

Profitability and agronomic yield of aquaponic lettuce

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Abstract

In order to innovate an aquaculture production system that increases water productivity, an experiment was conducted at an aquaculture farm in Saltillo, Coahuila, where lettuce cultivation was established under a hydroponic system called floating root, under shade net conditions and foliar fertilization, agronomic variables were analyzed: root length, stem thickness, height, fresh weight, number of leaves, foliar area and crown diameter in four different treatments and different indicators of profitability were analyzed: net present value, internal rate of return (TIR), cost-benefit ratio and return on investment, to determine the economic feasibility of the system, so, the objective of this research was to determine the agronomic yield and economic profitability of the floating root lettuce production system under shade net conditions and foliar fertilization. Results obtained in agronomic yield variables showed increases in height, fresh weight, number of leaves, foliar area and crown diameter compared to their absolute witness of 41.77%, 113.9%, 30.43%, 155.92% and 22.22%, respectively. The profitability analysis shows favorable results for additional investment. This research demonstrates the economic viability and an improvement in agronomic productivity of floating root lettuce under shade net conditions and foliar fertilization.

Keywords: aquaponics, floating root, production, shadow net, water sustainability.

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Introduction

Growth in the agricultural sector is based on the expansion of growing areas, however, today the potential for growth is declining due to population growth, availability of arable land and water scarcity (Wada *et al.*, 2014). Considering that agriculture is the world's main consumer of water and it is responsible to produce 70% of the world's food (Smilovic *et al.*, 2018; Zheng *et al.*, 2018; Kazem, 2020) mentions that there are three sources of water loss in agricultural irrigation, evaporation of water on the land surface, loss by drainage filtration (runoff and percolation) and losses from spillage.

In addition to this, the agricultural sector faces two major challenges, water stress and food insecurity and the most affected regions will be the arid and semi-arid rural areas of the world, where rainfed agriculture is carried out and the use of water for irrigation is limited by lack of technology or economic resource (Jin *et al.*, 2018; Mandal, 2020). Therefore, alternative and sustainable production systems that help optimize the efficient use of water for food production are required (Cabrera, 2014; Rios, 2016; Velazco, 2018).

The integration of production systems is an alternative to optimize the use of natural resources and generate a more sustainable food production (Huong *et al.*, 2018). Aquaponic systems, which due to their dual purpose, the production of fish and vegetables, are a sustainable activity by improving water productivity (Bosma *et al.*, 2017; Mirzoyan *et al.*, 2018) through the increase and product diversification. Several authors mention that it should be noted that any water reuse activity in basins or irrigations can compensate perceived losses at the field level in terms of amount of water (Brauman, 2013; Gheewala, 2017).

Li *et al.* (2020) mentions that water productivity is defined as the relationship between the net profits of crops and the amount of water used in different production systems. Therefore, aquaponics is considered as an alternative to solve problems of fertile soil depletion, water availability, environmental pollution and food demand (Huong *et al.*, 2018). Leaf vegetables are common in these systems, for their short production cycles and low nutritional requirements (Rakocy, 2012).

Lettuce is one of the most consumed vegetables in the world (Kim *et al.*, 2016; Yang *et al.*, 2019), it is consumed fresh and has a high content of nutrients such as vitamins A, C, E, B1, B2, B3, B9, as well as phosphorus, iron, calcium, potassium and are rich in antioxidants and amino acids (Carranza, 2009) compared to other vegetables that are cooked or processed (Xiao *et al.*, 2012).

However, Yagi and Kokubu (2018) mention that any productive project must be supported by a financial economic profitability analysis, different authors mention that by their valuation in monetary units, financial economic profitability analyses serve as a basis for decision-making through different financial feasibility indicators (Smith *et al.*, 2014; Ofileanu, 2014; Ramli and Iskandar, 2014), being VAN, TIR, RB/C and ROI the most common financial indicators for determining economic profitability analyses (Zhao, 2016). Based on the above and with the aim of seeking a solution to mitigate or reduce the problems currently faced by agricultural sector, the objective of this work was to determine the economic and productive viability of a floating root lettuce aquaponic system under shade net conditions with foliar fertilization.

