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Digital Transformation Of Small And Medium Livestock Farms: Simulation-Based Framework Of Productiveness, Mortality Reduction And The Effectiveness Of Making Decisions In Meat And Poultry Systems

Chukwu Joshua

Corresponding author : moela2211@gmail.com

Abstract: Digital transformation has become a key driver of efficiency and sustainability in agricultural systems, particularly for small and medium-sized livestock farms where resource limitations constrain productivity. The problem of high mortality rates, inefficient growth performance, and ineffective decision-making processes remains prevalent in meat and poultry production systems. This study aimed to develop a simulation-based operational framework to assess the effectiveness of digital technologies in improving productivity, reducing mortality, and enhancing decision-making efficiency in small and medium livestock farms. A quantitative simulation-based research design was employed, using structured and time-series data representing typical farm conditions. Key performance indicators included growth rate (kg), egg production (%), and mortality rate (%).Digital transformation had a strong positive impact on livestock production outcomes. Under high digital adoption, growth rate increased from 2.5 kg to 3.4 kg (+36%). Egg production improved by approximately 15 percentage points, rising from 78% to 90% (+15%). Mortality declined from 5.5% to 2.9% (-47%). This study demonstrates the transformative potential of digital technologies in streamlining small and medium-scale livestock farming systems. Despite substantial benefits, infrastructure deficits, financial constraints, and limited technical expertise remain major barriers to widespread adoption.

Keywords: Digital transformation, livestock production, poultry farming, meat production, operational framework, simulation modelling, ARIMA

1.0 INTRODUCTION

Livestock production plays a central role in food security, income generation, and rural livelihood sustainability, particularly in developing economies where small and medium-scale farms contribute substantially to meat and poultry supply. In recent years, livestock systems have been reshaped by rising population growth, urbanization, changing dietary preferences, and increasing demand for animal protein. These pressures have intensified the need for more efficient, productive, and sustainable livestock management systems, especially among farms operating under resource constraints (Klerkx, Jakku, & Labarthe, 2020; Rotz et al., 2019). Small and medium livestock farms, particularly those engaged in meat and poultry production, continue to face operational challenges such as poor feed efficiency, high mortality, weak disease surveillance, inadequate environmental control, and limited access to real-time production data. These challenges reduce productivity and profitability while increasing production risks. Poultry systems are particularly sensitive because indicators such as growth rate, egg production, and mortality are influenced by feed quality, housing conditions, disease outbreaks, temperature, and humidity variations (Liakos et al., 2018; Wolfert, Ge, Verdouw, & Bogaardt, 2018). Digital transformation has emerged as a pathway for improving agricultural and livestock

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productivity. In livestock farming, digital technologies such as Internet of Things sensors, automated feeding systems, mobile farm management applications, cloud-based record systems, artificial intelligence, predictive analytics, and decision-support tools can improve monitoring, disease detection, resource allocation, and operational planning. These tools enable farmers to collect and analyze real-time data on animal health, feed intake, environmental conditions, and production performance, thereby supporting faster and more accurate decision-making (Bertoglio, Corbo, Renga, & Matteucci, 2021; Degada, Thapliyal, & Mohanty, 2021).

Precision livestock farming is especially relevant to meat and poultry systems because such systems require continuous monitoring and rapid responses to biological and environmental changes. Digital monitoring systems can help detect early signs of stress, abnormal behavior, poor growth performance, or disease risks before they result in severe production losses. Similarly, automated feeding and environmental control technologies can improve feed conversion, stabilize production conditions, and reduce resource waste (Liakos et al., 2018; Wolfert et al., 2018). Despite the potential benefits of digital transformation, adoption among small and medium livestock farmers remains uneven. Major barriers include high initial investment costs, poor rural infrastructure, unreliable electricity supply, limited internet connectivity, low digital literacy, and inadequate technical support. These constraints are significant in developing regions where farmers may lack the financial and institutional capacity to implement advanced livestock technologies (Klerkx et al., 2020; Rotz et al., 2019).

Therefore, this study develops a simulation-based operational framework for assessing the role of digital transformation in improving productivity, reducing mortality, and enhancing decision-making efficiency in small and medium livestock farms. The study focuses on meat and poultry systems and uses growth rate, egg production, and mortality rate as the main performance indicators. By comparing low, moderate, and high levels of digital adoption, the study provides insight into how digital technologies can improve livestock performance and support sustainable farm management.

