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Yield of lettuce grown in aquaponic system using different substrates

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intensive fish farming

ABSTRACT
In the aquaponic system, the characteristics of the materials used as substrate directly affect plant development, because besides acting as a support base, they must present a surface to fix microorganisms, responsible for the conversion of nutrients into forms more easily available to plants. Thus, the objective of this study was to evaluate the effect of four growing substrates on the yield of lettuce grown in aquaponic system. The experimental design was randomized blocks with four treatments, which corresponded to the substrates, and six replicates. Plants were grown using the nutrient film technique (NFT) system. The substrates used in the experiment were: coconut shell fiber with crushed stone #3, expanded vermiculite, zeolite and phenolic foam. The treatment with phenolic foam was considered as the least suitable for lettuce cultivation in aquaponic system, because it caused lower yield (20.8 t ha^{-1}). The treatment using coconut shell fiber with crushed stone #3 was considered as the most adequate, since it led to higher yield (39.9 t ha^{-1}) compared with the other substrates analyzed.

Palavras-chave:
biofiltro
biodigestão
cultivo sem solo
criação intensiva de peixe

Produtividade da alface cultivada em sistema aquapônico sob diferentes substratos

RESUMO
No sistema de aquaponia as características dos materiais utilizados como substrato afetam diretamente no desenvolvimento das plantas, pois além de atuarem como base de sustentação, devem apresentar uma superfície para fixação de microrganismos, responsáveis pela conversão de nutrientes para formas mais facilmente disponíveis para plantas. Assim, o objetivo desta pesquisa foi avaliar o efeito de quatro substratos de cultivo sobre a produtividade da alface cultivada em sistema de aquaponia. O delineamento experimental utilizado foi em blocos ao acaso, com quatro tratamentos que corresponderam aos substratos e seis repetições. O cultivo das plantas foi realizado utilizando o sistema do tipo NFT (Nutrient Film Technique). Os substratos utilizados no experimento foram: fibra de casca de coco com brita número 3, vermiculita expandida, zeólita e espuma fenólica. O tratamento em que se utilizou espuma fenólica foi considerado o menos adequado para o cultivo da alface em sistema aquapônico, pois apresentou menor produtividade (20,8 t ha^{-1}). O tratamento em que se utilizou fibra de casca de coco com brita número 3 foi considerado o mais adequado, uma vez que proporcionou maior produtividade (39,9 t ha^{-1}) em relação aos demais substratos analisados.

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Introduction

Plant cultivation integrated with fish farming in a system with water recirculation, i.e., an aquaponic production system, is a technique successfully used in many countries, including United States, Australia and also in European countries. In Brazil, there are no reports of commercial production in aquaponic system. However, due to some characteristics of the system, such as low water consumption, reduction of environmental impacts, production of two income sources in one single system, it becomes necessary to conduct studies that provide information to allow the implementation of this system under Brazilian conditions (Geisenhoff et al., 2016).

Aquaponics consists in a set of agricultural technologies that sustainably integrate intensive fish farming in a water recirculation system with hydroponics (Roosta & Afsharipoor, 2012). Such integration allows the conditioning of water for fish farming, through the cultivation of plants, and at the same time, with water recirculation, the use of residues generated in fish farming and plant cultivation (Ihejirika et al., 2012; Geisenhoff et al., 2016).

This system behaves as a symbiotic relationship, in which fish provide the nutrients for plant cultivation (Martins et al., 2010; Roosta & Afsharipoor, 2012) and plants remove the metabolites present in the water, which are harmful to the fish, allowing their development (Hundley et al., 2013).

Water recirculation between fish farming and plant cultivation provides conditions of optimization of both activities, so that, during the recirculation, the characteristics of water and fish farming environment are monitored and conditioned (Dalsgaard et al., 2013). Hence, fish farming and plant cultivation occur under adequate conditions, resulting in a product with high standard of commercial quality (Dediu et al., 2012; Geisenhoff et al., 2016).

Substrates are fundamental components for soilless cultivation (hydroponics and aquaponics) because, besides performing the function of plant support, they act as a small reservoir of nutrients. Hence, the use of inadequate substrates may create adverse conditions for plant cultivation, causing reduction in the production parameters of the crops, as observed for the aquaponic lettuce and tomato (Salam et al., 2014; Geisenhoff et al., 2016).

