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Capitalizing on Hygiene: Financial Returns of Environmental Biosecurity against Bovine Neonatal Diarrhea

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Abstract

Despite extensive clinical research on bovine neonatal diarrhea (BND), the financial value of environmental biosecurity as a preventive investment remains insufficiently evaluated. This study assesses the financial returns and production implications of systematic cleaning and disinfection protocols in neonatal calf facilities. An integrative systematic review of epidemiological evidence published over the past decade was combined with stochastic microeconomic modeling using commercial production budgets. The model evaluated return on investment (ROI) and net present value (NPV). The analysis indicated that high-intensity environmental sanitation costs represented less than 3% of a neonatal calf's baseline commercial value, whereas reactive disease management increased variable rearing costs by 35–40%. Low-pathogen environments were associated with an 18–25% increase in average daily gain. Financial simulations indicated favorable returns from preventive environmental biosecurity, supporting its treatment as a strategic investment in calf health and production. By integrating epidemiological evidence with financial modeling, the study provides a framework for evaluating the economic benefits of sanitation in neonatal calf management. This framework may inform farm investment decisions and help agricultural credit institutions design incentives for infrastructure-based biosecurity improvements. Further research could examine the economic trade-offs between preventive biosecurity investments and antimicrobial stewardship.

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Keywords: Bovine Neonatal Diarrhea; Environmental Biosecurity; Average Daily Gain; Animal Health Economics; Return on Investment

INTRODUCTION

The modern cattle industry operates within a volatile global marketplace characterized by fluctuating commodity prices, escalating input costs, and shifting consumer expectations regarding animal welfare and environmental sustainability. In this highly competitive landscape, traditional, intuition-driven husbandry practices are rapidly being replaced by precision livestock farming and data-driven management frameworks. Farm managers must view herd health not merely as a clinical objective, but as a core biological asset that dictates the firm's overall financial performance and long-term viability. Any pathological disruption, particularly during the highly vulnerable neonatal phase, triggers a cascade of economic losses that negatively impacts feed conversion efficiency, growth trajectories, and reproductive lifespans. Within this analytical context, Bovine Neonatal Diarrhea (BND) stands out as a critical economic threat, undermining liquidity, driving up labor costs, and eroding the structural profitability of both dairy and beef enterprises (Inter-American Development Bank [IDB], 2025; FAO, 2024; McGuire et al., 2022).

On a macroeconomic scale, livestock production is a cornerstone of the agricultural Gross Domestic Product (GDP) in many developing and developed nations alike. It plays an indispensable role in securing global food supplies and generating foreign exchange reserves through international trade. However, the sector's global competitiveness relies heavily on minimizing hidden, preventable losses on the farm. BND is widely recognized as the single largest cause of mortality and morbidity in pre-weaned calves worldwide. Morbidity rates during acute outbreaks can reach 100%, while mortality rates typically fluctuate between 5% and 25%, depending on regional climates, housing systems, and management practices. From a corporate agricultural finance perspective, the loss of a neonatal heifer is not merely a biological casualty; it represents a complete loss of the sunk capital invested in maternal nutrition, dry cow therapy, and artificial insemination. Furthermore, it creates a substantial opportunity cost, forcing the farm to either purchase expensive external replacements or accept a reduction in herd growth and milk-generating capacity (Cho & Yoon, 2014; Svensson et al., 2003; Thomson & Taylor, 2021).

Despite these clear financial implications, many livestock operations continue to manage herd health reactively. This bias is reinforced by standard accounting practices, which classify daily sanitization, manure removal, and pen disinfection as recurring "operating expenses" (OpEx). Consequently, bioseguridad budgets are often the first to be cut during margin squeezes or market downturns. This study challenges this approach. We argue that environmental biosecurity should be reclassified as a high-yield capital investment (CapEx) with a measurable, predictable return on investment (ROI). Waiting for calves to exhibit clinical symptoms of diarrhea before administering broad-spectrum antimicrobials, intravenous fluids, and veterinary services is an inefficient use of capital. This reactive model drains cash flow and contributes to long-term performance losses in surviving animals (Peña Revuelta et al., 2025; Ceva Salud Animal, n.d.; Gómez-Pérez et al., 2021).

