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Hydroponic watercress production through fish farming water reuse and varied nutrient solution recirculation times[1]

Produção de agrião hidropônico por meio de reuso de água em piscicultura e tempos variados de recirculação de soluções nutritivas

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HIGHLIGHTS:
Fish farming effluent is a viable alternative for use in hydroponic watercress cultivation.
Integrated production between aquaculture and hydroponic vegetable can increase water use efficiency.
The use of effluent from fish farming reduces the use of nutrient solution in NFT hydroponic system.

ABSTRACT: Aiming at a more sustainable food production, the reuse of effluent from fish farming in hydroponics can be a viable option. Thus, the objective of present study was to evaluate the effects of the use of effluent from fish farming on the development of ‘Folha Larga’ watercress and the possibility of reducing the use of fertilizer in a hydroponic system. The assay was carried out in a greenhouse from October 2021 to February 2022 (two cycles). The treatments were distributed in randomized blocks, with four replications, with split plots, consisting of two times of recirculation of the solution in the plots (T1 = 15 min operating by 15 min off and T2 = 15 min operating by 30 min off) and five solutions, in the subplots, obtained by mixing different proportions (0, 25, 50, 75, and 100%) of nutrient solution and effluent from fish farming. The variables analyzed were: plant height, number of leaflets, leaf area, SPAD index, fresh and dry weight of the aerial part and roots. The use of effluent from fish farming reduces the amount of fertilizers for the yield of ‘Folha Larga’ watercress. Nutrient solution recirculation time of 15 minutes is suitable for hydroponic watercress.

Key words: *Nasturtium officinale*, water quality, *Oreochromis niloticus*

RESUMO: Visando uma produção de alimentos mais sustentável, a reutilização de efluente da piscicultura na hidroponia pode ser uma opção viável. Assim, objetivo desta pesquisa foi avaliar os efeitos do uso de efluente da piscicultura no desenvolvimento do agrião ‘Folha Larga’ e a possibilidade de redução do uso de fertilizantes em sistema hidropônico. A pesquisa foi realizada em casa de vegetação entre outubro de 2021 e fevereiro de 2022 (dois ciclos). Os tratamentos foram distribuídos em blocos ao acaso, com quatro repetições, com parcelas subdivididas, consistindo em dois tempos de recirculação da solução nas parcelas (T1 = 15 min operando por 15 min desligado e T2 = 15 min operando por 30 min desligado) e cinco soluções, nas subparcelas, obtidas pela mistura em diferentes proporções (0, 25, 50, 75 e 100%) de solução nutritiva e efluente da piscicultura. As variáveis analisadas foram: altura de plantas, número de folíolos, área foliar, índice SPAD, massa fresca e massa seca da parte aérea e raiz. O uso de efluente da piscicultura reduz a quantidade de fertilizantes para a produção de agrião ‘Folha Larga’. O tempo de recirculação da solução nutritiva de 15 minutos é adequado para o agrião hidropônico.

Palavras-chave: *Nasturtium officinale*, solução nutritiva, qualidade da água, *Oreochromis niloticus*

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Introduction

With the increase in the world population, there is enormous pressure on the use of water, mainly by activities such as agriculture and fish farming, given that these activities use approximately 70% of the water resources exploited by human actions (UNESCO, 2021), posing risks of deteriorating the quality and quantity of water (Correa et al., 2020).

In order to mitigate these impacts, the reuse of water from fish farming in agriculture can be a viable option, which can generate benefits for agricultural crops with nutrient recycling to reduce input costs such as with the use of fertilizers (Jonh et al., 2022), increased production efficiency (Mustapha & Bakali, 2021) and decreased production cost per unit of water used (Guimarães et al., 2018).

Several studies demonstrate the potential use of wastewater in hydroponic systems, among which we can highlight the use of treated sewage in hydroponic lettuce (Cuba et al., 2015), brackish water in watercress (Souza et al., 2020a) and treated effluent from the ice cream industry in cherry tomato yield (Malheiros et al., 2012). All these studies demonstrate the high potential for yield of vegetables in hydroponic systems using low quality water.

Watercress (*Nasturtium officinale*) is a leafy vegetable consumed in Brazil in salads, standing out among vegetables as a source of manganese, phosphorus, iron, zinc, and vitamins A, B1, B2, and C (Lana & Tavares, 2010). The hydroponic production of watercress with reuse of water has been explored by several authors under different conditions. Lira et al. (2019), using calcium chlorinated water from wells in the semi-arid region, observed high yields for this crop. Souza et al. (2020a) observed that the circulation of the nutrient solution at intervals of 15 minutes promoted the best results for hydroponic watercress, even with the use of brackish water. Nhan et al. (2019), using an aquaponic system in the production of watercress, observed high nutritional contents in this system, benefiting the crop.

In view of the above, the objective of the present study was to evaluate the effects of the use of effluent from fish farming on the development of 'Folha Larga' watercress (*Nasturtium officinale*) and the possibility of reducing the use of fertilizer in a hydroponic system.