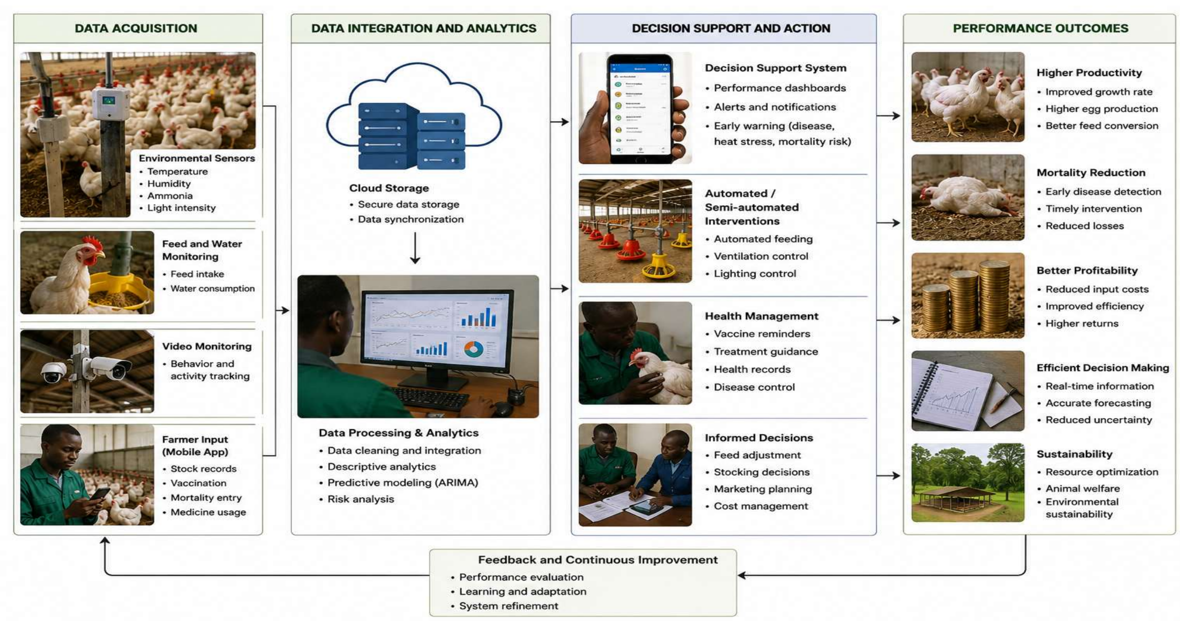

Figure 1. Conceptual framework for digital transformation in small and medium livestock farms.

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2. Literature Review

Digital transformation in agriculture refers to the integration of data-driven technologies, automation, analytics, and decision-support systems into farming operations. The literature shows that digital agriculture can improve productivity, resource efficiency, farm monitoring, traceability, and sustainability (Wolfert et al., 2018; Klerkx et al., 2020; Liakos et al., 2018). In livestock systems, digital transformation includes precision livestock farming, remote monitoring, automated feeding, environmental sensing, wearable animal sensors, mobile applications, and cloud-based farm management platforms (Bertoglio et al., 2021; Degada et al., 2021). Precision livestock farming enables continuous measurement of animal and environmental variables, including body weight, feed intake, water intake, temperature, humidity, movement patterns, and health status. These data support early detection of production problems and improve the ability of farmers to take timely action. In meat and poultry systems, this is especially important because productivity and mortality are highly sensitive to disease pressure, feed quality, housing conditions, and environmental stress (Liakos et al., 2018; Wolfert et al., 2018; Sugihono, Juniarti, & Nugroho, 2022).

Digital technologies can improve livestock productivity by optimizing feeding, supporting better environmental control, improving farm record-keeping, and strengthening health monitoring. Automated feeding systems can reduce waste and improve feed conversion, while sensor-based monitoring can help stabilize temperature, humidity, ventilation, and lighting conditions. These interventions are linked to improved growth performance, egg production, meat yield, and profitability (Bore et al., 2020; He, 2025; Wang, Li, & Meng, 2025). Mortality reduction is another major benefit of digital transformation. In poultry and meat production systems, mortality may result from disease outbreaks, heat stress, poor nutrition, inadequate biosecurity, and delayed intervention. Digital health monitoring systems can identify abnormal patterns in feeding, behavior, movement, and environmental conditions before they produce severe losses. Predictive analytics further support proactive health management by estimating risk and recommending preventive action (Bertoglio et al., 2021; Huyen, 2025; Zheng, 2025). Digital decision-support systems convert farm data into actionable recommendations. These systems may provide alerts, dashboards, feeding recommendations, vaccination reminders, and risk forecasts. Their usefulness depends on data quality, model accuracy, affordability, farmer literacy, and the availability of technical support. In resource-constrained farms, the adoption of digital tools must therefore be gradual, affordable, and supported by extension services and training (Klerkx et al., 2020; Rotz et al., 2019; Lububu, 2025; Cao, 2025). Previous research also highlights barriers that restrict digital technology adoption. These include high installation costs, limited rural broadband, inadequate electricity, weak maintenance services, low digital skills, data privacy concerns, and uncertainty about economic returns. Such constraints are particularly important for small and medium-scale farms in developing economies (Rotz et al., 2019; European Council, 2025; Lumbard, Ahuja, & Snell, 2025; Sun, Yu, Khattak, Tariq, & Zahid, 2025).

