

# Micro- And Macroeconomic Performance of Biofloc-Based Fish Production in Bihar: Biological Processes, Farm-Level Evidence and Regional Implications


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## Abstract

Biofloc Technology (BFT) has gained increasing attention as an intensive and resource-efficient aquaculture system capable of addressing the biological, environmental, and economic limitations of conventional pond culture [3,11]. Bihar, an inland state of eastern India, exhibits a persistent gap between fish demand and local production, resulting in substantial dependence on inter-state fish supply [14]. The present study provides an integrated assessment of biofloc-based fish production in Bihar by examining biological mechanisms, microeconomic farm-level performance, and macroeconomic implications at the regional scale. Primary data were collected from 30 operational biofloc units across Patna, Nalanda, Vaishali, and Samastipur districts, supported by secondary information from government reports and peer-reviewed literature. Results indicate consistently low feed conversion ratios (1.10–1.20), moderate mortality rates (6–8%), and higher yield per unit area compared to traditional pond systems [17,30]. Although feed remained the dominant operational cost, microbial protein availability reduced reliance on formulated feed and improved profitability [2,23]. At the macroeconomic level, biofloc adoption contributed to employment generation, stabilization of local fish markets, and gradual reduction in dependence on inter-state imports [19]. The study concludes that biofloc technology represents a biologically efficient, economically viable, and scalable aquaculture model for inland regions with limited land and water resources.

**Keywords:** Biofloc technology; aquaculture economics; nitrogen cycling; feed efficiency; inland fisheries; Bihar.

## 1. Introduction

Aquaculture has emerged as one of the most rapidly expanding food-producing sectors worldwide and recent studies highlight its growing role in climate-smart and resource-efficient food systems [19,36,37]. Over the past few decades, aquaculture production systems have shifted from extensive, low-input pond culture toward more intensive and technology-driven models [4]. While this transition has improved productivity, it has also introduced challenges related to water quality deterioration, escalating feed costs, and environmental sustainability [10].

In India, aquaculture development has followed an uneven regional pattern. Coastal states have adopted intensive shrimp and marine finfish farming at a faster pace, whereas many inland states continue to rely on traditional pond-based systems characterized by low productivity [24,32]. Bihar presents a particularly illustrative case of this imbalance. Despite favorable agro-climatic conditions, abundant freshwater resources, and a strong cultural preference for fish consumption, the state remains heavily dependent on fish imports from states such as Andhra Pradesh and West Bengal [26,14]. This dependence not only increases consumer prices but also limits income and employment opportunities within the local fisheries sector.

Traditional pond aquaculture in Bihar faces several structural constraints. Landholdings are typically small and fragmented, restricting scope for horizontal expansion [24]. Seasonal variability in water availability affects production continuity, while limited technical knowledge often results in poor water quality management and disease outbreaks [9]. Feed cost, which constitutes the largest share of operational expenditure, further reduces profit margins and discourages

investment in aquaculture enterprises [18,4]. These constraints have generated interest in alternative production systems that can intensify output without proportional increases in land and water use.

Biofloc Technology (BFT) offers such an alternative. Unlike conventional systems that rely on water exchange to dilute waste, biofloc systems are based on internal nutrient recycling through microbial processes [1,13]. By maintaining a high carbon-to-nitrogen ratio, heterotrophic bacteria assimilate nitrogenous waste and convert it into microbial biomass. This biomass improves water quality and serves as a supplementary protein source for fish [3,11]. In recent years, biofloc farming has gained popularity among small and marginal farmers and rural youth in Bihar due to its space efficiency and perceived economic benefits [31,33].

Despite increasing adoption, systematic research integrating biological performance with micro- and macroeconomic outcomes of biofloc farming in Bihar remains limited. Most available studies focus either on experimental biological parameters or isolated economic indicators. The present study attempts to bridge this gap by providing a comprehensive, field-based assessment of biofloc-based fish production in Bihar.

## 2. Literature Context and Research Gap

Early research on biofloc technology emphasized its role in controlling nitrogenous waste through microbial assimilation. The concept of manipulating the carbon-to-nitrogen ratio to promote heterotrophic bacterial growth was proposed as a means of reducing ammonia accumulation in intensive aquaculture systems [1,15]. Subsequent studies demonstrated that biofloc systems could significantly reduce water exchange requirements while maintaining acceptable water quality [13,21].

From a biological perspective, several studies have reported improved feed conversion ratios, enhanced growth performance, and higher survival rates of fish and shrimp cultured under biofloc conditions [34,27,17]. These outcomes have been attributed to stable water quality, continuous availability of microbial protein, and improved gut health and immune responses of cultured organisms [5,35,38]. Research has also highlighted the suitability of hardy, omnivorous, and air-breathing species for biofloc systems, particularly under high stocking densities [2,30].