Material and Methods

The study covered two production cycles of the watercress cultivar 'Folha Larga', carried out between October and November 2021 (1^{st} cycle) and between January and February 2022 (2^{nd} cycle). Both experiments were carried out in a greenhouse (arched ceiling and area of 78 m^2, 6.50 m wide and 12.0 m long and height of 4.5 m and covered with low density polyethylene film), in the experimental area of the Agrometeorological Station of the Federal University of Ceará (UFC), Fortaleza, Ceará, Brazil, (located at the geographic coordinates of 3° 44' S; 38° W and 19.5 m altitude).

Daily data on air temperature and relative humidity were collected using a thermometer and a hygrometer, respectively, installed inside the greenhouse to monitor the experimental weather conditions. For the first cycle (Figure 1A), the average temperature (T) was 34.7 °C and relative air humidity (RH) was 53.6%; in the second cycle (Figure 1B), the averages of T and RH were 32.7 °C and 66.0%, respectively.

Sowing of watercress seeds was carried out in trays containing coconut fiber substrate and, after complete germination, the seedlings were irrigated with a nutrient solution (NS) recommended by Furlani et al. (1999), diluted by 50%. The seedlings were thinned when they reached five centimeters in height, maintaining one plant per cell, and 30 days after sowing, the seedlings were transplanted to the hydroponic system, starting the treatments.

The treatments were arranged in a randomized complete block and split-plot design, with four repetitions, and they consisted of: two times of recirculation (TR) of the nutrient solution (NS) in the main plots (T1 = 15 minutes operating at 15-minute interval and T2 = 15 minutes operating at 30-minute interval); and five mixtures, in the subplots, with different proportions of NS in fish farming reuse water (RW), treated by biological filtration (S1: 0% NS and 100% RW; S2: 25% NS and 75% RW; S3: 50% NS and 50% RW; S4: 75% NS and 25% RW; S5: 100% NS and 0% RW), totaling 40 experimental units

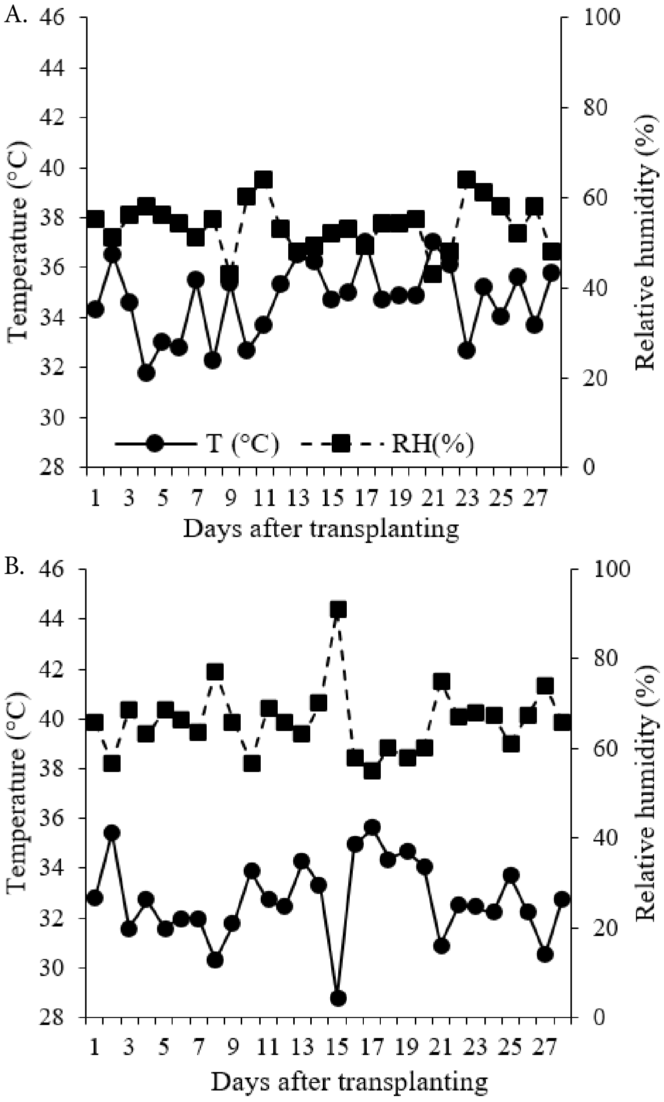


Figure 1. Air temperature and relative humidity in the greenhouse in the first (A) and second (B) production cycles

composed of an independent hydroponic profile containing 9 plants.

The hydroponic system adopted was the Nutrient Film Technique – NFT, with independent profiles spaced 0.25 m apart. The profile consisted of a PVC tube (100 mm in diameter and 2.7 m in length) containing ten holes (5 cm in diameter; spaced 0.25 m apart), where the plants were grown. The structure was installed at a height of 0.85 m, with a slope of 3.0% to promote drainage. Each experimental unit also contained a 50 L plastic reservoir, where the solutions were stored, and an electric pump (0.25 hp) used to recirculate the solution through PVC tubes and inject it into the hydroponic profile through a microtube at a flow rate of 1.5 L min^{-1}.

