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ADDIS ABABA UNIVERISTY

COLLEGE OF VETERINARY MEDICINE AND AGRICULTURE

EVALUATION AND DEVELOPMENT OF SMART DAIRY SYSTEM FOR ENHANCING REPRODUCTIVE HERD HEALTH MANAGEMENT IN SMALLHOLDER FARMS IN BISHOFTU TOWN, ETHIOPIA

MVSc THESIS

BY:

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MSc PROGRAM IN VETERINARY CLINICAL MEDICINE

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Thesis submitted to the College of Veterinary Medicine and Agriculture of Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Veterinary Clinical Medicine

By:

Dejene Zegeye Adugna

DEPARTMENT OF CLINICAL STUDIES

MSc PROGRAM IN VETERINARY CLINICAL MEDICINE

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As members of the Examining Board of the final MSc open defense, we certify that we have read and evaluated the Thesis prepared by Dejene Zegeye Adugna entitled: **Evaluation of smart Dairy system for enhancing Reproductive herd health management in smallholder farms in Bishoftu town,** and recommend that it be accepted as fulfilling the thesis requirement for the degree of **Masters of Science in Veterinary Clinical Medicine** complies with the regulations of the university, and meets the accepted standards with respect to originality and quality.

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STATEMENT OF THE AUTHOR

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ABBREVIATIONS

AAiT	Addis Ababa Institute of Technology
AAU	Addis Ababa University
A2P	Application to person
AI	Artificial Insemination
AI	Artificial Intelligence
AMS	Automatic Milking Systems
AMCU	Automatic milk collection unit
ANOVA	Analysis of Variance
AR	Augmented Reality
ATA	Agricultural Transformation Agency
BCS	Body condition score
BHBA	Beta-hydroxy butyrate
BTLFDO	Bishoftu Town Livestock and Fishery Development Office
CMT	California Mastitis test
CSA	Central Statistical Agency
CI	Calving Interval
DALAI	Days after last artificial insemination
DALC	Days after last calving
DoE	Duration of estrus
EPR	Enterprice Planning Resouce
FCC	Fertility control camp
FSC	First service conception rate
FW	Fertility window
GDP	Gross Domestic product

GLM	General Leaner Model
IoT	Internet of Things
IP	Internet protocol
KPI	Key performance indicators
ODK	Open Data Kit
ML	Machine Learning
NAIC	National Artificial Insemination Center
NSC	Number of service conception
PD	Pregnancy Diagnosis
PLF	Precision Livestock Farming
RFM	Retained fetal membrane
RHHM	Reproductive Herd Health Management
SDGs	Sustainable Development Goals
SCC	Somatic Cell count
VER	Vaginal electrical resistance

ABSTRACT

The integration of smart dairy farming technologies, encompassing sensors, mobile applications, and data analytics, presents a transformative opportunity for enhancing the productivity, profitability, and sustainability of smallholder dairy farms, particularly in regions like Ethiopia. To evaluate the practical application and impact of a smart dairy system, this study enrolled 30 smallholder farmers managing 519 animals into a virtual "Fertility Control Camp". Their daily operations were augmented through the experimentation of data acquisition, digital recording via ODK-Collect, data analytics, generation of actionable insights, and a mobile alerting system. From this cohort, 40 cows whose estrus was characterized by CowsVille, dairy farm management software, were randomly selected for monitoring. Estrus detection tools and chemical pregnancy tests provided data that is processed by CowsVille, delivering mobile alerts to farmers. Mean Number Service Conception (NSC), days the last artificial insemination (DALAI), and days last conception (DALC) were 3.12±0.39, 68.23±10.37 days, and 249.07±35.4 days, respectively. The fertility window was identified in all cases (100%), averaging 14.82±0.4 hours, resulting in a FSC rate of 65.8%, significantly higher than the national average. CowsVille integrated with a mobile alert system has proven to be a valuable resource for guiding farmers in making AI-related decisions. Further analysis of 62 cows (38 normal-cycling, 24 repeat-breeding) from the CowsVille database explored estrus detection using physicochemical profiles and Vaginal Electrical Resistance (VER). Conception rates were significantly different ($P < 0.05$) between normal-cycling (70.6%) and repeat-breeding cows (41.7%). Body weight, insemination time, and VER significantly affected conception rates ($P < 0.05$), with optimal results at 7-12 hours post-standing estrus (71.43%), and VER of 181-220 Ω (84.21%). Sperm penetration, spinnbarkeit, VER, and crystallization patterns of cervical fluid proved useful in predicting optimal insemination time. The CowsVille system, combining digital record-keeping, with analytical capabilities and direct farmer feedback, effectively mitigated the limitations in traditional smallholder management, enabling evidence-based decisions.

Key Words: *CowsVille, Dairy, Estrus, Fertility Control Camp, Mobile alert*

1. INTRODUCTION

Globally, livestock contributes 40% to agricultural gross domestic product (GDP), with dairy vital for smallholder livelihoods in developing nations (Abbasi and Nawab, 2021; Janssen and Swinnen, 2019). However, Sub-Saharan African smallholder dairy, including Ethiopia, suffers from low productivity and slow technology adoption (Mekonnen *et al.*, 2010). Ethiopia faces increasing demand for milk and meat amidst poor livestock productivity. This is due to traditional management, poor genotypes, rampant diseases, and inadequate feed. Consequently, Ethiopia's annual per capita milk consumption is a mere 30 L, among the world's lowest. Zebu cattle, producing over 95% of Ethiopia's milk, exhibit low yields (500-700 L/lactation), short lactation (100 days), and poor reproduction (>500-day calving interval) (Yilma and Faye, 2006).

Despite a rising cattle population (CSA, 2022), per capita milk output remains low, highlighting a vast potential for genetic improvement. Additionally, growing consumer awareness and food safety regulations demand improved milk quality, pushing farmers towards using technologies (Kumar *et al*., 2016; Burkitbayeva *et al.*, 2019). Adopting animal health technologies can reduce disease spread, zoonotic risks, and combat antibiotic resistance (Sarrazin *et al.*, 2014; Ritter *et al*., 2016). On the other hand, smart dairy farming can enhance productivity, animal health, and sustainability through data-driven insights, automation, and efficient resource management, improving overall farm profitability.

Problem statement: Economical dairy farming heavily relies on efficient reproduction; the national conception rate in dairy cattle is barely 30% at best with long Calving interval (CI). A key challenge is the absence of record-keeping and standardized management, leading to uninformed decisions and poor performance, such as missed heat signs causing AI failures and prolonged calving intervals. Further, the smallholder system prohibits the application of herd health management simply because of the few number of animals managed in each farm (Gezu *et al*., 2018). While some studies explore dairy technology adoption in Ethiopia (Mekonnen *et al.*, 2010; Kebebe *et al*., 2015, 2017, 2019), they often focus on a limited range, and adoption rates remain slow (Russell and

Bewley, 2013; Barrios *et al*., 2020). Reproductive Herd Health (RHH) encompasses management, nutrition, medicine, and environmental control, aiming to maximize reproductive efficiency. Key components include record-keeping, nutritional and reproductive management, replacement heifer, vaccination, and disease management. Record-keeping is crucial for precision farming, where physiological indicators predict events (Noordhuizen and Cannas da Silva, 2009).

The main hypothesis in this work is considering “the cow’s speech” that can be translated into data, hence if one understands the cow’s way of speaking, it is possible to convert this data or signal into actionable insights that can be used to manage the animals and the dairy operation. For instance, data about rumination and activity coupled with milk yield and body weight can be used to identify dairy cows with health disorders, such as mastitis, metritis, lameness, and ketosis. The same data can also be used to predict severity of inflammatory conditions during the per partum period. If smallholders farms can be virtually clustered as one (Fertility Control Camp) it would be possible to apply a digitally enabled reproductive herd health management to improve efficiency and productivity. The technologies can include data acquisition sensors, farm management software for data analytic and insight generation and a mobile alert system. The database can be updated continuously by the farmer, enumerators, AI technicians and veterinarians enrolled in the system. Generated husbandry insights can be delivered as feedback text messages.

General objective: To evaluate a digitally enabled optimal reproductive performance, leading to shorter calving intervals, a steady supply of replacements, and maximized milk production and profitability as well as mitigate reproductive health problems.

Specific objectives

1. To evaluate functionality of a digital database created via ODK-Collect from smallholder cow herds (Fertility Control Camp)
2. To assess the potential of cow-side tests, Mobile application and IP cameras as sensors in data acquisition
3. To evaluate applicability of dairy farm management software platform in data processing and generation of actionable insights
4. To evaluate the integration of mobile alert system (A2P insight communication) with the data processing software
5. To evaluate the benefits of digital management in improving reproductive and productive performances based on selected key performance indicators (KPIs)

2. LITERATURE REVIEW

2.1. Digital Technology Integration

The initiative focuses on the integration of digital technologies to enhance the efficiency and productivity of dairy operations. By utilizing applications (mobile and computer based), data analytics, and automated systems, dairy farmers can optimize reproductive efficiency, feeding schedules, monitor animal health, and manage resources effectively, thus driving higher yields. These innovations will provide valuable insights into farm operations, enabling better decision-making and management practices (Korir *et al*., 2023).

A vital objective is to promote sustainable dairy farming practice and sustainability of the practices. By using smart systems and application of reproductive biotechnology, the project aims to reduce environmental impact while promoting high production standards. Further, providing training and ongoing support for farmers will be an essential component for the successful implementation of the project. This will ensure that farmers are well-equipped to utilize the new technologies and practices efficiently (Ivana and Nikola, 2024).

The dairy farm of the future is a place where technology, sustainability, and animal welfare are integrated to produce high-quality milk and dairy products. In the believe farms of the future will likely be more standardize, integrated, and data driven (Loučka *et al*., 2023). Some of the key features of the dairy farm of the future include: Smart sensors and cameras that monitor the health, behavior, and productivity of each cow, and alert the farmer of any issues or needs, Automatic or semi-automatic milking systems that reduce the need for labor and allow the cows to choose when and how often they want to be milked, reducing stress and increasing efficiency, Precision feeding and nutrition systems that optimize the diet and feed intake of each cow, reducing waste and emissions, Robotic systems that handle tasks such as cleaning, feeding, and manure management, freeing up time and resources for the farmer and Regenerative agriculture practices that enhance soil health, biodiversity, and water quality (Sangode, 2025).

