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Profitability Analysis of the White Leg Shrimp (*Litopenaeus vannamei*) Cultured at Different Stocking Densities in Brackish Ponds

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ABSTRACT

Over the past decade, the cultivation of the vannamei shrimp (*Litopenaeus vannamei*) has expanded across Indonesia's coastal regions due to its superior adaptability and economic potential compared to other shrimp species. Optimizing stocking density is crucial for maximizing productivity and profitability in shrimp farming. This study aimed to analyze the productivity and profitability of the vannamei shrimp cultivated under different stocking density systems in brackish water ponds. A census-based sampling approach was used to collect data from shrimp farms employing various stocking densities. Key production factors recorded included seed quantity, land area, feed usage, fertilizers, pesticides, probiotics, labor, supplements, shrimp yield, sales price, and water quality parameters. The collected data were analyzed using a t-test to determine statistical significance in profitability among different farming systems. The findings indicated that stocking density significantly impacts profitability. Among the cultivation systems analyzed, the intensive farming system with a stocking density of 208 shrimp/m^2 yielded the highest productivity and profitability, demonstrating superior economic performance compared to other systems. Intensive shrimp farming at 208 shrimp/m^2 is the most profitable system, suggesting that farmers should consider optimizing stocking density to enhance financial returns. Further research is recommended to assess long-term sustainability and environmental impacts.

INTRODUCTION

Vannamei shrimp (*Litopenaeus vannamei*) cultivation has been expanding in Indonesia since 2001 due to its economic advantages over other shrimp species. This shrimp species is known for its efficient land and feed utilization, high productivity, fast growth rate, disease resistance, and adaptability to varying salinity levels **(Engle *et al.*, 2017)**. Additionally, vannamei shrimp can be stocked at higher densities due to their ability to utilize different water column levels. Even undersized shrimp (>100 eggs/kg) retain market value, further contributing to their economic appeal.

Kolaka District, located in Southeast Sulawesi, Indonesia, is one of the key regions currently developing vannamei shrimp farming. Across twelve districts, initiatives are being implemented to expand shrimp cultivation **(Mekuo *et al*., 2020; Riani *et al*., 2023)**. The cultivation system is primarily influenced by stocking density and technological applications **(Engle *et al.*, 2017; Hai *et al.*, 2018)**. Traditional shrimp farming typically employs a stocking density of ≤10 shrimp/m^2, while semi-intensive systems range from 10–50 shrimp/m^2. More advanced systems use 4 to 16 paddlewheel aerators per hectare to enhance water quality and productivity. Researchs by **Navghan *et al.* (2015)**, **Triyatmo *et al.* (2016)**, **Cheal *et al.* (2017)**, **Junda *et al.* (2018)**, **Samadan *et al.* (2018)**, **Dauda *et al.* (2019)**, **Tantu *et al.* (2020)** and **Riani *et al.* (2022)** support these cultivation approaches and their correlation with improved yields.

In general, intensifying shrimp farming leads to higher production outputs **(de Barros *et al.*, 2014; Engle *et al.*, 2017; Na nakorn *et al.*, 2017; Mohanty *et al.*, 2018; Dauda *et al.*, 2019; Tantu *et al.*, 2020)**. However, achieving optimal profitability requires balancing input costs and output gains. A profitable farming system maximizes income while minimizing unnecessary expenses. Profitability is defined as the percentage of income generated relative to operational costs, while productivity measures shrimp yield per hectare. Efficient cost and land utilization result in higher profitability and productivity.

The novelty of this research lies in its localized focus on Kolaka District, Southeast Sulawesi, an emerging hub for shrimp aquaculture that has received limited attention in previous economic performance evaluations. Unlike broader studies that emphasize technical or biological aspects, this research integrates economic indicators to evaluate how different stocking densities influence productivity and profitability. By providing region-specific insights, the study contributes valuable knowledge to support the development of efficient, scalable, and sustainable shrimp farming practices in Eastern Indonesia. Therefore, this study aimed to assess the profitability and productivity of vannamei shrimp farming under different cultivation systems, focusing on the role of stocking density.

