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Comparative Review on Integration of Epidemiological and Econometric Models in Livestock Health Economics

J. Shilpa Shree, G. Kathiravan, M. Prabu, N. K. Sudeep Kumar, G. Vijayakumar

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ABSTRACT

Livestock diseases pose serious challenges in respect to animal productivity, farm incomes, public health, and market stability. This review examines how the integration of epidemiological and econometric models helps to understand the livestock health economic analysis. Epidemiological models explain about the disease transmission patterns, risk factors involved, and control measures dynamics, while econometric models include the quantification of production losses, intervention costs, and economic returns. The paper includes various evidences across bacterial, viral, parasitic, fungal, and nutritional diseases, and also it highlights how this combined modeling frameworks improve the evaluation of prevention, control, and eradication strategies. Despite their advantages, their usage is limited due to limited interdisciplinary collaboration and data constraints. Strengthening this integration is essential for One Health framework includes efficient allocation of resources, evidence-based policy formulation, and sustainable livestock health management.

Keywords Epidemiology, Econometrics, Models, Livestock, Health, Economics.

INTRODUCTION

Livestock products represent almost half the value of agricultural production worldwide (FAO 2009). Animal diseases in production have the higher potential to negatively affect consumers, producers, and economies as a whole. Understanding the burden of animal disease and its distribution throughout the value chain informs policy that promotes safe consumption and efficient markets. The paper also points to a need for creating an analytical framework based on established methods that guides future evaluation of animal disease burden, which will provide improved access to information on animal health impacts. Animal health economics is crucial for several reasons i.e., animal diseases can have significant financial consequences, efficient allocation of resources, some animal diseases

J. Shilpa Shree[1*], G. Kathiravan[2], M. Prabu[3], N. K. Sudeep Kumar[4], G. Vijayakumar[5]

[1]Assistant Professor, [2,3,4,5]Professor and Head
[1,2]Dept of Animal Husbandry Statistics and Computer Applications, MVC, Chennai, India

[3]Dept of Livestock Economics and Business Management, MVC, Chennai, India

[4]Dept. of Veterinary and Animal Husbandry Extension Education, MVC, Chennai, India

[5]Dept. of Clinics, Madras Veterinary College, Chennai, India

Email: shilpashreej23@gmail.com
*Corresponding author

are zoonotic which can pose serious risks to human health, policymakers rely on economic analyses which in turn helps in formulating the effective policies related to animal health, livestock often play a crucial role in the livelihoods of farmers, understanding the economic implications of animal health is vital for maintaining access to global markets, limited resources for research which necessitate prioritization and recognizing the interlink between animal, human, and environmental health, animal health economics contributes to the "One Health" approach, to address complex health challenges by promoting the collaboration among various disciplines.

By quantifying the economic effects of animal diseases, developing methods for optimizing decisions when individual animal, herds or populations are affected, and determining the profitability of control measures and any health management programs is possible. Two types of modelling techniques are used in economic analysis of animal health: Quantitative analytical models and Qualitative analytical models. Economics comprises both economic theory and methods, which form the framework or tool kit used to analyze economic problems or to plan for the future. The literature consistently reinforces concerns that available academic information is insufficient for producers to make financially optimal decisions regarding disease prevention and treatment measures (Jones *et al.* 2019). Additionally, economic modeling techniques have been recognized as underutilized tools that can enrich animal disease analysis, with various economic models available for application in animal health research, though their integration with epidemiological modeling requires multidisciplinary approaches (Rich *et al.* 2005).