2.2. Dairy production in Ethiopia

Ethiopia holds large potential for dairy development, mainly due to its suitable environment (Bereda *et al.,* 2014) and its large cattle population, which comprises over 71 million (Dasalegn, 2023). Even though there is a large dairy cattle population and favorable climatic conditions, self-sufficiency in milk production is low. Accordingly, they contribute an average of 1.37 liters of milk yield per cow per day and annually about 3.1 billion liters (Mebrate *et al.*, 2019; Hunde, 2018). Cattle are the main source of milk production, and they provide a significant contribution to family nutrition and money generation; however, goat and camel milk are also used in pastoralist areas of the country (Hunde, 2018; Kassa, 2019). With strong global expansion resulting from the increasing number of customers in developing nations, the dairy industry and market have altered dramatically (Gezu and Zelalem, 2018).

Milk is generally referred to as a full nutritious diet because it contains 87.2 percent water, 3.7 percent lipids, 3.5 percent protein, 4.9 percent lactose, and 0.7 percent ash. It is a valuable source of protein, fat, carbohydrates, vitamins, and minerals required by humans, especially young ones, for growth and development. However, the milk consumption rate in Ethiopia is low, at 19 lt/capital (Geleti *et al*., 2014), compared to other countries with 50 and 90 lt/capital rates in Uganda and Kenya (Kassa, 2019). According to (ATA, 2016; Eyassu and Reiner, 2014), there is no well organized milk marketing system in Ethiopia. Considering the important prospects for smallholder income generation and employment opportunities from high-value dairy, dairy production in the tropics is mostly subsistence, with poor output and productivity, reliance on native breeds, and management practices that include extensive grazing and unregulated breeding. Milk produced in these systems is mostly from indigenous breeds, with local breeds accounting for around 95 percent of milk produced in Ethiopia (CSA, 2019).

The demand for milk and milk products is increasing in developing countries, and the drivers of change in the dairy sector are demography, growing economies, underserved markets, conducive policy and an enabling environment, globalization, and market opportunities (Shapiro *et al.,* 2017). Dairy production has the highest potential to sustainably contribute to the Sustainable Development Goals (SDGs) due to its extended value chain. However, there is a need for periodic assessments of providing up-to-date information by policymakers (Yilma *et al.*, 2011). To support the dairy sector, different interventions have been made by the government, development partners, national and international research institutions, and non-governmental organizations (Tegegne *et al.*, 2010).

However, the sector has yet to fully realize its potential to produce enough milk and dairy products to meet domestic demand. As a result, the country is forced to import powdered milk and other milk products (Gebreyohanes *et al.*, 2021). The development of the dairy sector can contribute immensely to poverty alleviation and improved nutrition in the country (Ahmed *et al*., 2004).

The key impediments to livestock intensification in general and dairy expansion, in particular, include a lack of adaptive high-yielding better genes, a shortage of feed, animal illnesses, and poor animal health, extension, market services and lack of modern technology in the sector. In Ethiopia, genetic enhancement of indigenous breeds by crossbreeding and upgrading, as well as expedited production of crossbred cows from farmers' indigenous breeds using artificial insemination (AI) began more than 40 years ago with the founding of the National Artificial Insemination Center (NAIC). However, the number of improved breeds in the nation is still insufficient to transition the country's present subsistence-based smallholder dairy system to market-oriented commercial dairy products and increase milk output to satisfy current and projected future domestic demand (CSA, 2019).

2.3. Reproductive Herd Health Management

Herd Health Management (HHM) evolved with the development of the dairy sector and increasing demand of milk and milk products globally which changed the breeding policy and gave emphasis to cross-breeding with high genetic potentials bulls' semen. This results in higher reproductive and health problems in high producing dairy animals (DeKruif and Opsomer, 2004).

The success of dairy farming is associated with the quality of milk production. For improving the profitability of the dairy farm there should be focus on the production of good quality milk by ensuring a healthy herd, providing balanced ration and appropriate housing management (Noordhuizen and Cannas da Silva, 2009)

The lack of trained veterinarians and animal health technicians, especially in rural areas where most dairy farms are located and advanced tools for reproductive health management like ultrasound, hormone assays, and AI services are often unavailable or inaccessible. Many smallholder farmers do not keep proper records of breeding, calving, or health history. Without data, it is hard to track reproductive performance, detect problems like repeat breeding, or apply strategic interventions. Farmers often lack knowledge of reproductive physiology, early heat detection, and disease signs. Traditional beliefs and misconceptions may hinder the adoption of modern reproductive techniques and limited access to reproductive technologies such as Artificial insemination (AI) services is underdeveloped and inconsistently available. Lack of a cold chain for semen storage and transport limits AI programs. Embryo transfer and synchronization protocols are almost non-existent in most areas (Dehinenet *et al.,* 2014).

Many farmers can't afford regular vet visits or reproductive technologies and prioritization of immediate needs (feed, water, shelter) over reproductive health due to limited income. Feed and nutritional issues, poor nutrition leads to delayed puberty, anestrous, low conception rates, and longer calving intervals and seasonal feed shortages worsen reproductive performance and make herd management unpredictable. Although policies may exist on paper, enforcement and actual investment in reproductive health programs are limited and extension services often lack resources to make meaningful impacts. Fragmented and small-scale farming; majority of dairy production is done by smallholders with 1–3 cows that implementing standardized reproductive programs is more difficult across many scattered small-scale farms (Mitiku,2018 and Tsegaye,2024).

Reproductive disorders have been found to be a major reason for decreased reproductive efficiency in cattle and consequently reproductive efficiency is the major determinant of lifetime productivity of cows (Lobago *et al*., 2006). In the last few decades, as the major epidemic disease was brought under control, emphasis has increasingly shifted to economically important diseases to the dairy producers and animal health problems stand out as the most prominent (Msangi *et al.*, 2005).

Regular breeding depends upon the normal function of the reproductive system. In order to breed regularly, the cow has to have functional ovaries, display estrous behavior, mate, conceive, sustain the embryo through gestation, calve, and resume estrous cycling and restore uterine function after calving. Each of these aspects of reproductive function can be affected by management, disease and the genetic make-up of the animal. When the function of the reproductive system is impaired, cows fail to produce a calf regularly (Arthur *et al.*, 1996).

Among the major reproductive problems that have direct impact on reproductive performance of dairy cows are abortion, dystocia, retained fetal membrane (RFM), pyometra, metritis, prolapse (uterine and vaginal), anoestrus and repeat breeding. They are classified as before gestation (anoestrus and repeat breeding), during gestation (abortion, vagina prolapsed and dystocia) and after gestation (retained fetal membrane and uterine prolapsed) (Lobago *et al*., 2006).

Upon closer examination of reproductive processes in the dairy cattle, the postpartum period is the most varied and vulnerable to problems and that incidentally coincides with the peak of milk production, uterine involution, and resumption of ovarian activity, conception and greater risk to infection (Robert, 2000). These results in considerable economic loss to the dairy industry due to slower uterine involution, reduced reproductive rate, prolonged inter-conception and calving interval, negative effect on fertility, increased cost of medication, drop in milk production, reduced calf crop and early depreciation of potentially useful cows (Erb and Martin, 1980).

2.4. Smart Farming and Digital Technology

Smart farming integrates various advanced technologies designed to optimize different aspects of dairy production, including automatic and semi-automatic milking systems, innovative milk extraction methods, precision animal management tools, and on-farm milk analysis capabilities (Neethirajan, 2021). Digitalization is an integral part of the modern agriculture production system. Several digital technologies for different species of domestic animals and birds form the basis of digital animal husbandry, precise technologies (PLF - Precision Livestock Farming) allow the formation of a sufficient cloud of data in accordance with the physiological and technological requirements of different categories of dairy cattle.

It is not yet clear which digital technologies are most rationally used in dairy farming. Automatic Milking Systems (AMS), Precision Livestock Farming (PLF) Sensors, Dairy Management Software Platforms, Artificial Intelligence (AI) and Machine Learning (ML), Internet of Things (IoT) Devices, Automated Feeding Systems, Drones and Remote Sensing Technologies, Genomic Testing and Genetic Selection Technologies, Mobile Applications for Farm Management, Milk Quality Testing Devices, Augmented Reality (AR) for Training and Support, Climate Control and Environmental Monitoring Systems provide characteristics and grounds for the application with varying degrees of success of devices, configurations and robots in the development of modern technologies for dairy cows (Neethirajan and Kemp,2021; Alonso *et al*.,2020). At the same time, however, digitalization poses several threats and problems that we must not relate to cybersecurity, both for farmers and the state and society.

The scale of dairy farming has changed significantly in recent years with the shift to larger and more intensive, profit-oriented farms and complexes in line with market competition. The principles of management and logistics have also changed. The technology now allows for management and analysis of information about the structure of the herd, the age of the animals, and more (Dineva and Atanasova, 2021). In essence, the digital interventions aim to create a digitally connected and data-rich dairy ecosystem that empowers stakeholders to optimize their operations, improve product quality, and enhance market access, ultimately leading to a more sustainable and profitable dairy value chain. The design of these interventions emphasizes a holistic, data-driven approach to modernize the dairy value chain. It integrates diverse digital technologies, including IoT sensors, mobile applications, cloud computing, AI, and block chain, to address challenges across all stages, from on-farm production to consumer engagement. The design prioritizes user-friendliness, scalability, and sustainability, ensuring that solutions are accessible and beneficial to all stakeholders, particularly smallholder farmers (Tadele *et al.*, 2025). Specific examples of digital solutions to dairy farming include on-farm management and milk quality management.

2.4.1. On-Farm Management

This intervention covers areas of precision farming, feed management, reproductive management, and herd health management.

Precision Livestock Farming: The elements of precision farming constitute collecting physiological (temperature, activity, rumination) and environmental (Temperature, humidity) data through the use of sensors and IoT devices to monitor cow health and improve milk production and fertility. The application of data analytic will help to optimize feeding, breeding and health management decisions (Neethirajan, 2021).