An analog timer was used to control the frequency and time of recirculation of the NS. The NS used for the control treatment was prepared based on the recommendation by Furlani et al. (1999), while the other treatments were prepared from the mixture of this solution with the effluent from fish farming according to the desired proportion.

The fish farming effluent was obtained from the production of the Nile tilapia species (*Oreochromis niloticus*), during the growth phase (from 60 to 300 g), in a tank excavated and lined with plastic tarpaulin (2.0 m wide; 4.0 m long and 0.9 m deep) with a maximum stocking density of up to 20 kg of fish per 1000 L of water (Silva et al., 2002). The feed had a minimum of 32% crude protein and was provided in the quantity and frequency indicated by the manufacturer (Polinutri®), according to the average animal weight. Aeration was promoted by a pumping system (0.5 hp), with a waterfall in a recirculation system to the tank. Part of the wastewater was pumped into a decanter filter and, through an acrylic geotextile, proceeded to a biological filter filled with expanded clay, containing nitrifying bacteria.

After the filtering system, the effluent was stored in 1000 L water tanks for use in the above mentioned treatments, where the respective fractions of the NS were added and stored in 240 L drums for replacement when necessary, according to water consumption of the plants. The characterization of the effluent (APHA, 2012) is presented in Table 1.

Daily readings of electrical conductivity of the nutrient solution (EC_{ns}) and pH were performed in the reservoirs of each experimental unit, using a portable conductivity meter and pH meter, during the weeks of experimentation of both production cycles. There was an attempt to correct the pH of the NS using 0.1 mol L^{-1} of HCl, but it was significantly buffered.

The growth variables plant height (PH) (using a graduated ruler) and number of leaflets (NL) were measured weekly, at 7, 14, 21, and 26 days after transplanting (DAT), in both cycles (Santos et al., 2022). At the end of each cycle (30 DAT), the SPAD chlorophyll index was determined using a portable meter (SPAD 502, Minolta Co, Ltd, Osaka, Japan) on the largest expanded blade (Benati et al., 2021). Subsequently, the plants were collected to obtain the leaf area (LA), measured with an area meter (Area meter, LI-3100, Li-Cor, Inc. Lincoln, NE, USA), with a value expressed in cm^2 $plant^{-1}$. Fresh weight of aerial part (FWAP) and root fresh weight (RFW) data were also obtained using a precision scale (0.01g). Dry weight of aerial part (DWAP) and root dry weight (RDW) were obtained by drying in a forced-air circulation oven at a temperature of 65 °C until reaching constant weights.

Data were subjected to analysis of variance ('F' test) and, when significant effects were verified, quantitative data were subjected to regression analysis (aiming to fit regression models) and qualitative data were subjected to the Scott-Knott test at 0.05 probability level using SISVAR software version 5.8.

Results and Discussion

The EC_{ns} obtained during the cycle for T1 (Figure 2A) and T2 (Figure 2B) showed values between 1.04 dS m^{-1} for the treatment with 0% NS and 3.63 dS m^{-1} for the use of 100% NS. NS pH for T1 (Figure 2C) and T2 (Figure 2D) ranged from 5.8 for 100% NS to a maximum of 9.2 for 0% NS. Elevated pH values may contribute to the unavailability of nutrients to plants, as observed in NS 0% (100% RW and 0% NS) and may therefore reduce crop yield due to inadequate supply of nutrients by the NS. Such observations corroborate Santos et al. (2022), who observed high pH values of NS, in hydroponic arugula cultivation, thus reducing crop production.

According to the analysis of variance, there was no significant effect ($p > 0.05$) for the TR factor in the first and second production cycle for plant height data. For the NS factor, a significant effect ($p \leq 0.05$) was observed for all growth variables evaluated in the first cycle. There was no significant effect ($p > 0.05$) of interaction between TR and NS for all growth variables.

At 7 DAT (Figure 3A), there was an increase in plant height of 0.0172 cm for each unit increment of NS. At 14, 21, and 26 DAT, a quadratic fit was observed with higher values using 80.33, 65.92, and 62.00% NS, respectively. In the second production cycle, there was a significant effect ($p \leq 0.05$) for the NS factor on the plant height variable only on days 21 and 26 DAT (Figure 3B), with quadratic fit with higher values of the response variable with the use of 74.76 and 69.98% of NS.