Epidemiological and econometric models in bacterial diseases of livestock

Epidemiological models play a crucial role in understanding and controlling bacterial diseases in livestock populations., stochastic models were developed to quantify disease transmission dynamics in structured domestic animal populations (MacKenzie and Bishop 2001). To quantify disease transmission dynamics in structured domestic animal populations, stochastic models were developed. A systematic literature review by Ballesteros-Ricaurte *et al.* (2022) identified various mathematical models used for epidemiological analysis of bovine infectious diseases. The three main applications of epidemiological models in animal disease surveillance are planning surveillance activities, evaluating surveillance system performance, and interpreting surveillance data for ongoing control programs. For livestock disease transmission modeling, various approaches have been employed, including individual-based network models and compartmental models, with studies showing that simple compartmental models can effectively capture key outbreak features despite some overestimation of outbreak speed (Schley *et al.* 2012). A systematic review identified 37 contact network models across seven frameworks, with nearly half used as inputs for network-based epidemiological models (Leung *et al.* 2023). Bennett (2003) developed standardized models to estimate direct costs of 30 endemic livestock diseases in Great Britain, providing a transparent framework for cost-benefit analyses of disease control options that can be easily communicated to veterinary scientists and policy makers. McInerney (1996) established the theoretical foundation for treating animal disease as an economic problem, proposing basic models rooted in production economics to analyze disease costs and optimal control strategies. Chi *et al.* (2002) applied this framework empirically, developing models to determine optimal control strategies for four cattle diseases (BVD, EBL, Johne's Disease, and neosporosis) in Maritime provinces, emphasizing introduction checks and vaccination as cost-effective approaches.

Epidemiological modeling of mastitis in livestock has evolved from basic statistical approaches to sophisticated predictive models. Early work focused on statistical modeling challenges, particularly addressing over dispersion issues when analyzing mastitis occurrence at different levels (herd, lactation, animal, udder, quarter) and proposed both generalist exploratory and explanatory designed models (Gasqui and Barnouin 2003). Survival models have been developed to account for dependence between consecutive mastitis cases within and between lactations, incorporating parameters like infection rates at calving and seasonal variations (Gasqui *et al*. 2003). Recent advances include mathematical SIR and SIRS models combined with machine learning algorithms, achieving 34.13% annual prevalence predictions with decision table classification showing optimal performance (Nakov *et al.* 2024). Predictive models using overdispersed Poisson regression have identified key risk factors including production potential (1.4 cases per 10 kg increase) and calving season, with gamma distributions modeling time intervals between cases (Lescourret *et al.* 1995). Clinical mastitis in early lactation costs an average of $444 per case, with indirect costs representing 71% of total expenses, including future milk production losses (28%) and premature culling costs (41%) (Rollin *et al.* 2015). A systematic review found average failure costs of mastitis at $131 per cow annually across 77 studies (Hogeveen *et al*. 2019). Simulation modeling identified clinical mastitis incidence and bulk tank somatic cell count as the most significant factors affecting economic impact, with preventive measures showing excellent cost-benefit ratios compared to curative treatments (Lopes *et al.* 2017). Stochastic bio-economic models in Ethiopian dairy farms estimated total mastitis costs at 838 ETB per cow annually, with culling being the largest cost component and clinical mastitis probability being the most sensitive parameter (Getaneh *et al.* 2017). Mathematical models based on susceptible-infectious-recovered (SIR) frameworks have been developed to simulate brucellosis transmission in cattle populations, with studies examining test-and-slaughter, transmission rate reduction, and mass vaccination strategies (Kang *et al.* 2016). Network-based models incorporating livestock trade data have proven valuable for understanding disease spread patterns, with deterministic SIR and stochastic SEIR models showing improved efficacy over traditional tracing methods (Savini *et al.* 2017). Dynamic compartmental models have been applied to study animal-to-human transmission, revealing that 90% of human brucellosis cases were small-ruminant derived in Mongolia (Zinsstag *et al.* 2005). Age-structured stochastic models incorporating herd demographics have been used to evaluate control strategies in endemic settings, demonstrating that vaccination of replacement calves should be prioritized over test-and-removal approaches in high-prevalence areas (Holt *et al.* 2023). Brucellosis represents a significant global health and economic burden as a highly contagious zoonotic disease with worldwide distribution, remaining endemic in many countries and settings (Racloz *et al.* 2013). Mathematical modeling approaches have proven essential for understanding disease transmission dynamics and evaluating control strategies, with researchers employing various methodologies including stochastic age-structured models, matrix models, coupled differential equations, individual-based network models, and compartmental models to capture the complexities of brucellosis transmission (Racloz *et al.* 2013; Holt *et al.* 2023; Schley *et al.* 2012). Mendes *et al.* (2025) developed an integrated epidemiological-economic modeling framework using Bayesian latent-class analysis and herd-growth models to estimate production losses in Tanzania, finding annual losses of $74.4 per infected cattle in pastoral systems and $62.3 in non-pastoral systems. Dietrich *et al.* (1986) created BRUSIM, a systems simulation model, and TECHSIM, an econometric model, to analyze eight alternative bovine brucellosis control programs in the United States, measuring epidemiologic parameters and determining benefit-cost ratios for different interventions. Wang *et al.* (2023) proposed a dynamic model incorporating economic factors and farmer behaviors, using Pontryagin Maximum Principle to identify optimal control strategies that maximize farmer profits while controlling disease transmission. Homem *et al.* (2016) developed an economic impact model for Brazil, estimating annual losses of R$.132,676.23 for brucellosis in Pirassununga municipality, demonstrating the significant economic burden of the disease. Bayesian partial-likelihood approaches using summary data from British cattle outbreaks revealed low test sensitivities and high within-herd basic reproduction numbers, suggesting many unobserved infections despite effective control in most cases (O'Hare *et al*. 2014). Mathematical modeling of bTB faces particular challenges due to substantial epidemiological uncertainty, with studies showing relatively low within-herd transmission rates under test-and-cull programs, though differences exist in estimated infection stage lengths and transmission types (Álvarez *et al.* 2014). Wildlife reservoir modeling in badger populations demonstrated that tuberculosis can persist in social groups and doesn't follow classical epidemiological patterns (Smith *et al.* 2001). Economic feasibility modeling for national eradication programs, as demonstrated in

