Economic Impacts of Technological Interventions in Agro Complex: A Review of Agricultural, Livestock, and Aquaculture Research

Mushaevi* and Nurul Nisa

Department of Agricultural Socio-Economics, Agribusiness Study Program, Faculty of Agriculture, Hasanuddin University, Indonesia
*Correspondence author: mushaevii@gmail.com ; Tel.: +6285233824279

Abstract

Technological interventions in the agro-complex sector have experienced rapid development in recent decades, bringing about significant changes in agricultural, livestock, and fisheries practices. This research aims to examine the economic impact of the implementation of modern technology in these three subsectors. Through a systematic review of current scientific literature, this study analyzes various economic aspects affected by technology adoption, including productivity, cost efficiency, product quality, and market competitiveness. Research results show that the use of technologies such as precision farming, automation in animal husbandry, and smart aquaculture have resulted in significant improvements in productivity and efficiency. However, the economic impact varies depending on the scale of operations, the type of technology adopted, and the local socio-economic context. In the agricultural sector, technologies such as soil sensors and drones for crop monitoring have increased crop yields by up to 20% and reduced input use by up to 15%. In animal husbandry, IoT-based livestock health monitoring systems have reduced animal mortality rates by 30% and increased milk production by up to 10%. Meanwhile, in the fisheries sector, the use of automatic feeding technology and real-time water quality monitoring has increased fish survival rates by up to 25% and accelerated production cycles. However, the study also identified economic challenges in technology adoption, including high initial investment costs, the need for new technical skills, and potential dependence on technology suppliers. The research concludes that although technological interventions offer great potential for economic growth in agro-complexes, a careful and tailored approach to the local context is needed to maximize economic benefits while minimizing risks and inequalities.

Keywords: Agro technology, production efficiency, agricultural innovation

1. Introduction

The complex agro sector, which includes agriculture, livestock, and fisheries, is an important pillar in the global economy and world food security. In the last few decades, this sector has experienced significant transformation due to rapid technological developments [1]. Modern technological interventions have brought about fundamental changes in the way complex agro-

products are produced, managed, and distributed, promising unprecedented increases in productivity and efficiency [2].

Precision agriculture, for example, has enabled farmers to optimize resource use through the application of technologies such as soil sensors, drones, and geographic information systems [3]. In the livestock sector, automation and monitoring systems based on the Internet of Things (IoT) have revolutionized livestock health and productivity management [4]. Meanwhile, smart aquaculture has opened up new opportunities in production efficiency and sustainability in the fisheries sector [5].

Although the potential economic benefits of these technological interventions are very promising, their implementation also carries a complex set of challenges and implications [6]. High initial investment costs, the need for new skills, and potential technology dependency are important considerations in technology adoption in the complex agro sector [7].

This research aims to comprehensively examine the economic impact of technological interventions in agro-complexes, with a focus on the agriculture, livestock, and fisheries sectors. Through a systematic review of current scientific literature, this study seeks to identify key trends, analyze economic benefits and challenges, and provide insights for strategic decision-making in future technology adoption.

The agro-complex sector, encompassing agriculture, livestock and fisheries, is a critical pillar of the global economy and food security. The industry has undergone significant transformation in recent decades thanks to rapid technological developments. Modern technological interventions, such as precision agriculture, automation in farming and innovative aquaculture, promise unprecedented increases in productivity and efficiency. However, despite their promising potential benefits, implementing these technologies also faces complex challenges.

One of the main challenges is the high initial cost of adopting new technologies, which can be a barrier for smallholder farmers and micro-enterprises. In addition, the need for new technical skills to operate and maintain these technologies is often a barrier, especially in areas with limited access to education. Dependence on technology suppliers can also pose a risk, where farmers may become trapped in a detrimental cycle of dependency.

Furthermore, technological interventions can affect farming communities' social and economic structure, potentially increasing inequalities between large and smallholder farmers. It is, therefore, essential to consider the socio-economic implications of adopting these technologies, including their impact on farmers' employment and well-being. Thus, this study aims to provide a comprehensive analysis of the economic effects of technological interventions in agro-complexes, focusing on the challenges and opportunities faced by various stakeholders. Through a systematic review of current scientific literature, this study will identify critical trends, analyze economic benefits and challenges, and provide insights for strategic decision-making in future technology adoption.