Feed Management: Dairy feeding is a key issue in productivity and profitability of the business. A number of tools are available such as digital tools for feed formulation and ration balancing, sensors for monitoring feed inventory and quality and precision feeding systems like optimizing feed utilization and reducing waste. Most importantly, in the Ethiopian smallholder system, there is a possibility to create a digital platform for farmers to connect with feed suppliers and access up-to-date feed pricing.

Herd Health Management: The components include Digital records and tracking of animal health data; Early disease detection systems using sensors, AI, Telemedicine and remote veterinary consultations.

Reproductive Management: Constitute various heat detection systems; data-driven breeding programs, and improved record keeping of breeding events.

2.4.2. Milk Collection and Transportation

Real-time Milk Monitoring: Constitute use of sensors and mobile apps for milk collectors to record milk volume and quality data at collection points. The digital solution allows the installation of in-line milk quality sensors on collection tankers to monitor temperature, acidity, and bacterial load.

Digital Payment Systems: Two important digital solutions are proposed here 1) Implement a digital ledger system for tracking milk deliveries and payments; 2) Provide digital literacy training to farmers on using mobile payment platforms. This will integrate mobile money platforms into milk collection systems for instant farmer payments, increasing transparency and efficiency and encourage electronic record-keeping of milk collection and payments

Supply Chain Transparency: This will involve a block chain-based tracking system for milk from farm to consumer and create a digital platform (such as QR code system) for sharing milk quality data with stakeholders.

By introducing a digital solution, AI success rate can be increased by 70%, reduce the calving interval by 150 days and improve milk productivity by 20%, reduce cattle health expenses by 50%, and reduce post-harvest loss by 50%. The application of the Automatic Milk Collection Unit (AMCU) will prevent adulteration and improve milk quality. The installation of more AMCU is feasible and creates options for enrollment of small scale producers into the system and this will have a number of benefits such as increased milk flow, reduced procurement cost, improved farmer's payment and hence improved farmer's loyalty (Qi *et al*., 2022).

2.5. Factors influencing dairy farmers' decisions to adopt multiple dairy technologies

Due to a variety of technical and non-technical factors, farmers' adoption of dairy technology varies greatly throughout agro-ecologies and within the same agro-ecology (Dehinenet *et al.,* 2014). Researchers have studied numerous motivating factors and constraints to adoption by observing the different behaviors between adopters and non-adopters of technology (Ruzzante *et al.*, 2021). They found that the influence of many factors can be explained by, the level of diffusion of the specific technology, the economic constraints of the adopters, and the perception of adopters of the technology (Ruzzante *et al.,* 2021).

Technological, economic, institutional, and human specific factors have been found to be key determinants of technological adoption (Mwangi and Kariuki, 2015), coupled with unobserved cultural, contextual, and policy factors (Ruzzante *et al.*, 2021). Family size, farming experience, crossbred cow availability, dairy production extension services, saving institutions' accessibility, total milk and milk product income, livestock training availability, household head age, and involvement in off-farm activities are some of the factors that significantly influenced the likelihood and degree of adoption of dairy technology (Dehinenet *et al.,* 2014).

Higher levels of technology adoption are associated with better milk yield regardless of the breed of cattle (local or crossbred) owned by smallholder dairy farmers (Mekonnen *et al.,* 2010). Adoption of new practices and technologies is, however, limited by various factors such as affordability and limited access to information and training (Akzar *et al.*, 2019; Janssen and Swinnen, 2019), which is a major constraint to quality and higher milk yields. Two properties determine the adoption of agricultural technologies, namely the key aspects of decision-making and diffusion theory. The first is the change in the production function, that is, with the same level of inputs, the level of output may increase due to technology adoption. In other words, the same output level can be produced with fewer inputs, which can lead to improved efficiency of agricultural production (Nonvide, 2021).

The second attribute of the adoption of new agricultural technologies is the increase in profitability. Farmers base their adoption decision on the expected utility. In this case, and in line with neoclassical microeconomic theory, the farmer may decide to adopt a technology when it provides him a utility greater than non-adoption (Nonvide, 2021; Ruzzante *et al.,* 2021). In this case, farmers may be more likely to adopt multiple technologies as being complementary or substitutes for current practice, specifically to maximize their expected benefit from their adoption decisions despite being constrained by their limited budget and access to information (Akzar *et al.*, 2019).

3. MATERIAL AND METHODS

3.1. Description of the study area

The study was conducted in Bishoftu town from November 2024 to June 2025 G.C. Bishoftu is a separate district located in the East Shewa Zone at a distance of 45 km Southeast of Addis Ababa, Ethiopia. The town is located in east Showa Zone of Oromia Region and it lays 9° north latitude and 40° East longitude at an altitude of 1850 meters above sea level in the central highland of Ethiopia. It has an annual rainfall of 866 mm of which 84% is in the long rainy season (June to September) and the remaining in the short rainy season extending from March to May. The mean annual maximum and minimum temperatures of the area are 26°C and 14°C, respectively, with mean relative humidity of 61.3% (IPMS, 2005). A 2024 report by the Bishoftu Town Livestock and Fishery Development Office (BTLFDO) states that there are about 142 dairy farms, which are grouped into three categories: 24 were classified as large-scale, 68 as medium-scale, and 50 as small-scale farms.

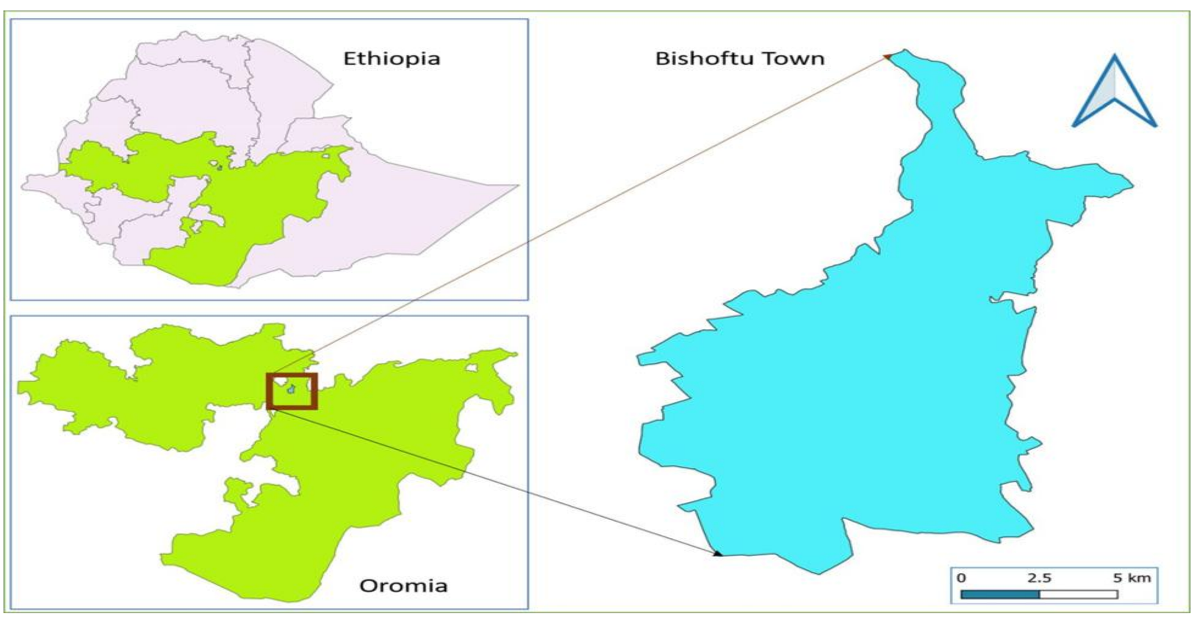


Figure 1: Geographical location of the study area

3.2. Study Design

3.2.1. Establishment of farm digital database and data acquisition system

As many as 30 smallholder farms managing a total of 519 animals, based on eligibility criteria of at least 5 animals per farm and access to smart phones, would be selected and enrolled into one virtual group designated as Fertility Control Camp (FCC). Animal and farm data were collected using ODK-Collect (an open source mobile app for real-time data acquisition). Animal data such as Cow ID, age, parity, BCS, reproductive status, milk yield, etc., were collected and verified through farm visits and stored in the server, further stored data were enabled for export into Microsoft Excel sheets for later analysis. Dairy owners were trained on the use of the mobile application; hence they were involved in the subsequent data entry and feedback management. The FCC serves as the basis for the introduction of the Smart RHHM program with contents of record keeping, nutritional control, reproductive and health management. The mobile phone was employed for ODK-Collect, data recording, alerting, and visualization interface that can be accessed by the dairy owner. The functionality and applicability of the ODK-Collect, establishment of a digital database consisting detailed information of animal and farm data were evaluated, and pitfalls were mitigated through consultation with developers.

Description of method: integration of a mobile based recording (ODK collect), animal biodata (IP camera, zigbee wireless sensor, microcontroller and processor) and cow-side tests (Estrus detection and early pregnancy diagnosis), data analytics and insight generation (CowsVille software) and mobile alerting (A2P SMS platform).

3.2.2. Deployment of data analytic and dairy farm management software

Developing software that can receive the digital information from the database, analyze and generate actionable insights, and communicate back the insights via a mobile alert system is critical. The CowsVille system was developed in collaboration with individuals from Addis Ababa University Institute of Technology (AAiT). The farm management software was developed using two software languages, REACT and JANGO, to process the front-end and back-end of the software, respectively. The CowsVille software is a comprehensive digital tool designed to help dairy farmers to efficiently manage their daily operations, improve productivity, and enhance profitability. It is planned to serve as a centralized platform to integrate recording, tracking, analyzing, and reporting various aspects of a dairy farm. The key features include 1) Individual records for each animal, including identification, health history, breeding information, milk production, and gynecology; 2) Herd Management; 3) Managing heat detection, insemination records, pregnancy diagnoses, calving information, and reproductive performance analysis; 4) Health Management; 5) Milk Production Management; 6) Feeding and Nutrition; 7) Generating customizable reports and dashboards on key performance indicators (KPIs) related to production, reproduction, and health, 7) Mobile Accessibility and 8) Integration Capabilities

3.2.4. Integrating mobile alert system for insight communication

The mobile alert system (A2P SMS platform) is designed to promptly notify farmers, AI technician, veterinarians, and other relevant personnel about critical events, enabling timely intervention and informed decision-making. These alerts are triggered by CowsVille generated actionable insights. For this purpose, the alert system is integrated within the CowsVille software platform, allowing visualization of detailed information related to the alert. The alert system has two main components: Real-time notifications, and actionable information.