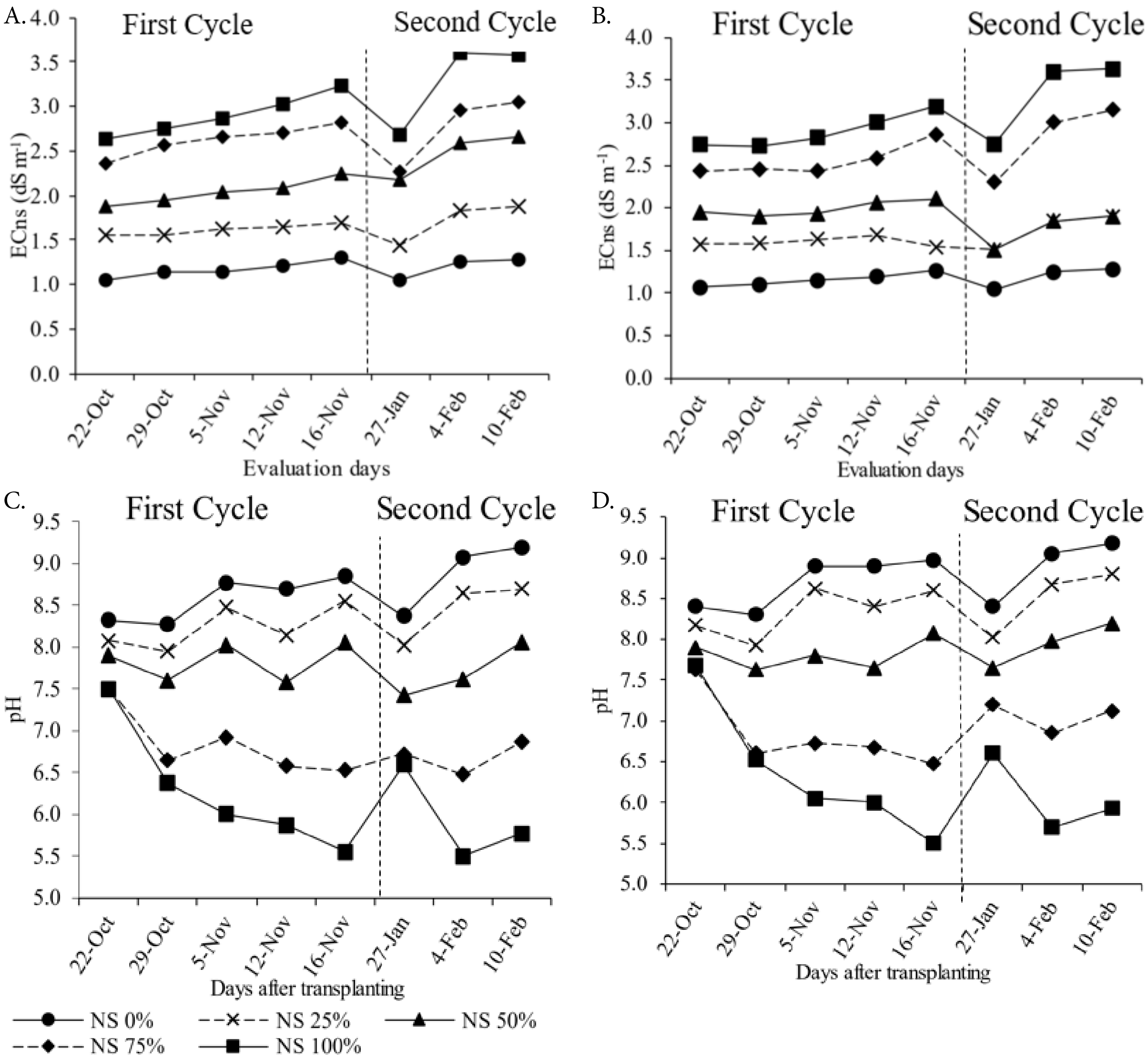
The reduction in the use of NS observed in first (7, 14, 21, and 26 DAT) and second (21 and 26 DAT) cycle for plant growth variable may be related to the increase in nutrients provided by the effluent from fish farming; according to the results, it is possible to reduce between 38% (first cycle) and 30.02% (second cycle) of NS, at the end of each cultivation cycle, and obtain satisfactory results.

Table 1. Physicochemical analysis of the fish farming effluent used in the hydroponic system

Variables	Tw (°C)	ECw (dS m^{-1})	pH	O_2 (mg L^{-1})	CO_2 (mg L^{-1})	$CaCO_3$ (mg L^{-1})	dGH (mg L^{-1})	OM (mg L^{-1})
Limnological	32.10	0.88	7.80	4.21	6.53	225.00	114.24	65.00

