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A paper from the Proceedings of the
17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture
13-15 July 2026
Porto Alegre, Brazil

DIGITAL TRANSFORMATION AND EFFICIENCY GAINS IN INTENSIVE LIVESTOCK SYSTEMS: EVIDENCE FROM BRAZILIAN FEEDLOTS

Abstract.

Precision livestock farming has emerged as central strategies to enhance productive efficiency, reduce waste, and improve the sustainability of agricultural systems. In beef cattle feedlots, digital technologies such feeding automation sensors is particularly relevant. The technology reduces feed waste, improves the planning of input purchases and cost control, and reduces the need for manual labor for weighing and distributing feed, allowing the team to focus on strategic activities. In the Brazilian context, feedlot digitalization represents a strategic opportunity to enhance competitiveness and optimize resource use. This study aimed to measure the technical efficiency of Brazilian beef cattle feedlots and to examine whether the adoption of sensors for automated feed distribution is associated with higher levels of technical efficiency. Additionally, control variables related to managerial capability and the use of formal contracts in cattle commercialization were assessed. The empirical analysis employed a Stochastic Production Frontier (SPF) model with Cobb-Douglas functional form and inefficiency effects, grounded in microeconomic production theory. This type of analysis allows for the computation of technical efficiency scores and for testing the association between efficiency and explanatory variables. The model was applied to an unbalanced panel dataset comprising 359 observations from 238 feedlots, collected between 2020 and 2023, covering all regions of Brazil. Output was measured in kilograms of finished cattle. The main inputs included total feed expenditure, feedlot static capacity, and number of workers. The inefficiency equation incorporated the following explanatory variables: adoption of feeding automation sensors, manager's educational level, difficulties in market comprehension, and use of formal sales contracts. The results indicate constant returns to scale on average and reveal substantial variation in technical efficiency across feedlots. Mean efficiency levels varied over time, suggesting significant room for managerial improvement. The adoption of feeding automation sensors was associated with an average gain of about 10

percentage points in technical efficiency. The use of formal contracts also exhibited a positive association with efficiency. These findings reinforce the role of digitalization as a strategic tool to enhance productive efficiency and promote greater economic and environmental sustainability in beef cattle feedlot systems.

Keywords.
precision livestock farming; feeding automation sensors; technical efficiency; stochastic frontier analysis; beef cattle feedlots.

Introduction

Digital transformation has become an important driver of productivity improvements in agricultural systems. In livestock production, precision livestock farming technologies create opportunities to improve operational control, optimize resource allocation, and reduce production inefficiencies (Makinde et al., 2022; Morrone et al., 2022). Among these technologies, automated feed delivery systems have gained increasing attention because feed represents the largest operational cost in beef cattle feedlots.

Automated feeding technologies combine sensors, data collection, and real-time control systems to improve feed distribution accuracy and reduce waste. In addition to improving feeding precision, these systems support production planning, inventory control, and labor allocation, allowing managers to focus on higher-value strategic activities (Flores et al., 2017; García et al., 2020). Despite their growing adoption, empirical evidence regarding their contribution to productive efficiency remains limited, particularly in emerging economies (Rosa, 2021; Vinholis et al., 2025).

Brazil is one of the largest beef producers in the world and has experienced rapid expansion of feedlot production systems over the last decade. In this context, understanding how digital technologies contribute to efficiency gains is important for both farm management and policy development. Therefore, this study evaluates the technical efficiency of Brazilian beef cattle feedlots and investigates whether the adoption of automated feed delivery systems is associated with higher levels of productive efficiency.

Materials and Methods

The analysis was conducted using a unique database comprising 359 observations collected from 238 commercial beef cattle feedlots located across all regions of Brazil between 2020 and 2023. The dataset represents a broad range of feedlot operations and production scales, covering an important share of the Brazilian feedlot industry.

Technical efficiency was estimated using a Stochastic Production Frontier (SPF) model with inefficiency effects. Output was measured as kilograms of finished cattle, while the production frontier incorporated the principal production inputs, including feed expenditure, feedlot production capacity, and labor. The inefficiency model included variables associated with the adoption of automated feed delivery technologies and integrated management software, as well as control variables related to managerial characteristics.

The analytical framework allows the estimation of technical efficiency scores while simultaneously assessing the association between technology adoption and productive performance. This approach has been widely employed to evaluate efficiency differences among agricultural production systems and the role of technology adoption in resource utilization (Carrer et al., 2022; Delay et al., 2022).

Results and Discussion

The estimated production frontier revealed positive contributions of feed, labor, and production capacity to feedlot output. The results also indicated substantial variability in efficiency levels among farms, suggesting that many operations remain below their production potential and could increase output through improvements in management and resource utilization.

The adoption of automated feed delivery systems was positively associated with technical efficiency. Feedlots using automation technologies achieved efficiency levels approximately 10 percentage points higher than those operating with conventional feeding systems. This result highlights the importance of feeding precision as a mechanism for improving productive performance in intensive livestock systems.

Several operational factors may explain these efficiency gains. Automated systems enable more accurate feed allocation according to animal requirements, reducing feed waste and improving feed conversion efficiency. Real-time monitoring and automated distribution also contribute to greater consistency in feeding practices, reducing operational variability and minimizing human error. Similar benefits have been highlighted in studies examining precision livestock farming technologies and automated feeding systems (Flores et al., 2017; García et al., 2020; Tzanidakis et al., 2023).

The findings further suggest that efficiency gains associated with automation tend to be more pronounced among smaller feedlots. This pattern indicates that digital technologies may help compensate for managerial and informational limitations that are often more restrictive in smaller operations. By introducing greater process standardization and operational control, automated systems allow these farms to move closer to their production frontier.

Beyond direct effects on feeding operations, automation contributes to broader management improvements. The information generated by automated systems can support purchasing decisions, inventory management, production planning, and performance monitoring. In addition, the reduction in manual feeding activities allows employees to dedicate more time to supervision and strategic management functions, increasing overall operational efficiency. These findings reinforce previous evidence that digital technologies can enhance operational efficiency by improving information availability and decision-making processes (Yang et al., 2021; Liu et al., 2023).

Conclusion or Summary

This study provides empirical evidence that automated feed delivery systems are associated with significant efficiency gains in Brazilian beef cattle feedlots. Feedlots adopting automation technologies achieved higher technical efficiency levels, indicating more effective utilization of production resources and improved operational performance.

The findings demonstrate that feeding automation contributes to greater feeding precision, reduced waste, improved process control, and better allocation of labor and managerial resources. These benefits appear particularly relevant for smaller feedlots, where the potential for efficiency improvement is greater.

From a practical perspective, the results support investments in precision livestock farming technologies as a strategy to enhance competitiveness, profitability, and sustainability in intensive beef production systems. As digital transformation continues to expand within agriculture, automated feeding systems are likely to play an increasingly important role in improving the efficiency and resilience of livestock operations.

Acknowledgments

This research work was supported by São Paulo Research Foundation – FAPESP [grant number 2022/02967-5; 2023/14466-3] and Brazilian Agricultural Research Corporation [Embrapa SEG 40.19.03.060.00.02.010].

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