3.2.3. Data collection and Analysis

Data was exported from ODK and CowsVille systems into a Microsoft Excel sheet and analyzed using appropriate statistical software. Functionality of the ODK and CowsVille system were assessed based on the accuracy of actionable insights. Variables from the showcase experimental data regarding estrus detection and pregnancy diagnosis were analysed using SPSS Version 20. Descriptive statistics (means, proportions) was used to explain reproductive parameters. Estrus response rates and conception rates were analysed using Chi-Sq test and Pearson rank Correlation. Effects of risk factors on estrus detection and pregnancy outcomes were analysed using ANOVA and GLM. The level of significance was held at $P<0.05$ for all statistics.

4. RESULTS

4.1. Creation of digital database for smallholders

4.1.1. Collection of farm and animal data (Digital Record of farms and animals)

ODK Collect is an open-source mobile data collection application that is part of the Open Data Kit (ODK) suite. It allows users to collect data in the field using Android devices. Key features and components include data collection form, deployment of the form, data collection, data validation, and submission. The form is created in two languages (English and Amharic) using ODK Build. These forms define the questions about individual animals and the farm, including physiological, reproductive, and health parameters (Annex.1). The response types are simplified with drop-off multiple choices (text and numeric) and logic for data collection (Figure 3). The forms in the ODK are uploaded to Google Drive, where they are accessed by farmers, the AI technicians, veterinarians, and the data admin. The ODK was uploaded on the Android devices of each user by the enumerator, and the forms were made available to all users. Data collectors can fill out forms offline, which means they do not need a continuous internet connection during data entry. The app can include validation rules to ensure that data entered meets specific criteria, helping to improve data quality.

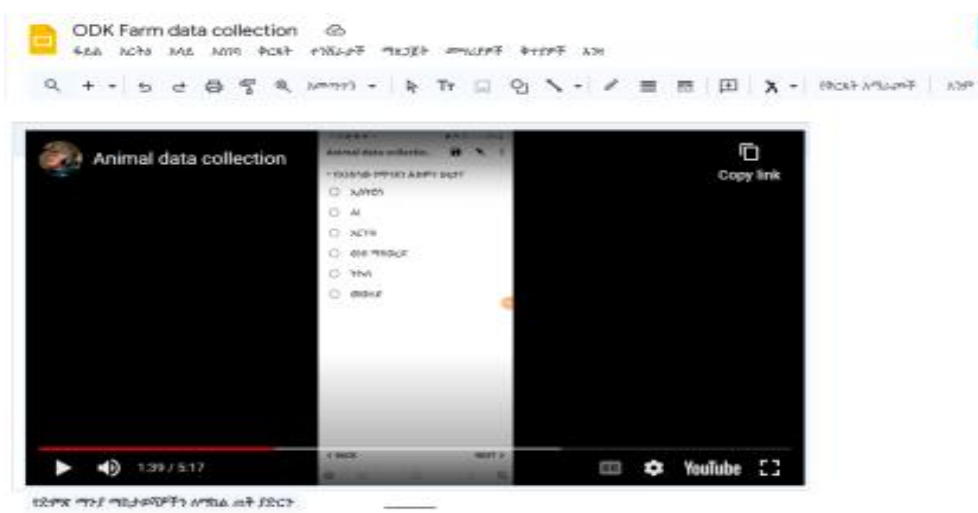
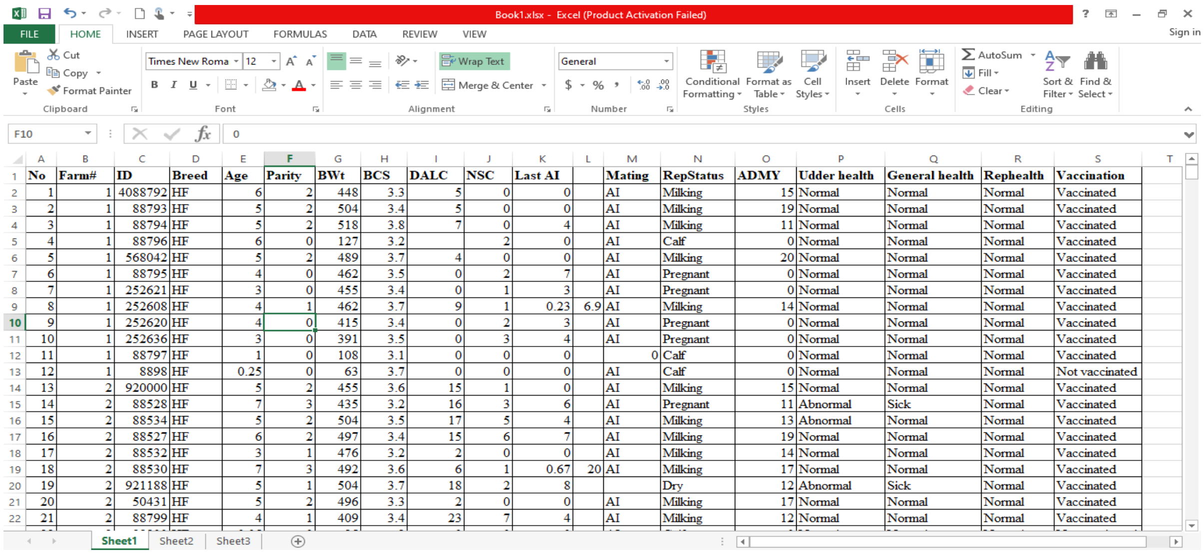


Figure 2: ODK collect format in local language (Screenshot from demo-video during farmers training)

4.1.2. Digital database in spreadsheet



No	Farm#	ID	Breed	Age	Parity	BWt	BCS	DALC	NSC	Last AI		Mating	RepStatus	ADMY	Udder health	General health	Rephealth	Vaccination
1	1	4088792	HF	6	2	448	3.3	5	0	0		AI	Milking	15	Normal	Normal	Normal	Vaccinated
2	1	88793	HF	5	2	504	3.4	5	0	0		AI	Milking	19	Normal	Normal	Normal	Vaccinated
3	1	88794	HF	5	2	518	3.8	7	0	4		AI	Milking	11	Normal	Normal	Normal	Vaccinated
4	1	88796	HF	6	0	127	3.2		2	0		AI	Calf	0	Normal	Normal	Normal	Vaccinated
5	1	568042	HF	5	2	489	3.7	4	0	0		AI	Milking	20	Normal	Normal	Normal	Vaccinated
6	1	88795	HF	4	0	462	3.5	0	2	7		AI	Pregnant	0	Normal	Normal	Normal	Vaccinated
7	1	252621	HF	3	0	455	3.4	0	1	3		AI	Pregnant	0	Normal	Normal	Normal	Vaccinated
8	1	252608	HF	4	1	462	3.7	9	1	0.23	6.9	AI	Milking	14	Normal	Normal	Normal	Vaccinated
9	1	252620	HF	4	0	415	3.4	0	2	3		AI	Pregnant	0	Normal	Normal	Normal	Vaccinated
10	1	252636	HF	3	0	391	3.5	0	3	4		AI	Pregnant	0	Normal	Normal	Normal	Vaccinated
11	1	88797	HF	1	0	108	3.1	0	0	0		0	Calf	0	Normal	Normal	Normal	Vaccinated
12	1	8898	HF	0.25	0	63	3.7	0	0	0		AI	Calf	0	Normal	Normal	Normal	Not vaccinated
13	2	920000	HF	5	2	455	3.6	15	1	0		AI	Milking	15	Normal	Normal	Normal	Vaccinated
14	2	88528	HF	7	3	435	3.2	16	3	6		AI	Pregnant	11	Abnormal	Sick	Normal	Vaccinated
15	2	88534	HF	5	2	504	3.5	17	5	4		AI	Milking	13	Abnormal	Normal	Normal	Vaccinated
16	2	88527	HF	6	2	497	3.4	15	6	7		AI	Milking	19	Normal	Normal	Normal	Vaccinated
17	2	88532	HF	3	1	476	3.2	2	0	0		AI	Milking	14	Normal	Normal	Normal	Vaccinated
18	2	88530	HF	7	3	492	3.6	6	1	0.67	20	AI	Milking	17	Normal	Normal	Normal	Vaccinated
19	2	921188	HF	5	1	504	3.7	18	2	8			Dry	12	Abnormal	Sick	Normal	Vaccinated
20	2	50431	HF	5	2	496	3.3	2	0	0		AI	Milking	17	Normal	Normal	Normal	Vaccinated
21	2	88799	HF	4	1	409	3.4	23	7	4		AI	Milking	12	Normal	Normal	Normal	Vaccinated

Figure 3: Animal and farm data (converted to excel sheet for demonstration during training)

After completing data entry, users can submit their forms back to the server when they have internet access. This can be done individually or in batches. Once data is submitted, it will be accessed through the server for analysis and reporting by the CowsVille system. Alternatively, collected data can be exported in various formats for further analysis in statistical software or other applications (Figure 4)

4.1.3. The CowsVille system

When the CowsVille system is opened at the admin end, the first page displayed is farm information (Figure 5), including the name of the owner (with options for personalized identification), the Farm ID, the total number of animals, and the total number of milking cows. Individual animal data and farm data are collected and summarized in the CowsVille system. Specific data can be exported in an Excel sheet for external evaluation and reporting.

