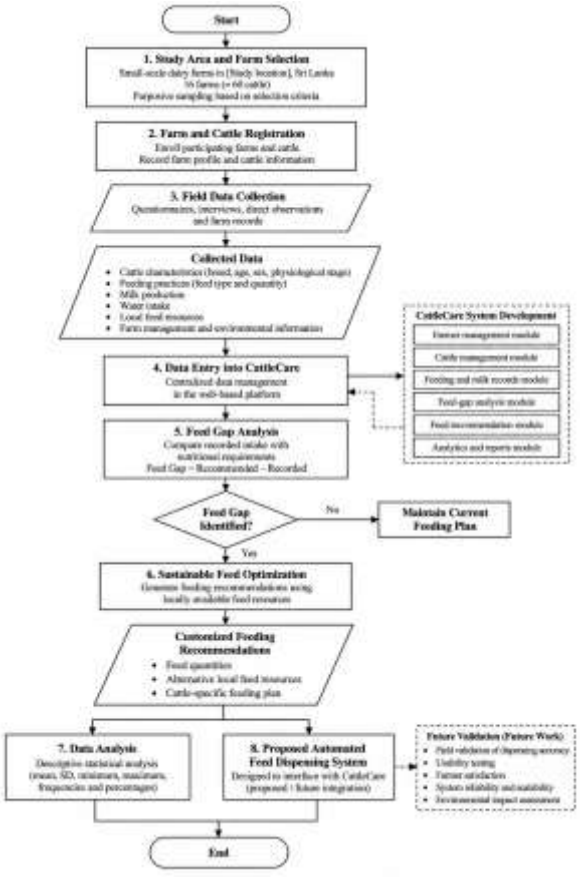
Feature	**Existing Research & Applications**	**Proposed System/CattleCare Webapp**
Farm and Cattle Management	✓	✓
Milk Production Monitoring	✓	✓
Feed Gap Analysis	✗	✓
Personalized Feed Optimization	Limited	✓
Sri Lankan Feeding Standards	✗	✓
Local Sustainable Feed Recommendations	✗	✓
Agricultural By-product Utilization	✗	✓

Low-Cost Solution for Small-Scale Farmers	Limited	✓
Environmental Sustainability Support	Limited	✓
Automated Feed Dispensing Integration	✗	✓

III. METHODOLOGY

The methodology followed a structured process of selecting small-scale dairy farms, collecting farm- and cattle-level data, entering the data into the CattleCare platform for feed-gap analysis, generating customized recommendations using locally available feed resources and agricultural by-products, performing descriptive statistical analysis, and proposing integration with a low-cost automated feed dispensing system for future field validation.

Figure1. Research Workflow of the Proposed CattleCare Framework



IV. RELATED WORK

Sustainable dairy farming has gained considerable attention due to increasing concerns regarding food security, environmental sustainability, and efficient utilization of agricultural resources [1], [2]. Recent studies have explored precision livestock farming, digital dairy management, automated feeding technologies, and sustainable feed resource utilization to improve milk production and farm profitability [11], [12]. However, most existing research focuses on individual aspects of dairy management rather than providing an integrated framework that combines nutritional assessment, feed optimization, automation, and performance evaluation.

A. Baseline Feeding and Nutritional Assessment

Several studies have reported that balanced nutrition based on cattle breed, age, physiological stage, and milk yield significantly improves animal health and milk productivity [5], [9]. Despite established feeding standards, many small-scale farmers continue to rely on traditional feeding practices due to limited technical knowledge and the lack of digital advisory systems.

B. Feed Optimization Using Sustainable Local Feed Resources

Recent research promotes the use of locally available fodder, agricultural by-products, and fruit residues to reduce feed costs and improve environmental sustainability [5], [6]. These sustainable feed resources reduce dependence on commercially packaged concentrate feeds while supporting circular agricultural practices.

C. Digital Dairy Management and Feeding Automation

The rapid development of IoT technologies has enabled digital transformation in dairy farming through automated monitoring, milk recording, environmental sensing, and precision feeding [11], [12]. However, most existing systems are designed for commercial dairy farms and do not integrate feed gap analysis using locally available sustainable feed resources [13], [15].