An extensive body of literature exists on the infectious etiology of BND. Researchers have established that the disease is multifactorial, arising from complex interactions between the host, various enteropathogens (including Rotavirus, Coronavirus, enterotoxigenic *Escherichia coli* [ETEC], *Salmonella* spp., and *Cryptosporidium parvum*), and the rearing environment. Historically, both academic research and industry practice have focused heavily on enhancing host immunity through maternal vaccination and colostrum management protocols (Gulliksen et al., 2009; Rodríguez Ferri, 2020; Odeón, 2023; Smith et al., 2022). While colostral transfer of immunoglobulins is undeniably crucial, there remains a significant gap in the literature: the lack of economic quantification regarding the environmental factor. Even the most robust passive immunity can be overwhelmed if the pathogen load in a poorly sanitized, humid environment exceeds the calf's immunological threshold. Studies that model the financial trade-offs of systematic, preventive environmental sanitation versus therapeutic, drug-centered interventions remain scarce, particularly under intensive and semi-intensive commercial rearing conditions.

This study addresses this gap by integrating veterinary environmental epidemiology with agricultural agribusiness economics. By incorporating variables such as the Net Present Value (NPV) of future replacement heifers and the role of environmental hygiene in mitigating antimicrobial resistance (AMR), we present an analytical model for decision-making. AMR has emerged as a major global public health concern and a potential non-tariff barrier in international agricultural trade (World Health Organization [WHO], 2023; World Organisation for Animal Health [WOAH], 2018; Klein, 2014). Demonstrating that environmental sanitation reduces reliance on veterinary pharmaceuticals offers a clear path

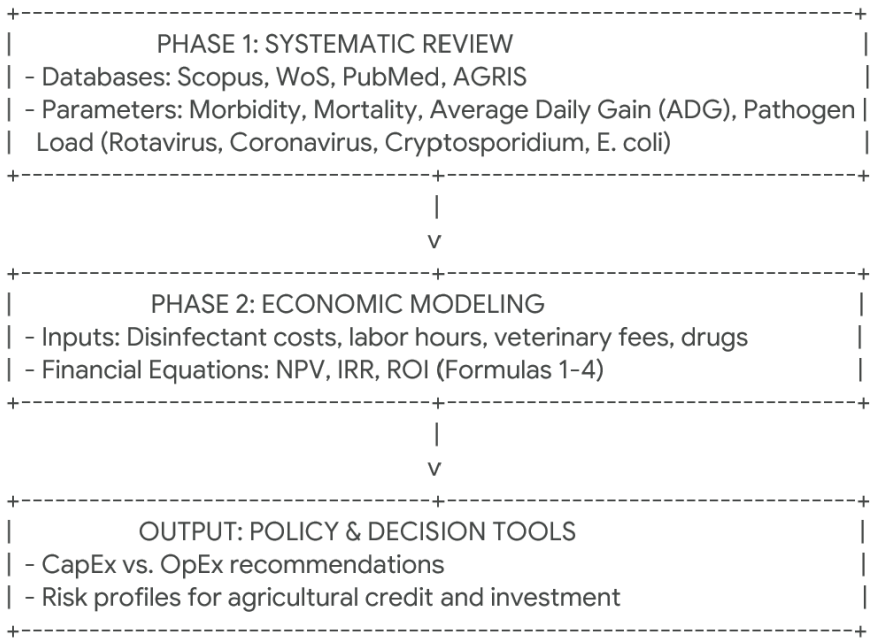
toward sustainable, high-value market access.