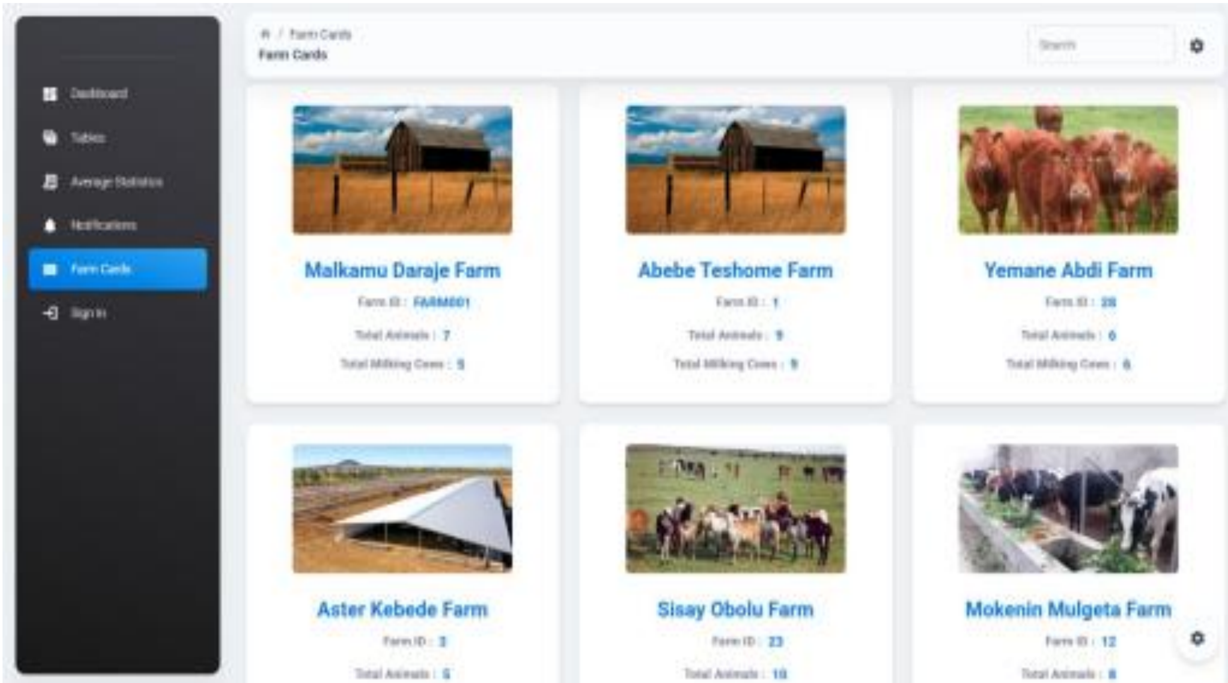


Figure 4: CowsVille system page encoding summarized farm information

The CowsVille system's digital database provides real-time data access and monitoring capabilities; ensuring information is readily available anytime and anywhere (with internet connectivity). This enables timely oversight of key performance indicators (KPIs) such as milk yield, feed intake, and health events. Furthermore, the integrated database and data analytics functionalities of the CowsVille system facilitate in-depth analysis of individual animal and farm-level data, empowering farmers to identify critical trends, patterns, and areas for potential improvement in productivity, health management, and breeding programs.

At the next click of the farm code, one gets access to a detailed description of individual animals and a further summary of performance indicators, which gives a quick overview of the condition of each farm (Figures 6). Digital record keeping in the CowsVille system provides improved accuracy and reduced errors, enhanced efficiency and time savings by streamlining data entry, retrieval, and analysis, saving significant time compared to manually searching through paper files. Automated reports can be generated quickly.

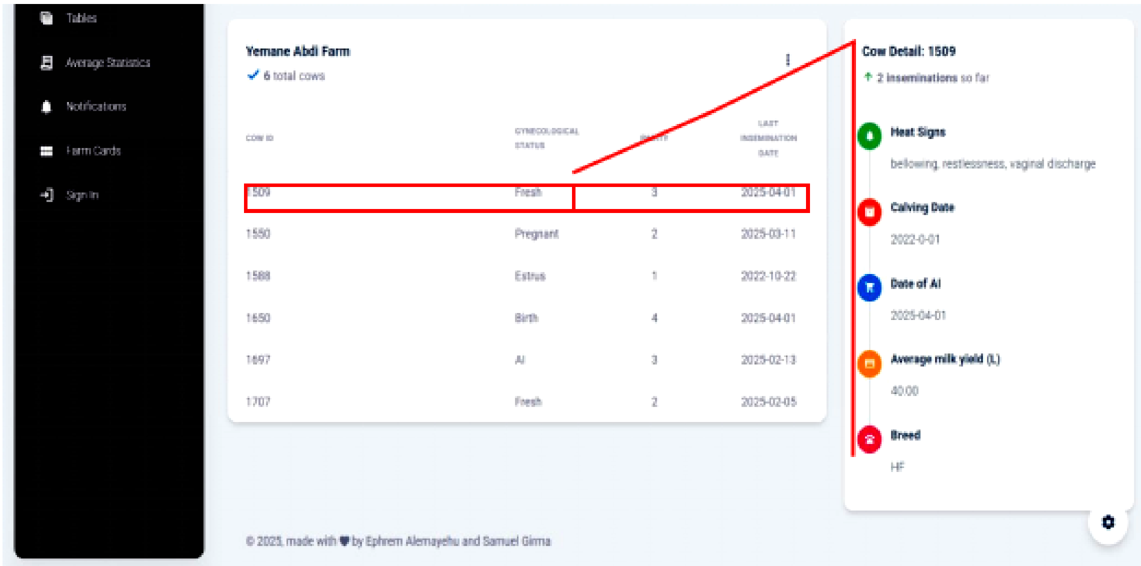


Figure 5: Detailed record of cows, in the Yemane Abdi farm within the CowsVille database

4.2. Data Acquisition

Data acquisition in a smart dairy system involves the collection, monitoring, and analysis of various types of data related to dairy animals and farming operations. This can include data about a dairy animal's health, reproductive condition and performance, milk production, feeding efficiency, environmental conditions, and more. The goal is to optimize dairy farm management and enhance efficiency of production while conserving animal welfare through the use of technology. The key components of data acquisition in the smart dairy systems include wearable sensors and IoT devices that are attached to cows to monitor health indicators like heart rate, activity level, rumination patterns, environmental factors in barns, and milk quality sensors or devices that analyze milk composition (fat content, protein levels, somatic cell counts) during milking to ensure quality. However, the sensors used in the "Fertility Control Camp," where the CowsVile system is applied, were estrus detection tools (estrus detectors based on vaginal electrical resistance and physicochemical analysis of vaginal discharge), pregnancy tests (analysis of metabolites in urine and milk and ultrasonography), and computer vision using IP cameras (Figure 7; which is currently under development) and have data integration platforms in the CowVille system.

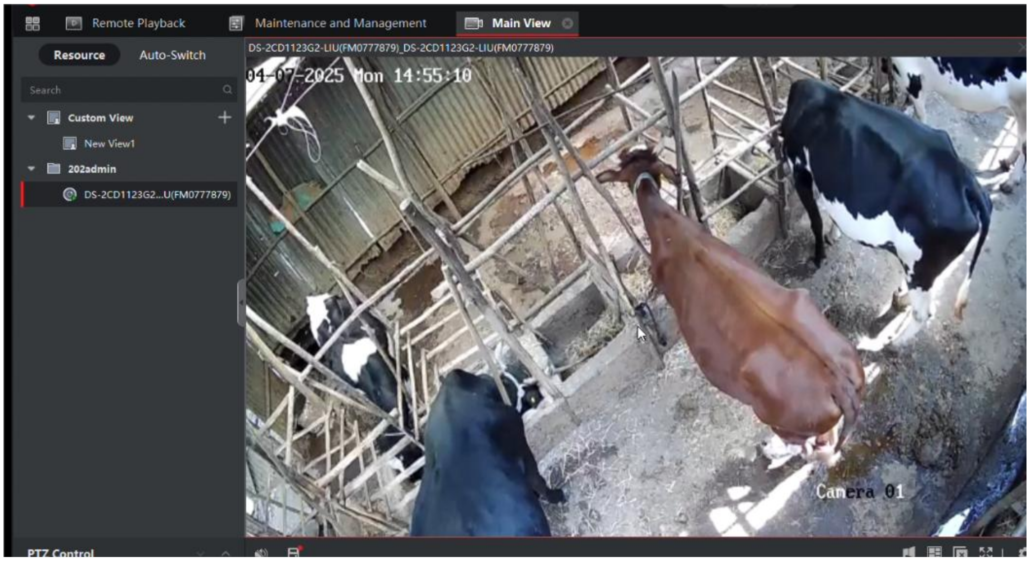


Figure 6: Video captured from a dairy farm using IP camera that streams to the CowsVille system for animal monitoring

As a showcase, data of 62 cows (38 normal-cycling and 24 repeat-breeding) was extracted from the CowsVille database and exported in Microsoft Excel for analysis. This was used in the study of estrus detection based on physicochemical profile and vaginal electrical resistance (VER) of cervical fluid (vaginal discharge) in estrus cows. The pH, spinnbarkeit [cm], sperm penetration [normal/ poor], and crystallization patterns [typical/atypical] were measured/scored, and pregnancy was diagnosed by ultrasonography 30 days post-AI. A significant difference ($P < 0.05$) was found in the rate of pregnancy between normal cycling cows (70.6%) and repeated breeders (41.7%). Body weight, time of insemination, and VER showed significant effects ($P<0.05$) on conception rate. Conception rates were highest for cows inseminated 7-12 hours (71.43%) after standing estrus and VER of 181-220 Ω (84.21%). The time of insemination with successful AI outcomes further confirms the significance of the CowsVille system in identifying the “Fertility Window” in estrous cows. Data collected and analyzed via this system concludes sperm penetration, spinnbarkeit, VER, and crystallization pattern to be useful predictors of optimal insemination time in dairy cows.

4.3. Data Analytics (Generation of actionable insights)

Data analytics is the backbone of a smart dairy system, transforming raw data collected from various sensors and devices into actionable insights for improved farm management and decision-making. CowsVille is a centralized software platform that aggregates data from the sources to provide a comprehensive view of the dairy operation. These platforms include dashboards for real-time monitoring and analytics tools for data analysis.

From data collection and integration, CowsVille utilizes sensors, data points that include information in the digital database (animal and farm data) and a centralized unified platform to process the data and generate actionable insights. CowsVille systems present analyses data through user-friendly dashboards with charts, graphs, and key performance indicators (KPI).