D. Research Gap and Proposed Framework

The literature indicates that no single system comprehensively integrates baseline nutritional assessment, sustainable feed optimization, digital dairy management, automated feed dispensing, and performance evaluation within an affordable platform for small-scale dairy farmers. To address this gap, this research proposes **CattleCare**, a web-based dairy management and feed optimization platform developed according to a four-phase methodology. The platform first evaluates existing feeding practices through baseline nutritional assessment, compares current feed intake with standardized feeding recommendations, and identifies nutritional deficiencies using a feed gap analysis model. Based on these findings, customized feeding recommendations are generated using locally available natural fodder, agricultural by-products, and fruit residues. The optimized feeding plans are then integrated with a low-cost automated feed dispensing system, while the final phase evaluates improvements in feed efficiency, milk productivity, resource utilization, and environmental sustainability. This integrated framework provides a practical and affordable

solution for promoting sustainable dairy farming across Sri Lanka.

V. CATTLE CARE WEB APP

The **CattleCare** platform was developed as a web-based dairy management and sustainable feed optimization system to support small-scale dairy farmers in Sri Lanka. The application provides an integrated digital environment for farm information management, livestock performance monitoring, feed analysis, and decision support, aligning with the principles of precision livestock farming and sustainable agricultural management [17], [18].

The proposed platform compares farmers' existing feeding practices with standardized nutritional requirements and generates customized feeding recommendations using locally available sustainable feed resources. In addition, the system is designed to interface with a low-cost automated feed dispensing framework, providing a planned interface for accurate feed allocation, with system-level validation required under real farm conditions.

The web application was developed using modern web technologies to provide an interactive, responsive, and user-friendly interface. HTML5 was used to design the structure of web pages, while CSS3 was used to create a responsive layout and improve the visual appearance of the user interface. JavaScript was implemented to provide dynamic functionalities, including real-time calculations, user interaction, form validation, dashboard updates, and feed gap analysis. Python was used for data processing and implementing the feed optimization logic, enabling the system to compare current feeding practices with recommended nutritional standards and generate customized feeding recommendations based on cattle characteristics and production data.

The platform follows a modular architecture consisting of Farmer Management, Cattle Management, Milk Records, Feed Optimization, Analytics and Reports, Transactions, Worker Management, Task Management, Security Logs, and the proposed Feed Dispenser module. Each module stores and processes farm information through a centralized database, enabling efficient record management and decision support.

The implementation begins with farmer registration, where farm information, geographical location, herd size, and management details are recorded. Individual cattle profiles are then created by entering breed, age, body weight, physiological stage, health status, lactation stage, and expected milk production. The system currently supports common dairy breeds in Sri Lanka, including Indigenous, Jersey Cross, Holstein Friesian Cross, and Sahiwal Cross cattle.

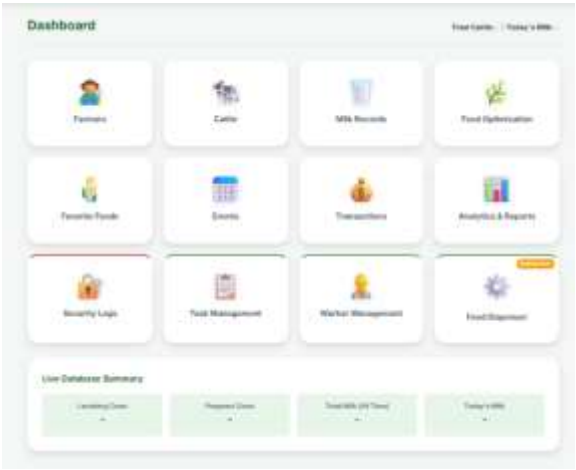
Farmers record daily information such as milk production, feed quantities, green fodder, dry roughage, concentrate feed, water intake, mineral supplementation, and locally available feed resources. The platform then performs a Feed Gap Analysis by comparing the recorded values with standardized feeding recommendations stored in the database. Feed deficits and milk production gaps are automatically calculated and displayed through the dashboard.