In the aquaponic system, the role of the substrate has greater importance compared with the hydroponic system, because unlike the latter, in which the soluble nutrients added to the water are adequate for utilization by plants (Pôrto et al., 2012), in aquaponics, the nutrients need to be converted into easily available forms, such as organic nitrogen, which through the action of microorganisms is converted into ammonia, which is later transformed into nitrate through the action of nitrifying bacteria (Tokuyama et al., 2004; Rakocy et al. 2006). Thus, the substrate for aquaponics has an additional function, acting as an adequate base for fixation of microorganisms (Hoque et al., 2012).

Considering the importance of using an adequate substrate in aquaponic plant cultivation, this study aimed to evaluate the effect of four growing substrates on the yield of lettuce cultivated in aquaponic system.

Material and Methods

The experiment was carried out in an agricultural greenhouse of the aquaponic experimental area of the Faculty of Agricultural Sciences (FCA), at the Federal University of Grande Dourados (UFGD), located in Dourados, Mato Grosso do Sul, Brazil (22° 11' 45'' S; 54° 55' 18'' W; 446 m).

The present study used the associated aquaponic system or direct system. In this system, the plant production bench is in series with the fish farming; the effluent removed during the cleaning of the bottom of the culture tanks, decanter and filters is subjected to biodigestion to reduce the content of total solids and subsequently used as nutrient solution (Goddek et al., 2016).

The aquaponic system that provided the residues was composed of two 1000 L fiberglass culture tanks, decanter, pumping tank, biofilter, cultivation bench and heating tank (Figure 1).

In the fish farming tank, the adopted population density was 100 fish per cubic meter (Coêlho et al., 2014), using a species of Tilapia, GIFT strain (*Oreochromis niloticus*). Fish farming started with fish in the juvenile stage, with mean weight of 142 g.

Through valves installed at the bottom of the culture tanks, decanted wastes were taken to the decanter twice a day (early morning and late afternoon). The decanter remained accumulating wastes for one week and, subsequently, it was cleaned and the decanted fraction was removed.

The decanted fraction was sent to batch biodigesters, mounted with 50 L drums. The time taken for decanted effluent biodigestion was 15 days. The liquid fraction (wastewater) was separated and stored for subsequent mixture with the biofertilizer. The nutrient solution consisted in a mixture of wastewater and biofertilizer at volumetric proportion of 100:6.

This solution remained in a fiberglass tank, with volume of 500 L. Subsequently, the solution was pumped to the aquaponic system using a mini pump with power and flow rate of 130 W and 6000 L h^{-1}, respectively. The aquaponic system was mounted on a bench with 3 m long NFT (Nutrient Film Technique) hydroponic profiles, supported by a metal structure, with 3% slope and spaced by 20 cm.

Irrigations were performed in 15 min cycles, actuated by a time switch. Every seven days, the volume in the tank was replaced by a new nutrient solution.

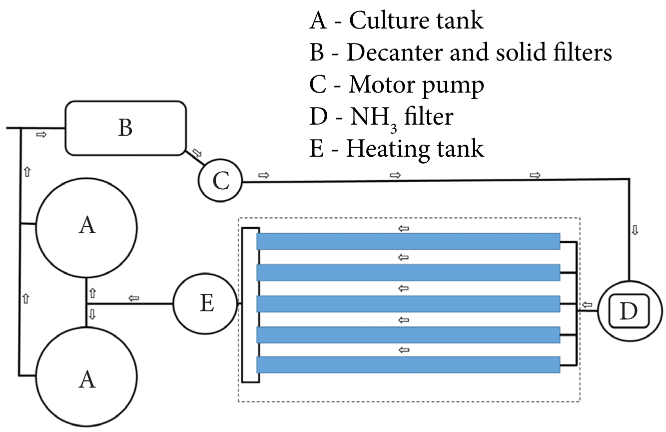

Figure 1. Aquaponic system operation scheme

The experiment was set in a randomized block design with four treatments, represented by the substrates, and six replicates. The substrates were: coconut shell fiber with crushed stone #3 (CFCS3), phenolic foam (PF), expanded vermiculite (EV) and zeolite (Z). Each plot was formed by 10 plants, as done by Geisenhoff et al. (2016). The experimental unit was represented by six plants of each plot, disregarding plants on the extremities.

