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Lettuce production in hydroponic and fish-farming aquaponic under different channel slopes and nutrient solutions in the NFT system[1]

Produção de alface hidropônica e aquapônica sob diferentes declividades e soluções nutritivas no sistema NFT

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HIGHLIGHTS:
A slope of 8% in PVC tubes increases production of lettuce in hydroponics and aquaponics systems.
Solution of 18% protein in tilapia feed increases the production and accumulation of N and P in aquaponic lettuce.
The percentage of crude protein in the tilapia diet directly influences lettuce production in aquaponics.

ABSTRACT: The slope of cultivation channels and types of nutrient solutions in hydroponics and aquaponics influence nutrient absorption and plant production. This research aimed to evaluate lettuce production under different channel slopes and nutrient solutions in hydroponic and aquaponic systems using the nutrient film technique (NFT). A randomized block design was used, with three replicates, in a 3 × 5 split-plot scheme, with three nutrient solutions (conventional hydroponic solution and two wastewaters from the tilapia fish diets, with 15 and 18% of crude protein) and five slopes (2, 4, 6, 8 and 10%) of cultivation channels (PVC tubes). The following variables were evaluated: fresh and dry mass of shoot and roots and the chemical elements of the solutions. In the tilapia feed, the nutrient solution with 18% of protein (wastewater) provides greater production and accumulation of nutrients (N and P) in the lettuce shoot. The slope of 8% on cultivation channels provides greater production of iceberg lettuce, cultivar Lucy Brown. The different slopes and nutrient solutions studied did not influence the potassium (K) accumulation in the lettuce shoot.

Key words: *Lactuca sativa* L., plant nutrition, laminar flow of nutrients

RESUMO: A declividade dos canais de cultivo e os tipos de solução nutritiva em hidroponia e aquaponia influenciam a absorção de nutrientes e produção vegetal. O objetivo da presente pesquisa foi avaliar a produção de alface sob diferentes declividades de canais e soluções nutritivas em sistemas hidropônico e aquapônico, em fluxo laminar de nutrientes (NFT). Utilizou-se o delineamento em blocos ao acaso, com três repetições, em esquema de parcelas subdivididas 3 × 5, com três soluções nutritivas (solução hidropônica convencional e duas águas residuárias provenientes da dieta de tilápias, a 15 e 18% de proteína bruta) e cinco declives (2, 4, 6, 8 e 10%) de canais de cultivo (tubos de PVC). Foram avaliadas as seguintes variáveis: massa fresca e seca da parte aérea e das raízes; e elementos químicos das soluções. A solução nutritiva com 18% de proteína (água residuária), na alimentação da tilápia, proporciona maior produção e acúmulo de nutrientes (N e P) na parte aérea da alface. A declividade de 8% nos canais de cultivo proporciona maior produção de alface americana, cv. Lucy Brown. As diferentes declividades e soluções nutritivas estudadas não influenciaram o acúmulo de potássio (K) na parte aérea da alface.

Palavras-chave: *Lactuca sativa* L., nutrição de plantas, fluxo laminar de nutrientes

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Introduction

Lettuce (*Lactuca sativa* L.) is one of the vegetables with greater demand; however, its limitations of climate and regions for cultivation in soil (Marklein et al., 2020), restriction of planting area, and current water scarcity promoted soilless cultivation systems, such as hydroponics and aquaponics, with sustainability (Nguyen et al., 2022).

Both aquaponics and hydroponics can use cultivation channels where plant roots are suspended in nutrient-rich solutions (EMBRAPA, 2015; Sambo et al., 2019; Lei & Engeseth, 2021). Hydroponics uses a prepared nutrient solution and, in aquaponics, wastewater from aquaculture, mostly tilapia (Pérez-Urrestarazu et al., 2019), forms an advantageous symbiotic system with plant production, saving water and nutrient (Jordan et al., 2018). The NFT (nutrient film technique) is the most used aquaponic system (Martins et al., 2010; Diem et al., 2017; Dholwani et al., 2018).

The slope of the cultivation channel is one of the most influential aspects in aquaponic and hydroponic production, and variations of this characteristic provide different flows, nutrient absorption, availability of oxygen, and mass of lettuce root and shoot (production).

The scientific literature presents a wide variation in the channel slope (between 2 and 12%) for NFT without a consensus on the subject. López-Pozos et al. (2011) reported common use of 2% slope in temperate regions. In Brazil, Faquin et al. (1996) suggested 2-5% for hydroponics, Furlani et al. (2009), between 2 and 4%, for channels with a maximum length of 30 m; Mello et al. (2016) recommended higher slopes for hydroponics (3-8%), and EMBRAPA (2015) presented slopes between 8 and 12% for aquaponics. Van Os et al. (2019) considered up to 2% for soilless cultivation systems, and Niu & Massabni (2022), between 1 and 3% for channels up to 15 m in length to ensure uniformity and ease of handling.

However, current information about the best nutrient solution and the ideal slope of PVC channels for lettuce production in hydroponics and aquaponics is still scarce. Therefore, the present research aimed to evaluate lettuce production under different channel slopes and nutrient solutions in hydroponic and aquaponic systems in NFT.