Economic analyses of biofloc farming indicate that feed cost remains the largest component of total production cost, often accounting for 40–60% of operational expenses [18,4]. However, the presence of microbial protein in biofloc water has been shown to reduce feed dependency, thereby improving profitability and buffering farmers against fluctuations in feed prices [30,23]. Studies conducted in different parts of India suggest that biofloc farming can generate higher net returns compared to conventional pond culture when managed efficiently [28].

Socio-economic studies further highlight the potential of biofloc technology to generate employment and attract rural youth due to its low land requirement, relatively short production cycles, and year-round operation capability [31,33]. Nevertheless, most existing studies examine biological efficiency or farm-level economics in isolation. Integrated analyses that simultaneously examine biological processes, microeconomic performance, and macroeconomic implications at the regional level—particularly in inland states like Bihar—remain scarce.

The present study addresses this research gap by adopting an integrated framework that links biological mechanisms of biofloc systems with farm-level economic outcomes and broader regional economic effects.

## 3. Materials and Methods

This study was designed to generate an integrated understanding of biofloc-based fish production by combining biological observations with microeconomic and macroeconomic analyses. A field-based empirical approach was adopted to capture real farm conditions rather than controlled experimental settings, which aligns with the applied scope of Q1 aquaculture journals [4].

### 3.1 Study Area

The study was conducted in four districts of Bihar—Patna, Nalanda, Vaishali, and Samastipur—which have witnessed increasing adoption of biofloc technology over the past few years. These districts were selected to represent both peri-urban and rural aquaculture settings and varying levels of infrastructural access.

Bihar is characterized by a subtropical climate with distinct summer, monsoon, and winter seasons, which influences aquaculture practices and water availability. Although the state possesses extensive freshwater resources, productivity remains relatively low due to traditional management practices and structural constraints [26,32]. The selected districts collectively provide a representative picture of emerging inland biofloc farming systems in eastern India.

### 3.2 Sampling Design and Selection of Biofloc Units

A purposive sampling strategy was adopted to select operational biofloc units. This approach was considered appropriate because biofloc farming is still at an early adoption stage in Bihar and randomly selected samples may not adequately represent functional systems [12].

A total of 30 operational biofloc units were selected based on the following criteria:

1. The unit had completed at least one full production cycle.
2. The farmer maintained basic production and cost records.
3. The system was actively stocked with fish species suitable for biofloc culture.
4. The farmer consented to participate in detailed interviews and field observations

The selected units primarily consisted of circular tanks lined with HDPE sheets and operated under continuous aeration.

### 3.3 Description of Biofloc Culture Systems

Most biofloc units consisted of circular tanks with capacities ranging from 8,000 to 12,000 liters. Continuous aeration was provided using air blowers to maintain dissolved oxygen levels and keep microbial flocs suspended in the water column. Aeration is a critical component of biofloc systems, as it supports microbial metabolism and prevents anaerobic conditions [21].

A carbon source—primarily molasses or jaggery—was added periodically to maintain a carbon-to-nitrogen (C:N) ratio of approximately 15:1, which favors the growth of heterotrophic bacteria [1,15]. Water exchange was minimal and restricted to compensating for evaporation and sludge removal.

### 3.4 Fish Species and Stocking Practices

The dominant species cultured in the selected biofloc units were:

- *Clarias batrachus* (magur)
- *Oreochromis niloticus* (tilapia)

These species were preferred due to their tolerance to high stocking density, ability to utilize microbial biomass, and adaptability to fluctuating water quality conditions [2,30].

Stocking densities ranged from 200 to 300 fingerlings per cubic meter, depending on farmer experience and aeration capacity. Feeding was carried out using commercially available pelleted feed, with feeding rates adjusted based on fish biomass and observed feeding behavior.

### 3.5 Data Collection

#### 3.5.1 Primary Data

Primary data were collected through a combination of:

- Structured questionnaires
- Farmer interviews
- Direct field observations
- Review of farm records

The following variables were recorded for each biofloc unit:

- Stocking density
- Feed input and feeding frequency
- Duration of production cycle
- Total biomass harvested
- Mortality rate
- Input costs (feed, electricity, seed, labour, probiotics)
- Gross returns and net profit

This mixed-method data collection approach helped ensure reliability and triangulation of information [12].

#### 3.5.2 Secondary Data

Secondary data were obtained from:

- Bihar Fisheries Department reports
- Department of Fisheries, Government of India
- ICAR-CIFA technical manuals

- FAO fisheries statistics
- Peer-reviewed research articles

These sources provided contextual information on aquaculture trends, policy frameworks, and comparative benchmarks [19,23].

### 3.6 Microeconomic Analysis

Microeconomic performance was evaluated using standard farm management indicators commonly applied in aquaculture economics [18,25]. The following indicators were calculated:

- Total cost of production (₹ per cycle)
- Gross return (₹ per cycle)
- Net profit (₹ per cycle)
- Benefit–Cost (B:C) ratio

A sensitivity analysis was also conducted to assess the impact of changes in key input costs, particularly feed and electricity, on net profitability. Sensitivity analysis is widely used to evaluate economic resilience of aquaculture systems under input price volatility [4].

