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CARACTERIZAÇÃO FÍSICO-QUÍMICA DE SUBSTRATO DE FIBRA DE CASCA DE COCO APÓS O CULTIVO HIDROPÔNICO DE PIMENTÃO COM ÁGUA DE REÚSO E DIFERENTES LÂMINAS DE SOLUÇÃO NUTRITIVA[1]

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1 RESUMO

Este trabalho objetivou caracterizar a partir de análises físicas e químicas, o substrato de fibra de casca de coco antes e após o seu uso com a cultura do pimentão, cultivada em vasos com solução nutritiva preparada com água de reúso e água potável e diferentes lâminas de reposição dessa solução (100, 75 e 50% da evapotranspiração da cultura). O cultivo foi realizado em ambiente protegido ao longo de 175 dias, em vasos com capacidade volumétrica de 15 L, preenchidos com fibra de casca de coco. A cada 30 dias mediu-se o pH e a condutividade elétrica do substrato em laboratório. Após a colheita das plantas, foram coletadas amostras do substrato, com as quais avaliaram-se as características químicas e físicas: condutividade elétrica, pH, teores de NH_4^+, NO_3^-, P, K, Ca, Mg, S, Cl, B, Fe, Mn, Cu, Zn, capacidade de troca catiônica (CTC), capacidade de retenção de água (10kPA) e densidade volumétrica seca. A reposição de solução nutritiva no substrato através da evapotranspiração da cultura proporcionou aumento dos teores de nutrientes, condutividade elétrica, CTC do substrato e densidade. Os maiores valores desses parâmetros foram verificados para os tratamentos cultivados com solução nutritiva preparada com água de reúso.

Palavras chave: salinização, nutrientes, água residuária, hidroponia, efluente.

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PHYSICAL AND CHEMICAL CHARACTERIZATION OF IN COCONUT HUSK FIBER SUBSTRATE AFTER THE CULTIVATION OF PEPPER IN A HYDROPONIC SYSTEM WITH WATER REUSE AND DIFFERENT DEPHTS OF NUTRIENT SOLUTION

2 ABSTRACT

This work aimed to characterize the physical and chemical characteristics of the coconut husk fiber substrate before and after its use with the pepper crop, cultivated in pots with a nutritive solution prepared with reuse and drinking water and different depths of this solution replenishment (100, 75 and 50% of crop evapotranspiration). Cultivation was conducted in pots greenhouse with a volumetric capacity of 15 L, filled with coconut husk fiber. The plants were grown for 175 days and every 30 days, the pH and electrical conductivity of the substrate were measured in the laboratory. After the plants were harvested, samples of the substrate were collected and the chemical and physical characteristics were evaluated: electrical conductivity, pH, NH_4^{+}, NO_3^{-}, P, K, Ca, Mg, S, Cl, B, Fe, Mn, Cu, Zn, cation exchange capacity (CTC), water retention capacity (10kPA), and dry bulk density. The replacement of the nutrient solution in the substrate through crop evapotranspiration provided an increase in nutrient content, electrical conductivity, CTC of substrate and density. The highest values for theses parameters were verified for the treatments cultivated with nutritive solution prepared with water reuse.

Keywords: salinization, nutrients, wastewater, hydroponic, effluent.

3 INTRODUCTION

Pepper cultivation in protected environments has gained prominence in Brazil (SANTOS et al., 2017), as, according to Casais et al. (2018), it is possible to achieve higher quality and regularity in production throughout the year. However, successive soil use, with intense application of mineral fertilizers in protected environments, can lead to salinization, which is one of the problems reported for this cultivation system (AZEVEDO et al., 2018).

In addition to the problem of salinization, the presence of pathogens that limit production is another factor that can make soil cultivation unfeasible, such as the presence of root-knot nematodes (*Meloidogyne* spp.), which reduce pepper crop productivity (CHARLO et al., 2012). An alternative to this problem is to replace the soil with substrates in pots, gutters, or bags and to provide nutrients through nutrient solutions recommended for the crop.

The use of substrates for seedling and flower production is quite common (LUDWIG et al., 2014), and for fruit vegetables, this use has been increasing in recent years (ARAÚJO et al., 2014). Purchasing a substrate represents an additional cost for the farmer and can limit its application. One alternative to minimize costs is reusing it; however, for this practice, it is necessary to understand the chemical and physical characteristics of each substrate before and after use so that the most appropriate management can be adopted.