Based on these analyses, the feed optimization module generates customized feeding recommendations using environmentally sustainable feed resources, including Guinea grass, CO-3 Hybrid Napier grass, *Gliricidia sepium*, *Leucaena leucocephala*, rice straw, maize fodder, coconut poonac, soybean meal, mineral salt supplements, and agricultural by-products such as banana, mango, jackfruit, and pineapple residues. These recommendations encourage the use of locally available resources, reduce dependence on commercially packaged feeds, minimize agricultural waste, and support circular agricultural practices.

The dashboard provides real-time summaries of cattle records, milk production, feed deficits, and nutritional recommendations. Analytical reports enable farmers to evaluate feeding efficiency, monitor milk productivity, and identify opportunities for improving farm performance. Furthermore, the optimized feeding recommendations generated by CattleCare are designed to interface with the proposed low-cost automated feed dispensing system, enabling accurate feed delivery while reducing feed wastage, labour requirements, and operational costs.

Overall, the CattleCare platform demonstrates how web technologies, digital decision support, and sustainable feed management can be integrated into an affordable solution for improving dairy farm productivity while promoting environmentally responsible livestock farming in Sri Lanka.

Figure 2.CattleCare Webapp User Interface



VI. PROPOSED SYSTEM AND RESULTS

The proposed **CattleCare** framework integrates digital dairy management, sustainable feed optimization, and an automated feed dispensing system into a unified platform for supporting small-scale dairy farming in Sri Lanka. The framework was designed to improve feed utilization, increase milk productivity, reduce operational costs, and encourage environmentally sustainable feeding practices through the utilization of locally available feed resources.

The operational workflow of the proposed system is illustrated in Fig. 1. Initially, farmer information, cattle profiles, and daily farm records are entered into the CattleCare platform. The collected information includes cattle breed, age, body weight, physiological stage, milk production, feeding

schedule, feed quantities, water intake, and environmental conditions. These records are securely stored in the database and processed by the feed optimization engine.

The platform compares the farmer's existing feeding practices with standardized nutritional recommendations according to cattle breed and production stage. The comparison is performed using the Feed Gap Analysis module, which automatically identifies nutritional deficiencies in green fodder, dry roughage, concentrate feed, and water intake. Simultaneously, the recorded milk production is compared with the expected production range of the selected breed to estimate the production gap.

Based on the calculated feed deficits, the optimization module generates customized feeding recommendations using sustainable feed resources that are readily available in Sri Lanka. Recommended feed materials include Guinea grass, CO-3 Hybrid Napier grass, Gliricidia, Leucaena, maize fodder, rice straw, coconut poonac, soybean meal, mineral salt supplements, and agricultural by-products such as banana, mango, jackfruit, and pineapple residues. The use of these locally available materials reduces agricultural waste, minimizes dependence on commercially packaged concentrate feeds, and promotes circular agricultural practices.

The optimized feeding recommendations are designed to interface with the proposed low-cost automated feed dispensing system. The proposed dispensing unit is designed to receive the calculated feed quantities from the CattleCare platform and dispense the required amount of feed according to the nutritional plan.

TABLE II: COMPARISON OF CURRENT FEEDING PRACTICES WITH RECOMMENDED DAILY FEED REQUIREMENTS

Feed Component	Daily Feed Intake		
	Current Intake	**Recommended Intake**	**Variance**
Green Grass	15.0 kg/day	27.0 kg/day	−12.0 kg/day
Dry Roughage	0.0 kg/day	4.0 kg/day	−4.0 kg/day
Concentrates	1.0 kg/day	4.0 kg/day	−3.0 kg/day
Water Intake	40 L/day	80 L/day	−40 L/day

Table II presents a comparison between the farmer's current feeding practices and the recommended daily nutritional requirements generated by the **CattleCare** platform for a Holstein Friesian Cross dairy cow. The feed gap analysis indicates deficiencies across all major feed components. The largest deficit is observed in **green grass (−12.0 kg/day)**, followed by **water intake (−40 L/day)**, **dry roughage (−4.0 kg/day)**, and **concentrate feed (−3.0 kg/day)**. These identified differences indicate potential nutritional gaps that may require further assessment in relation to animal health and milk productivity. Based on these identified gaps, the CattleCare platform generates customized feeding recommendations,the CattleCare platform generates customized feeding recommendations using locally available natural fodders, agricultural by-products, and mineral supplements to improve feed efficiency while promoting environmentally sustainable dairy farming.

