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Financial viability of inserting the biofloc technology in a marine shrimp *Litopenaeus vannamei* farm: a case study in the state of Pernambuco, Brazil

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Abstract This study analyzed the financial viability of inserting the biofloc technology (BFT) system and maintaining the conventional culture system for the marine shrimp *Litopenaeus vannamei* in a farm located in the state of Pernambuco, northeastern Brazil. To obtain information related to investment and operating costs, we used three ponds (625 m^2 each) covered with high-density polyethylene operating with the BFT system and data from three conventional ponds (2.86 ha each) used in a farm during 2014. The total production costs of BFT were eight times higher than the conventional system. Operating profit and profitability index were US$ 51,871.54 ha^{-1} $year^{-1}$ and 30.22 % for BFT, and US$ 21,523.83 ha^{-1} $year^{-1}$ and 59.79 % for the conventional system, respectively. In investment analysis, indicators were favorable for both systems, with greater expressiveness of the net present value (NPV) for the BFT (US$ 142,004.42) and internal rate of return (IRR) 4.5 times higher for conventional system (131.86 %). To achieve favorable results of profitability and viability, combined with the ability to contribute to the sustainable development of marine shrimp farming, the BFT system is a promising alternative to replace traditional systems used in northeastern Brazil.

Keywords Biofloc · Costs · Internal rate of return · Net present value · Profitability · Sensitivity · Shrimp farming

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Introduction

The development of an agricultural activity depends on several factors, mainly the growing demand for the product, its technical and economic viability, as well as the possibility of expansion in area (Buarque 1984; Brandão et al. 2006; Varian 2006). As a new activity in the country, settled only in 1993 with the commercial use of the exotic *Litopenaeus vannamei*, Brazilian shrimp farming is still in development and adaptation to its requirements (Wainberg et al. 2011; Cavalcanti 2012).

There has been a great speculation about the growth potential of shrimp farming in Brazil, due to its 8000 km of coastline and the favorable climate for the culture of *L. vannamei* (Rocha and Rodrigues 2004; Pinheiro et al. 2007). However, after more than 10 years, the country has yet to overcome the 90,000-ton mark registered in 2003 (Natori et al. 2011; MPA 2012). There are several factors that limit the expansion of the Brazilian shrimp farming, such as restrictions related to the implementation of new projects, as well as the culture system used in the country (Natori et al. 2011; Wainberg et al. 2011).

Most shrimp farms in Brazil use semi-intensive systems with water renewal, in semi-excavated ponds, usually close to estuaries along the coastline (Rocha et al. 2013). Known as "conventional," this model has been associated with several problems, such as destruction of mangrove areas, discharges in the adjacent environment, as well as disease outbreaks (Valiela et al. 2001; Abreu et al. 2011; Ha et al. 2012). In conventional shrimp farming, besides the dependence on constant water renewals due to accumulation of organic and inorganic matter in the ponds, there is also a limitation on increasing the stocking density (Hossain et al. 2004; Avnimelech 2012).

The biofloc technology (BFT) system is a new shrimp farming model that has been studied due to need to develop sustainable production systems, reducing or even eliminating negative impacts on the environment, since it requires little or no water exchange, thus reducing the emission of waste and the escape of the cultivated species to the ecosystem (Burford et al. 2003; Wasielesky et al. 2006; De Schryver et al. 2008; Avnimelech 2012). Furthermore, the BFT system tolerates high stocking densities, which allows increase in productivity and makes the most efficient use of the area (Krummenauer et al. 2011). When comparing the conventional and BFT system of shrimp farming, there are differences in the requirements and management of the production process. In intensive models, as in the case of BFT, a greater technological support is needed, such as an aeration system, the frequent monitoring of water quality and more specific feed (Avnimelech 2012). These factors increase the production costs, and the investment becomes expensive, raising doubts on producers in relation to the financial viability of this new technology.

The success of an aquaculture enterprise depends not only on the improvement of farming techniques, but also on cost control and cash flow analysis. Proper management of production will possibly increase productivity, whereas an efficient administration will bring benefits related to the reduction in expenditures, as well as the analysis of cash flow with specific tools will enable the visualization of future economic returns (Buarque 1984; Rocha et al. 2013).