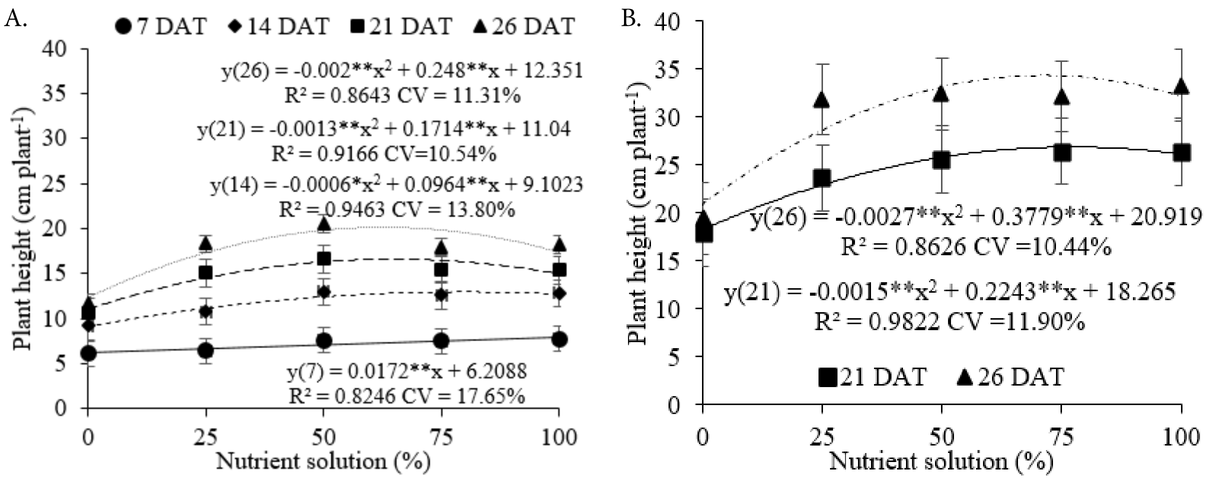
	N (mg L^{-1})	P (mg L^{-1})	K (mg L^{-1})	Ca (mg L^{-1})	Mg (mg L^{-1})	Fe (mg L^{-1})	Zn (mg L^{-1})	Mn (mg L^{-1})	Cu (mg L^{-1})
Chemicals	5.01	3.4	14.52	24.11	10.27	0.39	0.07	0.12	0.05

Tw – Water temperature; ECw – Electrical conductivity of water; O_2 – Dissolved oxygen; $CaCO_3$ – Alkalinity; dGH – Hardness; OM – Organic Matter



NS 0% - 0% NS and 100% RW; NS 25% - 25% NS and 75% RW; NS 50% - 50% NS and 50% RW; NS 75% - 75% NS and 25% RW; NS - 100% NS and 0% RW

Figure 2. Electrical conductivity of the nutrient solution (EC_{ns}) and pH values observed during first (A and C) and second (B and D) production cycles for different recirculation times - T1 (A and C) and T2 (B and D)



** - Significant at $p \leq 0.01$ by the F test. Vertical bars represent the standard deviation of the mean

Figure 3. Plant height as a function of nutrient solution (%) and water from fish farming in the 1st (A) and 2nd (B) watercress production cycle

Souza et al. (2020a), in a study using brackish water in hydroponic watercress, observed values of 34.09 cm at 25 DAT, using water with electrical conductivity of 0.6 dS m^{-1} in the second production cycle. Such values are close to those observed in the present assay for the second cycle (34.14 cm) and higher than the values found in the first cycle (20.04 cm).

The low values observed in the first cycle can be explained by the high temperature (Figure 1A) recorded within the greenhouse, since according to Hirata & Hirata (2015) watercress yield is strongly influenced by the temperature of the environment, while the higher values observed in the second cycle were possibly caused by a greater supply of nutrients provided by the RW with the growth of the fish throughout the cycle and a considerable increase in the amount of their excrements in the water (Correa et al., 2020; Carneiro et al., 2022).

According to the analysis of variance, there was no significant effect ($p>0.05$) for the TR factor on number of leaflets (NL) variable. For the NS factor, there was a significant effect($p \leq 0.05$) on the NL variable in all evaluations performed, except for the analysis at 7 DAT of the second production cycle. There was no significant effect ($p > 0.05$) of the interaction between TR and NS factors for the studied variables.

In the first production cycle (Figure 4A), the fit was quadratic with higher NL values observed with the use of 54.17 (7 DAT), 73.08 (14 DAT), 62.77 (21 DAT), and 63.86% (26 DAT) of NS. For the second cycle (Figure 4B), the fit was quadratic with higher NL values achieved using 63.36 (14 DAT), 70.04 (21 DAT), and 72.04% (26 DAT) of NS.

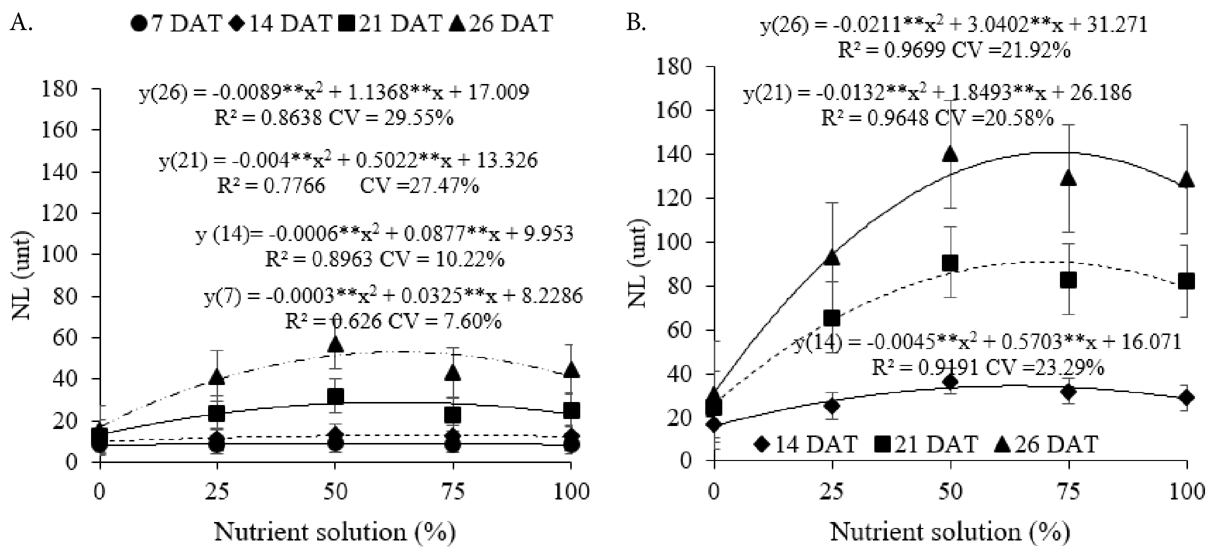
The highest values of NL observed in the present study, in relation to the optimal value of NS, are in line with those observed by Lira et al. (2018), who found average values for hydroponic watercress of 40 leaves plant^{-1} in studies using brackish water and NS. Supplementation of NS with fish farming effluent was necessary as shown in the first and second cycle.