The key area of data analytics in the CowsVille system is currently focused at improving reproductive efficiency by analyzing heat detection data, insemination records, and calving intervals to optimize breeding programs, reduce calving intervals, and improve conception rates. Figure. 8 show the FW of a cow in the FCC that is determined by the CowsVille system. This “mobile alert” generated this way by the CowsVille system was sent to a farmer and AI technician. The most probable time for impregnating the specific cow is shown in green. Probability of conception will be relatively lower in the yellow region and minimal or none in the red region. An AI technician would know his chances of success based on the time reference sent to him.

Figure 7: Fertility window as determined by CowsVille for a cow at Yemane Abdi farm

As a showcase, 30 smallholders, managing 519 animals, were enrolled in the FCC. From this cohort, forty cows whose estrus was characterized by the CowsVille system were randomly selected for monitoring. CowsVille processed the data, generating actionable insights that were sent via mobile alert. Number of services, days after last AI (DALAI), days after last calving (DALC), onset and duration of estrus (DoE), and observed heat signs were documented. The mean number of services, DALAI, and DALC were 3.12±0.39, 68.23±10.37days, and 249.07±35.4 days, respectively. The fertility window was successfully identified in all cases (100%) with an average duration of 14.82±0.4 hrs. Most notably, the first-service conception (FSC) rate reached 65.8%, more than double the national average. The mobile alert system has proven to be a valuable resource for guiding farmers in making AI-related decisions. The significant improvement in FSC rate within the FCC highlights the significant impact of improved estrus detection and timely insemination facilitated by the CowsVille system and mobile alerts.

4.3.1. Application of reproductive herd health management using the CowsVille system

Reproductive herd health management in dairy focuses on optimizing the reproductive efficiency of the entire herd. The goal is to achieve optimal reproductive performance, leading to efficient calving intervals, a steady supply of replacements, and maximized milk production and profitability.

Summaries of the key performance indicators (KPIs) for a given farm are generated through the data analytics of the CowsVille system based on predetermined reproductive goals. These goals are set in accordance with the principles of the reproductive herd health management program. The system hence provides concrete evidence for decision-making by comparing the KPI generated through the CowsVille with the predetermined values of the RHHM program goals. The farmer would easily know the status of his farm and make the necessary decision based on the evidence available (Figure 9).

Figure 8: Display of key performance indicator (KPIs) for Yemane Abdi Farm

4.4. Mobile Alert System

It involves integration with the “Afro Messaging” (Integrated A2P service by Afro-Reach Company, Addis Ababa, Ethiopia) that provides the application-to-person (A2P) SMS messages consisting of specific actions generated by CowsVille data analytics. The text messages are sent in the local language so that the users understand and act. In the estrus detection, dairy owners receive the text message that advises them to follow the cows' estrus 24 hours ahead of the predicted time of ovulation. This is followed by another message on the day of estrus advising on the optimal time for insemination (Fertility window). The same message is communicated to the AI technician. Both the farmers and the AI technicians will have the option to send out reports of the AI, using ODK that will be streamed to the CowsVille server.

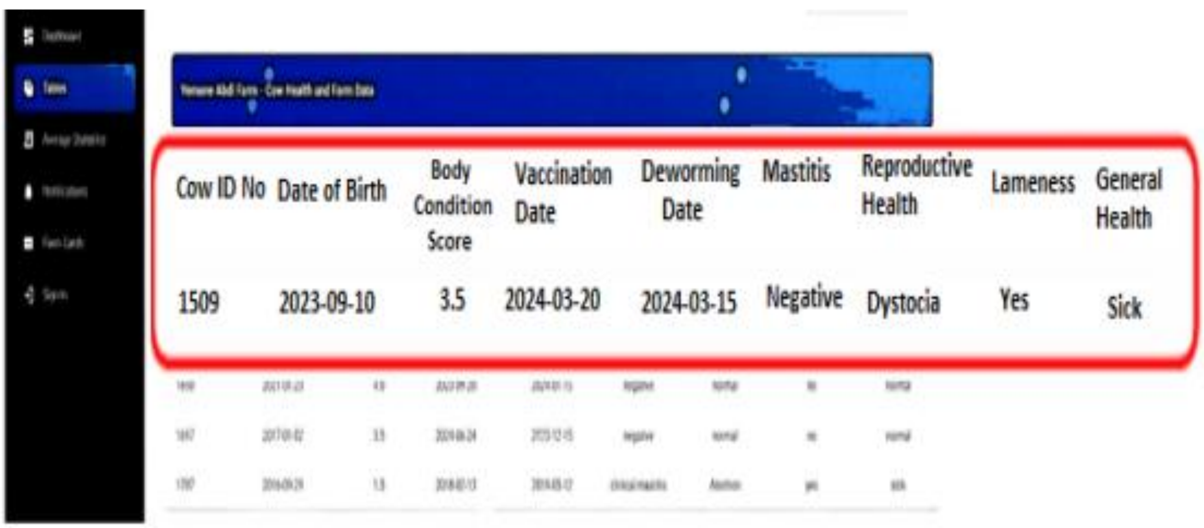


Figure 9: CowsVille digital database with record of health information at Yemane Abdi farm

The digital database contains information regarding the health of individual animals (Figure 10). This database is created through the ODK at the beginning and continuously updated by the dairy owners and the veterinarian. Signs of health problems can be encoded and streamed to the CowsVille system where it is processed to generate actionable insight which is communicated to the veterinarian and the dairy owner. Once actions (Such as treatment or vaccination of animals) are taken, reports of the health management will be filled out in the ODK. Prescriptive analytics generated via the CowsVille system can be accessed from the dashboard.

5. DISCUSSION

5.1. Digital record keeping

Dairy farming inherently produces a substantial volume of data originating from diverse sources, including sensor technologies, herd management software platforms, and milk analysis systems. However, the effective integration of this multifaceted information into a cohesive and user-friendly system presents a considerable challenge (Cabrera *et al*., 2025). Issues such as disparate data formats, a lack of standardization, and the absence of a unified national animal identification system impede farmers' ability to leverage their data efficiently. Consequently, these limitations result in missed opportunities for significant improvements in productivity, animal health management, and overall farm operational efficiency. Particularly in the dominant smallholders the lack of standardization in dairy operation has impacted further expansion. The role of ODK in alleviating data collection in the creation of digital record keeping is apparent according to the current study. A digital database from 30 smallholders has been successfully created and stored in the CowsVille server. Fundamentally, robust digital record-keeping infrastructure is essential for providing the comprehensive, accurate, and timely data necessary to power the intelligence of a smart dairy system, thereby enabling proactive management strategies, enhanced operational efficiency, improved animal welfare outcomes, and ultimately, increased farm profitability.

ODK collect has numerous advantages such as its open-source nature, flexibility, offline capabilities that does not require internet during data collection, and wide community support, when choosing a data collection tool. While ODK Collect is a powerful and widely used tool for digital data collection, it does have some disadvantages or limitations such as mobile compatibility (above 5 android version), form issues, limited customization of appearance in collect, and reliance on external tools for form building (Hartung *et al*, 2010).

5.2. Digital database in spreadsheet

Data acquired on spreadsheets can be directly used for data analysis since it is compatible with almost all statistical software. CowsVille system operates via its own integrated analytics. Data that was previously converted to Excel have been used to summarize the field data that was also supportive in the insight generation. However, one of the challenges with spreadsheets in the CowsVille system is its interoperability. Exporting and importing data collected via the ODK collect need to be worked out. It remains to be an area for upgrading since ODK also operates with Kobotoolbox which is an open source server that has a limitation of only up to 5000 data points. This shows that mobile applications perform better than ODK since the application avoids the use of Kobotoolbox and can directly send data to the CowsVille server.

5.3. Data Acquisition

In a smart dairy system, data acquisition is the process of gathering diverse information from various sources on the farm and converting it into a digital format for analysis and decision-making. This forms the foundation of the entire smart farming approach (Palma *et al*, 2025). The goal of data acquisition is to obtain comprehensive, accurate, and timely data that can then be analyzed to generate actionable insights for optimizing various aspects of farm management, ultimately leading to improved animal health, increased productivity, and enhanced profitability.

Different reports confirm that data acquisition in dairy farms consist of sensor technology that basically utilize wearable IoT devices such as collars, ear tags monitoring physiological parameters like activity levels, body temperature, heart rate, rumination patterns, and estrus detection (Alonso *et al.*, 2020).

The CowsVille system utilized mobile device and cow-side tests as sensors, a slightly different approach where health events, treatments, and diagnoses, breeding records and outcomes, and calving details are effectively collected. This is supported by various authors that reported inclusion of pregnancy test (Laven, 2009), mastitis tests (Tangora *et al,* 2024), milk conductivity and SCC (Matera *et al*., 2022), BHBA (Dirksen and

Breitner, 1993) and cow side test for ketosis (Ravi, *et al.*, 2019). While advanced IoT hardware's have the advantages because of automation, cow side tests still serve as an important tool in dairy data acquisition. A significant impediment to widespread adoption of IoT sensors on the other hand, is the cost-effectiveness and return on investment. The considerable initial capital outlay for collar-integrated sensors, coupled with recurring maintenance and software update expenditures, can deter farmers, especially those with smaller herds. The CowsVille system is yet to develop sensor devices and utilize installed IP cameras for computer vision (which is currently under development). This will add a significant value in the acquisition of more detailed data in addition to the currently employed estrus detection tools (estrus detectors based on vaginal electrical resistance and physicochemical analysis of vaginal discharge), and pregnancy tests (analysis of metabolites in urine and milk and ultrasonography).

5.4 Data Analytics (Generation of actionable insights)

In essence, data analytics acts as the "brain" of a smart dairy system, transforming raw information into valuable knowledge that empowers farmers to make more informed, timely, and effective decisions, ultimately leading to more sustainable and profitable dairy operations. Data analytics involves collecting, integrating, and analyzing data from various sources to gain actionable insights, ultimately improving farm operations, decision-making, and sustainability (Loučka *et al*. 2023). By leveraging this data, dairy farmers can enhance productivity, optimize resource allocation, and make informed choices regarding herd management, feeding strategies, and other aspects of their operations (Cabrera *et al*., 2025). Likewise the present work uses the CowsVille as data analytics. CowsVille is a centralized software platform that aggregates data from the sources to provide a comprehensive view of the dairy operation. These platforms include dashboards for real-time monitoring and analytics tools for data analysis. From data collection and integration, CowsVille utilizes sensors, data points that include information in the digital data base (animal and farm data) and a centralized unified platform to process the data and generate actionable insights. CowsVille systems present analyzed data through user-friendly dashboards with charts, graphs, and key performance indicators (KPIs).