Material and Methods

The present research was conducted from March to April 2020 in the 'Sonho Verde' nursery, partnered with the Instituto Federal Goiano, Morrinhos Campus, GO, Brazil. The nursery was located in the municipality of Itumbiara, in the same State, at 18°24'58.6" S and 49°15'12.8" W, with 885 m of altitude. The local climate was classified as Aw-type, according to Koppen classification, as a tropical climate with a dry winter season, characteristic of the Cerrado biome (similar to savanna), with an average temperature of the year coldest month greater than 18 °C, an average annual temperature of 24.6 °C and precipitation of the less rainy month of less than 60 mm.

The nursery had dimensions of 7 × 15 m, with a ceiling height of 2 m, and screen cover and sides at 80% shading. The temperature inside the nursery was monitored using a digital thermometer at different times during the lettuce cycle (Figure 1).

The cultivation channels were built with polyvinyl chloride (PVC) tubes of 100 mm diameter, installed on different slopes, in a cultivation bench of 1.2 m wide × 3 m long, with an average height of 1.0 m. The cultivation bench was built using pallets, wooden slats, and nails and spaced 1.0 m apart.

The experiment was conducted in a randomized block design, with three replicates, in a 3 × 5 split-plot scheme, with three nutrient solutions and five slopes (2, 4, 6, 8, and 10%) of PVC tubes used for the cultivation.

The nutrient solutions were composed of a conventional hydroponic solution (HS) and two wastewater solutions from tilapia (*Oreochromis niloticus*) with diets of 15% (WS15%) and 18% (WS18%) of crude protein, with 50% of the feed provided at 9 am and the other half at 4 pm. The HS was composed of a mix of essential macro and micronutrients from organic fertilizer for hydroponics (NPK+8 nutrients, Forth Hortaliças™), applying, per liter, 236.3 mg of N, 39.0 mg of P, 224.9 mg of K, 228.0 mg of Ca, 33.7 mg of Mg, 46.3 mg of S, 0.24 mg B, 0.02 mg Cu, 5.0 mg Fe, 0.23 mg Mn, 0.03 mg Mo, and 0.05 mg Zn, according to Gualberto et al. (1999).

Each experimental unit consisted of PVC pipe 3.0 m long and 100 mm in diameter, with perforations spaced 25 cm apart, totaling 10 plants. The spacing between parallel tubes was 30 cm (Figure 2), adapted from EMBRAPA (2015).

Outside the nursery, three 1000 L water tanks were placed so that the nutrient solution level in the boxes was one meter below the average height of the PVC tubes on the cultivation bench, allowing the solution to return by gravity into the PVC tubes of 100 mm. One box was separated for the preparation of a conventional hydroponic solution, and the other two boxes were for tilapia fish cultivation, with 60

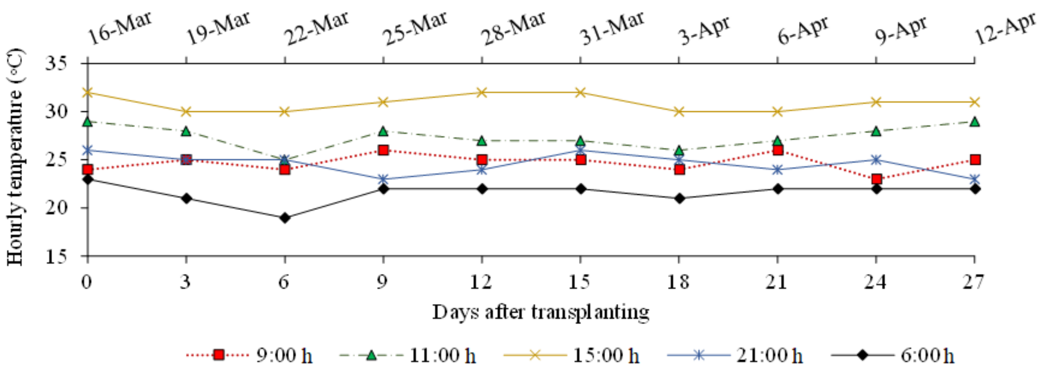

Figure 1. Hourly average air temperature inside the nursery during the lettuce cycle