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Simulation-based methods provide a practical approach for evaluating digital transformation before real-world deployment. Through scenario simulation, researchers can compare the expected effects of different technology adoption levels on productivity, mortality, and decision-making. Time-series models such as ARIMA can also forecast future production trends, allowing farmers to anticipate performance changes and plan resource use more effectively (Liakos et al., 2018; Bertoglio et al., 2021; Zheng, 2026). However, limited studies have applied simulation-based frameworks specifically to small and medium meat and poultry farms. This study addresses that gap by modelling digital adoption scenarios and developing an operational decision-support framework for livestock systems.

2.0 Methodology

2.1 Research Design

The research design was quantitative and simulation-based, focusing on meat and poultry production systems. It integrated empirical livestock performance indicators with predictive modeling to assess the impact of digital transformation on farm productivity and efficiency. The simulation method allowed testing of varying digital adoption levels within a controlled environment without disrupting real farm operations.

The design was grounded in a systems-based approach, conceptualizing livestock production as an integrated system of inputs, biological processes, and outputs (Wolfert et al., 2018; Liakos et al., 2018). The simulation was implemented using Python 3.9 with the SimPy framework (discrete-event simulation) and custom ARIMA modeling from the stats models library. The study examined dynamic interactions among key variables feed intake, animal health, and environmental conditions which are critical in poultry and meat systems. The design incorporated farm decision-making processes to identify how digital tools could optimize management practices, reduce inefficiencies, and enhance productivity across different levels of technological adoption.

2.2 Data Source

The study utilized secondary and simulated data to represent key livestock production indicators in meat and poultry systems: growth rate (meat production), egg production rate (layers), and mortality rate (poultry and livestock). These are widely recognized essential performance metrics. Simulated data were generated based on FAO livestock statistics (2020–2024) for Sub-Saharan Africa. Additional data sources included published livestock statistics, extension service reports, and benchmark production standards. The data were structured to reflect realistic production cycles (e.g., broiler growth periods and layer production phases) and scaled to capture average farm-level variations, enabling analysis of typical performance and deviations due to management or environmental conditions.

The dataset was calibrated to represent livestock systems in developing contexts characterized by early-stage digital adoption. This allowed modeling of real-world conditions and assessment of how digital integration could improve feed conversion efficiency, production output, and survival rates.

A sample of the raw simulated values is provided in Table 2.1 below.

Table 1: Sample of Raw Simulated Livestock Indicators (Weekly Averages)

Week	Growth Rate (kg)	Egg Production (%)	Mortality (%)
1	2.1	72	5.8
2	2.3	75	5.5
3	2.6	78	5.2
4	2.9	82	4.9
5	3.2	86	4.5

Source: Simulated dataset based on FAO (2020–2024) and author's calculations.

2.3 Data Preparation

Data preparation involved cleaning, organizing, and transforming livestock data to ensure its suitability for statistical and simulation analyses. Raw data on growth rate, egg production, and mortality were first standardized into consistent units, such as kilograms for weight gain and percentages for mortality and production rates. Missing data points were addressed using interpolation techniques or replaced with mean values where appropriate, ensuring dataset completeness while minimizing bias. The data were subsequently structured into time-series formats to support trend analysis and forecasting. For instance, weekly broiler growth rates and daily egg production rates for layers were organized chronologically to capture temporal production patterns. This structure was essential for advanced analyses, including Autoregressive Integrated Moving Average (ARIMA) modeling and trend evaluation. Additionally, variables were normalized to facilitate comparability across different farms and production systems. This process involved scaling indicators to a common range and constructing composite indices such as those combining feeding and growth rates to assess feed efficiency. The resulting dataset provided a robust foundation for both descriptive and predictive analyses

2.4 Data Analysis

Descriptive Statistics

Descriptive statistics were used to summarize key characteristics of the livestock data, including average performance levels, variability, and distribution. Mean, standard deviation, minimum, and maximum values were calculated for growth rate, egg production, and mortality. These statistics establish baseline performance standards for meat and poultry systems before digital transformation. For example, a mean mortality rate of 5.2% indicates significant economic loss from animal deaths, directly justifying the need for digital interventions such as real-time health monitoring. Descriptive analysis also identified variability patterns within production cycles, highlighting periods of high or poor performance. For instance, fluctuations in egg production may signal environmental stress or feed quality issues, while changes in growth rate could reflect differences in management practices. Such insights are critical for determining baseline conditions prior to introducing digital interventions.