The coconut fiber was provided by the company Vida Verde® and had apparent dry density of 150 kg m^{-3}. Phenolic foam came from the company Green-up® and had 2.0 x 2.0 x 2.0 cm cells and apparent density of 10 to 12 kg m^{-3}. The expanded vermiculite came from the company Carolina Soil do Brasil®, model Carolina II, fine, with apparent density of 155 kg m^{-3}. Zeolite was provided by the company Celta Brasil®, with granulometry of 3.0 to 8.0 mm and apparent density of 980 kg m^{-3}.

The experiment used curly lettuce (*Lactuca sativa*), cultivar 'Pira verde', which was sown on October 5, 2014. For 20 days, the seedlings were manually irrigated, with a mixture at proportion of 50% wastewater and replacement water, water from an artesian well.

Regarding the water used during the experiment with the aquaponic system, compared with the replacement water, the fish farming system led to increment in the concentrations of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), sulfur (S), iron (Fe) and sodium (Na). It can also be noted that the contents of nutrients in the biofertilizer are higher than those in the wastewater (Table 1).

After 35 days, on November 22, 2014, the experimental units of each treatment were harvested. After that, the following parameters were evaluated: total fresh matter, shoot fresh matter, number of leaves and yield of the crop.

For the evaluation of total fresh matter, plants were weighed considering the stem, leaves and roots. For shoot fresh matter, roots were removed and shoots (stem and leaves) were weighed. In addition, leaves were counted separately. Yield was obtained based on shoot fresh matter, considering the adopted plant population (20 plants m^{-2}).

The results were subjected to analysis of variance by F test and subsequent comparison of means through the Bonferroni test at 0.05 probability level ($p \leq 0.05$).

Table 1. Concentration of nutrients (mg L^{-1}) in the replacement water and fish-fertilized water

Determination*	Replacement water	Wastewater	Biofertilizer
Phosphorus (P)	-	5.0	17.0
Potassium (K)	-	13.0	15.0
Calcium (Ca)	5.0	25.0	155.0
Magnesium (Mg)	1.0	7.0	24.0
Sulfur (S)	-	34.0	130.0
Iron (Fe)	0.2	1.2	4.5
Manganese (Mn)	-	0.1	1.0
Copper (Cu)	-	-	-
Zinc (Zn)	0.1	0.2	0.3
Boron (B)	-	0.1	0.2
Sodium (Na)	3.0	270.0	300.0
pH	7.9	8.0	5.5
Electrical conductivity, dS m^{-1}	0.07	4.3	5.8

*Analysis made by the Unithal Laboratory, located in Campinas, SP; Data represented by a dash were below the detection level; Analyses made according to the methodology described by Eaton et al. (2005)

Results and Discussion

Regarding the quality of the water used in the experiment, there was high Na concentration in the wastewater and biofertilizer. This can be attributed to the excess of this element in the fish feed, being frequently excreted into the water. Electrical conductivity (EC) substantially increased compared with the replacement water. The most adequate EC for hydroponic cultivation of lettuce is highly variable in the literature, and it is believed that it may vary according to the adopted cultivar and climatic conditions (Costa et al., 2001).

In lettuce cultivation in hydroponic system, the most adequate EC is around 2.5 to 2.6 dS m^{-1} (Costa et al., 2001; Gondin et al., 2010). The EC values found in the present study were higher. In aquaponic systems, EC has higher values due to the lower rate of water replacement, promoting greater accumulation of ions in the solution. However, due to the supply and continuous recirculation of water, the conditions become satisfactory for plant cultivation (Rakocy et al., 2006).

Regarding total fresh matter (TFM), the treatment in which plants were grown in phenolic foam resulted in lower fresh matter (185.8 g $plant^{-1}$), exhibiting statistical difference in relation to the others, which were statistically similar. The highest total fresh matter (312.5 g $plant^{-1}$) was found in the treatment in which plants were grown in expanded vermiculite (Table 2).

Lettuce cultivation in hydroponic system using phenolic foam as substrate led to similar results of total fresh matter (192.3 g $plant^{-1}$) (Zanella et al., 2008). However, compared with the data obtained using expanded vermiculite, these results were inferior. Thus, the increase in total fresh matter found in the present study can be attributed to the effect of the adopted substrate.