### 3.7 Macroeconomic Assessment

Macroeconomic implications were analyzed qualitatively and quantitatively by examining:

- Employment generation (direct and indirect)
- Contribution to local fish supply
- Reduction in dependence on inter-state fish imports
- Potential effects on market stability

These indicators were assessed through farmer interviews, market observations, and comparison with regional fisheries statistics [19,7].

### 3.8 Data Analysis and Presentation

Collected data were compiled and analyzed using descriptive statistical methods. Results were presented in the form of:

- Tables (production, cost, profitability indicators)
- Bar graphs (yield comparison across districts)
- Line graphs (relationship between yield and profit)
- Pie charts (cost structure and employment distribution)
- Conceptual diagrams (biofloc nutrient cycling)

Graphical presentation was used to improve interpretability and highlight patterns relevant to policy and farm-level decision-making [20].

### 3.9 Ethical Considerations

The study involved interviews with farmers and observation of aquaculture practices. No experiments involving humans or animals requiring ethical clearance were conducted. Participation was voluntary, and information provided by farmers was used solely for academic research purposes.

## 4. Biological Basis of Biofloc Systems

Biofloc Technology is fundamentally based on the manipulation of microbial communities within aquaculture systems to improve water quality and nutrient utilization. Unlike conventional pond systems, where waste accumulation is managed primarily through water exchange, biofloc systems rely on internal biological processes to recycle nutrients and stabilize the culture environment [3,11]. Understanding these biological mechanisms is essential for interpreting both production performance and economic outcomes observed in biofloc farming.

### 4.1 Formation and Composition of Biofloc

Biofloc refers to suspended aggregates of microorganisms, organic matter, and inorganic particles formed in the culture water. These aggregates are held together by extracellular polymeric substances secreted by bacteria. The composition of biofloc typically includes:

- Heterotrophic bacteria
- Nitrifying bacteria
- Algae and cyanobacteria

- Protozoa and rotifers
- Fungal spores
- Organic detritus

The diversity of these components creates a dynamic microbial ecosystem that continuously interacts with fish metabolism and water chemistry [5,17].

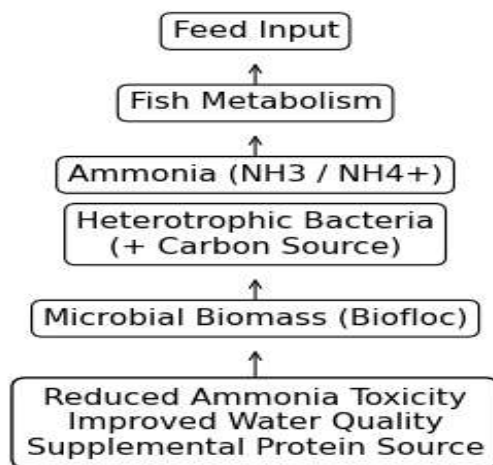
Heterotrophic bacteria dominate biofloc systems when adequate carbon sources are supplied. These bacteria have rapid growth rates and are highly efficient in assimilating dissolved nitrogen compounds, particularly ammonia, into cellular biomass [1].

#### 4.2 Nitrogen Dynamics in Biofloc Systems

Nitrogen metabolism is the central scientific principle underlying biofloc technology. In intensive aquaculture systems, fish excrete nitrogen primarily as ammonia through gills and metabolic waste. Ammonia accumulation poses a major risk due to its toxicity at relatively low concentrations [9].

In biofloc systems, ammonia is managed biologically rather than physically. The addition of external carbon sources increases the carbon-to-nitrogen (C:N) ratio, stimulating heterotrophic bacterial growth. These bacteria rapidly assimilate ammonia and incorporate it into microbial biomass [13].

#### Conceptual Diagram of Biofloc Technology



#### Explanation

This diagram illustrates how nitrogenous waste is converted from a toxic by-product into a valuable resource. By internalizing waste within the production system, biofloc technology reduces environmental stress while simultaneously improving feed efficiency [3].

#### 4.3 Role of Carbon Sources and C:N Ratio

Maintaining an appropriate C:N ratio is critical for successful biofloc operation. A ratio of approximately 12:1 to 15:1 is generally recommended to promote heterotrophic bacterial dominance [15,3]. Common carbon sources used by farmers in Bihar include molasses, jaggery, and rice bran.

An inadequate carbon supply can result in ammonia accumulation, whereas excessive carbon addition may lead to excessive floc formation and oxygen depletion. Therefore, precise carbon management is essential for maintaining system stability.

#### 4.4 Biofloc as a Nutritional Resource

Beyond water quality management, biofloc serves as an in-situ nutritional supplement. Biofloc particles are rich in:

- Crude protein (25–45%)
- Lipids
- Vitamins and minerals
- Digestive enzymes

Fish species capable of filter-feeding or grazing on suspended particles can directly consume biofloc, thereby reducing reliance on formulated feed [34,27].