These results demonstrate that the proposed feed-gap analysis can identify differences between existing farm practices and defined nutritional or production reference values. The identified deficiencies are consistent with previous Sri Lankan research emphasizing the importance of appropriate feed resources and balanced feeding practices for dairy cattle [9], [19]. In contrast to approaches that mainly investigate individual feed resources, CattleCare integrates these assessments into a digital decision-support workflow, enabling the identified gaps to be translated into customized feeding recommendations.

The comparison with the recorded daily milk production with the standard milk production range of a Holstein Friesian Cross dairy cow. The current milk yield of **10.0 L/day** is below the expected range of **15–25 L/day**, indicating a production deficit of **5.0 L/day** relative to the minimum recommended standard.The CattleCare platform identifies the productivity gap alongside the observed nutritional deficiencies and management conditions. By implementing the optimized feeding recommendations including increased green fodder, improved roughage intake, adequate concentrate supplementation, sufficient water supply, mineral supplementation, and the use of locally available sustainable feed resources the system aims to improve milk production while reducing feed wastage, lowering dependence on commercially packaged feeds, and supporting environmentally sustainable dairy farming practices.

Overall, the proposed CattleCare framework combines digital farm management, feed optimization, and affordable automation to provide an integrated solution for sustainable dairy farming. The framework enables continuous monitoring of feeding practices, identifies nutritional deficiencies, generates optimized feeding plans, and supports environmentally responsible livestock production through the effective utilization of natural feed resources and agricultural by-products.

The identified feeding gaps are consistent with previous research emphasizing the importance of balanced forage, roughage, concentrate, and water provision for maintaining dairy cattle productivity [9], [19]. Previous studies on Sri Lankan dairy systems have also highlighted the importance of locally available feed resources and improved feeding management for supporting milk production [9], [19]. The present framework extends these findings by incorporating feed-gap analysis and digital recommendations within a smallholder-oriented platform. However, the numerical feed-gap values presented in this study are used to demonstrate the decision-support functionality of CattleCare and should not be interpreted as a controlled experimental evaluation.

VII. CONCLUSION & FUTURE WORK

This paper presented **CattleCare**, a web-based dairy management and sustainable feed optimization platform developed to assist small-scale dairy farmers in Sri Lanka. The platform enables digital farm management by recording cattle information, milk production, and feeding practices,

while comparing existing feeding methods with standardized nutritional recommendations. Based on the identified feed gaps, the system generates customized recommendations using locally available feed resources, including natural fodder, agricultural by-products, and fruit residues. This approach supports improved feed management while encouraging the use of environmentally sustainable feed materials.

The proposed framework demonstrates how digital technologies can support data-driven decision-making in dairy farming. By promoting the efficient use of locally available feed resources, the system has the potential to reduce feed wastage, lower dependence on commercially packaged concentrate feeds, and encourage sustainable resource utilization. These features contribute to environmentally responsible dairy farming and support the broader objective of circular agriculture.

Future work will focus on integrating the CattleCare platform with a low-cost IoT-based automated feed dispensing system to validate the optimized feeding recommendations under real farm conditions. The system will also be extended to monitor milk quality parameters, animal health, and environmental conditions in real time. To further improve sustainability, future research will investigate the utilization of cow dung for **biogas production** and the use of digester slurry as an **organic fertilizer** for fodder cultivation. Such integration would enable dairy farms to utilize livestock waste efficiently, reduce environmental pollution, and establish a more sustainable and circular dairy farming system.

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