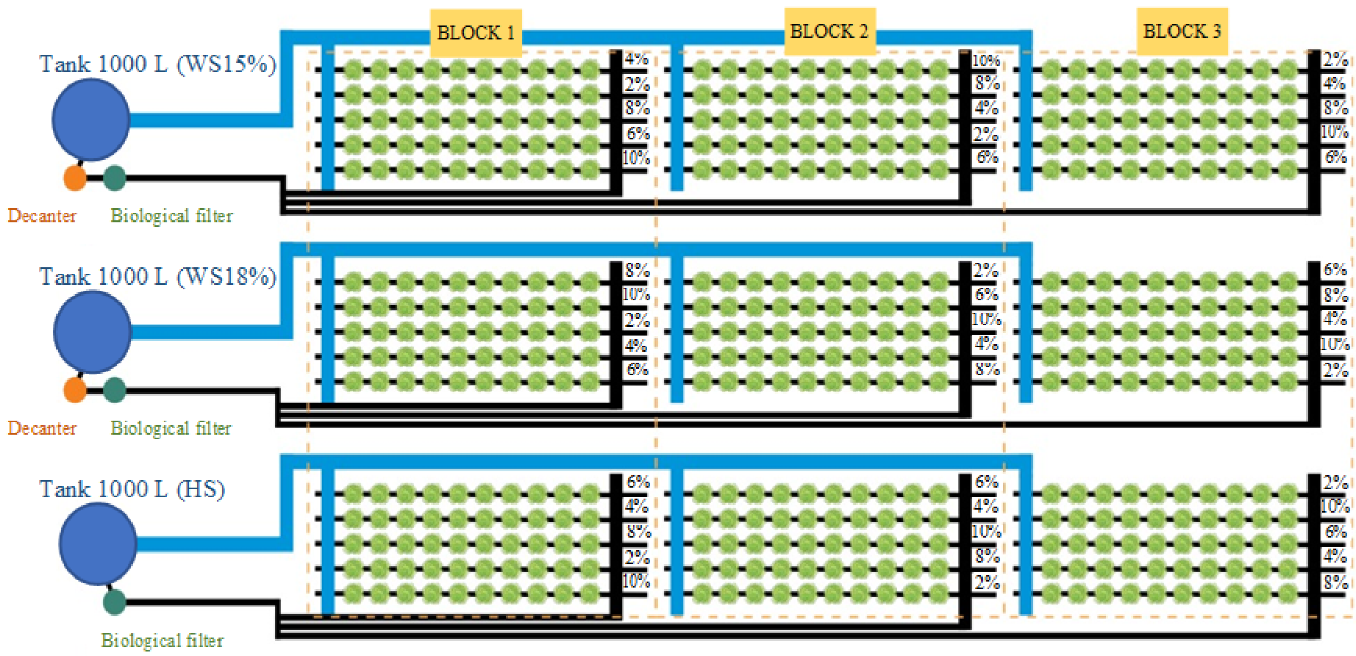

Figure 2. Installation scheme of hydroponic (HS) and aquaponic (WS) systems and casualization of slopes and solutions (%) in the blocks

juveniles per box, for a final storage density of 60 kg of live fish per m^3 of water. The recirculation and daily renewal of the solution were approximately six times the box volume (EMBRAPA, 2015).

The water from each fish tank passed through a solid decantation system and a 200 L biological filter, with 67.1 L of expanded clay to house bacterial colonies. After passing through the biological filter, the nutrient solution was pumped, by a motor pump submerged in the tanks, to the cultivation channels, returning to the fish tanks. In the pumping, a 13 mm polyethylene pipe was used, buried into de soil inside the greenhouse, with derivations for each plot. Connectors and flexible microtubes of 5 × 7 mm were used in the plots to feed the subplots with the respective nutrient solutions (EMBRAPA, 2015).

After introducing the tilapia juveniles, it took 30 days for the bacteria to multiply in the biological filter and for the nitrification cycle to be in equilibrium to introduce the plants.

The type, amount, and particle size of the feed used were organized according to the tilapia live weight and development (juvenile, growth, and fattening phase), with percentages of crude protein of 15 and 18%, applying, on average, 75 g day^{-1} of feed in the first week for 60 tilapias of about 100 g each. The amount of feed was gradually increased to 200 g day^{-1}, up to the ninth week, with the feeding and number of fish being controlled according to the ammonia and nitrate weekly monitoring in the system.

The Nutrient Film Technique (NFT) was used, according to Geisenhoff et al. (2016), applying intermittent flows of nutrient solution every 20 minutes, leaving the motor pumps inactive for another 40 minutes between 6 am and 8 pm. At night, the pumps were activated at 10:00 pm, 1:00 am, and 4:00 am for 20 minutes each. A digital "timer" with 40 settings was used to control the flow times, turning on and off the three centrifugal motor pumps of 1000 L h^{-1}, with a manometric height of 23 mca and a unitary power of ½ hp.

The following nutrient solution variables were monitored daily: temperature, using a thermometer with a datalogger; electrical conductivity (EC); pH, using a pH meter; dissolved oxygen (O_2); and free ammonia. Physical and chemical analyses of the solution were conducted during cultivation to determine the amount of salts in the system and the amount of residues present in the solutions. When necessary, solid waste was cleaned in filters and tanks.

The solution pH was established between 6.4 and 6.8. The pH adjustments were made with a limestone reservoir, removed or with addition, as needed, as well as the essential nutrients supplementation if necessary, considering the electrical conductivity below 1.8 mS and the lettuce development stages. Ammonia concentration below 2.0 mg L^{-1} and nitrite below 0.5 mg L^{-1} were maintained to avoid fish stress. The nitrate content was maintained at around 10 mg L^{-1} using the Prodac Tape Test Ph Gh Kh NO_2 NO_3 Cl_2 (Speedy Test) to ensure the adequate development of vegetables (EMBRAPA, 2017).