Materials and methods

Location of the experiment

The experiment was established on a cooperating producer's farm in the La Joya, located at 25° 14' 52.1" north latitude 101° 16' 0.5" west longitude, in the ejido Derramadero, in the municipality of Saltillo, Coahuila, Mexico. The farm has an aquaculture fattening system, consisting of 12 circular ponds of high-density polyethylene geomembrane (HDPE.75 Mn) with metal support skeleton, with 10 m diameter and 1.2 m height per pond to store a water volume of 94 248 L in its maximum capacity per pond. Within each pond 2 200 rainbow trout fry (*Oncorhynchus mykiss*) were sown in order to produce two tons of trout per pond.

Vegetal material

Lettuce (*Lactuca sativa*) Climax variety, from the commercial house Western Seeds, was used as vegetative material. This is a Roman-type lettuce that is characterized by well-formed heads with large, enveloping leaves, with a planting-to-harvest time of approximately 90 to 95 days.

Seedling development and transplantation

The seedlings were established at the Universidad Autónoma Agraria Antonio Narro (UAAAN), located at 25° 21' 19" north latitude, 101° 01' 48" west longitude, at a height of 1 779 masl in Buenavista, Saltillo, Coahuila, in May 2019 in the department of Horticulture in a medium-tech greenhouse, in polystyrene trays of 200 cavities, using as substrate peat-moss and perlite in a ratio of 70/30, once the seed sprouted, these were watered twice a day, up to obtain seedlings with three true leaves and a height of 12 cm (30 days after the emergence), they were taken to the aquaculture farm for transplantation where they were extracted from the tray with everything and the root ball, and then a root wash was performed in order to remove the substrate and incorporate them into the aquaculture effluent.

The transplantation was performed 30 days after the plants had emerged, where they were placed in expanded polystyrene plates five centimeters thick and one square meter, plotting a population density of 20 plants m⁻², in geomembrane tanks.

Plant nutrition

Foliar fertilization was performed using as reference the Steiner solution (1961) reduced to 75% and this was applied in different concentrations depending on the phenological stage of the crop, following a foliar fertilization to 25% in its transplanting stage, 50% development, 75% in growth stage and 100% in the final stage, applying every third day after transplanting.

Treatments

Four treatments (T) were analyzed with 10 repeats per treatment. T1) without shade net (SM) and without foliar fertilization (SF); T2) without shade net (SM) and with foliar fertilization (CF). T3) with shade net (CM) and no foliar fertilization (SF); T4) with shade net (CM) and foliar fertilization (CF).

Agronomic performance measuring

For the measurement of agronomic variables, all vegetative material from the La Joya ranch experiment was collected, around 10:00 am for its field measurement and it was subsequently taken to the tissue culture laboratory of the department of Horticulture at UAAAN. The variables evaluated were: root length, stem thickness, plant height, fresh weight, number of leaves, foliar area and crown diameter.

For root length and height measurement a tape measure was used, where the base of the lettuce to the tip of the root was taken into account for the root measurement and for the height the base of the lettuce to the top of the leaf was taken into account, the fresh weight was obtained from the individual weights of the plants of the different treatments in the final harvest stage, for the above, a balance scale of the brand And Hr-200 (Max 210 g d= 0.1 mc) was used, the foliar area was measured at the end of the study with a portable leaf area meter model LI-500, the commercial diameter was considered the length of the circumference of the crop in its final stage when harvesting (C/π), to obtain the crown area the half of the commercial diameter per plant (r^2) was taken into account and a digital vernier of the brand Steren Her-411 with accuracy: (± 0.1 mm) and resolution: (0.1 mm) Version 0.0 was used to measure stem thickness.

Measurement of economic feasibility

An economic feasibility analysis was carried out using the investment project methodology and the production costs of the alternative shade net system with foliar fertilization were introduced by extrapolating the production to one hectare, pricing the products and equipment used in the area near the city of Saltillo, Coahuila, they are shown in Tabla 1.

Table 1. Production costs of lettuce aquaponic system with shade net and foliar fertilization.