Coconut husk fiber is a raw material with characteristics that make it suitable for use as a substrate, such as good aeration and water retention capacity, thermal buffering, and a partially inert nature. It is also a renewable, recyclable, and low-cost option (MARTINEZ, 2017). The main changes in substrates after cultivation are due to mineral fertilizers and the speed of decomposition.

In addition to the search for more efficient cropping systems, interest in alternative water sources has led to the development of several studies related to the use of wastewater in agriculture (CARVALHO; BASTOS; SOUZA, 2018; CHEKLI et al., 2017; RANA et al., 2011). When applied to soil, wastewater can alter its chemical and physical characteristics, requiring periodic monitoring of salinity (URBANO et al., 2015). Its potential application in hydroponic systems is noteworthy.

In view of the above, this work aimed to characterize, through physical and chemical analyses, the coconut husk fiber substrate before and after its use with pepper crops was grown in pots with a nutrient solution prepared with reused water and different replacement layers of this solution.

4 MATERIAL AND METHODS

The experiment was carried out in a greenhouse installed in the experimental area of the Department of Rural Engineering, School of Agricultural Sciences, Unesp, Botucatu campus, São Paulo, Brazil, located at 22° 51' S latitude, 48° 26' W longitude, and 786 m altitude. The climate of the region is classified as Cfa by the Köppen method, with a warm temperate (mesothermal) humid climate, and the average temperature of the hottest month is above 22 °C (CUNHA; MARTINS, 2009; ALVARES et al., 2013). Throughout the experimental period, from March to August 2018, the temperature and relative humidity were monitored daily inside the greenhouse, and the monthly averages are presented in Table 1.

Table 1. Environmental data on minimum, average and maximum air temperatures and minimum, average and maximum relative air humidities recorded during the experimental period inside the greenhouse , Botucatu, SP.

Months	Air temperature (°C)			Relative humidity (%)		
	Maximum	Minimum	Average	Maximum	Minimum	Average
March	38.8	18.5	28.0	99.0	37.4	75.0
April	40.4	10.1	25.0	99.0	13.0	68.2
May	39.7	5.2	21.7	99.0	18.0	67.7
June	35.1	8.5	21.1	99.0	21.0	67.5
July	37.0	8.1	22.6	99.0	20.0	54.9
August	32.0	7.3	19.3	99.0	19.0	68.6

The plants were grown in a hydroponic system without nutrient solution recirculation in 15-liter pots filled with coconut husk fiber substrate. The treatments were characterized by the type of water used to prepare the nutrient solution, potable water, and reused water (from domestic sewage treatment) and different rates of nutrient solution replacement in the substrate (100, 75, and 50% crop evapotranspiration), as described below:

- TP1: nutrient solution prepared with drinking water and 100% crop evapotranspiration;
- TP2: nutrient solution prepared with drinking water and 75% crop evapotranspiration;

- TP3: nutrient solution prepared with drinking water and 50% crop evapotranspiration;
- TR1: nutrient solution prepared with reused water and 100% crop evapotranspiration;
- TR2: nutrient solution prepared with reused water and 75% crop evapotranspiration;
- TR3: nutrient solution prepared with reused water and 50% crop evapotranspiration.

The nutrient solution was distributed through two independent irrigation systems, one for drinking water and the other for reused water. Each system consisted of a 500 L nutrient solution reservoir, a digital controller, a 1/3 hp motor pump, a 32 mm disc filter, a pressure gauge, three electric solenoid valves for opening and closing each treatment, a main PVC line, and three secondary polyethylene hose lines (20 mm diameter).

Each pot was equipped with a self-compensating dripper with an average flow rate of 2 L h $^{-1}$, spaced 0.50 m apart and interconnected by a microtube. This study used 60 polyethylene pots (15-liter volumetric capacity) filled with coconut fiber substrate, each with a bell pepper plant, which were evenly distributed among the six treatments. A container was placed beneath each pot to collect excess nutrient solution; however, drainage was not provided throughout the growing season.

The uniformity of the distribution of the nutrient solution was verified via the Christiansen uniformity coefficient (CUC). From the data collected in the experiment, the CUC was calculated (Equation 1), and a distribution coefficient of 98% was obtained for both systems (potable water and reused water), which is considered excellent according to Mantovani (2001).

$$\mathrm{CUC} = \left[\frac{\sum_{I=L}^{N} X_I - \bar{X}}{N * \bar{X}}\right] \quad (1)$$

where N represents the number of collectors; X_I represents the water depth applied at the i-th point on the soil surface; and $\bar{X}$ represents the average depth applied.