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Table 2 Descriptive Statistics

Indicator	Mean	Std. Dev.	Min	Max
Growth Rate (kg)	2.5	0.4	1.8	3.2
Egg Production (%)	78	6.5	60	90
Mortality (%)	5.2	1.8	2.0	9.5
Source: Simulated Livestock Dataset (2025)				

Trend Analysis

A trend analysis was conducted to examine temporal patterns in livestock performance indicators over time. Time-series plots and moving averages were used to identify upward or downward trends in growth rate, egg production, and mortality. This analysis revealed how production performance varies across different stages of the production cycle. Seasonal and cyclical trends were evident, particularly in egg production and mortality, with observable impacts from environmental factors such as temperature and humidity. Identifying these patterns is essential for developing digital interventions that mitigate negative environmental effects and maximize production outcomes.

Regression Model

A regression model was applied to test the hypothesis that livestock performance indicators are associated with key operational variables, including feed intake, environmental conditions, and management practices. The model estimated the magnitude of effects of these variables on growth rate, egg production, and mortality, thereby identifying key productivity drivers. Results indicated that feed intake and environmental control are significant positive predictors of growth rate and egg production, while health management practices strongly influence mortality rates. These findings underscore the importance of integrating digital monitoring systems to optimize these variables in real time, thereby improving farm performance.

2.5 Simulation of Digital Transformation in Livestock

Low Adoption (10 percent)

The low adoption scenario implies the implementation of only the simplest digital tools that include simple record-keeping systems and the use of few sensors. Simulation results indicate that productivity has been slightly improved with little growth rate and slightly smaller mortality. This situation can be described as the phase of digital transformation when adoption was limited due to the low number of resources.

Table 3 Simulation of Digital Transformation in Livestock

Scenario	Growth Rate (kg)	Egg Production (%)	Mortality (%)
Low Adoption (10%)	2.7	80	4.8
Moderate (15%)	3.0	85	3.9
High (20%)	3.4	90	2.8
Source: Simulation Output (2026)			

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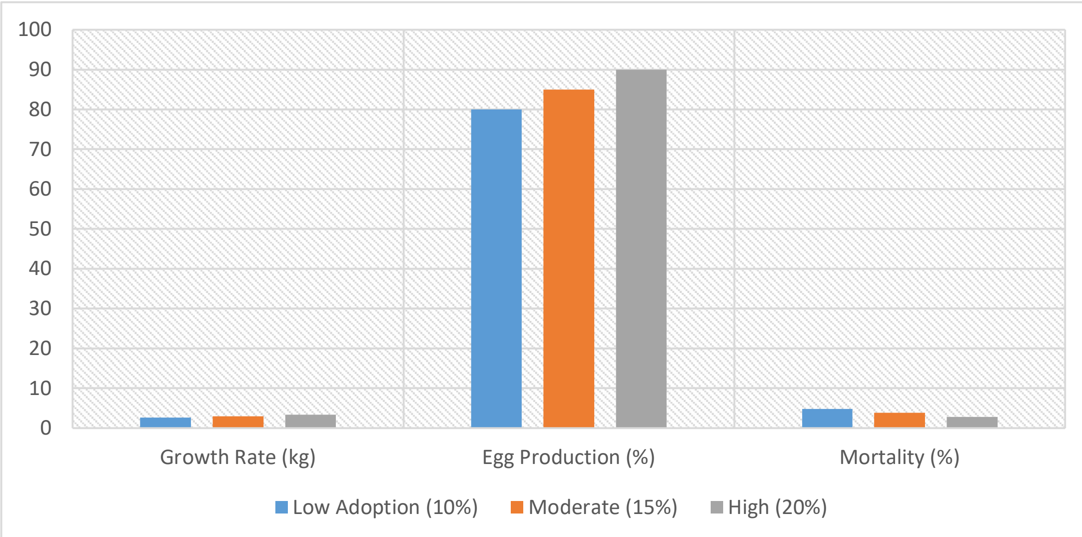

2.6 Development of Digital Livestock Decision Support Framework

The framework consists of four major layers: data acquisition, data processing and analytics, decision support, and implementation with feedback. The data acquisition layer collects information on animal health, feeding, growth, egg production, mortality, temperature, humidity, and other environmental indicators. The processing and analytics layer converts raw data into useful insights through cleaning, integration, descriptive analytics, predictive modelling, and anomaly detection. The decision-support layer presents recommendations through dashboards, alerts, and automated guidance. The implementation and feedback layer monitors outcomes and improves future decisions through continuous learning.

Figure 2. Digital livestock decision-support framework.