Items	Unit cost	Units per hectare	Cost per hectare
Variable cost			
Seed	\$0.0017	200 000	\$1 026.00
Seedlings	\$0.30	199 680	\$179 712.00
Fertilizers 75%	\$14.05	40 days a/transplant	\$1 686.00
Fertilizers 50%	\$7.02	70 days a/transplant	\$1 474.20
Fertilizers 25%	\$3.51	90 days a/transplant	\$947.70
Amino acids	\$800.00	4.25 L day ⁻¹ (30 days)	\$306 000.00
Bralic garlic repellent	\$500.00	4.25 L day ⁻¹ (30 days)	\$191 250.00
Total variable cost			\$682 095.90
Additional investment			
Shade net	\$9500.00	128 structures	\$1 216 000.00
Fastener	\$0.30	199680	\$59 904.00
Trays	\$65.00	9984	\$648 960.00
Total additional inv.			\$1 924 864.00

Items	Unit cost	Units per hectare	Cost per hectare
Fixed costs			
Administrative expenses	\$15 000.00	12	\$180 000.00
Operating expenses	\$31 300.00	12	\$375 600.00
Total fixed cost			\$555 600.00
Total cost			\$1 237 695.90

Note: the production costs of the lettuce aquaponic system with shade net and foliar fertilization were calculated for three production cycles in one year, considering production costs as an additional investment to the cooperating producers' aquaculture farm, the data was extrapolated to one hectare of production.

Net present value (VAN)

Equation $VAN = -I_0 + \sum_{n=0}^N \left(\frac{F_n}{(1+r)^n} \right) = -1 + \frac{F_1}{(1+r)} + \frac{F_2}{(1+r)^2} + \frac{F_n}{(1+r)^n}$ 1) proposed by Stewart *et al.* (2001) was used to determine the (VAN). Where: $-I_0$ is the initial investment of the project; F_n = difference between the cash flow of incomes and expenditures over the useful life of the project; n = project life; and r = the minimum rate of return (TMR) or interest rate attributed to the project.

To interpret the results of the net present value equation the following scale is used: $VAN > 0$, the project is accepted; $VAN < 0$, the project is rejected; $VAN = 0$, the decision is indifferent whether accepted or rejected.

Internal rate of return (TIR)

To obtain the TIR we used $VAN = -I_0 + \sum_{n=0}^N \left(\frac{F_n}{(1+TIR)^n} \right) = -1 + \frac{F_1}{(1+TIR)} + \frac{F_2}{(1+TIR)^2} + \frac{F_n}{(1+TIR)^n} = 0$ 2) within equation (1) the value of r^* is replaced by 0 and the value of the TIR that varies depending on the percentage of profit that the investor is willing to generate by the use of his capital in the project (Canales, 2015); in order to interpret the results of the TIR equation, the following scale is used: $TIR > TMR$, the project is accepted; $TIR < TMR$, the project is rejected; $TIR = TMR$, the decision to accept or reject the project is indifferent. Mellichamp (2017) mentions that the TIR, a widely used measure of return, is the discount rate that yields net present value (VAN) = 0 for a flow of positive and negative cash flows.

Cost-benefit ratio (RB/C)

To obtain the result of the cost-benefit ratio indicator, the profit or utility calculated at the end of the project was divided by the total cost of the project according to equation $R_{B/C} = \frac{\sum_{j=0}^n \frac{B_j}{(1+i)^j}}{\sum_{j=0}^n \frac{C_j}{(1+i)^j}}$ 3)

used by Daniels *et al.* (2019). Where: B_j = revenue generated over the life of the project; C_j = cost generated over the course of the project; j = the period of time being evaluated within the project; i = interest rate or TMR; and n = project time or life span.

To interpret the results of RB/C , we use the following scale: $RB/C < 0$, the project costs are greater than the expected benefits, the investment project is rejected. $RB/C > 0$, the benefits or profits of the project are greater than the investment costs, the investment project is accepted.