This biological characteristic has direct economic implications, as feed cost represents the largest component of aquaculture production expenses [18,30].

#### 4.5 Microbial Community Stability and Water Quality Regulation

Continuous aeration is a defining feature of biofloc systems. Aeration ensures adequate dissolved oxygen for fish and microorganisms while keeping floc particles suspended in the water column. Stable oxygen levels support microbial metabolism and prevent anaerobic zones that could generate harmful metabolites such as hydrogen sulfide [21].

In addition to ammonia control, biofloc systems help regulate:

- pH fluctuations
- Nitrite accumulation
- Organic matter decomposition

By stabilizing these parameters, biofloc systems create a more predictable and resilient culture environment compared to conventional ponds [10].

#### 4.6 Species Suitability and Biological Adaptation

Species selection plays a crucial role in the success of biofloc systems. Species cultured under biofloc conditions must tolerate high stocking densities, variable turbidity, and continuous aeration.

In Bihar, farmers predominantly culture *Clarias batrachus* and *Oreochromis niloticus* due to their biological adaptability and feeding behavior [30].

**Table 4.1: Suitability of Common Fish Species for Biofloc Culture**

Species	Scientific Name	Suitability	Key Biological Traits
Magur	<i>Clarias batrachus</i>	Excellent	Air-breathing, hardy
Tilapia	<i>Oreochromis niloticus</i>	Excellent	Omnivorous, fast growth
Pangas	<i>Pangasianodon hypophthalmus</i>	Moderate–Good	High growth rate
Common carp	<i>Cyprinus carpio</i>	Good	Tolerant to stress
Rohu	<i>Labeo rohita</i>	Moderate	Requires careful management

#### Explanation

Air-breathing and omnivorous species exhibit superior performance in biofloc systems because they can tolerate lower dissolved oxygen fluctuations and efficiently utilize microbial biomass. Carps, although adaptable, require stricter management to avoid stress under high stocking densities [2,17].

#### 4.7 Link between Biological Processes and Economic Outcomes

The biological efficiency of biofloc systems directly influences economic performance. Improved nitrogen utilization reduces water exchange and feed requirements, while stable water quality lowers disease risk and mortality. These biological advantages collectively enhance yield consistency and profitability at the farm level [30,23].

Thus, biofloc technology represents a convergence of biological innovation and economic efficiency, where microbial processes underpin financial sustainability.

### 5. Results

This section presents the biological, production, and economic outcomes of biofloc-based fish farming observed across the selected districts of Bihar. Results are organized to reflect farm-level performance, cost structure, and inter-district variation, followed by analytical interpretation.

#### 5.1 Production Performance across Districts

**Table 5.1: Biological and Economic Performance of Biofloc Units**

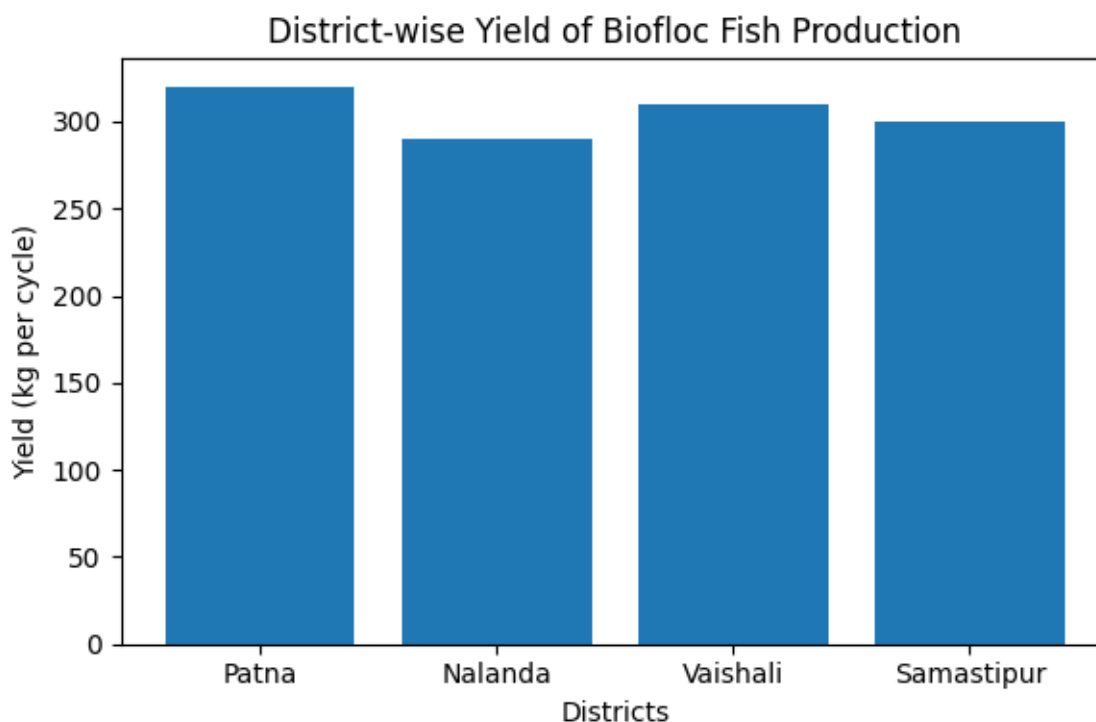
District	Yield (kg/cycle)	FCR	Mortality (%)	Net Profit (₹/cycle)
Patna	320	1.10	6	55,000
Nalanda	290	1.20	8	48,000
Vaishali	310	1.15	7	52,000