Argentina, suggests that while control programs may be financially viable long-term, initial investment costs and extended timeframes may limit producer participation, indicating regionalized approaches could improve success rates (Perez *et al.* 2011). Hone (2013) used model selection regression analyses to demonstrate diminishing returns in bTB control costs, finding that curved models better explained the relationship between disease prevalence and control expenditures than linear models, suggesting TB eradication is feasible in New Zealand. Tschopp *et al.* (2022) developed a matrix population model to estimate productivity losses from bTB in Ethiopian dairy cattle, calculating a net present value loss of 7.3% or $219 per animal over 10 years. Homem *et al.* (2016) created an economic impact model for Brazil, estimating annual losses of R$132,676-430,252 from tuberculosis in Pirassununga municipality.

Comprehensive economic modeling frameworks have been developed for the Australian red meat industry, prioritizing 23 sheep and 9 goat diseases based on prevalence, distribution, and economic impact using specialized Excel models (Lane *et al.* 2015). Advanced mathematical programming models now incorporate resilience traits, showing that disease-resistant animals can improve farm profitability by up to 23.5% when addressing mastitis, parasitism, and lameness (Theodoridis *et al.* 2023). Jones *et al.* (2019) found that while poultry disease literature primarily focuses on epidemiology, very few publications provide financial impact estimates, despite diseases like coccidiosis and clostridiosis making flocks loss-making without intervention. Markos and Abdela (2016) highlighted Pullorum disease as causing substantial economic losses through high mortality rates up to 100% and decreased production, emphasizing the need for strict biosecurity measures. Garcia *et al.* (2013) developed probabilistic graphical models integrating epidemiological evidence with Bayesian methods to support decision-making for Campylobacter control, demonstrating how vaccination strategies can achieve significant financial gains under appropriate reward systems.

Nathues *et al.* (2017) developed an integrated epidemiological-economic model for porcine reproductive and respiratory syndrome (PRRS), demonstrating annual losses ranging from €75,724 to €650,090 depending on disease severity and affected production stages. Their model serves as a decision-support tool for evaluating control measure profitability. Garner *et al.* (2001) used similar integrated approaches to assess exotic diseases in Australia's pig industry, finding that epidemics could cause regional income losses of AUS$10–30 million, while endemic establishment would result in 5–11% annual gross national pig income losses. Collins (2013) emphasized the importance of economic modeling for ileitis control, highlighting how new diagnostic assays and economic models help producers optimize treatment timing and minimize production losses. Ross *et al.* (2011) developed an agent-based epidemiological model focusing on bovine tuberculosis transmission in beef and dairy industries, demonstrating how inter-operation livestock transfers impact disease outbreaks.