The solution losses in the system were complemented in the tanks every two days, and the solution was renewed every 30 days, replacing 50% of the volume of each tank. The flow (L h^{-1}) in the cultivation channels was evaluated according to the PVC tubes slopes before transplanting, obtaining values of 16.5, 18.1, 20.3, 21.6, and 23.4 L h^{-1} on slopes of 2, 4, 6, 8, and 10%, respectively. At 25 days after transplanting, a new flow measurement was made in the channels with the presence of root systems, depending on the type of solution and slopes used.

Iceberg lettuce seedlings of the Lucy Brown cultivar were used, adapted to local climate conditions, and obtained from a commercial nursery. The lettuce harvest was conducted 26 days after the seedlings transplant.

The following variables were evaluated 26 days after transplanting: shoot fresh mass (SFM), shoot dry mass (SDM), root fresh mass (RFM), and root dry mass (RDM), all obtained by measuring the mass in g per plant. The macro and micronutrient concentrations and chemical elements in the solution were evaluated at Venturo Laboratory Environmental Analysis, Araraquara, SP, Brazil. The evaluations of macro and micronutrient concentrations in the lettuce shoot were conducted at the Laboratory of Foliar and Fertilizer Analysis - LAFF, from the Universidade Federal de Goiás - Samambaia Campus, Goiânia, GO, Brazil). The RDM/SDM ratio and the ratio of macronutrients N-leaf/N-solution, P-leaf/P-solution, and K-leaf/K-solution, accumulated throughout the cycle, were estimated by dividing the concentration value of each nutrient in the leaf by the value of each nutrient in the solution.

The evaluated variables were submitted to the analysis of variance. The means from solutions were compared using the Tukey test (p≤0.05). The means from channel slopes were submitted to the analysis of regression.

Results and Discussion

The pH of the residual water in the aquaponic systems presented an average value of 7.5 after passing through the tilapia tanks. After the biofilter, the pH was reduced to average values of 6.0 to 6.5, depending on the nitrification process, as described by Courtens et al. (2014). During periodic samplings, the pH oscillated between 5.5 and 6.9, controlled and similar to those used by Van Rijn (2013). According to this author, the above-cited pH oscillation concerns the greater amount of feed and waste generated, also providing fish growth. These pH values are within the range considered ideal for lettuce growing in an aquaponics NFT system, fish survival, and better performance of nitrifying bacteria.

After the biofilter, the solution pH in the hydroponic system showed an average value of 6.5. The root system is considered a biofilter in conventional hydroponics, as it absorbs ions. Consequently, the pH was reduced to 5.7 due to nutrient absorption by the plants. After passing through the limestone reservoir, the pH was raised to about 6.2, proving the viability of this reservoir to control the solution pH.

The electrical conductivity (EC) in the aquaponic and hydroponic reservoirs ranged from 1.2 to 2.0 mS cm^{-1}, remaining in the adequate range for good lettuce development. The change in the EC of nutrient solutions was insignificant after draining from the tanks to the channels.

Comparing the concentration of the dissolved nutrients in wastewater and nutrient solution (Table 1), most nutrients in wastewater solution from diets with 15% (WS15%) and 18% (WS18%) of crude protein were in amounts close to or greater than those found in the hydroponic solution, except for potassium and manganese.

The concentration of micronutrients in both wastewaters was higher than that obtained in the nutrient solution proposed by Gualberto et al. (1999), as shown in the second and fourth columns of Table 1. The results of most studies integrating fish farming and plant cultivation were similar, as in Cortez et al. (2009).

The macro and micronutrients concentrations in the lettuce shoot (Table 2) varied in the three solutions, being the contents of N (WS18%), Fe, and Mn (WS15% and WS18%) similar to those found in the nutrient solutions in the tanks.

Table 1. Chemical elements concentration in nutrient solutions, in the tanks of the aquaponic and hydroponic systems, at 26 days after transplanting

Macronutrients, micronutrients, and heavy metals	Wastewater solution (WS)		Hydroponic solution (HS)
	15% crude protein (WS15%)	18% crude protein (WS18%)	
N (g kg^{-1})	0.193	0.247	0.239
P (g kg^{-1})	0.071	0.070	0.064
K (g kg^{-1})	0.073	0.071	0.426
Ca (g kg^{-1})	0.284	0.280	0.170
Mg (g kg^{-1})	0.165	0.170	0.026
S (g kg^{-1})	0.046	0.046	0.036
Cu (mg kg^{-1})	0.320	0.330	0.045
Fe (mg kg^{-1})	18.500	19.000	5.000
Mn (mg kg^{-1})	1.300	1.000	0.480
Zn (mg kg^{-1})	0.312	0.330	0.300
B (mg kg^{-1})	0.615	0.620	0.320
Cd (mg kg^{-1})	-	-	-
Pb (mg kg^{-1})	0.013	0.012	-
Ni (mg kg^{-1})	0.014	0.011	-
Cr (mg kg^{-1})	-	-	-

Table 2. Macro and micronutrient concentration in the shoot of lettuce plants, determined 26 days after transplanting, under electrical conductivity of solution stabilized of 1.8 dS m^{-1} ± 0.2, in the tanks