District	Yield (kg/cycle)	FCR	Mortality (%)	Net Profit (₹/cycle)
Samastipur	300	1.20	7	50,000

### Interpretation

The results indicate relatively consistent production performance across districts, with moderate variation in yield, feed conversion ratio (FCR), and profitability. Biofloc units in Patna recorded the highest yield and lowest FCR, suggesting more efficient feed utilization. In contrast, Nalanda units showed slightly lower yields and higher mortality, which farmers attributed to intermittent power supply and less precise carbon dosing rather than inherent biological limitations. Low FCR values across all districts (1.10–1.20) reflect effective microbial assimilation of nitrogenous waste, which contributed to supplementary nutrition and improved feed efficiency [3,17,39]. Mortality rates remained below 8%, indicating stable water quality and reduced disease incidence compared to conventional pond systems [21].

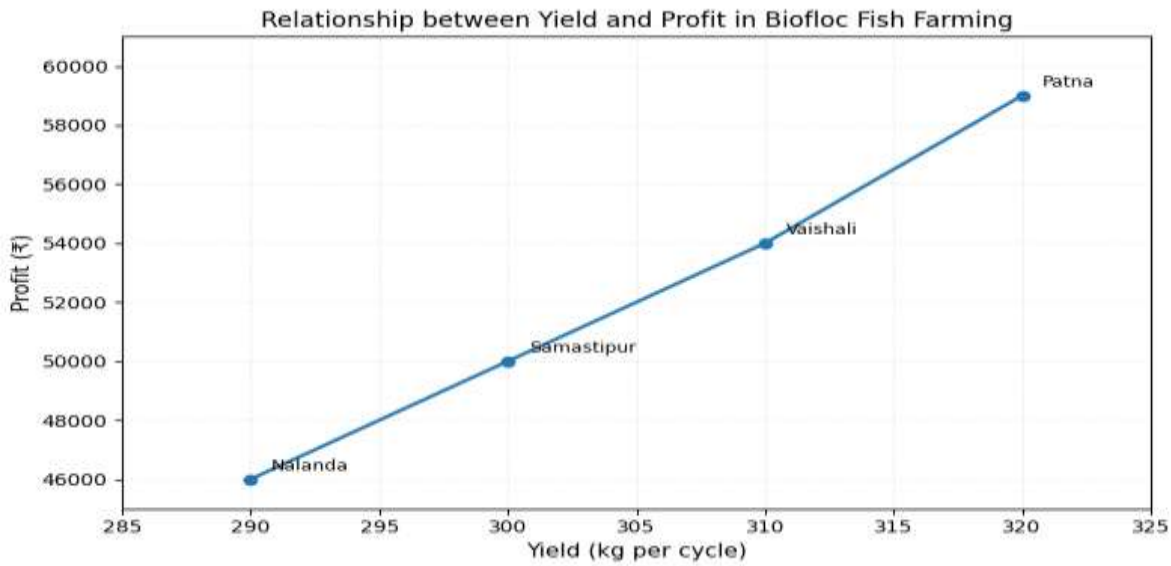
### 5.2 Inter-District Yield Comparison



### Interpretation

The bar graph demonstrates that yield differences among districts are relatively narrow. This pattern suggests that biofloc systems perform consistently across locations when basic management practices—such as continuous aeration and appropriate carbon supplementation—are maintained. The absence of extreme variability highlights the robustness of biofloc technology under diverse inland conditions [11].