The cultivated pepper hybrid was Gaston, a green/red type that is suitable for greenhouse cultivation. Pepper seedlings were purchased from a nurseryman accredited by the Ministry of Agriculture, Livestock, and Supply (MAPA), approximately 30 days after emergence. The plants were trained by leaving one stem, followed by two, then four, and finally, allowing them to grow freely with an indeterminate number of stems.

The two types of water used to prepare the nutrient solutions were previously characterized, as shown in Table 2. Reclaimed water was supplied monthly by the domestic sewage treatment plant (STP) belonging to the Basic Sanitation Company of the State of São Paulo (SABESP), Botucatu, SP. Samples were collected at the reservoir outlet and then analyzed for the following parameters: pH, electrical conductivity, macro- and micronutrients, and sodium. Drinking water was also analyzed monthly for the same parameters, with samples collected directly from the faculty's water supply system.

Table 2. The drinking water and reused water used throughout the experimental period were characterized .

Parameters	Reused Water		Drinking Water	
	Average	Standard Deviation	Average	Standard Deviation
pH	6.28	0.15	6.3	0.06
EC (dS m $^{-1}$)	0.55	0.13	0.07	0.22
NT (mg L $^{-1}$)	57	3.84	20.0	1.33
PT (mg L $^{-1}$)	3.0	0.17	0.00	0.00
K (mg L $^{-1}$)	32.0	2.45	15.0	2.01
Ca (mg L $^{-1}$)	36.0	3.08	13.0	2.12
Mg (mg L $^{-1}$)	5.0	0.55	2.1	0.17
S (mg L $^{-1}$)	15.0	2.19	7.2	0.75
B (mg L $^{-1}$)	0.12	0.07	ND	-
Cu (mg L $^{-1}$)	ND	-	ND	-
Fe (mg L $^{-1}$)	0.21	0.07	ND	-
Mn (mg L $^{-1}$)	0.03	-	ND	-
Zn (mg L $^{-1}$)	ND	-	ND	-
Na (mg L $^{-1}$)	59.4	1.5	3.5	0.16

Note: Average of 5 samples collected throughout the experimental period. EC: electrical conductivity; NT: total nitrogen; PT: total phosphorus; K: potassium; Ca: calcium; Mg: magnesium; S: sulfur; B: boron; Cu: copper; Fe: iron; Mn: manganese; Zn: zinc; Na: sodium; ND: not detectable.
Source: Laboratory of Plant Mineral Nutrition, FCA- UNESP.

The nutrient solution used during plant cultivation was that proposed by Furlani et al. (1999), recommended for pepper, with the following contents of N, P, K, Ca, Mg and S: 170; 42; 162; 128; 40; 52 mg L $^{-1}$, respectively; and the contents of micronutrients B, Cu, Fe, Mn, Mo, Ni and Zn: 0.40; 0.40; 1.81; 0.40; 0.09; 0.08 and 0.18 mg L $^{-1}$, respectively. During the fruiting phase, 43, 34.5 and 0.30 mg/L K, P and B, respectively, were added to the nutrient mixture used in the vegetative phase. The amount of fertilizer used was the same for drinking water and reused water, following the recommendation of Oliveira-Barcelos (2016), which suggests that the discount should occur when the value of a given macronutrient exceeds 25% of what would be added to the solution and 50% for micronutrients.

Irrigation management was carried out on the basis of direct measurements of crop evapotranspiration in three constant water table lysimeters installed inside the protected environment, and a pepper plant with the same development stage as the treatment plants was grown, as described in Carvalho et al. (2020).

Crop evapotranspiration (ETc) measurements were taken daily, and the arithmetic mean of the evapotranspiration depth of the three lysimeters was used to calculate the depth to be applied in treatments with 100% ETc replacement. The percentage was calculated for the other treatments with 75% and 50% ETc replacement. The calculated depth was distributed across six applications throughout the day.

The substrate was characterized in the laboratory before and after cultivation, considering the following parameters: dry volumetric density, water retention capacity (WRC) at 10 kPA and cation exchange capacity (CEC), according to the methodology established by Normative Instruction No. 17 of May 21, 2007, of the Ministry of Agriculture, Livestock and

Supply (BRASIL, 2007), and Normative Instruction No. 31 of October 23, 2008 (BRASIL, 2008), which establish criteria and standards for substrate analysis in Brazil.