Given the scarcity of economic information that helps entrepreneurs in decision making related to investments, this study aimed to analyze the financial viability of inserting the BFT system compared to the conventional system of the marine shrimp *L. vannamei* in a farm in the state of Pernambuco, Brazil.

Materials and methods

The study was carried out on a commercial farm in the coast of Pernambuco State, Brazil. Information related to the investment in the BFT system, as well as data concerning the operational costs, was obtained from the construction of the ponds, the purchase of items needed for the operation and from intensive culture in BFT system during the year of 2014. The data from the conventional systems were obtained from the history of production in the farm for the same period and from information about the values for the acquisition of new equipment and maintenance of existing structures. The investment analyses were based on real enterprise scenarios, considering the implementation of BFT system on a previously structured farm with own land and logistical buildings.

The BFT culture system was carried out in three ponds, with an area of 625 m^2 each, covered with high-density polyethylene (HDPE) with a thickness of 0.8 mm. The ponds were stocked with PL_{10} (post-larvae with 10 days after mysis metamorphosis) at the density of $113 \pm 7.2\ m^{-2}$, and the cultures were performed without water exchange. Sugarcane molasses were used as a carbon source to the formation of bioflocs, maintaining the carbon/nitrogen ratio of 20:1 in the BFT system (Avnimelech 1999; Ebeling et al. 2006). In order to promote constant aeration, as well as horizontal and vertical movement of the water, a paddlewheel aerator (2 HP) was used in each pond of the BFT system, providing 32 HP ha^{-1} (Avnimelech 2012).

The conventional culture system was performed in three semi-excavated ponds with an average of 2.86 ha each and constant exchange water. The mean density used was $20 \pm 1.8\ PL_{10}\ m^{-2}$, with the possibility of four cycles per year. Because the conventional system had low stocking densities, it did not require mechanical aeration, and electricity was needed only for water pumping. For both systems, post-larvae were acquired in a commercial hatchery located in northeastern Brazil.

Shrimp were fed in both systems a commercial diet with 40 and 32 % crude protein (CP) during the first 30 days and the rest of the culture, respectively. The amount of feed offered in both production systems was regulated through weekly biometrics, as well as the use of trays and feeding table according to Jory et al. (2001).

When the animals of both systems reached commercial size (above 10 g of mean weight), they were harvested and commercialized. The retail price was adjusted according to the local market pricing at the time.

Survival (%), mean final weight (g), productivity (kg ha^{-1} cycle) and feed conversion ratio (FCR) were recorded in both systems. FCR was calculated as the ratio between the weight of supplied feed (kg) and the gain of biomass (kg). These data were obtained throughout the year of 2014, totaling 9 and 12 harvests in the BFT and conventional systems, respectively.

In order to standardize the comparison between the systems, the area of production considered was one hectare, that is, 16 ponds of 625 m^2 in BFT and one pond of 10,000 m^2 in conventional system.

The cost analysis was based on the method by the Institute of Agricultural Economics (IAE) proposed by Matsunaga et al. (1976), in which the effective operating cost (EOC), total operating cost (TOC) and total production cost (TPC) were evaluated. EOC comprised the labor force (time required to perform each operation in both systems) as well as the quantities of inputs used during the production cycle. The expenses with depreciation using the linear method were additionally calculated for TOC, corresponding to the items of fixed capital of the activity (with respective initial or acquisition values—Vi, and residual or final values—Vf) regarding their life span (Vu), expressed by D = (Vi − Vf)/Vu; as well as other expenses, corresponding to 5 % of the EOC, and the costing interest, related to the rural credit rate applied to half the EOC. By adding to the TOC the entrepreneur's remuneration ("pro-labore") and investment remuneration (fixed capital), the total production cost (TPC) was obtained. Mean prices refer to the year 2014 and were registered in Reais (R$).[1]

The profitability indicators used in the analysis were proposed by Martin et al. (1998) and are considered as follows: gross revenue, which is the production multiplied by the mean unit price paid to producers; operational profit, calculated as the difference between the gross revenue and total operating costs; and profitability index, which refers to the proportion of the gross revenue that constitutes the available resources, corresponding to the net income obtained. There was also a leveling point of production (balance production), characterized by the minimum production necessary to cover total production costs, and cost per kilogram (balance value) resulting from the total production cost over the obtained production.