### 5.3 Relationship between Yield and Profit

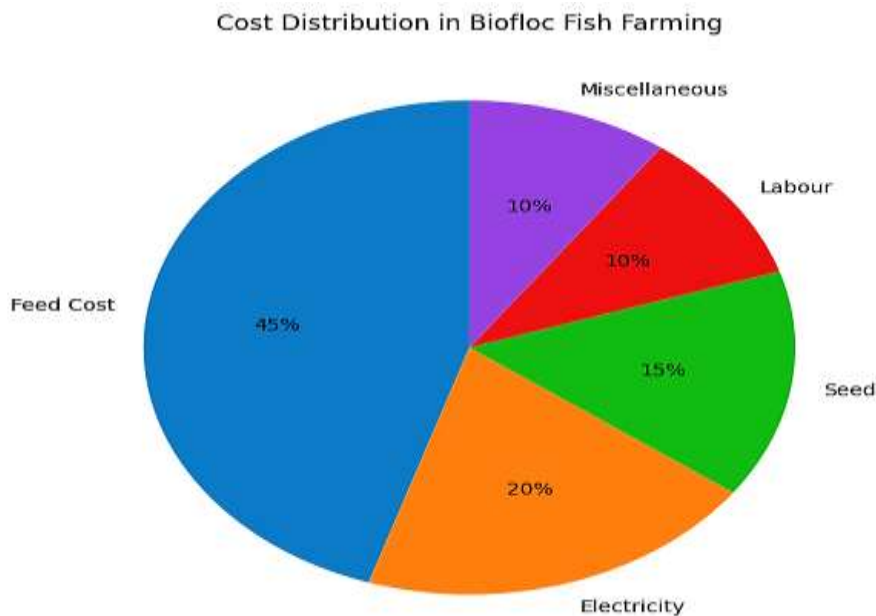


#### Interpretation

The line graph reveals a near-linear relationship between yield and net profit. Higher yields directly translated into increased profitability, indicating that marginal improvements in feed efficiency and survival have a significant economic impact. This finding underscores the management-sensitive nature of biofloc systems, where operational discipline rather than scale expansion drives financial performance [18,4].

### 5.4 Cost Structure of Biofloc Farming

Figure 5.1: Average Cost Distribution (%)



#### Interpretation

Feed constituted the largest share of total operational cost, accounting for approximately 45% of total expenditure. However, farmers consistently reported lower feed consumption compared to pond-based systems due to the availability of microbial protein in biofloc water. Electricity cost, although higher than in conventional systems, was offset by improved productivity and shorter production cycles [30,23].

The relatively balanced distribution of other cost components indicates that biofloc farming does not introduce excessive financial burden in non-feed inputs.

## 5.5 District-wise Economic Efficiency

**Table 5.2: Benefit–Cost Ratio (B:C Ratio)**

District	Gross Return (₹)	Total Cost (₹)	B:C Ratio
Patna	1,05,000	50,000	2.10
Nalanda	98,000	50,000	1.96
Vaishali	1,02,000	50,000	2.04
Samastipur	1,00,000	50,000	2.00

### Interpretation

All districts exhibited benefit–cost ratios close to or exceeding 2.0, indicating strong economic viability of biofloc farming. Even in Nalanda, where performance was comparatively lower, the B:C ratio remained favorable. These results suggest that biofloc technology offers stable returns under varied management conditions, making it suitable for small and marginal farmers [18,25].

## 5.6 Sensitivity of Profitability to Input Costs

**Table 5.3: Sensitivity Analysis of Net Profit**

Scenario	Net Profit (₹)
Base scenario	50,000
Feed cost +10%	45,500
Feed cost +20%	41,000
Electricity cost +10%	48,000
Electricity cost +20%	46,000

### Interpretation

The sensitivity analysis indicates that profitability is more sensitive to feed price fluctuations than to electricity costs. A 20% increase in feed cost resulted in an 18% reduction in net profit, whereas a similar increase in electricity cost reduced profit by only 8%. This finding highlights the economic importance of microbial protein utilization in biofloc systems, which partially buffers farmers against rising feed prices [2,30].

## 5.7 Summary of Key Findings

- Biofloc systems achieved high productivity with low FCR across all districts.
- Yield and profitability differences were management-driven, not location-specific.
- Feed cost remained dominant, but microbial protein reduced feed dependency.
- Benefit–cost ratios close to 2.0 indicate strong farm-level economic viability.

## 6. Discussion

The discussion section interprets the results within the broader context of aquaculture science, farm-level economics, and regional development. Rather than reiterating numerical outcomes, this section focuses on explaining why the observed patterns emerged and what they imply for inland aquaculture systems such as those in Bihar.

### 6.1 Biological Efficiency as the Foundation of Economic Performance

The consistently low feed conversion ratios (1.10–1.20) observed across all districts indicate effective nutrient recycling within biofloc systems. This finding aligns with the core biological premise of biofloc technology, wherein heterotrophic bacteria rapidly assimilate ammonia into microbial biomass when an appropriate carbon-to-nitrogen ratio is maintained [3,13].

From a biological standpoint, this process reduces ammonia toxicity while simultaneously generating an in-situ protein source. The relatively low mortality rates (6–8%) further suggest that water quality remained within safe physiological limits for cultured fish. Compared to conventional pond systems, where nitrogenous waste accumulation often triggers disease outbreaks, biofloc systems provide a more stable rearing environment [21,9].

Importantly, these biological advantages are not isolated outcomes but form the basis of economic efficiency. Improved feed utilization directly translates into lower feed requirements per unit biomass, thereby reducing the most significant cost component in aquaculture production.

### **6.2 Management Sensitivity and Inter-District Variation**

Although production performance varied across districts, the differences were relatively narrow. Patna units consistently outperformed those in Nalanda and Samastipur; however, field observations revealed that these differences were driven primarily by management practices rather than environmental conditions. Continuous aeration, precise carbon dosing, and timely feeding emerged as critical determinants of performance.