Nutrients	Wastewater solution (WS)		Hydroponic solution (HS)
	15% crude protein (WS15%)	18% crude protein (WS18%)	
N (g kg^{-1})	17.90	21.03	20.30
P (g kg^{-1})	6.54	5.65	7.35
K (g kg^{-1})	58.10	67.30	59.10
Ca (g kg^{-1})	17.30	14.90	18.05
Mg (g kg^{-1})	8.20	6.90	7.50
S (g kg^{-1})	2.12	2.81	3.11
Cu (mg kg^{-1})	47.60	44.80	44.30
Fe (mg kg^{-1})	1284.00	1498.00	1168.00
Mn (mg kg^{-1})	203.00	162.00	141.00
Zn (mg kg^{-1})	235.00	267.00	301.00

The absorption of nutrients by lettuce does not follow the same pattern as the solution contents, probably due to the pH reduction and EC increase, during the solution flow, from the tanks to the channels.

Factors such as fish population and quality and quantity of feed provided to the fish during the fattening period influence the wastewater nutrient content. Wastewater from Fish-farming can provide significant levels of plants' essential nutrients, except potassium and magnesium, regardless of the fish species used (Cortez et al., 2009), being necessary mineral supplementation of these nutrients for lettuce production.

Nutrient solutions and channel slopes had a significant effect (p≤0.01) on all evaluated variables except for the K-leaf/K-water ratio (Table 3). There was significant interaction (p≤0.01) between solutions and slopes on the same variables, except for the K-leaf/K-water ratio, accumulated during the lettuce cycle.

The channels flow rate (Q), at 25 days after transplanting, was higher in the WS18%, in slopes of 2 and 10%. The Q on 4, 6, and 8% slopes did not differ from the conventional hydroponic solution (Table 4). The WS18% provided the highest values of

Table 3. Analysis of variance (F-value) of flow rate (Q) 25 days after transplanting, and root length (RL), shoot fresh matter (SFM), shoot dry matter (SDM), root fresh matter (RFM), root dry matter (RDM), root length (RL), RDM/SDM ratio, and the ratio of the macronutrients N-leaf/N-solution, P-leaf/P-solution, and K-leaf/K-solution, at 26 days after transplanting, accumulated during the iceberg lettuce (Lucy Brown cultivar) cycle according to the nutrient solutions and channel slopes (%) of hydroponic and aquaponic cultivation systems

Evaluated variable	Source of variation				CV_A (%)	CV_B (%)
	Block	Nutrient solution (A)	Channel slope (B)	A × B		
	2	2	4	8		
Q	1.40^{NS}	92.3^{**}	4466.4^{**}	14.9^{**}	1.04	0.85
RL	1.20^{NS}	1121.8^{**}	3340.7^{**}	41.5^{**}	0.37	0.63
SFM	1.50^{NS}	224.5^{**}	8618.8^{**}	11.8^{**}	0.97	1.23
SDM	1.30^{NS}	1326.3^{**}	21982.2^{**}	156.8^{**}	0.57	0.52
RFM	0.40^{NS}	425.7^{**}	4767.2^{**}	61.8^{**}	0.96	0.64
RDM	1.20^{NS}	629.1^{**}	1030.0^{**}	25.4^{**}	2.77	3.92
RDM/SDM	0.10^{NS}	375.6^{**}	132.4^{**}	9.6^{**}	2.63	5.40
N-leaf/N-solution	0.60^{NS}	656.3^{**}	240.5^{**}	46.1^{**}	1.73	0.94
P-leaf/P-solution	0.12^{NS}	142.8^{**}	173.6^{**}	80.2^{**}	1.61	1.67
K-leaf/K-solution	1.00^{NS}	0.2^{NS}	1.3^{NS}	1.4^{NS}	16.62	16.63

^{NS} = not significant; * = significant at p≤0.05 by the F-test; and ** = significant at p≤0.01 by the F-test; CV_A = coefficient of variation of the plot (nutrient solutions); CV_B = coefficient of variation of the subplot (slope)

Table 4. Flow rate values (Q, L h^{-1}), at 25 days after transplanting, and shoot fresh matter (SFM), shoot dry matter (SDM), root fresh matter (RFM), root dry matter (RDM), all in g per plant, root length (RL, cm) and RDM/SDM ratio, at 26 days after transplanting, accumulated during the iceberg lettuce (Lucy Brown cultivar) cycle according to the nutrient solutions and channel slopes (%) of hydroponic and aquaponic cultivation systems