The use of 100% RW without complementation with NS did not promote satisfactory growth of the crop in the present study. These results are in line with those observed by Kazoki et al. (2019), who reported that in aquaponic systems supplementation with iron is of vital importance, while John et al. (2022) verified better results in crops such as spinach with the use of potassium supplementation in an aquaponic system, thus demonstrating the need for nutritional supplementation for the development of crops produced with water from fish farming.

For the variables fresh weight of aerial part (FWAP) and root fresh weight (RFW) only the NS factor showed a significant effect ($p \leq 0.05$) in both production cycles. The fit of the regression analysis models studied (Figure 5A) for FWAP were quadratic in both production cycles, with higher values observed (9.64 and 28.45 g plant^{-1}) with the use of 66.19 and 72.75% of NS in the first and second cycle, respectively. For the RFW variable (Figure 5B), the highest values (0.97 and 2.94 g plant^{-1}) were found using 62.00 and 52.81% of NS for the first and second cycle.

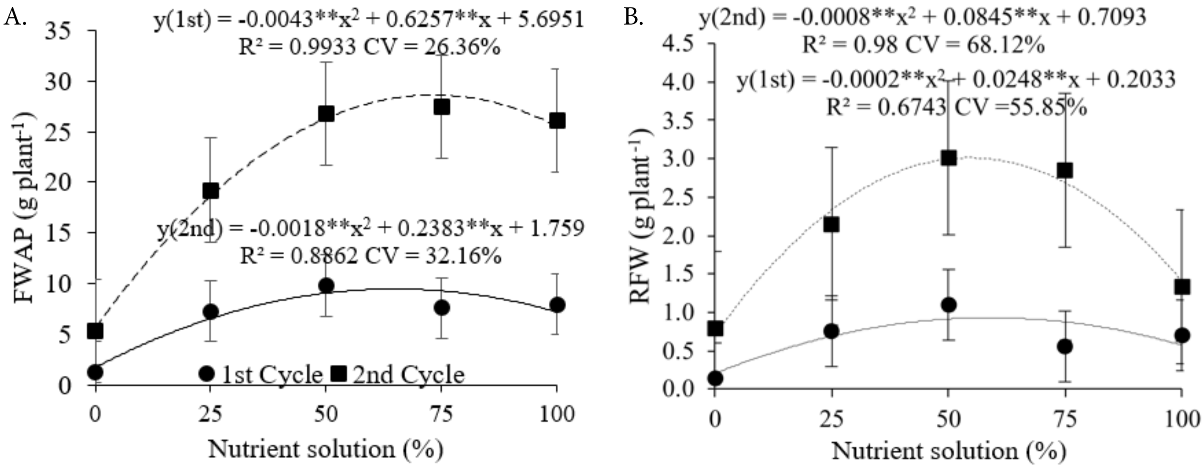
The values observed in the present study are consistent with those reported by Souza et al. (2020b) and Lira et al. (2019) in studies on hydroponic watercress, where these authors obtained values of 32.25 and 12.58 g plant^{-1} for the FWAP variable, while for RFW the values of this study were lower than those presented by Souza et al. (2020b) who observed averages greater than 6 g plant^{-1}. Such differences may be related to the low availability of nutrients in treatments without the use of NS because, in addition to a lower supply of nutrients, the high pH can contribute to their unavailability, temperature of the solution, recirculation interval of NS in the system and cultivation season, as observed by Walters & Lopez (2021).

The low values observed for the variables FWAP and RFW (Figure 5) with the use of 100 and 75% of the effluent (S1 and S2) may possibly be related to the high pH that these solutions had throughout the two production cycles, with values varying between 7.8 and 9.2. According to Martinez & Clemente (2011), the pH is related to the solubility of nutrients for plants, and values above 6.5 can lead to the precipitation of elements such as calcium, phosphorus and manganese. The reduced development and less intense coloring of the leaves (Figure 6) of the mentioned treatments corroborate this point, so the correction of the acidity of the solution is an important point to be studied. In the present study, as shown in Figure 2, the pH values in the NS increased throughout the cycle, in the treatments that used RW, which possibly contributed to the unavailability of some nutrients to the plants, causing chlorosis.