Return on investment (ROI)

Equation $ROI = \frac{\sum_{t=0}^T Rt / (1+i)^t}{\sum_{t=0}^T Ct / (1+i)^t}$ 4) was used to obtain the calculation of the return-on-investment

indicator. Where: R_t = benefit or profit generated over time by the investment made; C_t = total cost of investment over time; and i = interest rate. One way to corroborate the result of the ROI equation is as follows: where net income is income minus cost of production, with equation $ROI = (I - C) / C * 100$ 5). Where: I = income or profit generated; C = cost of the investment elaborated. To interpret ROI results, the following scale was used: $ROI < 0$, the investment project is not profitable, $ROI > 0$, the investment project is profitable. Obtaining as a result the percentage that equals the profit of the investment. Kousky (2019) mentions that it is a tool traditionally used in the private sphere. To evaluate and compare investment projects, a simple way to interpret it is the net profits of a project divided by project costs.

Experimental design

The experiment was established with a completely randomized experimental design under factorial arrangement 2×2 , where the first factor is the use of shade net and the second factor is the application of foliar fertilization, without fertilization (SF) and fertilization (CF), with a total of four treatments (T) and 10 repetitions per treatment.

Statistical analysis

The results of each of the agronomic variables evaluated were analyzed using analysis of variance (Anova), and the Fisher's least significant difference test was applied to compare the means ($p \leq 0.05$), in the InfoStat/L statistical program.

Results and discussion

Agronomic yield analysis

Shade net factor

For the root length variable there were no statistical differences between treatments (Table 2), indicating in this case that root growth was not modified when using shade net; however, Reyes (2016) mentions that it depends a lot on the aquaponic culture that is developing as well as the aquaponic system with which it is being worked.

Table 2. Interaction between production environments for agronomic lettuce variables grown in an aquaponics system with shade net and foliar fertilization.

Factor	Root length	Stem thickness	Height	Fresh weight	Number of leaves	Foliar area	Crown diameter
Without net	22.38 a	1.76 a	6.44 b	37.62 b	11.5 b	39.16 b	9 b
With net	21.06 a	1.59 b	9.13 a	80.47 a	15 a	100.22 a	11 a
Without fertilization	21.56 a	1.73 a	7.19 b	54.74 a	13 a	65.63 a	9.88 a
With fertilization	21.88 a	1.63 a	8.38 a	63.34 a	13.5 a	73.75 a	10.13 a
SM SF	21.63 a	1.83 a	5.63 c	34.84 b	11.5 b	36.13 b	8.88 b
SM CF	23.13 a	1.7 a	7.25 b	40.4 b	11.5 b	42.19 b	9.13 ab
CM SF	21.5 a	1.63 b	8.75 a	74.64 a	14.5 a	95.13 a	10.88 ab
CM CF	20.63 a	1.55 b	9.5 a	86.29 a	15.5 a	105.31 a	11.13 a

SM= no shade net; CM= with shade net; SF= no foliar fertilization; CF= with foliar fertilization, values with different literal are significantly different (Fisher LSD ≤ 0.05).

The results of the statistical analysis show for the stem thickness variable that, the absolute witness (T1) has 10.69% more than T4, which was in shade net and with foliar fertilization. Choosakul (2017) obtained similar results, where the stem thickness of his lettuces is also higher in the lettuce grown without shade net.

For variables height, fresh weight, number of leaves, foliar area and crown diameter, T4 shows statistical difference compared to the absolute witness, being 41.77%, 113.9%, 30.43%, 155.92% and 22.22% respectively greater than T1, different authors such as, Espinoza *et al.* (2016) and Ayala *et al.* (2011) reported positive effects in height with the use of shade net in manzano chili (*Capsicum pubescebc*) and tomato (*Solanum lycopersicum*) respectively, Gaurav *et al.* (2016) mentions that plants grown under shade net produce more biomass and foliage than those grown in the open field.

Choosakul (2017) in his research mentions that the foliar area of lettuce that were in shade net of different colors were recorded larger than those in open field conditions. Fu *et al.* (2012) points out that the high intensity of light promotes the growth of lettuce; however, this growth-promoting effect is saturated at a certain level of light intensity and the recommended ranges for lettuce production are 400 to 600 $\mu\text{mol m}^{-2} \text{s}^{-1}$.

Foliar fertilization factor

For foliar fertilization factor no significant differences were present (Table 2), in the agronomic variables evaluated of root length, stem thickness, fresh weight, number of leaves, foliar area, crown diameter, Nozzi *et al.* (2018) obtained similar results, where when developing a study with different foliar nutrition applications to a floating root lettuce system they did not obtain significant differences between treatments, just as Pickens (2015) reported that there were no significant differences between treatments when evaluating cherry tomatoes (*Solanum lycopersicum* var. *cerasiforme*) watered with aquaculture effluent and foliar fertilization.