Evaluated variable	Nutrient solution	Channel slope (%)				
		2	4	6	8	10
Q	WS15%	12.50 c	14.20 b	17.20 b	18.50 c	20.10 b
	WS18%	13.20 a	14.80 a	17.90 a	19.30 b	21.60 a
	HS	12.90 b	14.70 a	18.10 a	19.60 a	20.40 b
SFM	W15%	149.70 b	243.50 c	348.50 b	448.30 c	385.00 c
	W18%	160.70 a	267.10 a	365.70 a	483.60 a	414.70 a
	HS	146.80 b	256.00 b	333.50 c	468.60 b	399.80 b
SDM	W15%	8.60 b	12.60 c	14.10 b	18,.30 b	15.00 b
	W18%	9.00 a	13.20 a	15.60 a	19.70 a	17.50 a
	HS	8.70 b	12.80 b	14.00 b	17.90 c	14.80 b
RFM	W15%	39.80 b	51.10 b	53.20 c	58.10 c	53.90 c
	W18%	42.10 a	56.10 a	59.10 a	65.80 a	61.50 a
	HS	40.50 b	51.70 b	56.60 b	61.20 b	56.20 b
RDM	W15%	0.95 b	1.38 b	2.70 b	3.10 c	2.30 b
	W18%	1.38 a	2.31 a	3.10 a	4.10 a	3.70 a
	HS	1.01 b	1.45 b	2.80 b	3.80 b	2.40 b
RL	W15%	12.50 b	15.4 b	16.10 b	17.50 b	17.10 b
	W18%	13.20 a	15.8 a	16.70 a	18.50 a	17.80 a
	HS	12.40 b	15.2 b	15.90 b	16.50 c	16.50 c
RDM/SDM	W15%	0.11 b	0.11 b	0.19 a	0.17 b	0.15 b
	W18%	0.15 a	0.17 a	0.20 a	0.21 a	0.21 a
	HS	0.11 b	0.11 b	0.20 a	0.21 a	0.16 b

WS15% = solution from diet feed with 15% crude protein; WS18% = solution from diet feed with 18% crude protein; HS - hydroponic solution prepared according to Gualberto et al. (1999). Means followed by the same letter in columns for each variable do not differ statistically by the Tukey test (p≤0.05)

SFM, SDM, RFM, RDM, RL, and RDM/SDM, regardless of the channel slope, although the RDM/SDM ratio on the 6% slope did not differ from the other solutions. The slope of 8% showed no statistical difference in the RDM/SDM between the solutions WS18% and HS. The WS15% was less efficient for lettuce production (Table 4).

The WS18% provided higher values for SFM and SDM (Table 4) in almost all channel slopes (increase of 3.2 and 10.0% over HS), probably due to higher N (Jordan et al., 2018) and Mg concentration, which influence the leaf area, being Mg a component of the chlorophyll molecule (Malavolta, 2006). Greater plant development was observed mainly from the second cultivation week. The highest RDM/SDM ratio (average of 0.19), using WS18%, there was a greater root system development concerning the lettuce shoot when there is a higher concentration of soluble phosphorus in the water and a lower nitrogen content.

The lower development of the lettuce shoot, in WS15%, possibly occurred due to lower soluble N concentration (0.193 g kg^{-1}) in this wastewater (Table 1). In addition, the low concentration of Ca (0.170 g kg^{-1}), Mg (0.026 g kg^{-1}), and P available (0.064 g kg^{-1}) in HS, compared to WS18% also shows the lower phytomass of shoot and roots of lettuce plants.

The flow rate (Q) drained in the aquaponic system channels was influenced both by the solutions and the channel slope (Table 4 and Figure 3G), with possible interference of lettuce root length and mass in Q, especially in the slope of 8%, where the highest values of RFM and RL in WS18% caused flow reduction, compared to HS (Figures 3C and E).