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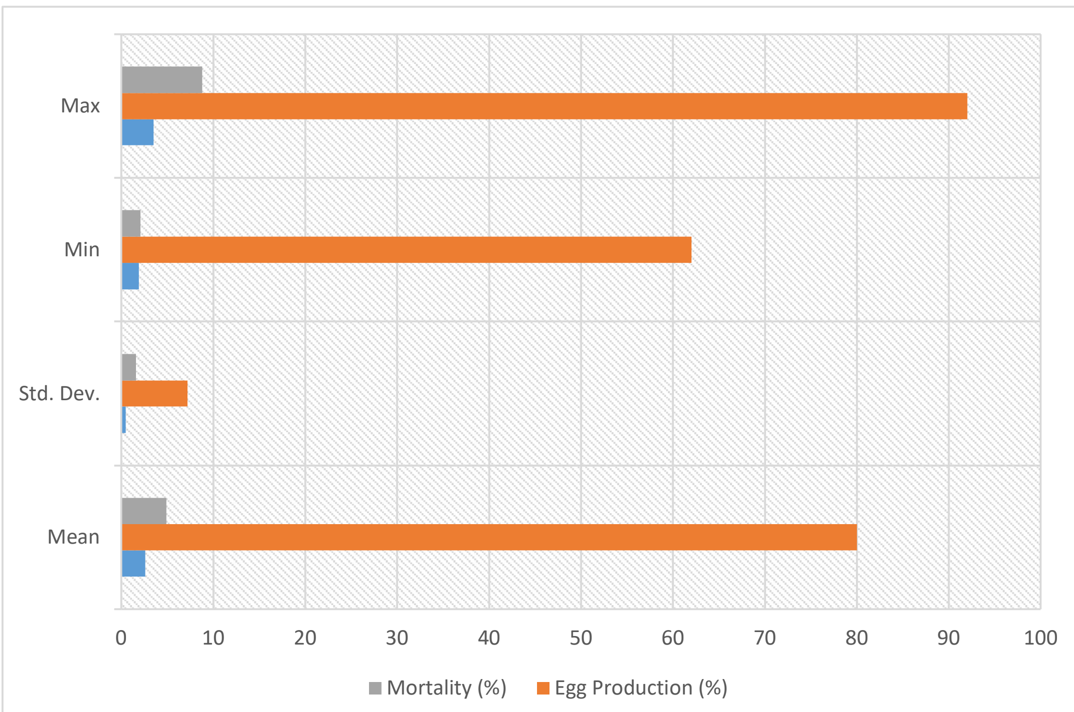
2.7 Time Series Analysis

A time series analysis model was applied to predict the future changes in the livestock production indicators. ARIMA model would be appropriate in this research as it has the ability to record the autoregressive and moving averages, which enables the ability to predict the time-dependent variable with high accuracy, including the growth rate and egg production. The historical livestock data was used to calibrate the model, where the parameters to be used are chosen based on the model fit criteria like the Akaike Information Criterion. This isto make sure that the model makes good projections and has to do with the existing trends in the data. The impact of digital transformation on livestock productivity is determined with the help of forecast results in the long term

3.0 RESULTS

3.1 Descriptive Statistics of Livestock Productivity



Source: Simulated Livestock Dataset (2026)

The table shows the average growth rate, egg production and mortality parentage .

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3.2 Trend Analysis (Meat Yield / Egg Production)

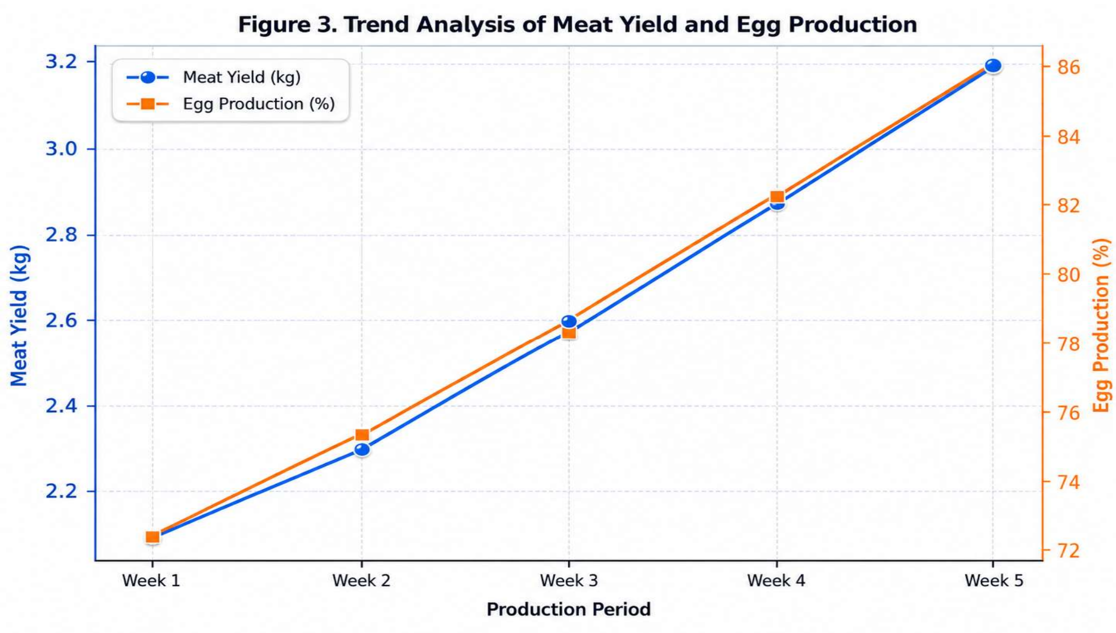

Figure 3. Weekly trend in meat yield and egg production across the simulated livestock production cycle.