The highest mean values of shoot fresh matter (SFM) and yield were obtained in the treatment that used coconut shell fiber with crushed stone #3, equal to 199.4 g $plant^{-1}$ and 39.9 t ha^{-1} for SFM and yield, respectively. The treatment with phenolic foam led to the lowest mean values of SFM (104.0 g $plant^{-1}$) and yield (20.8 t ha^{-1}), statistically differing from the others. For lettuce cultivation in conventional system with soil, shoot fresh matter values of 166 g $plant^{-1}$ (Kano et al., 2012) and 90.30 g $plant^{-1}$ (Duarte et al., 2012) have been found, which are inferior to that in the present study (199.4 g $plant^{-1}$).

In general, the yield obtained in hydroponic and aquaponic systems are higher than those of conventional system with

Table 2. Total fresh matter - TFM (g $plant^{-1}$), shoot fresh matter - SFM (g $plant^{-1}$), yield (t ha^{-1}) and number of leaves - NL of lettuce, cultivated in different substrates (coconut shell fiber with crushed stone #3 - CFCS3; expanded vermiculite - EV; zeolite - Z; and phenolic foam - PF) in a aquaponic system

Substrates	TFM (g $planta^{-1}$)	SFM (g $planta^{-1}$)	Yield (t ha^{-1})	NL
CFCS3	275.9 a	199.4 a	39.9 a	29.2 a
EV	312.5 a	172.6 ab	34.5 ab	31.3 a
Z	265.0 a	143.4 b	28.7 b	31.0 a
PF	185.8 b	104.0 c	20.8 c	21.8 b

*Values followed by the same letter in the column do not differ by Bonferroni test at 0.05 probability level ($p \leq 0.05$)

soil. In hydroponic cultivation, maximum lettuce yield of 51.12 t ha^{-1} was reported by Martins et al. (2009), whereas using the conventional system with soil, mean yields varied between 5.75 and 35.8 t ha^{-1} during five crop cycles (Peixoto Filho et al., 2013). The results reported by this study, relative to yield, were similar to the maximum values found by Peixoto Filho et al. (2013). However, since it is an aquaponic system, plant cultivation can be analysed as an alternative to complement the profit obtained with fish farming (Roosta & Afsharipoor, 2012).

The number of leaves (NL) corresponds to a qualitative parameter for the lettuce crop; higher number of leaves can add value to the crop during its marketing. The substrate expanded vermiculite led to highest number of leaves, with mean values among the harvested plants of 31.3 leaves $plant^{-1}$. The lowest number of leaves occurred in the treatment cultivated with phenolic foam (21.8 leaves $plant^{-1}$).

Comparing the three cultivation systems, similar results were obtained for number of leaves, with mean values of 34.96, 31.54 and 33.42 leaves $plant^{-1}$ for organic, conventional and hydroponic cultivation, respectively (Santos et al., 2010). These authors suggested that the variation in the number of leaves of the lettuce crop may be more related to genetic factors than to plant nutrition.

According to an overall analysis of all results obtained with the adopted substrates, it can be noted that the treatment using phenolic foam led to the lowest values for all parameters evaluated (TFM, SFM, Yield, NL). Hence, among the analysed substrates, phenolic foam can be considered as the least recommended for lettuce cultivation in aquaponic system.

The phenolic foam degraded along the cultivation, which possibly caused an adverse condition for plant development, so that, besides reducing the time of retention of the nutrients, it led to reduction in the surface of fixation for the microorganisms, essential components in the aquaponic cultivation for the nutrients to be converted into forms more easily available to plants (Silva et al., 2013; Lam et al., 2015).

The highest yields were obtained by plants grown in coconut shell fiber with crushed stone #3. Therefore, technically analysing, under the conditions of the present study, this substrate is the most adequate for lettuce cultivation in aquaponic system. To contribute to the recommendation regarding the most adequate substrate for lettuce cultivation in aquaponic system, economic viability analyses should be conducted to define, based on a balance between technical and economic viability, which substrate is the most adequate.

Conclusions

1. The substrate made of coconut shell fiber with crushed stone #3 was considered as the most adequate for lettuce cultivation in aquaponic system, since it led to higher values of crop yield (39.9 t ha^{-1}), total fresh matter (275.9 g $plant^{-1}$), shoot fresh matter (199.4 g $plant^{-1}$) and number of leaves (29.2).

2. Phenolic foam resulted in lower values of crop yield (20.8 t ha^{-1}), total fresh matter (185.8 g $plant^{-1}$), shoot fresh matter (104.0 g $plant^{-1}$) and number of leaves (21.8), being considered as the least adequate substrate for lettuce aquaponic cultivation.

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