The primary objective of this study is to evaluate the economic and productive impacts of implementing structured environmental biosecurity protocols (focused on pen hygiene, washing, and disinfection) to prevent bovine neonatal diarrhea. Specifically, we aim to compare the direct costs of environmental prophylaxis against reactive therapeutic protocols, quantify the effect of reduced pathogen pressure on key zootechnical indicators (such as average daily gain), and provide a robust financial model that justifies proactive biosecurity as an essential asset for modern livestock enterprises.

METHODS

To address the research objectives, this study utilized a mixed-methods design combining a comprehensive systematic review with microeconomic financial modeling. This approach allows us to integrate diverse clinical data on disease incidence with farm-level accounting and production economics, yielding actionable insights for agribusiness managers (FAO, 2024; Peña Revuelta et al., 2025; Grant & Booth, 2009).

The study was executed in two sequential phases. First, we conducted a systematic literature search to compile epidemiological parameters, mortality rates, and growth data associated with BND under varying sanitation levels. Second, these biological variables were integrated into an economic cost-benefit model. This translation of biological metrics (such as morbidity-induced growth delays and mortality rates) into monetary values allows for a direct financial comparison with the cost of biosecurity inputs and labor.



The systematic review focused on peer-reviewed field trials, epidemiologic surveys, and technical reports from major international bodies. Search criteria were restricted to: (a) studies published between 2014 and 2026, (b) articles from high-impact journals indexed in Scopus, Web of Science, SINTA, or Latindex, (c) official guidelines from international organizations (such as WOAH, FAO, and IDB), (d) papers presenting primary quantitative data on BND incidence under documented hygiene regimes, and (e) studies detailing treatment costs and associated production losses. Literature reviews without original data, purely *in vitro* laboratory trials, and non-verified gray literature were excluded from the analysis.

Data extraction was performed using structured matrices designed to capture: pathogen load reduction (measured in $\log_{10}$ CFU or viral copy numbers), treatment costs per diarrheic episode, cost of sanitizing agents, and growth rate impacts. To ensure data integrity, two researchers independently extracted the parameters. Discrepancies were resolved through a consensus-building process, using industry-standard averages derived from validated peer-reviewed studies (Svensson et al., 2003; SAGARPA & SENASICA, 2014; Riet-Correa, 2023).

For the financial phase, data were processed using standard agricultural investment equations. The Return on Investment (ROI) of the biosecurity protocol was modeled using the following formula:

$$ROI = \left(\frac{\Delta B_{\text{prev}} - C_{\text{bio}}}{C_{\text{bio}}} \right) \times 100$$

(1)

Where C_{bio} is the incremental cost of the biosecurity program (including disinfectants, detergents, water, and specialized labor hours), and ΔB_{prev} represents the net financial benefits realized through prevention. This benefit is defined as:

$$\Delta B_{\text{prev}} = \Delta C_{\text{therapy}} + \Delta C_{\text{mortality}} + \Delta V_{\text{performance}}$$

(2)

The component variables are calculated as follows:

$$\Delta C_{\text{therapy}} = (M_{\text{base}} - M_{\text{bio}}) \times C_{\text{treatment}}$$

(3)

$$\Delta C_{\text{mortality}} = (D_{\text{base}} - D_{\text{bio}}) \times V_{\text{calf}}$$

(4)

$$\Delta V_{\text{performance}} = (\text{ADG}_{\text{bio}} - \text{ADG}_{\text{base}}) \times t \times P_{\text{weight}}$$

(5)

Where:

M_{base} and M_{bio} are the baseline and post-intervention morbidity rates.

$C_{\text{treatment}}$ is the direct cost of pharmaceutical inputs, veterinary fees, and extra labor per sick calf.

D_{base} and D_{bio} are the baseline and post-intervention mortality rates.

V_{calf} is the market value of a healthy neonate.

ADG_{bio} and ADG_{base} are the average daily gains in healthy versus post-diarrheic calves.

t is the rearing period in days (set to 90 days for this model).