However, for the variable height, T4 showed a difference of 16.55% compared to the absolute witness, which agrees with Roosta and Hamidpour (2011, 2012), where they mention that the foliar nutrient supplement in aquaponics systems improves plant productivity.

Mesh factor and fertilization

In the interaction of factors (Table 2), no statistical differences are observed for the root length variable; however, for the variables stem thickness, height, fresh weight, number of leaves, foliar area and crown diameter, statistical differences were obtained between treatments that were due to the shade net that favored the growth of the crops, to which Mudau *et al.* (2017) mentions in his work made with spinach (*Spinacia oleracea* L.) that crop vegetative growth is more pronounced in plants grown under shade net compared to plants grown in open field, also Choosakul (2017) mentions that the use of shade net of any type of color manages to increase crop growth.

Moreover, the use of shade net with foliar applications increased the crown diameter, to which Yep *et al.* (2019) mentions that the foliar nutrient supplement does improve plant productivity in aquaponic systems, because the missing elements in aquaculture effluents are additionally supplied.

Economic analysis

The economic analysis was carried out in a scenario with low sale price to have pessimistic panorama and to be able to offer a better alternative in decision-making, for the calculation of the project useful life, a six-year panorama described in (Table 3) was established, being this feasible with the results of the different positive indicators.

Table 3. Analysis of economic profitability of the production system.

Six years	0	1	2	3	4	5	6
Plants		199680	199680	199680	199680	199680	199680
Sale price		\$ 9.50	\$ 9.50	\$ 9.50	\$ 9.50	\$ 9.50	\$ 9.50
Revenue		\$1896960.00	\$1896960.00	\$1896960.00	\$1896960.00	\$1896960.00	\$1896960.00
Fixed Cost		\$555600.00	\$583 380.00	\$612 549.00	\$643 176.45	\$675 335.27	\$709 102.04
Variable Cost		\$682095.90	\$716 200.70	\$752 010.73	\$789 611.27	\$829 091.83	\$870 546.42
Total Cost		\$1237695.90	\$1299580.70	\$1364559.73	\$1432787.72	\$1504427.10	\$1579648.46
Balance		\$659264.10	\$597379.31	\$532400.27	\$464172.28	\$392532.90	\$317311.54
Cash Flow	-\$1924864.00	\$659264.10	\$597379.31	\$532400.27	\$464172.28	\$392532.90	\$317311.54
VAN	\$47908.30						

Six years	0	1	2	3	4	5	6
TIR	16%	VPN	\$0.00	\sum Net income	\$1972772.30	TI	15%
				\sum Gross income	\$7179012.29		
		R B/C	1.379	\sum Costs	\$5206239.99	ROI	\$ 1.02
				\sum Costs + investment	\$7131103.99		

Note: the sale price issue was the worst possible scenario for the sale of lettuce in the period.

The TIR is only 1% higher than the TMR or interest rate and the RB/C of 1.38 means that for each peso invested in the project 0.38 cents are generated, like the ROI for each peso invested the return on investment is 0.02 cents, being these results low, meaning that the risk is greater as it is a result that is within acceptable limits, this is due to the pessimistic panorama in which the economic analysis was developed and the useful life of the project.

Conclusions

The cultivation of aquaponic lettuce under floating root and shade net conditions showed to be more efficient in terms of crop development, presenting increases in agronomic yield.

The floating root lettuce system under shade net conditions and foliar fertilization showed to be profitable through different economic indicators.

No influence of foliar fertilization and shade net interaction was observed on the different yield variables evaluated, so it can be achieved to be more profitable by lowering variable production costs by omitting foliar fertilization expenditure, which shows a productive efficiency in the use of aquaculture effluent as nutrition for lettuce cultivation, it is important to note that the floating root lettuce system under shaded net conditions presents positive economic feasibility over a useful life of six years, in addition lettuce that comes from systems under protected agriculture conditions is characterized by being overpriced and it is more accepted in the market.

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