To analyze the financial viability of the shrimp farming investment, we evaluated the net present value (NPV), defined as the present value of cash flows over 10 years minus the initial value of the investment. This means that if the present value of cash inflows is, at least, equal to the present value of cash outflows, then the investment is viable. In this study, the minimum rate of attractiveness (MRA) was the usual discount rate of 10 % per year (Brazilian rate of the Special System for Settlement and Custody—SELIC), referring to 2014. From the cash flows for a horizon of 10 years with the investment fully implemented in year zero, the internal rate of return (IRR) was determined, by definition, as the indicator that makes the net present value of the flow equal to zero (Noronha 1981). As criteria, in case that MRA remains below IRR, more gain is expected in investing in the project than leaving the money retained in a Brazilian financial application based on the SELIC rate. Another important investment analysis used in the study was the payback period discounted that determines the company's operating time required to recover the invested capital (Buarque 1984). This analysis considered the amount of annual profits at current values (discount rate of 10 % per year) required to cover the total value of the investment.

From the possibility of different scenarios during the project implementation period, the sensitivity analysis was performed in order to verify how much changes in the retail price (US$ kg^{-1}) and productivity (kg ha^{-1} cycle) affect the financial results of BFT and conventional systems (Buarque 1984; Kam and Leung 2008). Due to the uncertainty of the future behavior, variations of 10, 20 and 30 % were considered in the items evaluated in the sensitivity analysis.

Results

Production systems showed differences in the results of zootechnical performance for survival, productivity and FCR (Table 1). The mean productivity of the BFT system was five times higher than in the conventional system.

Regarding the investments needed to implement a productive hectare for each system, BFT demanded greater expenditure on fixed capital, corresponding to a value ten times higher compared to the conventional system (Table 2). When analyzing the largest

[1] Reference value (November/2014—US$ 1.00 = R$ 2.49).

Table 1 Zootechnical variables (mean ± SD) and information of *Litopenaeus vannamei* culture carried out in the BFT and conventional systems from a farm located in Pernambuco, Brazil, in 2014

Variables	BFT	Conventional
Density (shrimp m^{-2})	113.0 ± 7.2	20.0 ± 1.8
Survival (%)	58.0 ± 19.6	73.0 ± 4.6
Final mean weight (g)	11.9 ± 3.6	10.4 ± 0.2
Productivity (kg ha^{-1} cycle)	7775.0 ± 1955.7	1537.0 ± 185.2
Feed conversion ratio (FCR)	1.8 ± 0.3	1.4 ± 0.1
Cultivation period (days)	98.0 ± 13.2	90.0 ± 0.5
Retail price (US$ kg^{-1})	5.91 ± 0.9	5.77 ± 0.6

Table 2 Values of fixed investments (US$ and %) for the project implementation of the shrimp *Litopenaeus vannamei* production in one hectare in BFT and conventional systems in Pernambuco, Brazil, in 2014

Items	BFT		Conventional	
	US$	%	US$	%
Project	7630.52	5.14	763.05	5.16
Regularization rates	481.18	0.32	481.18	3.25
Earthmoving	8502.49	5.73	5367.20	36.27
Supply/drainage system[a]	22,894.78	15.43	3433.73	23.21
Acquisition and installation of geomembrane (0.8 mm)[a]	46,555.82	31.39	–	–
Electrical installation[a]	7988.76	5.39	647.79	4.38
Area isolation[a]	6425.70	4.33	–	–
Platform scale, 150 kg × 50 g[a]	406.02	0.27	406.02	2.74
Equipment and reagents for water analysis[a]	9975.35	6.73	1970.28	13.32
Generator (60 kVA)[a]	16,465.86	11.10	–	–
Paddlewheel aerators (2 HP) (×16)[a]	19,277.11	13.00	–	–
Centrifugal pump (7 HP)[a]	923.69	0.62	923.69	6.24
Others[b]	803.21	0.54	803.21	5.43
Total	148,330.51	100.00	14,796.17	100.00

[a] Derogatory items (useful life of machinery and equipment considered between 5 and 10 years and infrastructure of 25 years)

[b] Items related to operations like harvests and maintenance (networks, wheelbarrow, etc.)

investments, the purchase and installation of geomembrane represented more than 30 % of the total investment in the implementation of BFT system, followed by the purchase and installation of water supply and drainage system (concrete structures, PVC pipes and valves) representing 15.43 %. As for the conventional system, the greater expressiveness was related to the movement of the soil (earthworks, leasing and construction of dikes) representing 36.27 % of the investment.