5.4.1. Application of reproductive herd health management using the CowsVille system

Current herd fertility programmes generally use a management cycle approach that is a continuous process of establishing and updating farm objectives, assessment of current status, planning, execution and assessment (Brand and Guard, 1996). Such programmes require reliable record-keeping, regular farm visits, consultation and record analysis, with interpretation of data resulting in actions. To allow decision-making, objectives and targets need to be established using clearly defined reproductive indices.

Many of the reproductive performance measures used as key performance indicators (KPI) for year-round calving (Fetrow *et al*., 1988) are inappropriate for seasonal calving systems (Macmillan, 2002; Morton, 2010). Despite these differences between systems, the important point is that the key performance indicators have been agreed upon and precise definitions are consistently monitored and used objectively to assess a herd's performance. Once the key performance indicators are defined, data collected at both the herd and cow level are required to allow the calculation of indices for a specific farm. A wide range of data must be collected to aid decision-making, given the complex interactions between genetics, physiology, nutrition and management.

When the indicators are met, monitoring is all that may be subsequently required. However, when the indicators are not met, it is necessary to identify the deficiencies ('gaps' in performance) within the farm system, evaluate potential options to improve performance and implement appropriate interventions (Brand and Varner, 1996). Likewise in the present work the goal is to achieve optimal reproductive performance, leading to efficient calving intervals, a steady supply of replacements, and maximized milk production and profitability. This involves a multi-faceted approach in the CowsVille system encompassing: Monitoring, Health Management, Heat/Estrus Detection, Breeding Management, Pregnancy Diagnosis, Record Keeping and Analysis. The system hence provides concrete evidence for decision-making by comparing the KPI generated through the CowsVille with the predetermined values of the RHHM program goals. The farmer would easily know the status of his farm and make the necessary decision based on the evidence available.

5.5. Mobile Alert System

A mobile alert system in the dairy industry utilizes mobile technology to send alerts to farmers or dairy staff about critical issues or events, enabling prompt action and improved herd management. This system can be integrated with various technologies, including sensors and AI, to provide real-time data and alerts. In the present works mobile alert system involves integration with the “Afro Messaging” (Integrated A2P service by Afro-Reach Company, Addis Ababa, Ethiopia) that provides the application-to-person (A2P) SMS messages consisting of specific actions generated by CowsVille data analytics. The text messages are sent in the local language so that the users understand and act. In the estrus detection, dairy owners receive the text message that advises them to follow the cow’s estrus 24 hours ahead of the predicted time of ovulation. This is followed by another message on the day of estrus advising on the optimal time for insemination (Fertility window). The same message is communicated to the AI technician. Both the farmers and the AI technicians will have the option to send out reports of the AI, using ODK that will be streamed to the CowsVille server.

5.6. Limitation of the study

Although the result has great benefits for the dairy farms, there are certain limitations that do not apply IoT (Internet of things) devise sensor whereby data is also conducted manually using open data kit (ODK), which has need extra time and labor.

6. CONCLUSION AND RECOMMENDATIONS

The digital record-keeping, combined with analytical capabilities and direct farmer feedback, effectively mitigate the limitations of the traditional management in smallholders. This new approach to the smart dairy system offers compelling evidence that integrating digital technology can substantially enhance reproductive efficiency, providing a scalable solution for breed improvement and dairy expansion endeavors in Ethiopia.

Most notably, the dramatic increase in the first-service conception rate is evidence that CowsVille system offers an untapped opportunity for the smallholder dairy operation in Ethiopia. The mobile alert system proved to be a valuable tool in guiding farmers' AI-related decisions. The findings of this initiative indicate the transformative potential of digitally enabled reproductive management in tackling the critical challenges within Ethiopia's smallholder dairy sector. The stark contrast between the national conception rate and FSC rate within the "Fertility Control Camp" highlights the significant impact of improved estrus detection and timely insemination facilitated by the CowsVille system and mobile alerts pointing towards the feasibility of achieving one calf per cow per year. Based on the above conclusion the following recommendations are forwarded:

- ➢ Although ODK collect provides a free and workable data acquisition tool, its limitation in the volume of data and lack of flexibility, a new mobile application has to be developed and employed for smallholder setup in Ethiopia.
- ➢ Data acquisition currently rely on cow side tests and mobile application, however the use of IoT sensors and computer vision to collect diverse physiological data and farm data is mandatory for precision farming
- ➢ The success of CowsVille functionality relies on proper implementation of the mobile feedback. Therefore, continuous training of dairy farm owners, AI technicians and veterinarians enrolled in the system is mandatory.
- ➢ CowsVille software still has the potential for improvement to include features such as market place, feed procurement, replacement heifers and financial management. Hence more research is required in this regard

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8. APPENDICES

Table 1: Comparisons of parameters Estrus Vs Pregnancy

Parameter	During Estrus (High Estrogen)	During Pregnancy / Diestrus (High Progesterone)
PH	↑ Alkaline (around 7.5–8.5)	↓ Slightly acidic (around 6.5–7.0)
Spinnbarkeit (stretch ability of mucus)	↑ High (10–20 cm or more) – mucus is thin and elastic	↓ Low (1–5 cm) – mucus is thick, sticky
Sperm Penetration Test	Normal / Good – sperm move freely and quickly	Poor – mucus is thick, sperm motility is restricted
Crystallization Pattern (Ferning)	Typical – clear, structured fern or palm-leaf pattern due to high NaCl content	Atypical or Absent – broken, amorphous, or no crystals due to progesterone and mucosal changes

Source: Leigh *et al*., 2019

Annex 1: ODK Mobile farm and Animal data collection format

Farm data collection

* Owner's full name

* Farm identification

* Address

* Telephone number

GPS location

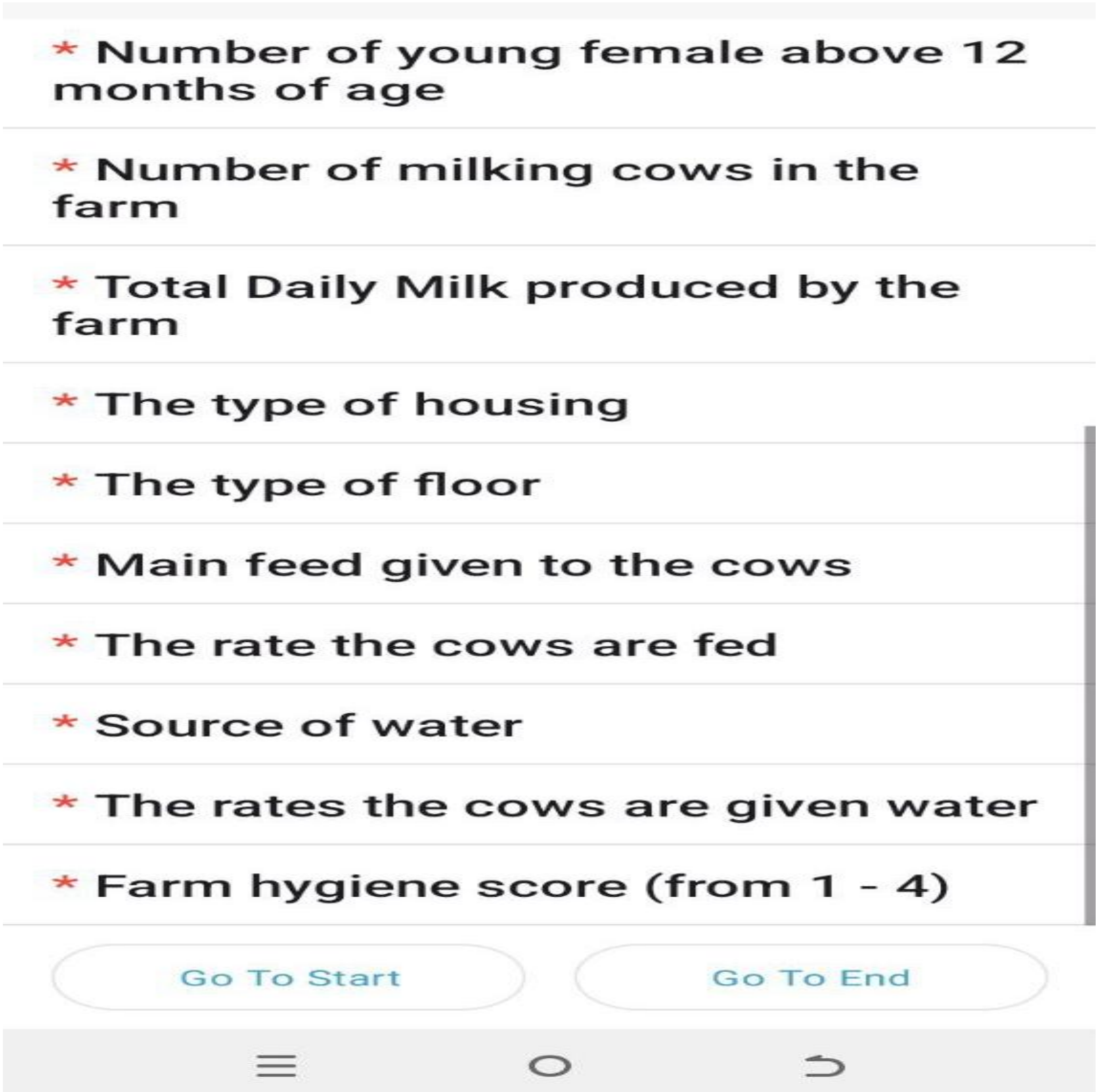
* Fertility control camp (or cluster) number

* Total number of animals

* Number of calves

* Number of young female above 12 months of age

* Number of milking cows in the farm



* Number of young female above 12 months of age

* Number of milking cows in the farm

* Total Daily Milk produced by the farm

* The type of housing

* The type of floor

* Main feed given to the cows

* The rate the cows are fed

* Source of water

* The rates the cows are given water

* Farm hygiene score (from 1 - 4)

Go To Start

Go To End

Animal data collection form

* What is the farm id?
* Insert Cow ID?
* Select breed from the list?
* Age of the animal in days?
* Sex of the animal?
* Parity of the animal?
* Body weight of the animal estimated from heart girth?
* BCS(on 5 scale)
* Gynecological status?
* Lactation number?
* Number of days in milk?