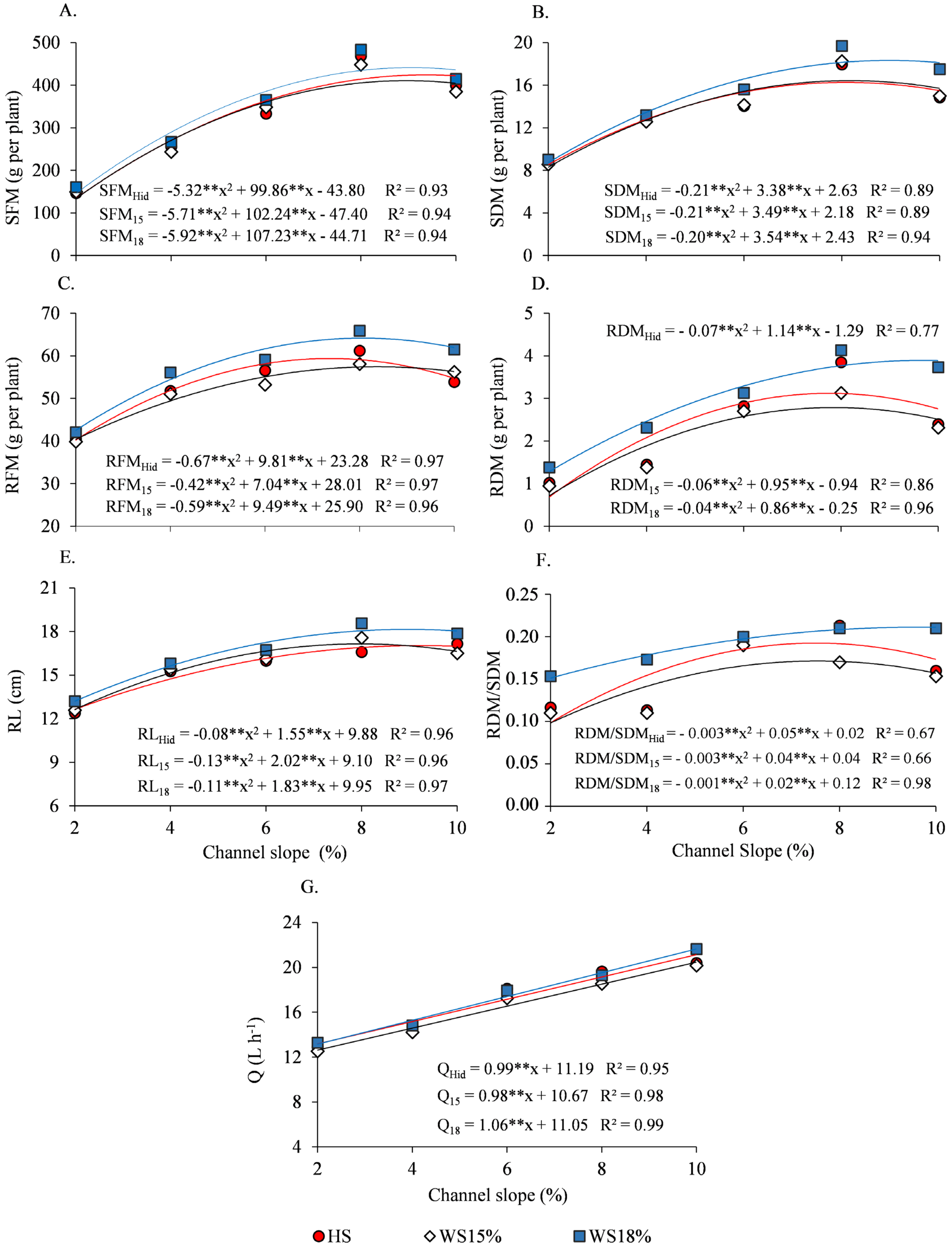

Figure 3. (A) shoot fresh matter (SFM), (B) shoot dry matter (SDM), (C) root fresh matter (RFM), (D) root dry matter (RDM), (E) root length (RL), and (F) ratio between root and shoot dry mass (RMR/SDM) of iceberg lettuce (Lucy Brown cultivar) at 26 days after transplanting, and (G) flow rate in the cultivation channels (Q) at 25 days after transplanting, according to the channel slopes and solutions of hydroponic (HS) and aquaponic systems, in diets with 15% (WS15%) and 18% (WS18%) of crude protein

The flow rates (Q) in the tubes showed an increasing linear effect with the slope increase, even in the presence of a root system at 25 days after transplanting, and it was directly related to SFM, which represents the lettuce production and the variable most desired by costumers. For every 1% slope increase, medium increases in Q of 0.99, 0.98, and 1.06 L h^{-1} are estimated for HS, WS15%, and WS18%, respectively (Figure 3G).

The increase of Q increased production (SFM) until the slope of 8-9% (Table 4 and Figure 3G), getting constancy of value after that inclination in all studied solutions (HS, WS15%, and WS18%), confirming the preference of the slope of 8-9% for hydroponics and aquaponics. In other words, slopes lower than 8-9% generate less lettuce production in HS, WS15%, and WS18%, and slopes greater than 8-9% do not generate an increase in lettuce production, in addition to increasing the difference in slope between the beginning and end of the channel, the which will reduce the recommended length or cause possible discomfort to the hydroponics and aquaponics worker, during the management stages of the lettuce crop (Furlani et al., 2009).

The quadratic equations were fitted to the RL data (Figure 3E). Optimal slopes were estimated at 9.2; 8.0, and 9.0% for HS, WS15%, and WS18%, which resulted in a maximum RL of 17; 17.1, and 18 cm, respectively. There was less root development with 2 and 4% of the channel slope, which can be explained by the greater osmotic effect caused by the longer contact time of the roots with the solutions (Paulus et al., 2010).

The salinity range of the three solutions, with EC maintained between 1.2 and 2.0 mS cm^{-1}, presented symptoms of sodium toxicity in the 2% slope, which probably reduced the RFM, RDM, RL, and RDM/SDM ratio, generating plants dwarfing, leathery leaves of more intense green color (Table 4 and Figures 3C, D, E, and F). According to Paulus et al. (2010), a longer draining time of nutrient solution on the 2% slope can increase the water saline concentration. It promoted a linear increase in the solution's electrical conductivity and osmotic potential. Consequently, the longer contact time with the root system is the main evidence of a greater osmotic effect on the roots, which may be associated with the lower absorption of nutrients, such as N, by mass flow and the consequent decrease in lettuce production (SFM and SDM) with 2% of channel slope.

The saline effect mentioned above was also observed by Paulus et al. (2010), evaluating two lettuce cultivars, where that saline water with higher EC caused a linear reduction in RFM and RDM, as well as the dry mass of plant leaves and stems. According to these authors, the salinity effect on roots is lower than on shoot of hydroponic lettuce. This effect is associated with a faster osmotic adjustment and a slower loss of root turgidity compared to the leaves (Shalhevet et al., 1995).