Similarly as observed in the investments, BFT operating costs were ten times higher than the conventional system (Table 3). Regarding EOC, the inputs corresponded to the higher cost item, accounting for 84 and 77 %, respectively, for the BFT and conventional systems. The feed was the most representative item for both systems, corresponding to 54 % (BFT) and 79 % (conventional) of the expenses with inputs. The smallest percentage

Table 3 Estimated operating cost (US$ and %) for the culture of the shrimp *Litopenaeus vannamei* in BFT and conventional systems carried out in one hectare in the state of Pernambuco, Brazil, in 2014

Description	BFT		Conventional	
	US$	%	US$	%
Labor	4547.04	13.66	716.19	17.62
Feed	12,617.07	37.89	1894.91	46.62
Electricity	4813.98	14.46	125.53	3.09
Others[a]	5870.20	17.63	387.18	9.53
Effective operational cost (EOC)	27,848.29	83.64	3123.81	76.86
Other expenses[b]	1392.41	4.18	156.19	3.84
Depreciation	1598.75	4.80	152.25	3.75
Interest cost[c]	1218.36	3.66	136.67	3.36
Total operating cost (TOC)	32,057.82	96.28	3568.91	87.81
Entrepreneur's remuneration ("pro-labore")	401.61	1.21	401.61	9.88
Investment remuneration[d]	835.45	2.51	93.71	2.31
Total production cost (TPC) cycle^{-1}	33,294.87	100.00	4064.24	100.00
Total production cost (TPC) year^{-1}	124,369.00		16,482.73	

[a] Other inputs (post-larvae, bicarbonate, etc.)

[b] Refers to 5 % of the EOC

[c] This refers to the interest rate of 8.75 % per year on 50 % of the EOC during the production cycle

[d] Refers to the interest rate of 12 % per year on the EOC

index assigned to the BFT system resulted in higher proportional expenses with energy, equivalent to US$ 4813.98, when compared to US$ 125.53 in the conventional system.

Overheads, depreciation and financial charges (interest cost) represented an increase in operating costs of 15 % for the BFT and 14 % for conventional systems. Regarding the depreciation of the corresponding items for BFT (US$ 1598.75) and conventional (US$ 152.25) systems, we highlight that it is not an actual cash disbursement for the producer, but it must be computed for replacement after their useful lives.

After the remuneration of production factors (entrepreneur and investment) were summed, we obtained the total production costs of a cycle, corresponding to US$ 33,294.87 for the BFT and US$ 4064.24 for the conventional system. It is noteworthy that

Table 4 Profitability of *Litopenaeus vannamei* shrimp culture in BFT and conventional systems undertaken in one hectare in Pernambuco State, Brazil, in 2014

Variables	BFT	Conventional
Production (kg year^{-1})	29,042.05	6234.75
Mean price (US$ kg^{-1})	5.91	5.77
Gross revenue (US$ year^{-1})	171,619.67	35,997.76
Total production cost (US$ year^{-1})	124,369.00	16,482.73
Operating profit (US$ year^{-1})	51,871.54	21,523.83
Profitability index (%)	30.22	59.79
Balance production (kg year^{-1})	21,046.13	2854.78
Balance value (US$ kg^{-1})	4.28	2.64

Table 5 Viability of production of the shrimp *Litopenaeus vannamei* in BFT and conventional systems carried out in one hectare in state of Pernambuco, Brazil, in 2014

Analysis	BFT	Conventional
Net present value (US$)	142,004.42	105,115.23
Internal rate of return (%)	29.44	131.86
Payback period (years)	3.96	0.83

the value related to the "pro-labore" fees remained constant, considering the standard of work in one hectare for both systems.

The productivity of the systems directly influenced the economic profitability. Since BFT was more productive, its revenue was 377 % superior compared to the conventional system (Table 4). Comparatively to the production costs, the BFT system obtained an annual operating profit of US$ 51,871.54 for one productive hectare, corresponding to a value 141 % higher than the conventional system. However, the profitability index was superior in the conventional system (59.79 %), due to the costs being considerably lower than those of the BFT system.

Regarding the required minimum amount (balance production) to cover all annual production costs, it is necessary to produce 21,046.13 kg year^{-1} in the BFT system, but only 2854.78 kg year^{-1} in the conventional system.