MATERIALS AND METHODS

1. Study sites

The current study was conducted from December 2019 to September 2020 using survey research methodology. Data were collected from the cultivation of the vannamei shrimp in Kolaka District of Southeast Sulawesi, which is located at 3^{o}37'-4^{o}38' South latitude and 121^{o}05'-121^{o}46' Eastern longitude. Kolaka has a tropical climate with high humidity, average temperatures of 26–32°C, and distinct wet and dry seasons. The area's brackish water resources, flat coastal land, and growing aquaculture infrastructure make it suitable for shrimp farming.

2. Data collection

The population in this study consisted of 69 plots with different breeding systems. The cultivation cycle was 2.5 cycles per year with the saturated sampling technique. Data were collected on key production factors, including seed quantity (units), land area (hectares), feed usage (kg), fertilizer application (kg), pesticide use (liters), probiotic application (ml), labor input (man-hours), and supplement usage (kg). Additionally, shrimp production yield (kg/ha) and market sales price (IDR/kg) were recorded.

Data were collected by surveying the fields and interviewing the breeders and field technicians. Water samples were obtained from each site and were analyzed in the laboratory for water quality parameters. Water samples were collected using a 500ml bottle in the morning by technicians and were then analyzed at the Kolaka Independent Pond Laboratory, Southeast Sulawesi. Total organic matter (TOM), NO2: nitrogen dioxide (NO_2), and total ammonia nitrogen (TAN) were measured using the American Public Health Association (APHA) method. *Vibrio* bacteria were detected in the water samples in different cultivation systems.

3. Statistical analysis

Different test analyses (t-test) were used to determine the significant differences in the profitability of cultivating vannamei shrimp in different cultivation systems. Data were analyzed using SPSS version 16.

RESULTS

1. Production factors of vannamei shrimp cultivation

The main productive factors in the cultivation of vannamei shrimp were land area, seeds, labor, feed, lime, fertilizer, probiotics, and water wheel. Table (1) shows that the stocking density in the intensive cultivation system was higher than in other cultivation systems, reaching 114,571.4 post larvae/ha. Similarly, the highest amount of feed was also found in intensive cultivation systems than in traditional and semi-intensive systems. Generally, all production factors were high in the intensive cultivation system of vannamei.

2. Production and revenue of vannamei breeding enterprises on different cultivation systems

The highest productivity of vannamei shrimp cultivation was found in the intensive cultivation system (14,847 kg/ha) with a longer cultivation period of 111 days (Table 2). However, the largest size of vannamei was found in the traditional plus cultivation system. Because the price was high in the intensive cultivation system, the highest revenue was found at Rp 1,164,669,810 ha/cycle. Therefore, the high productivity of the vannamei shrimp cultivation was found in intensive cultivation systems rather than in traditional plus, and semi-intensive cultivation.

Table 1. Production factors in different cultivation systems of vannamei shrimp

No.	Production factors	Unit	Average		
			Traditional Plus	Semi-Intensive	Intensive
1	Land area per plot	Ha	1.1	0.4	0.2
2	Stocking density	Post larvae/ha	5,006.4	60,785.7	114,571.4
3	Labors	Ind/ha	1.1	8.1	13.4
4	Amount of feed	Kg/ha	804.8	18,342.9	44,767.9
5	Amount of lime	Kg/ha	272.5	7,054	12,357
6	Amount of probiotic	L/ha	0.8	136	149
7	Amount of fertilizer	Kg/ha	210.8	1,634,3	4,206,5
8	Amount of water wheel	Unit/ha	0.0	28.1	35.8

Table 2. The revenue of vannamei shrimp cultivation on different cultivation systems

Cultivation System	Stocking Density (individual/ m^2)	Productivity (kg/ha)	Cultivation times (days)	Size (individual / kg)	Price (Rp/kg)	Revenue (Rp/ha/cycle)
Traditional Plus	5	402	61	95	48,885	19,162,195
Semi-intensive	61	4,292	102	38	74,900	357,046,429
Intensive	115	14,847	111	42	73,236	1,164,669,810