The 8% of channel slope showed higher lettuce production, with SFM values of 468.60, 448.30, and 483.60 g per plant, and SDM values of 17.90, 18.30, and 9.70 g per plant, for HS, WS15%, and WS18%, respectively (Table 4 and Figures 3A and B). Plants on 2 and 4% slopes had the lowest shoot phytomass (Table 4 and Figures 3A and B). There was greater SFM on optimal slopes ranging from 9.0 to 9.4% and greater SDM on 8.1 to 9.0%, depending on the solution type (Figures 3A and B). The maximum values of SFM and SDM (441.2 and 18.3 g per plant, respectively) were found at the slope of 9% in WS18%.

Root fresh and dry matter (RFM and RDM) and RDM/SDM ratio showed higher estimated values on channel slopes of 7.4-8.1% for RFM, 7.8-9.7% for RDM, and 7.5-9.8% for the RDM/SDM ratio (Table 4 and Figures 3C, D and F). The higher values of these variables were estimated at optimal channel slopes between 8 and 9%, depending on the solution type used: 61.20, 58.10, and 65.80 g per plant for RFM, 3.80, 3.10, and 4.10 g per plant for RDM, and 0.21, 0.17, and 0.21 g per plant for the ratio RDM/SDM, in HS, WS15% and WS18%, respectively.

The optimum slope was higher when using WS18% for most lettuce variables, including SDM, RFM, RDM, RDM/SDM ratio, and the ratio of macronutrients N-leaf/N-solution and P -leaf/P-solution, accumulated during the cycle.

On the channel slopes studied, the N and P accumulation in lettuce leaves (N-leaf/N-solution and P-leaf/P-water) was higher in WS18%, except for P-leaf/P-solution on the 2.0% slope, in which the solutions WS15% and HS showed higher values. On the 4.0% slope, the values of P-leaf/P-solution did not differ statistically from each other (Table 5).

Nitrogen (N) and phosphorus relations found in plant leaf under both wastewater solutions (WS15% and WS18%) were adequate (Table 5), according to Fátima et al. (2018), with values ranging between 17.9 and 21.0 g kg^{-1} of N and 58.1 and 67.3 g kg^{-1} of K. The P concentration in lettuce leaves (5.65-7.35 g kg^{-1} of dry matter) was close to that recommended by EMBRAPA (1999), 4-7 g kg^{-1} of dry matter.

For the channel slopes, the highest N absorption was observed at 6.4 and 6.6% channel slope for HS and WS15% (Table 5). In WS18%, the linear effect of slope on the N-leaf/N-solution ratio indicated that the higher the flow velocity, the lower the osmotic stress and, consequently, the greater the nitrate (NO_{3-}) absorption by mass flow.

The NFT system channels on an 8% slope confirmed better lettuce production in hydroponic (HS) and aquaponic

Table 5. Mean values of N-leaf/N-solution and P-leaf/P-solution ratio accumulated over the iceberg lettuce (Lucy Brown cultivar) cycle according to nutrient solution and channel slopes (%) of hydroponic and aquaponic cultivation systems

Evaluated variable	Nutrient solution	Channel slope (%)				
		2	4	6	8	10
N-leaf/N-solution	WS15%	17.73 b	18.01 b	18.56 b	19.52 b	17.80 b
	WS18%	21.06 a	22.35 a	20.47 a	24.55 a	22.35 a
	HS	17.66 b	17.97 b	18.48 b	19.60 b	17.45 b
P-leaf/P-solution	WS15%	6.37 a	6.66 a	7.15 b	6.38 b	6.38 b
	WS18%	5.59 b	6.70 a	7.80 a	8.27 a	7.55 a
	HS	6.23 a	6.62 a	7.34 b	6.28 b	6.55 b

WS15% = solution from diet feed with 15% crude protein; WS18% = solution from diet feed with 18% crude protein; HS - hydroponic solution prepared according to Gualberto et al. (1999). Means followed by the same letter in the columns for each variable do not differ statistically by the Tukey test (p≤0.05) systems (WS15% and WS18%), despite the greater tube slope compromising crop management and worker posture (Furlani et al., 2009).

The results from the fresh and dry matter of shoot and root and root length presented in the present research prove that aquaponics, supplying fish feed with 18% of crude protein, can satisfy the nutritional needs of lettuce plants, allowing the cultivar to express its production potential.

Compared to current conventional production systems, aquaponics shows that raising fish in recirculation or with hydroponic systems is more complex, requiring greater knowledge and technical follow-up. Many producers leave hydroponics due to its complexity; however, given the water scarcity for cultivation, the present study showed that the aquaponic system of integrated lettuce production with tilapia is promising.

Conclusions

1. The nutrient solution from the 18% crude protein diet in the tilapia feed provides greater production and greater accumulation of nitrogen (N) and phosphorus (P) in the lettuce shoot, both in comparison of hydroponics versus aquaponics and in aquaponics alone.

2. Channels of polyvinyl chloride (PVC) tubes with an 8% of slope increases production of iceberg lettuce (Lucy Brown cultivar).

3. The channel slopes and nutrient solutions evaluated did not influence potassium (K) accumulation in the lettuce shoot.

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