This finding reinforces earlier observations that biofloc systems are process-intensive rather than resource-intensive [17]. Unlike traditional aquaculture, where productivity is often constrained by land and water availability, biofloc outcomes depend largely on operational discipline and technical competence. As a result, investment in farmer training and extension services may yield higher returns than physical expansion of farming area.

### **6.3 Microeconomic Implications at the Farm Level**

At the microeconomic level, benefit–cost ratios close to or exceeding 2.0 across all districts indicate strong financial viability. Even under less optimal management conditions, biofloc farming remained profitable. This resilience is particularly relevant for small and marginal farmers, for whom production risk is a major constraint to adoption [18,25]. Sensitivity analysis revealed that profitability was more responsive to feed price fluctuations than to electricity costs. This outcome reflects the dominant share of feed in total production cost and underscores the economic significance of microbial protein availability. By partially substituting formulated feed, biofloc systems reduce farmers' exposure to volatile feed markets, which have become increasingly unstable in recent years [4].

Moreover, shorter production cycles and year-round operation enable faster capital turnover, improving cash flow and reducing financial stress at the household level.

### **6.4 Livelihood Effects and Labor Dynamics**

Biofloc farming altered the nature of labor engagement in aquaculture. While total labor requirements per unit were lower than in extensive pond systems, the demand for skilled labor increased. Farmers reported that routine activities such as water quality monitoring, aeration management, and feed adjustment required technical knowledge rather than physical effort.

This shift has important social implications. The relatively high technical orientation of biofloc systems makes them attractive to educated rural youth, who are often reluctant to engage in traditional agriculture. Previous studies have similarly reported higher youth participation in technology-driven aquaculture systems [31,33].

### **6.5 Aggregation of Micro-Level Gains into Macroeconomic Outcomes**

When examined collectively, farm-level gains generate broader macroeconomic effects. Increased local fish production contributes to improved market supply and price stabilization. In Bihar, where a substantial proportion of fish consumption is met through inter-state imports, even modest increases in local production can reduce dependence on external markets [19,14].

Employment generation extends beyond farm boundaries to input suppliers, feed dealers, seed producers, transporters, and local traders. Such multiplier effects strengthen rural economies and retain value within the region, aligning with broader goals of inclusive growth and rural development [7,8].

### **6.6 Biofloc Technology within the Circular Bioeconomy Framework**

From a sustainability perspective, biofloc systems exemplify circular bioeconomic principles by transforming waste into a productive input. Unlike conventional aquaculture, where waste is treated as an externality, biofloc systems internalize waste management within the production cycle. This approach reducing environmental discharge while improving resource-use efficiency [10,40].

Such integration of biological and economic efficiency positions biofloc technology as a viable pathway for sustainable intensification of inland aquaculture, particularly in regions facing land and water constraints.

### **6.7 Synthesis of Findings**

Overall, the discussion highlights that the success of biofloc-based fish production in Bihar is not accidental but rooted in the alignment of biological processes with economic incentives. Efficient microbial nutrient cycling underpins improved

feed utilization, which in turn drives profitability and resilience at the farm level. When adopted at scale, these micro-level efficiencies aggregate into tangible macroeconomic benefits.

## **7. Microeconomic Implications of Biofloc-Based Fish Production**

Microeconomic analysis focuses on how biofloc technology affects decision-making, cost structure, risk exposure, and income stability at the individual farm level. The results of the present study indicate that biofloc systems fundamentally alter the economics of inland aquaculture by shifting the cost–benefit balance in favor of more efficient resource utilization.

### **7.1 Cost Structure and Input Optimization**

At the farm level, feed remained the largest component of total production cost, accounting for approximately 40–45% of operational expenditure. However, compared to conventional pond culture, farmers operating biofloc systems reported lower effective feed consumption per unit of biomass produced. This reduction can be attributed to the continuous availability of microbial protein within the culture water, which supplements formulated feed intake [3,17].

Electricity costs were higher in biofloc systems due to continuous aeration requirements. Nevertheless, this increase did not undermine profitability, as higher yields and shorter production cycles compensated for additional energy expenses. Similar observations have been reported in other intensive aquaculture systems, where energy inputs are offset by improved productivity [18,6].

### **7.2 Profitability, Risk, and Income Stability**

Benefit–cost ratios close to or exceeding 2.0 across districts indicate that biofloc farming provides attractive returns on investment. Importantly, profitability was not confined to high-performing units alone; even moderately managed systems generated positive net returns. This suggests that biofloc technology offers a relatively low downside risk compared to traditional pond systems, which are more vulnerable to water quality deterioration and disease outbreaks [21].

Sensitivity analysis further revealed that feed price volatility posed a greater threat to profitability than fluctuations in electricity cost. However, the buffering effect of microbial protein reduced farmers' exposure to feed market instability. This characteristic is particularly important for small and marginal farmers, whose production decisions are highly sensitive to input price uncertainty [4].

Shorter production cycles also improved cash flow and reduced capital lock-in, enhancing income stability at the household level.