The study also revealed that no significant difference in the size and price of vannamei shrimp between the semi-intensive and traditional systems were observed. Table (3) shows that the operational fee, production, selling price, and profit differ significantly (P<0.05) between the cultivation of semi-intensive and traditional systems. These differences lead to variations in the productivity and profitability of vannamei shrimp farming across different farming systems. Fig. (1) demonstrates that the traditional plus cultivation system exhibited high profitability by 124.40%, followed by intensive (95%) and semi-intensive (71.6%) cultivation systems.

Table 3. The cost, production, and revenue of vannamei shrimp farming enterprises on different cultivation systems

No	Item	The difference between semi-intensive and intensive cultivation systems		The difference between traditional and semi-intensive cultivation systems	
		Semi-intensive	Intensive	Traditional	Semi-intensive
1	Operational Fee (Rp/ha)				
	Average	218,103,977	687,654,018	10,884,219	452,878,998
	T-hit		14		19.86
	Sig.		0.00		0.00
2	Production (kg/ha)				
	Average	4,291.67	14,846.95	759	10,085.00
	T-hit	0.3			59
	Sig.	0.06			0.00
3	Size of Vannamei (ind/kg)				
	Average	38	42	92.73	39.94
	T-hit		1.592		4.191
	Sig.		0.218		0.096
4	Selling Price (Rp/kg)				
	Average	74,900	73,236	50,508	74,068
	T-hit		0.119		36.7
	Sig.		0.733		0.00
5	Price (Rp/ha)				
	Average	357,046,429	1,164,669,810	23,083,304	760,858,119
	T-hit		11.141		90.613
	Sig.		0.003		0.00
6	Profit (Rp/ha)				
	Average	156,222,056	653,330,416	13,537,564	404,776,236
	T-hit		3.5		44
	Sig.		0.07		0.00

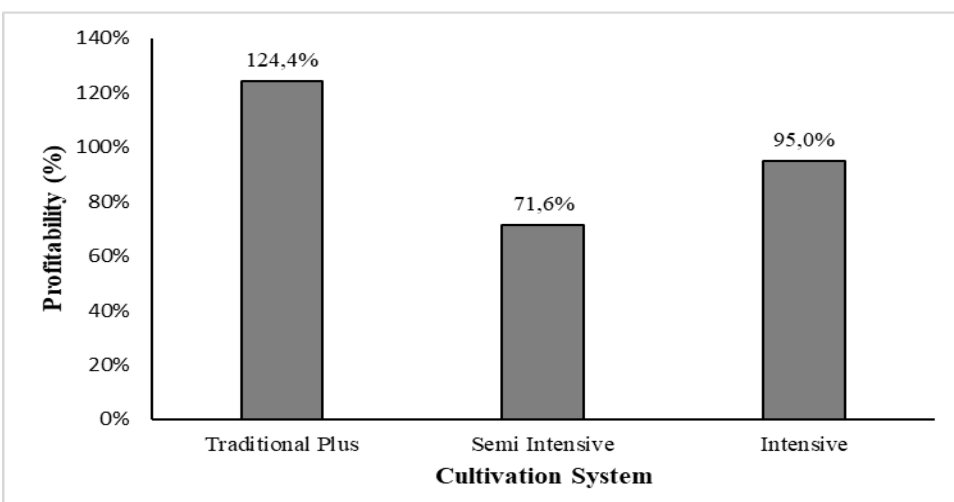

Fig. 1. Profitability of vannamei shrimp cultivation business in different cultivation systems

3. **The vannamei growing enterprise-intensive system demonstrates productivity and profitability across a variety of stocking densities**

Table (4) demonstrates that the highest productivity of vannamei shrimp was observed at the highest stocking density (208 ind/m²) in the intensive cultivation system. The highest stocking density of 208 individuals/m^2 produces a high profit of 1,396,000 ha/cycle. Furthermore, the intensive cultivation system of vannamei exhibits high profitability by 238% at a density of 70 individuals/m^2.