In the investment analysis for a planning horizon of 10 years, positive values of NPV were obtained for both systems, with greater expressiveness to the BFT system regarding the availability of capital for the producer (Table 5). The internal rate of return (IRR) also presented favorable values for both systems, i.e., above the cost of capital employed (10 % per year). However, from the perspective of assessing the return of activity, IRR results were 4.5 times higher for the conventional system (131.86 %) compared to the BFT. Thus, it is possible to obtain the return of capital invested in the conventional system in less than a year, whereas it will only happen in about 4 years with the BFT system.

Sensitivity analysis demonstrated how the BFT system is sensitive to market price fluctuations and productivity when compared to the conventional system (Figs. 1, 2). Only BFT showed negative NPV values to changes projected for the selected items. For an approximate price of US$ 5.70 kg^{-1}, NPV for both systems are equivalent. On the other hand, considering a worst-case scenario, lower prices favor the conventional system.

According to Fig. 2, only yields above 6000 kg ha^{-1} cycle economically enable the BFT system, whereas the NPV for the conventional system remained positive for all projections.

Discussion

The use of the BFT system in the commercial culture of *L. vannamei* is recent in world aquaculture (Avnimelech 2012). The general principles and design criteria to its default setting are still unknown, as there is a variety of models to be applied, demanding time to adapt this system to the local reality, which hinders its insertion and operation in traditional shrimp farming companies (Hargreaves 2013).

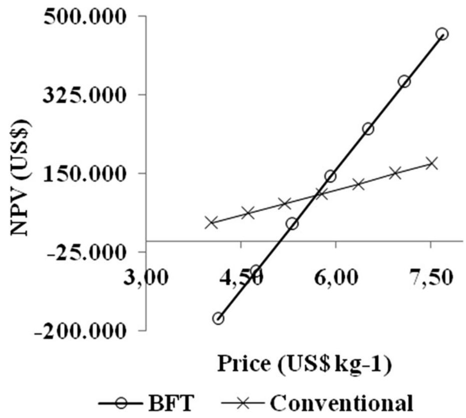

Fig. 1 Sensitivity analysis for the cultivation of *Litopenaeus vannamei* in BFT and conventional systems, in Pernambuco, Brazil, considering changes in market prices

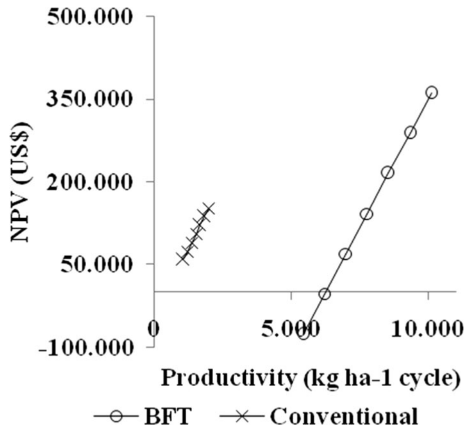

Fig. 2 Sensitivity analysis for the cultivation of *Litopenaeus vannamei* in BFT and conventional systems, in Pernambuco, Brazil, considering variations in productivity

The production data of this study are site and case specific, but reflect the reality faced by most enterprises in the aquaculture sector. To invest in a new or not yet established technology, it is needed to adapt it to the local scenario until the production process can be standardized and survival can be maximized (Buarque 1984; Sanches et al. 2014). Even with some difficulties related to the introduction of the BFT system, the results of growth performance for both systems are within the pattern registered in the literature (Avnimelech 2012; Silva et al. 2012). It is possible to use higher densities of shrimp in the BFT system, and as a result increase productivity, but adjustments are needed related to energy use, design and efficiency of the aeration system, among others, demanding higher financial expenditures.

The reduction of the feed conversion rate in an intensive system will depend on feed quality because there is less influence of natural food in the nutrition of organisms (Jory et al. 2001; Moss 2002). In the case of BFT, bioflocs can be used as feed for the shrimp and therefore allow the reduction of FCR. However, it still depends on feed of good quality, since this input may influence the nutritional profile of the microbial aggregates (Avnimelech 2012).