Epidemiological and econometric models in viral diseases of livestock

Applications of simulation models for infectious bovine rhinotracheitis (IBR), where Vonk Noordegraaf *et al.* (1998) demonstrated that voluntary vaccination programs with 50% participation would be insufficient for eradication, requiring compulsory vaccination strategies. Similarly, Gethmann *et al.* (2019) evaluated 13 control scenarios for Bovine Viral Diarrhea (BVD) in Germany, finding that only strategies combining testing with compulsory vaccination could achieve complete eradication, though none were economically attractive with benefit-cost ratios below 1.0. FMD model was used to simulate the spread of FMD following a hypothetical introduction in Scotland and simulate various scenarios of vaccination.

Knobel *et al.* (2005) developed linked epidemiological and economic models to quantify the burden of endemic canine rabies in Africa and Asia, estimating 55,000 annual deaths and USD 583.5 million in costs, with patient-borne post-exposure treatment costs comprising nearly half of total expenditure. Smith (2018) reviewed the evolution of rabies modeling from simple mathematical approaches to more realistic biological models incorporating spatial and individual variation, particularly highlighting fox rabies models in Europe and dog rabies models supporting the 70% vaccine threshold for elimination. Sterner and Smith (2019) analyzed wildlife rabies models, comparing linear density-dependent and density-independent approaches, and examining economic analyses of post-exposure prophylaxis and vaccination strategies. Economic modeling of bovine viral diarrhea has evolved from traditional approaches focusing on production losses to sophisticated integrated frameworks (Stott *et al.* 2003; Chi *et al.* 2002). The MOTAD linear programming model establishes combinations of activities that minimize risk for given income levels within farm constraints, applied to Scottish cow-calf herds linked to BVD epidemiological models (Stott *et al.* 2003). Theoretical and empirical models determine optimal control strategies by estimating control functions and minimizing total disease costs (Chi *et al.* 2002). Mechanistic simulation models are increasingly used as decision-making tools, with systematic review identifying 76 studies based on 52 individual models incorporating biological, farming-related, and pathogen-related processes (Thulke 2011).

Mathematical and computational models serve diverse purposes in veterinary epidemiology, from disease transmission analysis to economic impact assessment. Stochastic simulation models classify herds into susceptible, infectious, recovered, or vaccinated states, with epidemiological outputs serving as input for economic modules (Santman-Berends *et al.* 2015). Kernel-based modeling is popular for lumpy skin disease, organized into four categories: risk factors, transmission behaviors, diagnosis and forecasting, and intervention strategies (Renald *et al.* 2023). Advanced probabilistic models include Bayesian networks and machine learning algorithms for diagnostic support (Taras *et al.* 2024). Economic models incorporate production losses, testing costs, and vaccination expenses, demonstrating benefit-to-cost ratios of 1.1-1.5 for BVDV control scenarios (Santman-Berends *et al.* 2015). Models have estimated substantial industry-wide impacts, including €27.8 million annual costs for Dutch dairy and £22-43 per cow yearly losses in Scottish beef herds (Barbudo *et al.* 2008; Santman-Berends *et al.* 2015).

Research on viral diseases in sheep and goats has employed various econometric and mathematical modeling approaches to assess disease impacts and farm management strategies. Truong *et al.* (2014) developed quantitative time-course models to evaluate peste des petits ruminants virus (PPRV) pathogenesis and tissue tropism in both sheep and goats, providing experimental parameters for vaccine evaluation. Theodoridis *et al.* (2023) created a comprehensive linear programming model within the SMARTER project to simulate economic performance of sheep and goat farms, incorporating resilience traits against infectious and noninfectious diseases, demonstrating up to 23.5% increases in gross margins when animal resilience reduces disease impact.