Table 4. The profitability of vannamei shrimp with intensive cultivation at various densities

Stocking density (individual/m^2)	Productivity (kg/ha)	Size (Individual/kg)	Price (Rp/kg)	Revenue (Rp000.000/ha/cycle)	Operation fee (Rp000.000/Ha/cycle)	Profit (Rp000.000/ha/cycle)	Profitability (%)
70	4,500	39	73,000	839	251	588	238
83	7,000	40	71,000	497	424	73	17
90	10,000	52	53,500	541	274	266	138
93	10,667	52	65,100	694	431	263	61
96	19,687	35	86,000	1.693	589	1,104	187
100	13,520	43	69,733	964	492	473	100
108	12,800	55	61,100	782	477	305	64
127	11,667	52	65,100	760	448	312	70
208	25,000	46	80,000	2,288	892	1,396	157

4. **The water quality in different cultivation systems**

The water quality determines the production and growth (size) of the vannamei shrimp. Therefore, optimal water quality will lead to maximum shrimp production and size. Table (5) demonstrates that the alkalinity parameter was still quite low compared to the recommended standard. The levels of total organic matter (TOM) in intensive and semi-intensive farming systems exceeded suggested thresholds. TOM values in intensive systems with a density of 100–250 should be between 17.28–113.51ppm. The total amount of TOM increases with the more intensive vannamei shrimp farming. In general, the water quality for the cultivation of vannamei shrimp still meets the standard regulation of the **Minister of Maritime Affairs and Fisheries (2016)**.

Table 5. Water quality on individual seedlings in different cultivation systems

Cultivation System	pH	Salinity (ppt)	DO (P)	Temperature (P)	Hardness (Total)	Alkalinities (Total)	NO_2	TAN	TOM	Total *Vibrio* spp.
	7.5- 8.5	**26- 36**	**≥3**	**27 - 31**	**≥ 2,500**	**120-150**	**≤0.1**	**<0.2**	**<90**	**<3x10^3**
			ppm	**ºC**			**ppm**	**ppm**	**Ppm**	**CFU**
Traditional Plus	8.5	23.7	3.3	25.5	3,580.2	97.0	0.1	0.4	75.2	362.0
Semi-intensive	8.2	31.3	5.0	28.0	6,044.2	107.3	0.0	0.1	123.9	1,271.4
Intensive	8.0	30.5	4.7	27.9	5,677.7	89.3	0.4	0.5	150.0	2,414.3

Note: DO: dissolved oxygen; NO_2: nitrogen dioxide; TAN: total ammonia nitrogen; TOM: total organic matter.

DISCUSSION

The results indicated that feed was the most influential production factor across different vannamei shrimp cultivation systems. Feed not only plays a critical role in shrimp growth but also represents the largest operational cost in vannamei shrimp farming **(Hai *et al.*, 2018)**. **Navghan *et al.* (2015)** reported that feed costs accounted for 52% of the total expenses in shrimp farming operations. In the present study, feed costs comprised 63.68% of total operational expenditures. In addition to feed, other significant production cost components included seed (post-larvae) costs, electricity, labor, chemicals, and fixed costs such as equipment depreciation and infrastructure **(Mansaray *et al.*, 2018)**. Generally, the more intensive the cultivation of vannamei shrimp, the higher the production **(Navghan *et al.*, 2015; Triyatmo *et al.*, 2016; Cheal *et al.*, 2017; Jescovitch *et al.*, 2017; Dauda *et al.*, 2018; Junda, 2018; Yuni *et al.*, 2018; Xie *et al.*, 2019)**. The higher the output, the greater the general revenue (**Mohanty *et al.*, 2018)**. According to **Farionita *et al.* (2018)** and **Mansaray *et al.* (2018)**, the more intensive the cultivation of vannamei shrimp, the greater the reception. The average revenue of this study's results is higher than those recorded in **Triyatmo *et al.* (2016)**, **Wijayanto *et al.* (2017)** and **Ferionita *et al.* (2018)** studies. According to **Triyatmo *et al.* (2016)**, a solid area of 134–161 acres/m^2 with a production of 1,106–3,220 kg/ha yields a receipt of Rp 49.152.421–Rp 139.830.977. The research of **Wijayanto *et al.* (2017)** yielded a receipt of Rp 271.904.063–Rp 311.502.492 on a solid area of 100 acres/mm^2. According to **Ferionita *et al.* (2018)**, traditional cultivation systems yielded Rp 1,358,638,697/ha, whereas intensive cultivation systems yielded Rp 113,066,616/ha. However, the results of this research indicate a lower receipt from the cultivation of vannamei than those of **Mohanty *et al.* (2018)** by Rp 667,113,640–Rp 811,352,925.