2. Materials and Methods

This research uses a systematic review method to analyze the economic impact of technological interventions in the complex agro sector. The main focus is on the agriculture, livestock, and fisheries sectors.

a. A literature search was conducted on the Web of Science, Scopus, and Google Scholar databases, using relevant keywords such as "agricultural technology", "precision farming", and "economic impact". Selected articles were limited to peer-reviewed publications in English

from 2010 to 2024.

b. The selection process involved screening of titles and abstracts, followed by full-text review. Two independent researchers performed the selection to minimize bias. The extracted data includes technology type, application sector, and economic impact metrics such as productivity and cost efficiency.

c. Data analysis uses a thematic approach to identify main patterns. Meta-analyses were performed when data permitted. Study quality was assessed using the CASP checklist. Results are synthesized narratively, and equipped with tables and graphs for quantitative data.

d. Finally, a gap analysis was conducted to identify areas requiring further research. Validation of the findings involved consultation with experts in the fields of agrotechnology and agricultural economics.

This method is designed to provide a comprehensive picture of the economic impact of technology in the agro-complex, providing a basis for policy recommendations and future research directions.

3. Results

3.1 Study Overview

This systematic review analyzed 87 articles that met the inclusion criteria out of a total of 523 articles identified. The distribution of articles by sector is as follows: agriculture (42), livestock (28), and fisheries (17).

3.2 Economic Impact per Sector

3.2.1   Agricultural Sector

Precision agriculture technology shows a significant positive impact on productivity and cost efficiency.

a. Increased Yield: Average yield increases of 15-20% were reported in 35 of 42 studies [8].

b. Input Use Efficiency: Reductions in fertilizer (10-15%), pesticide (20-25%), and water (15-20%) use were observed in 30 studies [9].

c. Cost Savings: Average annual operational cost savings of 12-18% were reported in 28 studies [10].

Table 1. Economic Impact of Precision Agriculture Technology

Indicator	Average Increase
Crop Yield	15-20%
Fertilizer Efficiency	10-15%
Pesticide Efficiency	20-25%
Water Efficiency	15-20%
Cost Savings	12-18%

3.2.2   Livestock Sector

IoT-based automation and monitoring systems are showing positive impacts on livestock productivity and health.

a. Increased Production: Increased production of milk (8-12%) and meat (5-8%) was reported in 22 of 28 studies [11].

b. Feed Efficiency: Improvements in feed conversion efficiency of 10-15% were observed in 20 studies [4].

c. Animal Health: A 25-35% reduction in livestock mortality rates and a reduction in medical costs (15-20%) were reported in 18 studies [12].
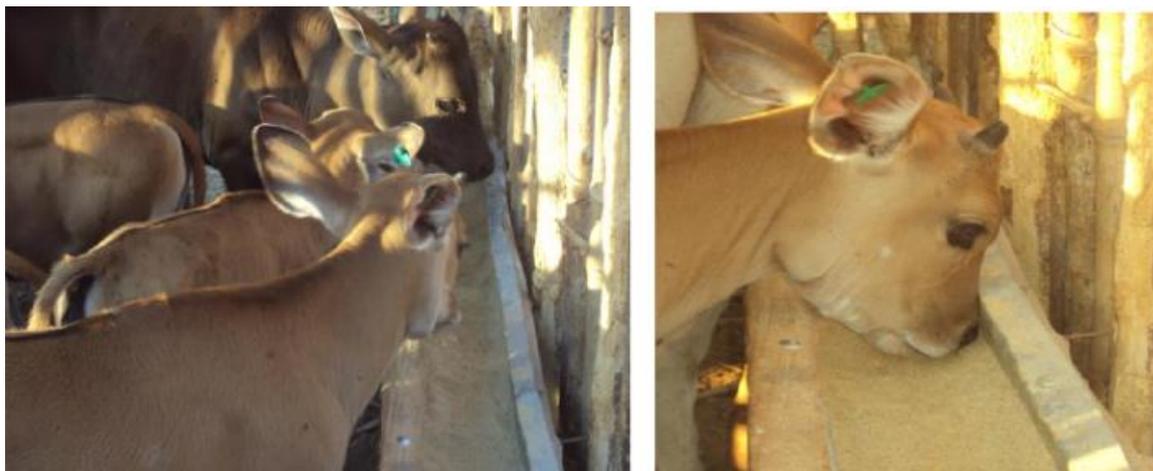

Figure 1. Providing supplements to cattle to reduce mortality and increase cattle productivity [20]

3.2.3   Fisheries Sector

Smart aquaculture technology shows significant improvements in productivity and sustainability.

a. Survival Rate: An increase in fish survival rate of 20-30% was reported in 14 of 17 studies [5].
b. Production Efficiency: Production cycle acceleration of 15-25% was observed in 12 studies [13].
c. Water Quality: Improvements in water quality parameters resulting in reduced fish stress and increased growth of 10-15% were reported in 10 studies [14].