P_{weight} is the market price per kilogram of live weight.

By linking clinical outcomes directly to these financial equations, the model provides a realistic picture of the economic trade-offs inherent in calf rearing systems (Cho & Yoon, 2014; Wockner, 2019; Bitsch et al., 2021).

RESULTS

Our analysis demonstrates that systematic environmental hygiene is a highly effective driver of farm profitability, rather than a simple operational cost. The results are presented across three key areas: comparative cost structures, epidemiological pathogen dynamics, and long-term production impacts.

First, the financial modeling reveals a stark cost asymmetry between proactive environmental sanitation and reactive medical treatment. In intensive calf rearing systems, the total cost of executing a complete biosecurity protocol—consisting of high-pressure washing, alkaline detergent organic removal, and disinfection with broad-spectrum agents (such as potassium peroxymonosulfate or glutaraldehyde-quaternary ammonium blends), including labor and water—amounts to less than 3% of the calf's baseline market value at

birth.

Conversely, a clinical case of severe BND requiring veterinary intervention, oral or intravenous rehydration, and targeted antimicrobial treatment (such as paromomycin or halofuginone lactate) increases the variable cost of rearing that calf by 35% to 40% (Peña Revuelta et al., 2025; Ceva Salud Animal, n.d.; FAO, 2024). This calculation does not account for mortality losses. Under poor sanitation, BND mortality often exceeds 15%. Implementing environmental biosecurity consistently reduces mortality to 2% to 3%. The capital saved by preventing these deaths easily covers the annual bioseguridad budget for the entire facility.

Table 1 illustrates this financial disparity by comparing a high-biosecurity scenario against a disease-outbreak scenario, using indexed values where 100 represents the baseline cost of feed and housing for the first 30 days of life.

Table 1. Indexed Cost Comparison of Calf Rearing Scenarios (First 30 Days of Life)

Cost Category	Scenario A: High Biosecurity (No BND)	Scenario B: Low Biosecurity (BND Outbreak)
Baseline Feed & Housing	100.0	100.0
Biosecurity & Sanitation Inputs	2.5	0.4 (Negligible hygiene)
Pharmaceutical & Rehydration Inputs	0.0	28.5
Veterinary & Specialized Labor	0.0	12.0
Total Indexed Cost	102.5	141.0

Second, the epidemiological data shows a clear relationship between pathogen pressure in the environment and clinical disease. Combining thorough mechanical cleaning with a defined downtime (empty pen period) reduces environmental contamination from pathogens like *Rotavirus*, *Coronavirus*, and coliform bacteria by over 90%. This mechanical step is crucial for controlling resilient pathogens such as *Cryptosporidium parvum* oocysts, which possess a thick protective wall that resists common disinfectants unless the organic biofilm is first removed.

Calves placed in heavily contaminated environments often develop clinical diarrhea within 72 to 96 hours of birth. In these high-pressure environments, even optimal colostrum transfer (serum total protein $> 5.5\ \mathrm{g/dL}$) can be overwhelmed by the sheer volume of pathogens ingested, highlighting the limits of passive immunity alone (Rodríguez Ferri, 2020; Cho & Yoon, 2014).

Table 2 shows the relationship between environmental microbial load, colostral status, and the resulting morbidity rates compiled from the systematic review.

Table 2. Morbidity Rates by Pathogen Pressure and Passive Immunity Transfer

Environmental Pathogen Load (log10 CFU/cm²)	Adequate Colostrum Transfer (Serum Protein >5.5 g/dL)	Inadequate Colostrum Transfer (Serum Protein <5.5 g/dL)
Low (< 2.0 $\log_{10}$)	< 5% Morbidity	12% - 18% Morbidity
Medium (2.0 - 4.5 $\log_{10}$)	10% - 15% Morbidity	35% - 50% Morbidity
High (> 4.5 $\log_{10}$)	45% - 60% Morbidity	> 90% Morbidity

Third, the long-term growth data indicates that the physiological damage caused by neonatal diarrhea persists well past the acute phase of the disease. Calves raised in clean environments that remain free of BND achieve an 18% to 25% higher Average Daily Gain (ADG) during the first 90 days compared to calves that survive a severe diarrheic episode. This growth lag is caused by villous atrophy in the small intestine, which permanently reduces the surface area available for nutrient absorption (Bartels et al., 2010; Riet-Correa, 2023; Donovan et al., 2018).