In addition to production, the price of shrimp determines revenue. The larger the shrimp, the higher the price per kilogram. The larger the vannamei, the longer the crop cycle lasts. In this study, the length of cycle cultivation was relatively the same as in **Engle *et al.* (2017)** and **Junda *et al.* (2018)**, which was 60–112 days/cycle. Farmers widely accept the cultivation of vannamei shrimp as an intensive system. This is due to the implementation of water quality management technologies, as well as the use of high-quality feed and medicines. These measures enable the vannamei shrimps to grow to their maximum potential and produce large-sized shrimps **(Farionita *et al.*, 2018)**.

The water quality factors that impact the lifespan, growth, and production of vannamei shrimp include temperature, pH, salinity, dissolved oxygen, alkalinity, hardness, nitrites-nitrogen, nitrates-nitrogen, ammonia, calcium, magnesium, TAN, and nitrates. According to **Chakravarty *et al.* (2016)**, **Abdelrahman *et al.* (2018) and Jaganmohan and Kumari (2018)**, these factors significantly influence the lifespan, growth, and production of vannamei shrimp. According to **Mohanty *et al.* (2018)**, **Na nakorn *et al.* (2017)** and **Samadan *et al.* (2018)**, TOM production generally increases with the intensity of vannamei shrimp cultivation. This study found TOM value of 123.9ppm in semi-intensive systems (density of 61/m^2) and 150ppm in intensive systems (density of 115/m^2), which was quite high compared to other studies. According to **Wijayanto *et al.* (2017)** and **Ariadi *et al.* (2019)**, TOM values in intensive systems with a density of 100–250 remain within the recommended range. Another study by **Samadan *et al*. (2018)** found that feed residues are the main source of organic matter in both semi-intensive and intensive systems. In intensive systems, where shrimp farming is denser (100 square feet/m^2), TOM values were higher at 185.15ppm. Studies conducted by **Mohanty *et al.* (2018)** have also reported similar findings. In anaerobic conditions, the organic material at the base will trigger the formation of ammonia and *Vibrio* sp. bacteria. Dissolved oxygen is crucial in the cultivation of vannamei shrimp. A sufficient amount of dissolved oxygen will prevent TAN formation and *Vibrio* spp. growth **(Mohanty *et al.*, 2018; Ariadi *et al.*, 2019)**. Consequently, semi-intensive and intensive systems incur higher costs for water quality management technologies. In addition to regular water quality monitoring during the grow-out period, these systems also involve pre-treatment of water before discharge into cultivation ponds. Management practices include the addition of probiotics to the effluent water, the removal of organic material from the pond bottom, and the replenishment of up to 10% of the water volume when water quality parameters fall below acceptable standards.