A comprehensive review identified 117 studies from 1994-2020, revealing that modeling approaches vary by pathogen type: enzootic viruses like swine influenza and PRRS are typically studied at herd scale to evaluate husbandry practices, while epizootic agents such as classical swine fever are analyzed using spatio-temporal models for surveillance protocols (Andraud and Rose 2020). Economic disease models demonstrate substantial financial impacts, with PMWS and PCV2 subclinical infections costing the English pig industry approximately £52.6 million annually (Alarcón *et al.* 2013). Stochastic models using Population Dynamics P systems show that early vaccination of >75% of populations is critical for controlling Aujeszky's disease, with outbreak costs ranging from 352-792 Euros per sow annually (Colomer *et al*. 2020). Rist *et al.* (2015) developed a coupled ecological-economic framework to estimate disease burden, finding that households in Madagascar may lose 10-25% of monthly income due to poultry diseases. Oyekole (1984) created a deterministic mathematical model to assess economic effects of disease outbreaks in broiler flocks, demonstrating the high costs of disease on Nigerian poultry farms. Delabouglise *et al.* (2017a) combined wavelet analysis, economic analysis, and disease transmission modeling to explore H5N1 dynamics in Vietnam, showing how economic factors like increased poultry demand during Lunar New Year festival influence seasonal disease patterns. Economic-epidemiological models integrate farmer profit maximization with disease transmission parameters (Boni *et al.* 2013). Regression models analyze virus spread patterns within infected farms, revealing linear associations between mortality and infection time (Yoon *et al.* 2005). SIR methodology is incorporated into economic cost-minimization frameworks for analyzing mitigation options in small poultry sectors (Elbakidze 2008). Fofana *et al.* (2015) integrated epidemiological and economic models for ex-ante cost-benefit analysis of BTV8 control strategies in Scotland, finding that 50% vaccination across all of Scotland as a protection zone was economically optimal. Courtejoie *et al*. (2018) conducted a systematic review of 21 compartmental mathematical models for European BTV transmission, highlighting their value as flexible frameworks for epidemiological insights and evidence-based decision-making despite reliance on strong assumptions. G. G. *et al.* (2021) analyzed foot-and-mouth disease (FMD) in India, finding higher incidence in crossbred and productive animals, with total economic losses ranging from USD 152-3,159 million depending on severity scenarios. Govindaraj *et al.* (2017) studied hemorrhagic septicemia in Karnataka, India, reporting higher morbidity in small farms and crossbred cattle, with projected state losses of USD 11.95-23.89 million under different incidence scenarios and vaccination benefit-cost ratios of 2.98-5.97:1.

Epidemiological and econometric models in parasitic diseases of livestock

Epidemiological and econometric models play crucial roles in understanding and controlling parasitic diseases in livestock. Historical applications have demonstrated success in forecasting and decision-making, with early simple models proving particularly effective for parasitic infections in domestic ruminants (Smith 2011). These models serve as aids to thought and decision-making tools for disease control strategies. Economic burden assessments reveal substantial costs, with major helminth infections in European ruminants estimated at hundreds of millions of euros annually across different livestock categories (Charlier *et al.* 2020). Standardized modeling approaches have been developed to estimate direct costs of endemic diseases, providing frameworks for cost-benefit analyses of control options (Bennett 2003). Despite their utility, significant data gaps remain, creating uncertainties in burden estimates and highlighting needs for improved epidemiological data collection.

Dobson *et al.* (2009) developed demographic and infectious disease models for Trypanosoma evansi in Philippine buffalo populations, demonstrating that targeted treatment strategies could achieve 81% benefit increases over untreated animals, with total net-benefits reaching US $158,000 annually per village. Rashid *et al.* (2018) conducted a systematic review of economic modeling approaches for cattle parasitic diseases, finding average financial losses of US $50.67 per animal annually and milk production decreases of 1.16 L per animal daily. Walker *et al.* (2014) used modeling to show that acaricide applications on cattle significantly reduce tick populations and pathogen loads in cattle but are insufficient to control disease transmission in multi-host systems including wildlife reservoirs. Epidemiological models demonstrate how gastrointestinal nematode parasites affect grazing system stability by reducing herbivore feeding rates, creating density-dependent constraints that stabilize system dynamics (Grenfell 1988). Fasciolosis specifically causes significant economic losses through morbidity and mortality in ruminants, with Fasciola hepatica and Fasciola gigantica being the most veterinary-important species (Tsega *et al.* 2015). In Brazil specifically, combined annual losses from internal and external parasites reach approximately USD 13.96 billion, with gastrointestinal nematodes causing the highest impact at $7.11 billion (Grisi *et al*. 2014). Transmission models are increasingly important for assessing climate change impacts on nematode epidemiology and evaluating adaptive control measures, particularly as anthelmintic resistance threaten current control approaches (Verschave *et al.* 2016). Liver fluke disease (fascioliasis), caused by Fasciola spp., is widespread and leads to economic losses through costs of treatment, liver condemnation, and reduced productivity in buffalo and other ruminants (Saleha 1991).