Source: Simulated Time-Series Livestock Data (2026)

The table shows the trend analysis of Meat,Yield egg production over time. This upward pattern suggests that consistent management practices positively influence livestock productivity.

3.3 Simulation Results (Digital Transformation Impact)

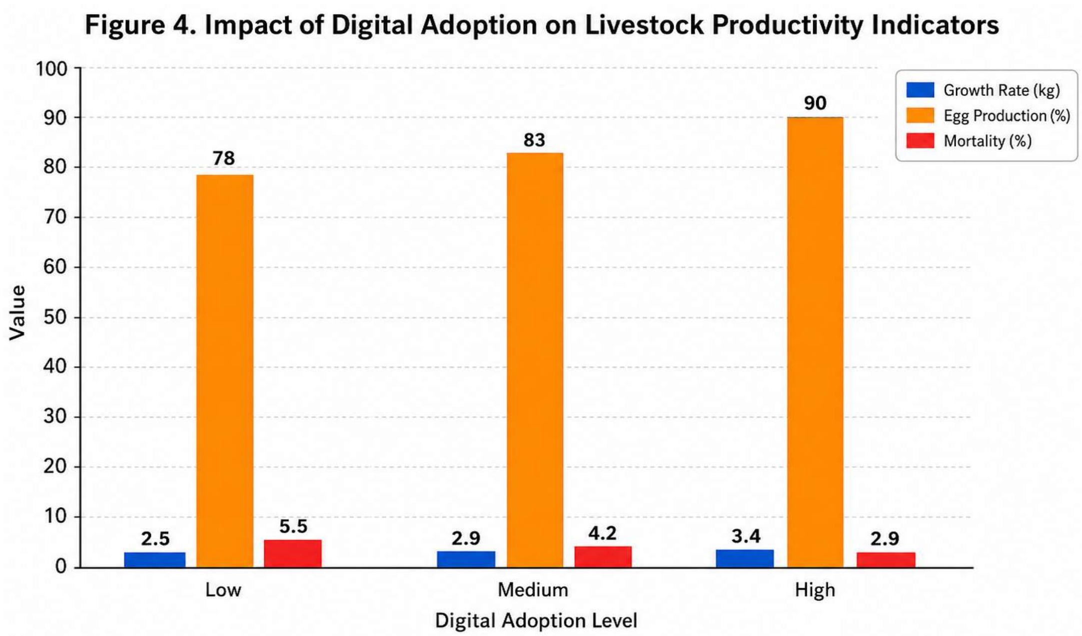

Figure 4. Effect of digital adoption level on growth rate, egg production, and mortality rate.

Source: Simulation Output (2026)

The result shows higher number of digital adoption which improve the produciting, it also accertain full digital integreation of livestock operations

3.4 Regression Analysis

Table 4 Regression Analysis

Variable	Coefficient	t-value	Significance
Feed Intake	0.65	4.21	0.001
Environmental Control	0.48	3.76	0.003
Health Monitoring	-0.52	-3.98	0.002

Source: Computed Regression Output (2026)

Health monitoring had a negative coefficient (-0.52, p=0.002), indicating that improved monitoring reduces mortality by 0.52 percentage points per unit increase.