The more intensive the cultivation system, the higher the cost of production factor. According to **Engle *et al.* (2017)** and **Filipski and Belton (2018)**, the cost of factor production increases with the intensity of the cultivation system. However, the more intensive the crab cultivation, the higher the productivity (**Triyatmo *et al.*, 2016)**. According to this study, vannamei shrimp-intensive systems produce 3.5 times more than semi-intensive farming systems. Although the production costs in the intensive farming system were 3.15 times higher than in other systems, the benefits were significantly greater due to substantially higher shrimp yields. **Engle *et al.* (2017)** reported that intensive farming systems result in lower unit production costs and higher overall profits. In this study, the unit cost of production in the intensive system is lower compared to the traditional cultivation system. Additionally, shrimp produced in semi-intensive and intensive systems were significantly larger in size, contributing further to the economic advantages of these farming methods. The size of shrimp in semi-intensive and intensive cultivation systems was relatively the same, with an average size of 32 and 42 squares/kg, whereas in traditional cultivation systems, it was 93 squares/kg. The results showed that the intensive cultivation system of vannamei shrimp has higher productivity of the land and income. The production in the intensive cultivation system was 3.5 times higher than the semi-intensive system and 33.6 times higher than the traditional system. Thus, the income of the intensively cultivated system is higher than other intensive systems. Although vannamei shrimp cultivation has the highest profitability, the land productivity and per-hectare income are low. The intensive farming system's profitability is 23.9% higher than the semi-intense system. As a result, the intensive farming system has the best productivity and profitability for cultivating vannamei shrimp.

Increasing the density to a certain point will increase production and revenue. However, an increase in a certain density can result in a decline in profit, despite an increase in production. This is because the increase in density also means increasing the use of other productive factors, especially increasing feed. It is consistent with previous research that the increased thickness of seeds can decrease the production and profit of shrimp farming enterprises **(Na nakorn *et al.*, 2017; Zhou & Hanson, 2017; Junda *et al.*, 2018)**. **de Barros *et al.* (2014)** and **Mohanty *et al.* (2018)** have also confirmed this finding. According to **Ravuru and Mude (2014)** and **Junda *et al.* (2018)**, the density remains the same, but the production of vannamei shrimp varies **(Engle *et al.*, 2017; Wijayanto *et al.*, 2017)**. Even an increase in seed density can reduce shrimp production and negatively impact the profitability of vannamei shrimp farming operations **(Na nakorn *et al.*, 2017; Zhou & Hanson, 2017; Junda *et al.*, 2018)**. According to **de Barros *et al.* (2014)** and **Mohanty *et al.* (2018)**, even an increase in seed density could reduce shrimp production. The study indicated that raising the seed density in intensive systems won't always result in greater production and profit. Conversely, higher density results in a higher utilization of other production resources, especially feed. Higher production factors result in higher costs. Therefore, effective agriculture business management is needed. When combined with strong growth, production and profit warnings contribute to effective crop management.

At the research site, seed density in intensive vannamei shrimp cultivation systems ranged from 70 to 208 seeds/m². The highest production and profit were achieved at a density of 208 seeds/m². Similar findings were reported by **Engle *et al.* (2017)** and **Tantu *et al.* (2020)**, who indicated that higher stocking densities tend to yield greater output and income. Overall, the results of this study show that productivity and total income were optimized at a density of 208 seeds/m². However, the profitability per unit area was higher at lower densities of 70 and 96 seeds/m².

At these lower densities, shrimp size was also larger, averaging 39 and 35 shrimp per kilogram, respectively. In contrast, at the highest density of 208 seeds/m², the shrimp were smaller, averaging 46 shrimp per kilogram. These findings suggest that while maximum production can be achieved at higher stocking densities, there is still a need for improvement in production management practices to optimize both shrimp size and farm profitability.

This study was limited to 69 plots in Kolaka District during a single cultivation period, which may not capture seasonal or regional variations. Data collection relied on self-reported information from farmers, introducing the potential for bias. Moreover, differences in farm management practices, feed quality, and seed sources were not fully controlled. Factors such as disease outbreaks, biosecurity measures, and fluctuations in market prices were also not comprehensively analyzed, which could affect the accuracy of the productivity and profitability estimates.

CONCLUSION

The intensive cultivation system, with a density of 208 acres/m², demonstrated optimal productivity, maximizing both income and profitability in vaname shrimp farming.

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