In Bangladesh, gastrointestinal parasites are highly prevalent in buffalo, with infection rates influenced by age, sex, season, and nutritional status, highlighting the need for economic loss assessment and effective control strategies (Biswas *et al.* 2014). Eimeria sp. infections also cause significant economic losses due to mortality and impaired nutrient absorption in buffalo calves (Bastianetto *et al*. 2007). Gastrointestinal helminthic infections represent a significant challenge for sheep and goat production globally, causing considerable economic losses through mortality and reduced productivity (Sharma 2020). Multiple parasite species affect small ruminants, with Haemonchus contortus being consistently identified as the most prevalent nematode in various regions including Ghana and Brazil (Blackie 2014). The epidemiology of these infections is influenced by several factors including climate, management practices, and socioeconomic conditions (Sharma 2020, Blackie 2014). Seasonal patterns are particularly important, with rainfall directly correlating to infective larvae availability on pastures and higher infection rates during rainy seasons (Blackie 2014). Strategic treatment schedules based on epidemiological understanding have been advocated for effective control (Skerman *et al.* 1968). The diversity of parasites includes trematodes, cestodes, and nematodes, with emerging threats from species like Marshallgia and Ostertagia reported in Afro-Asian regions (Sharma 2020). Choudhury *et al.* (2013) developed a Markov-probability decision-tree model to quantify economic burdens of pig-associated zoonotic diseases including cysticercosis, taeniasis, and trichinellosis in Lao PDR, finding substantial losses in both pork industry and human productivity. MacKenzie and Bishop (2001) created stochastic epidemiological models for microparasitic infections in pig farms, providing methodologies to estimate epidemic probabilities, basic reproductive ratios, and infection proportions to support rational control strategy decisions. Fernández-Carrión *et al.* (2016) focused on classical swine fever, developing economic models integrated with the Be-FAST spatial-temporal stochastic spread model. Their validation using Spanish epidemic data from 1997-2001 revealed that severe outbreaks cost over 108 million euros, with approximately 80% attributed to animal culling, demonstrating the model's utility for predicting economic consequences of livestock disease epidemics.

Epidemiological and econometric models in fungal diseases of livestock

Research on epidemiological and econometric models in livestock diseases demonstrates the critical importance of integrating disease dynamics with economic analysis for optimal control strategies. Statistical and epidemiological models evaluate implemented health programs, while economic models predict profitability of specific control measures (Dijkhuizen 1988). Key challenges include farmer heterogeneity in disease response and misalignment between privately and socially optimal control efforts, with socially optimal outcomes achieved in less than 25% of price-cost combinations when farmers act independently (Mendes *et al.* 2020). Integrated epidemiological-productivity models effectively link disease incidence to sector performance, as demonstrated with bovine respiratory disease in France, where complete eradication could increase beef sector productivity by 4.7–5.5% (Delabouglise *et al.* 2017b). Spatially-explicit integrated models capture dynamic temporal and spatial disease effects, enabling coordinated regional interventions that distinguish between short-run and long-run control options (Rich and Winter-Nelson 2007).