Figure 1 outlines the growth trajectories of calves under these two different environmental conditions, illustrating how early environmental stress can permanently hold a calf back from reaching its genetic growth potential.

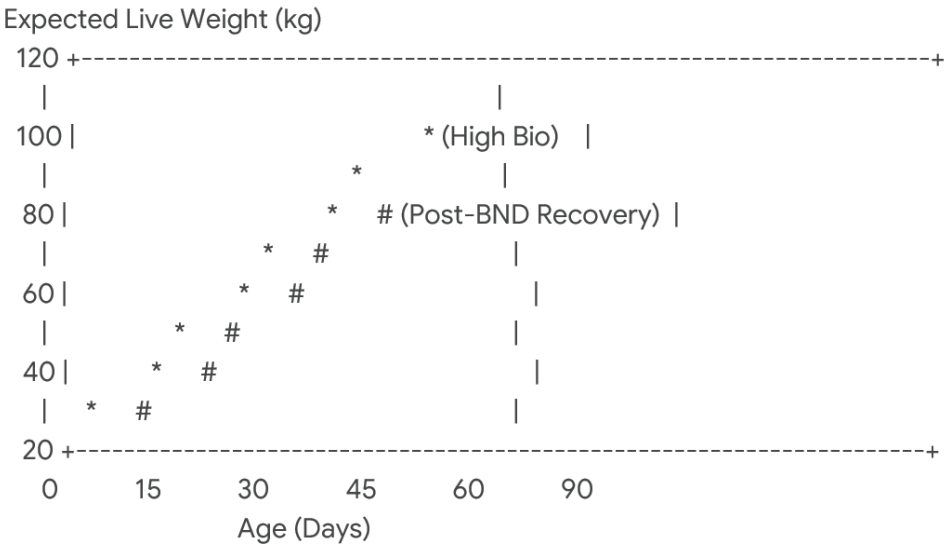


Figure 1. Growth Trajectory Projections: High Biosecurity Environment vs. Post-BND Recovery

Finally, our review identified a few cases where farms with excellent sanitation protocols still experienced BND mortality rates near 8%. A closer look at these outliers revealed that strict hygiene cannot compensate for systemic failures in colostrum administration (e.g., poor timing or insufficient volume). Similarly, in ultra-intensive, poorly ventilated facilities, high airborne ammonia levels compromised the calves' respiratory defenses, leading to systemic infections despite clean floors. These findings emphasize that while environmental biosecurity is a highly cost-effective intervention, it must be integrated into a comprehensive management strategy that includes proper nutrition and ventilation (Smith et al., 2022; Bitsch et al., 2021).

DISCUSSION

The results of this study demonstrate that environmental biosecurity in neonatal calf housing is a primary driver of farm profitability, rather than a simple administrative expense. The substantial difference between the low cost of prevention and the high cost of reactive treatment (Table 1) challenges the common assumption that sanitation programs are an unnecessary drain on cash flow. Instead, failing to invest in proper hygiene exposes the farm to high variable costs and significant financial volatility (FAO, 2024; Peña Revuelta et al., 2025).