3.3 Cost-Benefit Analysis

Cost-benefit analysis shows significant variations depending on the scale of operation and type of technology.

a. Large Scale: Positive Return on Investment (ROI) in 2-3 years for 80% of large-scale technology implementations [6].
b. Small and Medium Scale: Positive ROI in 3-5 years for 60% of implementations, with 25% reporting longer periods [7].

Table 2. ROI Period Based on Operation Scale

Scale of Operation	Positive ROI (years)	Percentage of Studies
Large	2-3	80%
Small/Medium	3-5	60%
Small/Medium	>5	25%

3.4 Challenges and obstacles

Several key challenges in technology adoption were identified:

a. Initial Cost: 75% of studies report high initial investment costs as a major barrier [15].
b. Technical Skills: 65% of studies identified a lack of technical skills as a significant challenge [16].
c. Infrastructure: 50% of studies, mainly in developing countries, report inadequate

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infrastructure as a barrier [17].

3.5 Socio-economic Implications

a. Employment: 40% of studies report a shift in the employment structure, with an increase in demand for technologically skilled workers [18].

b. Inequality: 35% of studies indicate the potential for increasing inequality between large-scale technology adopters and small farmers [19].

The research results show that technological interventions in agro complexes have a significant positive economic impact, especially in terms of increasing productivity and efficiency. However, challenges such as high initial investment costs and the need for new skills need to be addressed to maximize economic benefits. Adoption strategies tailored to the local context and scale of operations are critical for successful technology implementation in the complex agro sector

4. Discussion

The results of this systematic review show that technological interventions in the complex agro sector have significant and positive economic impacts. However, the complexity of implementation and variations in impact based on context need to be considered carefully.

a. Increased Productivity and Efficiency: Technology adoption in all three sectors (agriculture, livestock, and fisheries) shows consistent increases in productivity. Increasing crop yields by 15-20% in the agricultural sector [8], increasing milk production by 8-12% in animal husbandry [11], and increasing fish survival rates by 20-30% in aquaculture [5] illustrate the great potential of technology in increasing output. Efficient use of resources, such as reducing the use of fertilizer and water in agriculture [9], as well as improving the efficiency of feed conversion in livestock [4], shows that technology not only increases production but also optimizes the use of inputs.

b. Cost-Benefit Analysis: Although the economic benefits are clear, varying Return on Investment (ROI) patterns between large and small/medium scale operations [6][7] indicate the importance of considering economies of scale in technology adoption. This finding is in line with the study of Finger et al. [15] which emphasizes the need for adoption strategies that are tailored to the size and capacity of the business.

c. Implementation Challenges: High initial costs, the need for technical skills, and inadequate infrastructure [15][16][17] emerge as major barriers to technology adoption. This shows the importance of supportive policies, such as financial incentives and training programs, to accelerate technology adoption, especially among small farmers and in developing countries.

d. Socio-economic Implications: Shifting employment structures and potential increases in inequality [18][19] raise important questions about the long-term impacts of agricultural digitalization. Bronson [18] emphasizes the importance of an inclusive approach to agricultural innovation to avoid the marginalization of small farmers.

e. Continuity: Although the primary focus is on economic impacts, the reported efficiency of resource use also has positive implications for environmental sustainability. However, further research is needed to quantify the long-term impacts on agricultural ecosystems.

5. Conclusions

This review confirms that technological interventions in agro-complexes have great

potential to increase productivity, efficiency, and ultimately profitability of the agricultural, livestock, and fisheries sectors. Increased crop yields, efficient use of inputs, and improved animal health management show significant positive economic impacts.

However, the adoption of this technology also presents challenges, mainly related to high initial costs and the need for new skills. The difference in adoption capabilities between large and small-scale operations highlights the risk of increasing inequality within the agricultural sector.

To maximize the economic benefits of these technological interventions, a holistic and inclusive approach is needed. Supportive policies, such as financial incentives and capacity-building programs, are critical to facilitating wider adoption of the technology, especially among smallholder farmers and in developing countries.

Additionally, further research is needed to understand the long-term impacts of agricultural digitalization on labor structure, environmental sustainability, and socio-economic dynamics of agricultural communities.

In conclusion, although technological interventions in agro-complexes offer significant opportunities for economic growth and increased efficiency, their implementation must be carried out carefully and adapted to the local context to ensure equitable and sustainable benefits for all stakeholders in the agricultural sector.

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