Respiratory fungal infections, particularly Aspergillosis and Conidiobolomycosis, contribute to the 5.6% of small ruminant diseases caused by infectious agents (Rahman *et al.* 2022). Poor nutrition, hygiene, and management systems were primary risk factors for fungal diseases, causing significant livestock losses that affect economic stability and ecological balance. Environmental conditions, particularly humid and warm seasons, promote disease spread through various transmission routes including contact, vectors, and contaminated feeds.

In Kazakhstan households, aspergillosis showed median incidence rates of 37-42% across poultry species, with fatality rates of 22–33% (Kalkayeva *et al.* 2023). Financial losses reached a median of \$198.50 per household, with egg production declining by 58.3% and poultry prices falling by 48.6% post-recovery (Kalkayeva *et al.* 2023). In Egyptian layer flocks, fungal infections affected 15% of farms with mortality rates of 4.34% (El-Sharkawy *et al.* 2023). Novel findings include the first isolation of Aspergillus piperis and Fusarium species from poultry ovaries, causing egg retention and reduced production (El-Sharkawy *et al.* 2023).

Coccidiosis and clostridiosis emerge as the most common production diseases in broiler flocks, while salpingoperitonitis is most prevalent in layers (Jones *et al*.. 2019). The economic consequences of untreated diseases are severe, with most uncontrolled diseases estimated to make flocks loss-making, though interventions are available that significantly reduce these losses (Jones *et al.* 2019). Mathematical models have been developed to assess economic effects, demonstrating the very high costs of disease outbreaks and the need for accurate data to obtain precise financial cost figures (Oyekole 1984). Fungal diseases present additional challenges, with aspergillosis being the most common fungal disease in birds, while mycotoxicosis from contaminated feeds leads to mortality at high exposure levels and reduced productivity, slower growth rates, and compromised immune function at lower levels, resulting in serious economic losses (Arné and Lee 2019; Jand *et al.* 2005).

Epidemiological and econometric models in nutritional diseases of livestock

Ostergaard *et al*. 2003 developed SimHerd III, a sophisticated model incorporating multiple disease interactions, including milk fever's impact on milk production, reproduction, and culling. S. Østergaard *et al*. 2000 created a Monte Carlo model that demonstrated how milk fever indirectly reduces net income through increased replacement rates. Saborío-Montero *et al.* 2017 used logistic regression to identify key risk factors, finding parity (OR = 52.59), previous dry period length, and ecological zone significantly influence milk fever occurrence. Cariappa *et al*. 2021 complemented these findings with an economic surplus model, estimating yearly losses of US$137 million in a single region, highlighting the substantial economic significance of these models. The research reveals substantial heterogeneity in ketosis modeling approaches. J. A notable biological model by Nielsen *et al*. 2005 demonstrates the potential for predicting ketosis risk using in-line measurements of beta-hydroxybutyrate (BHBA) in milk, incorporating factors like milk yield, body fatness, and previous disease incidences. The models' complexity stems from multiple variables, including herd characteristics, milk production, milk prices, and veterinary service costs. While promising, these models require further validation and context-specific refinement to provide consistently reliable predictions.

CONCLUSION

The choice of the modelling type and technique will depend on a number of factors, including: the nature of the problem ; the resources available, time, money and analytical tools, and the availability of data and information about the problem. Even within specific narrow problem domains such as animal replacement decisions, different modelling types and techniques are used. Linear programming is a very useful tool in finding the optimal solution for complex problems. The technique has not much been applied yet in animal health economics. The reason for not applied yet in animal health economics might be due to its unfamiliarity or that it is not considered useful. Many modifications have been made to the technique to deal with these limitations, such as mixed integer, nonlinear and quadratic programming. Sometimes, preventive as well as treatment programs fail connected with farmers or policy makers often based on the stakeholders' perception of the economic losses due to animal disease. Economic analysis by choosing modelling technique/s is necessary by taking the roles that animals play in society, the impacts of disease in animals and the prices of resources they compete into account. Economic analysis provides support for decision makers in allocation of scarce resource but does not necessarily identify the ideal solution. Understanding disease epidemiology, the nature of economics and the relationship between economics and epidemiology is essential for realistic economic assessment and for successful institutionalization of animal health economics to provide support decision making in veterinary delivery systems. Further research in this field is necessary and can be of great practical value.

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