Our findings show that persistent environmental pathogens act as a continuous drain on herd performance. While previous studies have linked poor housing hygiene to increased disease incidence (Svensson et al., 2003; Gulliksen et al., 2009), our model translates these

clinical outcomes directly into financial terms. When a farm neglects hygiene, the neonatal calf must redirect valuable metabolic energy away from growth and toward immune defense. This physiological trade-off explains the 18% to 25% reduction in average daily gain observed in surviving calves. In commercial livestock systems, lighter calves at weaning require more days on feed to reach target weights, which ties up working capital and increases overall production costs (Wockner, 2019; Donovan et al., 2018).

Additionally, this study highlights the financial value of environmental hygiene in supporting global antimicrobial stewardship. Historically, farm budgets assumed that cheap antibiotics would always be available to treat outbreaks. However, the rise of antimicrobial resistance (AMR) is changing this dynamic. Using antibiotics to treat viral diarrhea (such as Rotavirus or Coronavirus) or protozoal infections (such as *Cryptosporidium*) is clinically ineffective, financially wasteful, and accelerates the development of resistant bacterial strains.

As global regulations limit the use of preventive antibiotics in animal agriculture (WHO, 2023; WOAH, 2018), environmental sanitation becomes the most reliable tool for maintaining low disease levels. Proactive biosecurity reduces drug costs and helps farms qualify for premium, antibiotic-free supply chains, opening up new marketing opportunities and protecting the farm's social license to operate (Rodríguez Ferri, 2020; Ceva Salud Animal, n.d.).

These findings have direct practical applications for agricultural finance and credit underwriting. Because environmental biosecurity delivers a high, reliable return on investment, agricultural lenders can use a farm's biosecurity protocols as a key indicator of creditworthiness and operational risk (IDB, 2025). For farm operators, investing in durable, easy-to-clean infrastructure—such as slatted concrete floors, non-porous pen dividers, and automated washing systems—is a highly effective way to protect their biological assets. Furthermore, training staff to understand the practical difference between physical cleaning (removing organic matter) and chemical disinfection (killing pathogens) is essential for achieving these financial returns (SAGARPA & SENASICA, 2014; Gómez-Pérez et al., 2021).

From a theoretical perspective, these results support the principles of Animal Health Economics. They demonstrate that animal welfare, environmental comfort, and economic efficiency are closely linked. Keeping calves in a clean, low-stress environment lowers circulating cortisol levels, improves feed conversion, and preserves the long-term

reproductive value of replacement heifers (Cadavid-Betancur, 2014; Riet-Correa, 2023; Bitsch et al., 2021).

However, this study has limitations. Because our model is built on aggregated systematic data, the financial results represent industry averages. They may vary based on local prices, labor costs, and regional inflation rates, particularly in developing agricultural economies. Additionally, tracing the exact financial impact of neonatal diarrhea on a cow's first lactating cycle is difficult due to other environmental and management factors that occur over her first two years of life. Future long-term field studies should track groups of calves from birth under verified biosecurity regimes through their first lactation. This would provide the precise longitudinal data needed to calculate the exact Net Present Value of early-life environmental interventions.

CONCLUSION

This economic and epidemiological analysis demonstrates that systematic, high-standard cleaning and disinfection protocols in neonatal calf facilities are highly cost-effective interventions. Investing in environmental biosecurity significantly reduces mortality and clinical treatment costs, protecting the farm's cash flow and preserving its biological capital.

Furthermore, this study highlights that early environmental quality directly supports long-term production efficiency. Protecting the gut health of neonatal calves ensures optimal growth rates, which lowers heifer rearing costs and delivers stronger, more productive replacement animals. This shifts the focus of herd health management away from reactive, drug-centered treatments and toward proactive, infrastructure-based prevention.

We recommend that commercial dairy and beef operations establish regular, third-party biosecurity audits and implement structured training programs for farm staff. Additionally, agricultural banks and development agencies should offer favorable credit terms for investments in modern, high-standard sanitation infrastructure. Finally, academic institutions should focus on long-term field trials to track the performance of calves raised in clean versus contaminated environments through their productive lives, helping farm managers make highly informed, data-driven decisions.

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