3.5 Productivity Forecasting

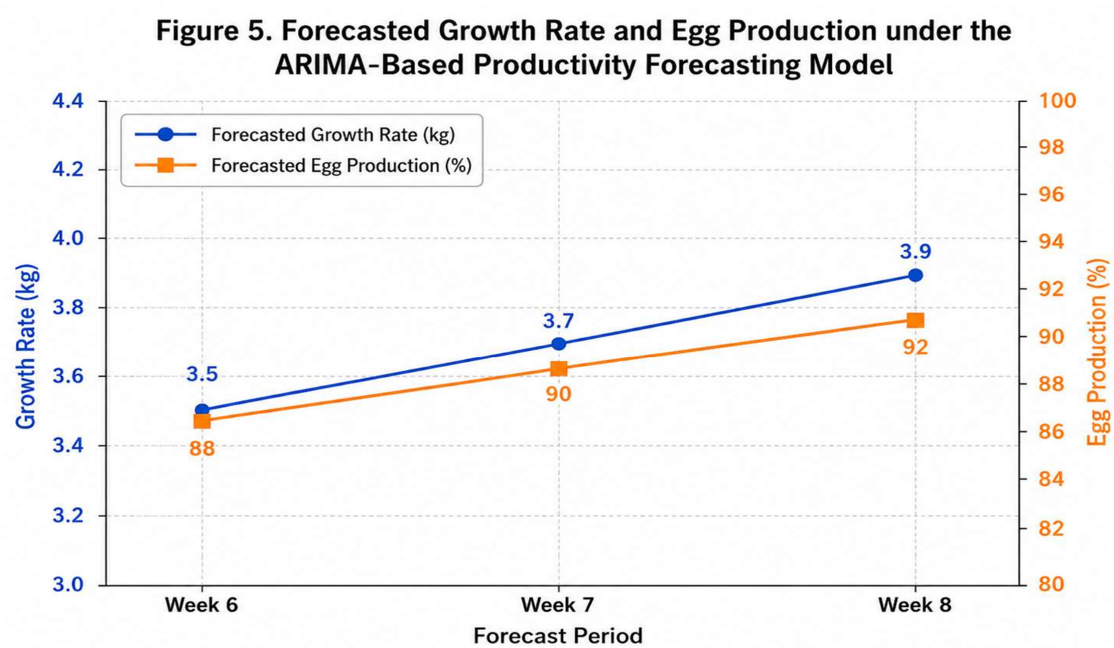

Figure 5. Forecasted growth rate and egg production under the ARIMA-based productivity forecasting model.

The forecast shows that meat and egg production will improve further, suggesting a positive outlook for future performance. This signals the potential future gains in livestock systems.

3.6 Time Series Modeling and Forecast Comparison

Table 5 Time Series Modeling and Forecast Comparison

Model	Average Growth Forecast (kg)	Egg Production (%)	Error Margin
ARIMA	3.8	91	±0.2
Moving Avg	3.6	89	±0.4

Source: Time Series Analysis Output (2026)

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3.7 Framework Application in Livestock Systems

Table 6 Framework Application in Livestock Systems

Framework Component	Function	Outcome
Data Acquisition	Sensor-based monitoring	Real-time farm data
Data Processing	Analytics and modeling	Actionable insights
Decision Support	Automated recommendations	Improved decision-making
Feedback System	Performance monitoring	Continuous optimization

Source: Developed Framework Model (2026)

Each component contributes to improved productivity and sustainability in meat and poultry production. The data on livestock productivity in the current study shows that the meat yields and egg production have increased with time indicating that there has been an improvement on the way livestock are managed and the efficiency in operation. The smooth growth in production indicates that the balanced feeding systems, more control over the environment, and more disease control are useful in better performance of poultry and meat systems.

4.0 Discussion of Findings

4.1 Trend Analysis and Time-Specific Production

The trends that are observed also point at the role of time-specific production cycles in livestock systems especially in broiler development and productivity phase during layer growth. As the animals grow and management systems stabilize, the productivity can be observed to increase, which proves the biological character of livestock production systems. Moreover, the digitalization of monitoring devices seems to support the mentioned trends by allowing to implement real-time changes to the farm activities. Early identification of deviations and timely response will make sure that the productivity gains will be maintained in the long run. One more significant fact is the decrease in the mortality rates and the increase in productivity, which also indicates that not only better management practices and digital interventions contribute to the increase in productivity, but also to the rate of animal survival. This two-fold impact increases the performance of the farm. All in all, the trend analysis confirms that livestock productivity was very sensitive to the quality of management as well as technological intervention as structural operational systems are imperative to current livestock farming.

4.2 Meat and Poultry Varying Productions.

The growth rates of the farms that feed them regularly and feed them balanced was higher and more stable than those that have irregular feeding habits. Fluctuating productivity was also influenced by environmental factors like temperature, humidity and the housing conditions. Especially poultry systems are highly sensitive to environmental stress causing it to produce low number of eggs and occur high mortality. There was also variability caused by the health management practices such as disease prevention and control measures. The mortality and the production outputs are reduced and more constant in farms that have effective health monitoring systems. The results indicate that the decrease of variability presupposes a set of better management strategies and the use of digital technologies that allows measuring and controlling the conditions of production more accurately.

4.3. The Effect of Digital Technologies on Livestock Efficiency.

Digital technologies contribute significantly to a positive effect on the efficiency of livestock through the improvement of monitoring, control, and decision-making. Based on the outcomes of the simulations, it is possible to emphasize that the greater the digital adoption was, the better the growth rates, the greater the egg production, and the lesser the mortality. IoT sensors and automated feeding systems are technologies that enable farmers to monitor the health and environmental conditions of the animals on a real-time basis and hence make informed decisions. This minimizes wastage and maximizes the use of resources.

Besides, digital sources allow enhanced record-keeping and data analysis, which allows farmers to connect the trends and enhance management practices in the long run. This leads to a continuous farm enhancement. The decreasing deaths in digitally integrated systems emphasize the importance of detecting and preventative interventions to eliminate early diseases. Digital solutions allow proactive health management that is essential in the system of poultry and meat production.