## **8. Macroeconomic Implications of Biofloc Adoption**

While microeconomic benefits accrue at the farm level, widespread adoption of biofloc technology generates broader macroeconomic effects that extend beyond individual producers.

### **8.1 Employment Generation and Skill Development**

Biofloc farming contributes to both direct and indirect employment. Direct employment is generated through system operation, monitoring, and maintenance, while indirect employment arises in input supply chains, including feed manufacturing, seed production, equipment supply, transport, and marketing.

Unlike traditional pond culture, biofloc systems demand technically skilled labor rather than manual labor. This shift has implications for rural employment structure, as it creates opportunities for educated youth and promotes skill development in aquaculture management [31,33].

### **8.2 Contribution to Local Fish Supply and Market Stability**

Bihar remains a fish-deficit state, meeting a substantial share of its demand through inter-state imports. Increased adoption of biofloc systems enhances local fish availability, which can help stabilize market supply and moderate price volatility. Even incremental increases in local production reduce dependence on external markets and retain economic value within the region [19,14].

Improved supply reliability also benefits consumers by ensuring fresher fish and reducing transportation-related losses.

### **8.3 Import Substitution and Regional Economic Retention**

From a macroeconomic perspective, biofloc technology contributes to import substitution by reducing the volume of fish sourced from other states. This substitution effect has multiplier implications for the regional economy, as income generated through local production circulates within local markets rather than being transferred externally [7,8].

#### **8.4 Alignment with Policy Objectives**

Biofloc technology aligns closely with national and state-level fisheries development policies that emphasize sustainable intensification, employment generation, and income enhancement. Programs such as the Pradhan Mantri Matsya Sampada Yojana (PMMSY) explicitly promote technological innovation and entrepreneurship in aquaculture [29,41].

The findings of this study suggest that targeted support for biofloc farming—through training, credit access, and infrastructure development—can accelerate progress toward these policy goals.

#### **9. Linking Micro- and Macroeconomic Outcomes**

A key contribution of this study lies in demonstrating how micro-level biological efficiency translates into macro-level economic outcomes. Improved feed efficiency and survival at the farm level aggregate into higher regional production, employment generation, and market stabilization.

This bottom-up pathway highlights biofloc technology as more than a production innovation; it represents a structural shift in inland aquaculture economics, where productivity gains are driven by process optimization rather than resource expansion.

#### **10. Conclusion**

This study provides a comprehensive assessment of biofloc-based fish production in Bihar by integrating biological mechanisms with microeconomic performance and macroeconomic implications. The findings demonstrate that biofloc technology enables efficient nutrient recycling through microbial processes, resulting in stable water quality, low feed conversion ratios, and acceptable survival rates under intensive culture conditions. These biological efficiencies translate directly into improved farm-level profitability, faster capital turnover, and reduced exposure to feed price volatility.

At the microeconomic level, biofloc systems exhibited strong benefit–cost ratios across districts, indicating financial viability even under moderate management conditions. Importantly, performance differences were driven primarily by operational discipline rather than geographic location, underscoring the central role of training and technical competence. At the macroeconomic level, aggregated farm-level gains contributed to increased local fish availability, employment generation, market stabilization, and gradual reduction in dependence on inter-state fish supply.

By internalizing waste as a productive input, biofloc technology aligns biological efficiency with economic sustainability, offering a viable pathway for intensifying inland aquaculture without proportional increases in land and water use. With appropriate institutional support, biofloc farming has the potential to become a cornerstone of sustainable aquaculture development in Bihar and similar resource-constrained inland regions.

#### **11. Limitations of the Study**

Despite its contributions, the study has certain limitations that should be acknowledged. First, the sample size was limited to 30 operational biofloc units, which may restrict the statistical generalization of results across the entire state. Second, the analysis was based primarily on single production cycles; longer-term ecological dynamics, system resilience, and cumulative economic performance over multiple cycles were not examined. Third, market price variability and policy changes were not explicitly modeled, although these factors can influence profitability and adoption decisions. Finally, the study focused on a limited number of species commonly cultured in biofloc systems; performance outcomes may vary for other species under different management regimes.

#### **12. Future Research Directions**

Future research could build on the present findings in several ways. Longitudinal studies covering multiple production cycles would provide deeper insights into system stability, disease dynamics, and long-term profitability. Comparative analyses between biofloc systems and other intensive technologies, such as recirculating aquaculture systems (RAS), could clarify relative economic and environmental trade-offs. Further work is also needed to quantify environmental footprints, including energy use and greenhouse gas emissions, to strengthen sustainability assessments. Finally, adoption studies using econometric models could help identify socio-economic and institutional factors influencing farmer decision-making and guide more targeted policy interventions.

#### **13. Data Availability Statement**

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

#### **14. Conflict of Interest Statement**

The author(s) declare no conflict of interest.



## 15. Author Contribution

Conceptualization, data collection, analysis, and manuscript preparation were carried out by the author(s).

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