* Average daily milk yield?

* Is the cow Inseminated before?

* Number of days after last calving

* Is the cow pregnant?

* Udder health

* Mastitis

* General health of the animal?

* Reproductive health of the animal?

* Metabolic disease of the animal?

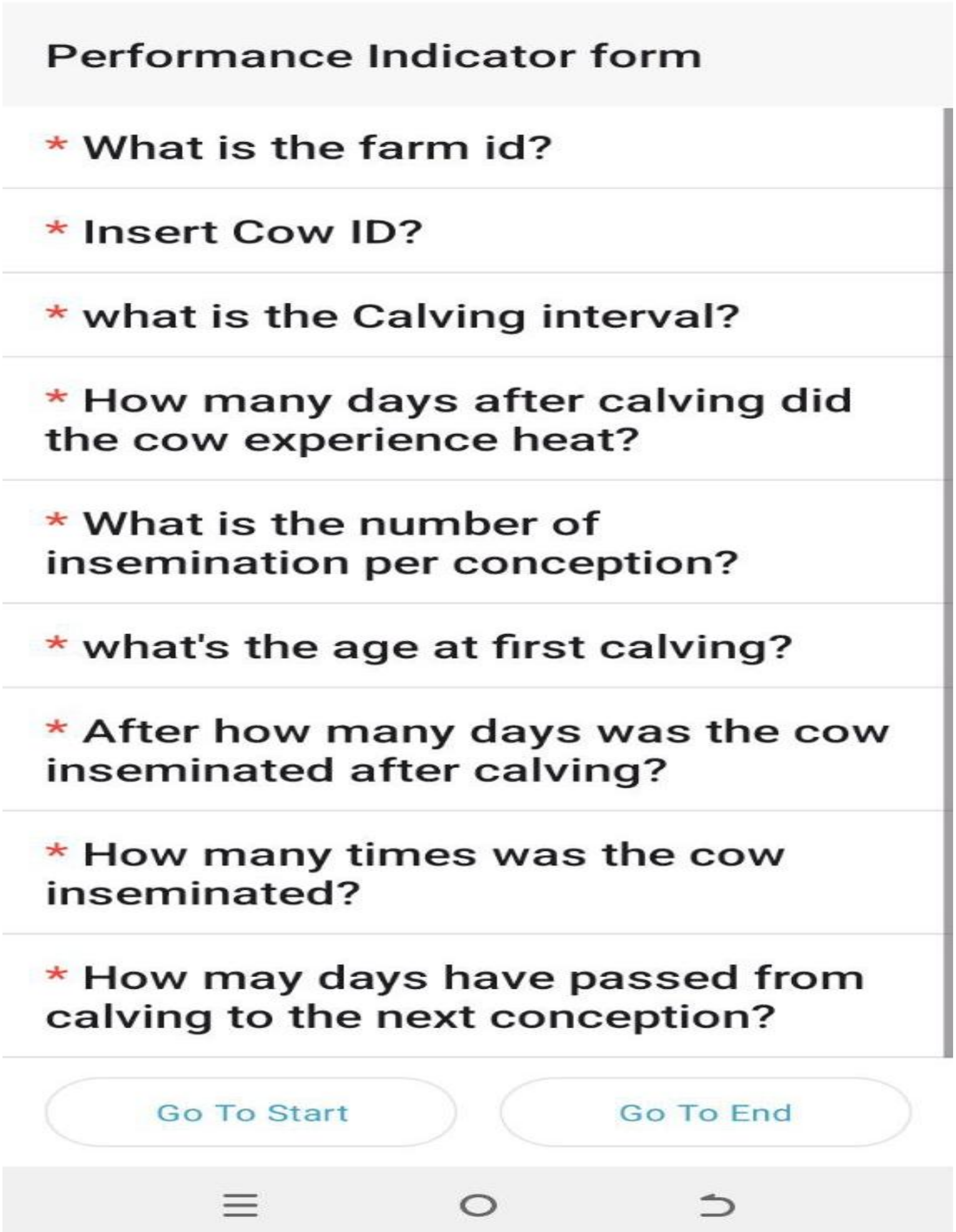
* is cow vaccinated?

* Has the cow taken deworming?

Go To Start

Go To End

Annex 2: ODK mobile for performance indicator data collection format


Performance Indicator form

* What is the farm id?

* Insert Cow ID?

* what is the Calving interval?

* How many days after calving did the cow experience heat?

* What is the number of insemination per conception?

* what's the age at first calving?

* After how many days was the cow inseminated after calving?

* How many times was the cow inseminated?

* How may days have passed from calving to the next conception?

Go To Start

Go To End

Annex 3: Heat sign monitoring format for farmer

Heat Sign Monitoring Form For Far...

* የእርሻ መለያ ቁጥር ምንድን ነው?

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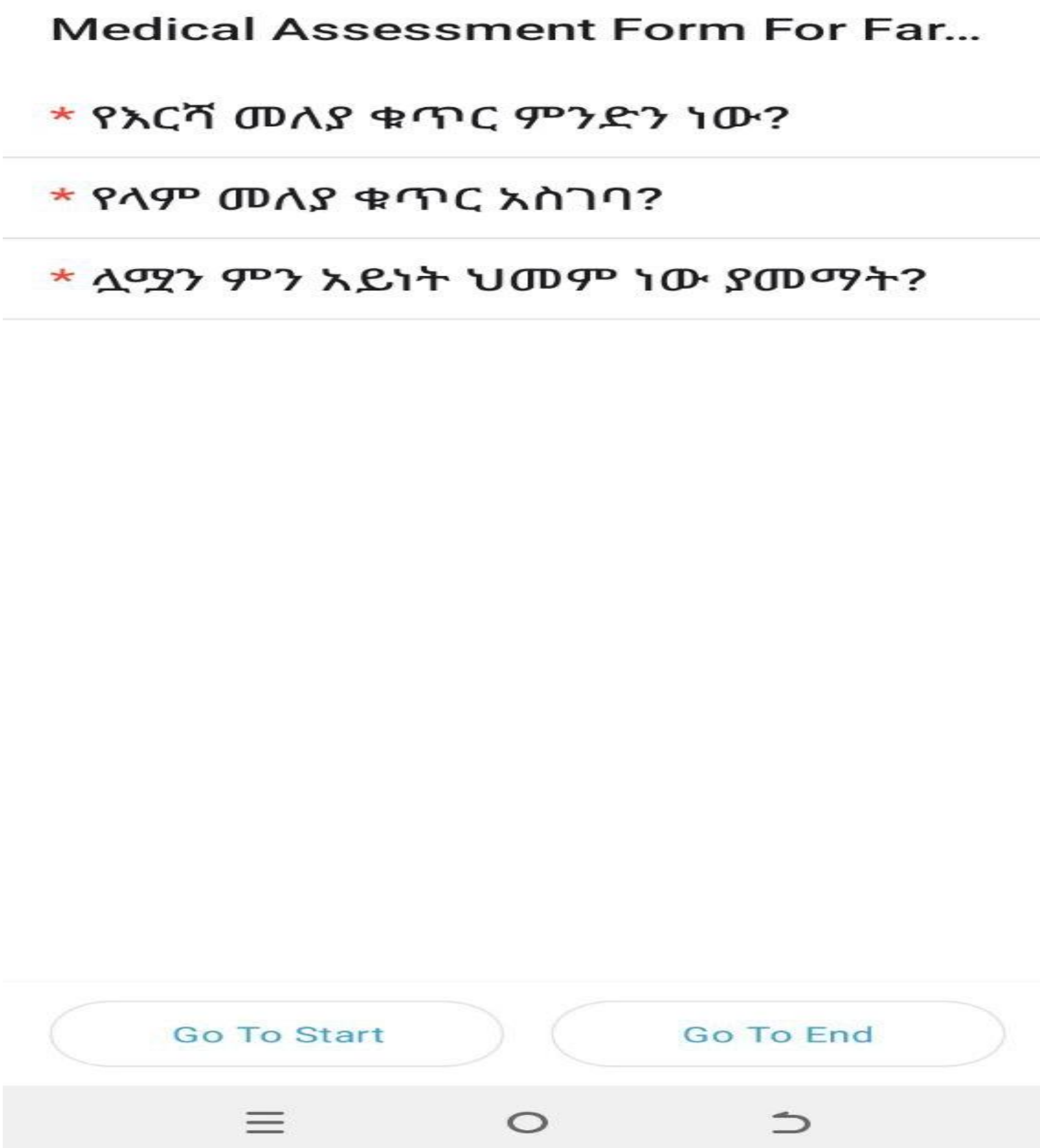
13:00

* የሙቀት ምልክቶች?

Go To Start | Go To End

Annex 4: Medical assessment form for farmer



Annex 5: Animal ethical clearance certificate

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ADDIS ABABA UNIVERSITY
College of Veterinary Medicine
and Agriculture
Bishoftu

Animal Research Ethical Review Committee

Ethical clearance certificate

Certificate Ref. No: VM/ERC/04/70/17/2025

Name of Applicant: **Dejene Zegeye** (DVM, MSc student)

Address: Clinical Medicine, College of Veterinary Medicine and Agriculture, Addis Ababa University

Title of the project: *Evaluation of smart dairy system for enhancing reproductive herd health management in small holder farms in Bishoftu town*

Date of application:	**December, 2024**
Nature of the project:	Farm investigation
Target animal species:	**dairy cattle**
Number of animals involved:	**30 dairy farms**
Study area:	**Bishoftu, Ethiopia**

Minutes No. and date of review: **VM/ERC/04/17/025, 25/02/2025**

The Institutional Animal Care and Use Committee of the College of Veterinary Medicine and Agriculture of the Addis Ababa University has reviewed the above research project and unanimously approved the application of Dejene Zegeye.

Professor Getachew Terefe (DVM, PhD)
Chairman

Signature

መልሱን በሚጽፉልን ጊዜ ባክዎን የእኛን ደብዳቤ ቁጥር ይጥቀሱልን
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Annex 6: Plagiarism Report

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