The possibility of controlling the environment in which animals are stocked allows the use of higher densities in the BFT system. This control is only possible by reducing or even eliminating the influence of the adjacent soil and environment as well as the use of specific equipment for monitoring water quality (Avnimelech 2012). Therefore, the use of geomembrane is required and represents the highest investment in the BFT system (31.39 %), probably due to the low supply of sales and installation of this material in Brazil (Buarque 1984).

The intensification of shrimp farming requires high investment and high operating costs (Avnimelech 2012; Hanson et al. 2013). To implement a productive hectare of BFT system in the state of Pernambuco, operating with 113 shrimp m^{-2}, an investment of US$ 148,330.51 was necessary, besides the total production cost of US$ 124,369.00 $year^{-1}$. Comparatively to a super-intensive BFT system, operating with densities of 500 shrimps m^{-3} in ten tanks of 500 m^3 each, located in Texas, USA, Hanson et al. (2013) estimated the initial investment of approximately US$ 992,000.00, with total production cost equal to US$ 983,950.00 $year^{-1}$, confirming the direct relationship between stocking density and expenses.

The high influence of feed in operating costs of semi-intensive aquaculture enterprises is already quite emphasized in the literature, but information about the proportion of their share in costs with the increasing of technology in order to enhance the production system is still scarce (Coelho 2005; Campos and Campos 2006; Silva et al. 2012). Corroborating the findings of the present study, Shang et al. (1998) found that the most important item in variable costs for intensive shrimp farming in Asia was feed, representing between 23 and 46 % of the costs. According to the authors, the feed also had the highest representation in the cost of inputs used in semi-intensive shrimp farms from that region.

Not only the biggest expense with feed justifies the high total production cost of the BFT system compared to conventional system, but also the high values of labor work and energy contribute significantly to this difference. The BFT technology demands technicians trained to perform specialized activities, requiring more staff compared to the conventional systems. The higher energy consumption in the BFT system is due to a high oxygen demand by the shrimp and heterotrophic bacteria in bioflocs, being mandatory the use of artificial aeration in the minimum ratio of 25 HP ha^{-1}, compared with the need for only 3 HP ha^{-1} of the conventional system (Hargreaves 2013).

The profitability analysis of the present work differs from the literature, not only by the variations in the productive system used, but also in the culture period and location. Silva et al. (2012) analyzed a conventional shrimp production in 2009, in Rio Grande do Norte, Brazil, when 2.5 cycles $year^{-1}$ were carried out. They obtained results of annual net revenues and profitability index equal to US$ 3843.37 ha^{-1} and 36 %, respectively, explained by lower retail price (US$ 3.13 kg^{-1}) and annual production (3375 kg ha^{-1}) compared to this study. In a BFT system conducted in Texas, USA, in 2012, where 5.6 cycles $year^{-1}$ were carried out, the retail price was equal to US$ 7.20 kg^{-1}, and the profitability index (33 %) and cost of production (US$ 4.80 kg^{-1}) were equivalent to those observed in Pernambuco of 30.22 % and US$ 4.28 kg^{-1}, respectively (Hanson et al. 2013).

The high cost of production per kilogram in the BFT system is directly related to the need for a greater technological support that enables the intensification. Accordingly, our results in Brazil are in line with shrimp farming facilities located in other countries such as China, the Philippines and Thailand, where the production cost per kilogram tends to increase with intensification of the system (Shang et al. 1998).

Regarding the economic viability of the BFT and conventional systems, both showed favorable results with respect to the NPV, IRR and payback period. These indicators are important for the inclusion of the BFT system on farms operating in Brazil, due to the need to replace the conventional system, which is often affected by new epidemics that cause economic losses (Burford et al. 2003; Abreu et al. 2011). The sensitivity analysis performed in this study demonstrated the fragility of BFT, but it is possible to increase productivity and reduce costs of this system with the improvement of production techniques and increase of the production scale, respectively, improving profitability and viability indicators (Guy et al. 2009). Thus, investment in BFT confirmed its viability, strengthening the benefit of being a higher biosafety system for the enterprise, mainly operating in closed method, avoiding contamination and spread of pathogens in the cultivation (Avnimelech 2012).

Conclusion

Despite having high investment values and costs compared to the conventional system, BFT proved to be viable regarding the return on invested capital in short and long terms. Mostly in relation to technical benefits, involving aspects related to productivity and biosafety, this study suggests that the BFT has potentiality to improve farming of *L. vannamei* in northeast Brazil.

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