4.4 Regression and ARIMA Model Comparisons.

The ARIMA and regression models employed in this study provide complementary insights into livestock productivity. Regression analysis identifies key factors contributing to productivity such as feed intake and environmental control while ARIMA forecasts future trends based on historical data.

The regression model confirmed significant correlations between operational variables and productivity outcomes, underscoring the importance of management practices in influencing livestock performance.

The ARIMA model was specified as ARIMA(1,1,1) based on the Akaike Information Criterion (AIC) and visual inspection of autocorrelation and partial autocorrelation functions. This specification includes one autoregressive term ($p=1$), one differencing order ($d=1$), and one moving average term ($q=1$).

To compare the predictive accuracy of both models, we calculated the Root Mean Square Error (RMSE) for growth rate forecasts over the validation period (weeks 6–8). The ARIMA model outperformed the regression model in forecasting accuracy, with lower RMSE values for both growth rate (0.09 vs. 0.18 kg) and egg production (1.1 vs. 2.4 percentage points). This suggests that time-series dependencies captured by ARIMA provide more reliable short-term forecasts, whereas regression is better suited for explaining the influence of specific operational variables.

4.5 Implications to Livestock Farmers.

The study has a great practical implication to livestock farmers and more so the small and medium meat and poultry farmers. The digital tools may be significantly implemented to improve the productivity and reduce the inefficiencies of the operations. Farmers can use simple digital devices such as automated feeders and environmental sensors since they provide real-time statistics and optimize the management decisions. The current farm systems can be introduced to these technologies. The other critical issue that the study raises is the applicability of training and capacity building so as to raise the capacity of farmers to utilize digital technologies effectively. The returns of digital transformation will not be fully achieved without proper knowledge and skills. In addition, through the assistance of predictive models, farmers will be given an opportunity to plan periods of production and make the best use of the resources that will lead to improved profitability and sustainability. Overall, the practical implication is that the utilization of technology to help livestock production systems must be done in a strategic manner, such as through the combination of technology, training, and favorable policies.

4.6 Limitations of the Study

1. Although the digital transformation offers some advantages, there are a number of constraints that inhibit the integration of the digital transformation in livestock systems. The important issue is the prohibitive price of digital technologies that can be too expensive to small-scale farmers.
2. The lack of access to infrastructure, including, but not limited to, consistent electricity and Internet access, is also a limitation to the implementation of digital solutions, especially in rural regions. This results in a digital gap between high-tech and traditional agricultural set ups.
3. Deficit in technical skill of the farmers is another constraint that can influence the implementation of digital tools by the farmers. This is where extension services and training programs are required.
4. Issues of data privacy and data security are also problematic especially in the systems that are based on data sharing and data storage that is supported by clouds. The farmers might not be willing to use technologies that demand sharing of confidential data.

5.0 CONCLUSION

This research concludes that digital transformation makes a strong positive contribution to livestock production systems, particularly in meat and poultry, by boosting sustainability, efficiency, and productivity. The results show that effective implementation of digital tools in livestock systems is possible only with structured operational frameworks, which improve coordination and optimize farm processes. Digital adoption also enables predictive simulation and modeling, supporting informed decision-making and strategic planning. Furthermore, the research highlights critical barriers to adoption including cost, infrastructure, and technical capacity that must be addressed for widespread implementation. On balance, digital transformation represents a major pathway for enhancing livestock production systems and meeting the growing demand for animal protein.

6.0 RECOMMENDATIONS

1. Livestock farmers should adopt digital technologies in a staged approach: start with low-cost tools (e.g., mobile-based record-keeping apps for under $50), then progressively integrate automated feeders and environmental sensors once basic digital literacy is achieved. This minimizes financial risk and builds capacity incrementally.

2. Governments and policymakers should provide targeted financial incentives, such as a 30% tax rebate on IoT sensors and automated health monitoring systems for farms with fewer than 500 animals, along with low-interest loans for digital infrastructure upgrades. They should also invest in rural broadband and reliable electricity to enable connectivity.

3. Agricultural extension services should be restructured to include dedicated digital advisory units that offer on-farm training, troubleshooting, and data interpretation support. A minimum of two hands-on training sessions per farm per year should be mandated and funded.

4. Research institutions should prioritize the development of cost-effective digital solutions tailored to small and medium-scale farms, such as solar-powered sensors and open-source farm management software. Funding agencies should require that at least 30% of agricultural technology research budgets be allocated to context-appropriate innovations for low-resource settings.

5. Multi-stakeholder partnerships (farmers, technology providers, policymakers, and financial institutions) should establish regional “digital livestock hubs” that provide shared access to sensors, cloud data storage, and analytics services on a subscription basis (e.g., $10–20 per month per farm). These hubs would lower entry costs and foster collective learning.

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