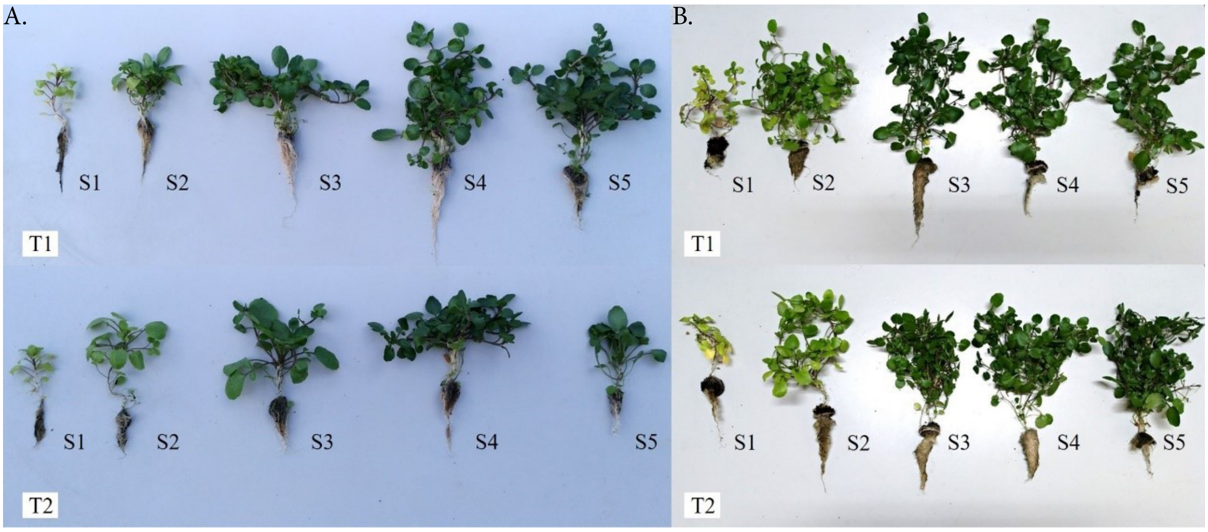
** - Significant at $p \leq 0.01$ by the F test. Vertical bars represent the standard deviation of the mean

Figure 4. Number of leaflets (NL) per plant as a function of percentage of nutrient solution and water from fish farming in the 1st (A) and 2nd (B) watercress production cycle



** - Significant at $p \leq 0.01$ by the F test. Vertical bars represent the standard deviation of the mean

Figure 5. Fresh weight of the aerial part – FWAP (A) and root fresh weight - RFW (B) in first and second production cycles of the hydroponic watercress crop as a function of the nutrient solution and water from fish farming



S1 - 0% NS and 100% RW; S2 - 25% NS and 75% RW; S3 - 50% NS and 50% RW; S4 - 75% NS and 25% RW; S5 - 100% NS and 0% RW. T1 = 15 minutes operating at 15-minute interval and T2 = 15 minutes operating at 30-minute interval

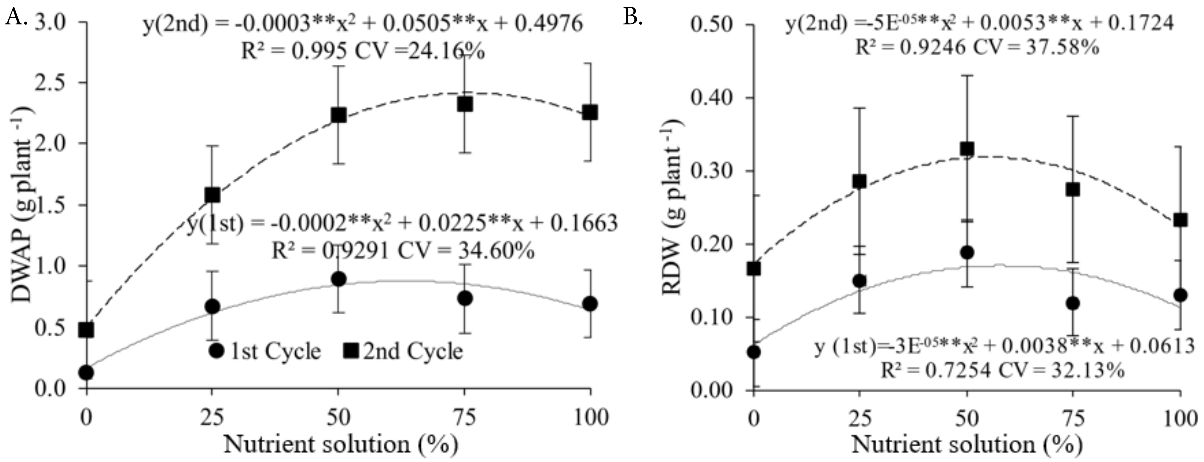
Figure 6. Visual effects on hydroponic watercress produced with a mixture of fish farming effluent and nutrient solution at different recirculation times in the first (A) and second (B) production cycles

Regarding the dry weight of aerial parts (DWAP) and root dry weight (RDW), it was observed in the analysis of variance that only the NS factor had a significant effect ($p \leq 0.05$) for the variables studied in both production cycles. For DWAP (Figure 7A), the fitted model was the quadratic, in both production cycles, with higher values observed with the use of 56.25 and 84.16% of NS in the first and second cycle, respectively. For RDW (Figure 7B), a quadratic fit was observed in both cycles with highest values observed with the use of 63.33% (first cycle) and 53.00% (second cycle) of NS.

Dry matter accumulation is directly related to the absorption of nutrients by plants. In hydroponic systems the insolubility of some elements can cause reductions in the dry matter of the plants, as observed by Santos et al. (2022) in studies with hydroponic arugula and reduced use of NS. Souza et al. (2020b) demonstrate that excess salts in the NS can also cause such reductions, negatively affecting the yield of leafy vegetables.

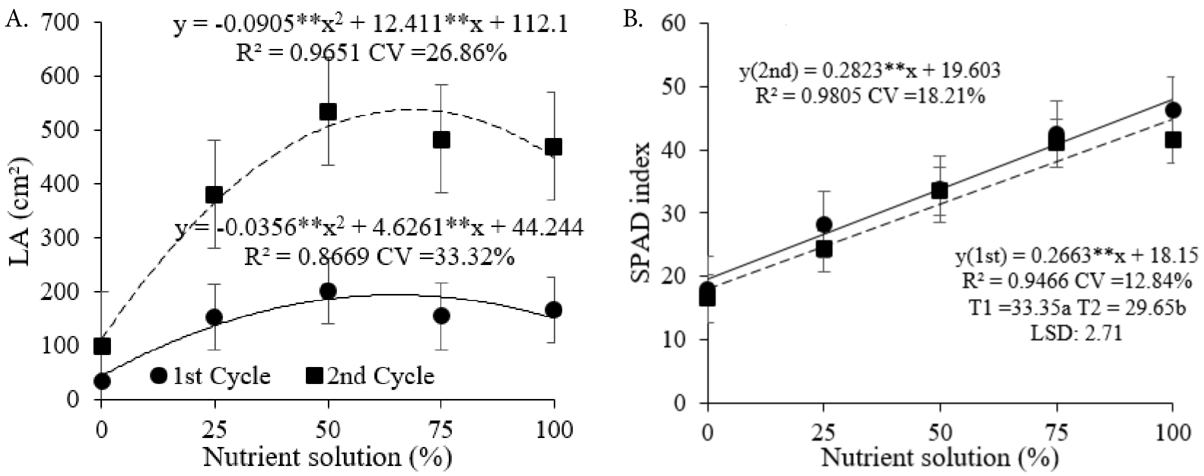
For the leaf area (LA) variable, it was observed by the analysis of variance that only the NS factor had a significant effect ($p \leq 0.05$). As shown in Figure 8A, the model fitted for LA was quadratic, in both evaluation periods, with higher values observed for 64.97 and 68.56% of NS. For the SPAD index variable, according to the analysis of variance, the individual factors, NS for both evaluations and TR only for the first cycle, significantly influenced ($p \leq 0.05$) the observed values, which, according to Figure 8B, had a linear fit with increases of 0.266 and 0.282, respectively, for first and second cycle in the SPAD index for each unit increment of NS.

The TR factor for the SPAD index in the first cycle showed that T1 had higher values compared to T2, possibly caused by greater absorption of nutrient solution and, consequently, nitrogen. Possibly, longer recirculation intervals can cause water deficit in hydroponic crops, due to the lack of substrate, which can reduce plant development, as observed by Souza et al. (2020b). According to Benati et al. (2021), the SPAD index is influenced by the dose of N, making it possible to use it to predict the yield of commercial crops.



** - Significant at $p \leq 0.01$ by the F test. Vertical bars represent the standard deviation of the mean 1st and 2nd production cycles

Figure 7. Dry weight of aerial parts - DWAP (A) and root dry weight - RDW (B) of hydroponic watercress as a function of nutrient solution and water from fish farming



** - Significant at $p \leq 0.01$ by the F test. Vertical bars represent the standard deviation of the mean in the 1st and 2nd cycles

Figure 8. Leaf area - LA (A) and SPAD index (B) of hydroponic watercress as a function of nutrient solution and water from fish farming

Conclusions

1. It is possible to produce hydroponic watercress satisfactorily with the use of effluent from fish farming in partial replacement of the nutrient solution.

2. The use of fish farming effluent reduces the amount of fertilizers required for growing 'Folha Larga' watercress.

3. Nutrient solution recirculation time of 15 minutes is suitable for hydroponic watercress.

Acknowledgments

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