The soluble contents of N (ammoniacal and nitrate), phosphorus, potassium, calcium, magnesium, sulfur, copper, boron, iron, manganese, zinc, sodium and chloride were also determined following the 1:1.5 (volume) extraction methodology described by Sonneveld, Ende and Dijk (1974).

Postcultivation coconut fiber sampling was performed by removing the aerial parts of the plants. The samples were then collected from three pots per treatment, removing one liter of substrate per pot. These three samples were then mixed in a container to obtain a composite sample per treatment. To characterize the coconut fiber before cultivation, a sample was collected from a pot after saturation with water and before transplanting the seedlings.

In addition to characterizing the substrate at the beginning and end of the growing season, pH and electrical conductivity measurements were also taken every 30 days on the coconut fiber in the pots of each treatment to verify whether salts had accumulated over time. These analyses were performed by collecting 200 mL of the substrate in a pot of each treatment via the extraction method adapted from Sonneveld, Ende, and Dijk (1974), which involves diluting the substrate in a 1:1.5 ratio to extract its solution.

To compare the pH and electrical conductivity variables, repeated-measures analysis of variance (ANOVA) was used with two factors (water type and nutrient solution replacement level as a function of ETc). Furthermore, considering the hypothesis that electrical conductivity could increase throughout plant development due to management practices involving nutrient solution application according to the crop's ETc, the F test was also performed, considering plant age as an independent variable expressed in days after transplanting. The regression model was adjusted according to the coefficient of determination to a significance level of 0.05. The other evaluated substrate characterization parameters were described and compared with those in the relevant literature.

5 RESULTS AND DISCUSSION

The initial and final analysis of the physical and chemical components of the coconut husk fiber from the different treatments (Table 3) demonstrated that the continuous application of nutrient solution throughout the pepper crop cycle promoted an increase in some characteristics of this substrate.

Table 3. Initial and final physicochemical characterization of the coconut fiber substrate used in the experiment .

Substrate	pH	CE dS/m	Density (dry) kg m $^{-3}$	CRA %v/v	CTC mmol/l kg $^{-1}$
Home	5.4	0.5	88.5	65.3	98.3
TP1 (final)	5.7	3.4	97.2	58.9	225.9
TP2 (final)	5.6	3.2	93.3	66.7	191.4
TP3 (final)	5.7	2.9	90.4	70.5	231.8
TR1 (final)	5.5	3.6	96.1	59.6	178.2
TR2 (final)	5.7	3.3	92.1	62	232.9
TR3 (final)	5.5	3.0	90	59.7	195.4

EC: electrical conductivity; pH: hydrogen potential; WHC: water retention capacity on the tension table at 10 cm of the water column (10 kPa); CEC: cation exchange capacity; TP1 (final): drinking water and 100% crop evapotranspiration (ETc); TP2 (final): drinking water and 75% ETc; TP3 (final): drinking water and 50% ETc; TR1 (final): reused water and 100% ETc; TR2 (final): reused water and 75% ETc; TR3 (final): reused water and 50% ETc.
Source: Soil and Plant Analysis Laboratory of the Agronomic Institute of Campinas, IAC

The physical characteristics of the substrates are as important as their chemical characteristics are (FERNANDES; CORÁ; BRAZ, 2006). The values obtained for the dry volumetric density of the initial coconut fiber and in the treatments are considered ideal since, according to Pardossi et al. (2011), densities between 80 and 120 kg m $^{-3}$ are desirable to facilitate management. The fiber density after use increased as a function of the water depth applied. According to Marin et al. (2017), an increase in density with use is common in coconut husk fiber substrates because of their decomposition.

Knowledge of the water retention capacity (WRC) of the substrate used is essential. The 10 hPa tension indicates the volume of air present in the substrate after the end of free drainage, which is important for irrigation management. The results were close to the average value for coconut fiber, 53.8% (v/v), proposed by Carrijo, Liz and Makishima (2002).

Analysis of variance for pH and electrical conductivity (Table 4) revealed that there was no difference in pH between treatments; however, electrical conductivity was significantly greater when comparing water types. Reclaimed water resulted in greater nutrient accumulation because it contains nutrients that are not completely removed by the sewage treatment process. There was no difference in the percentage of ETc replacement between the means.

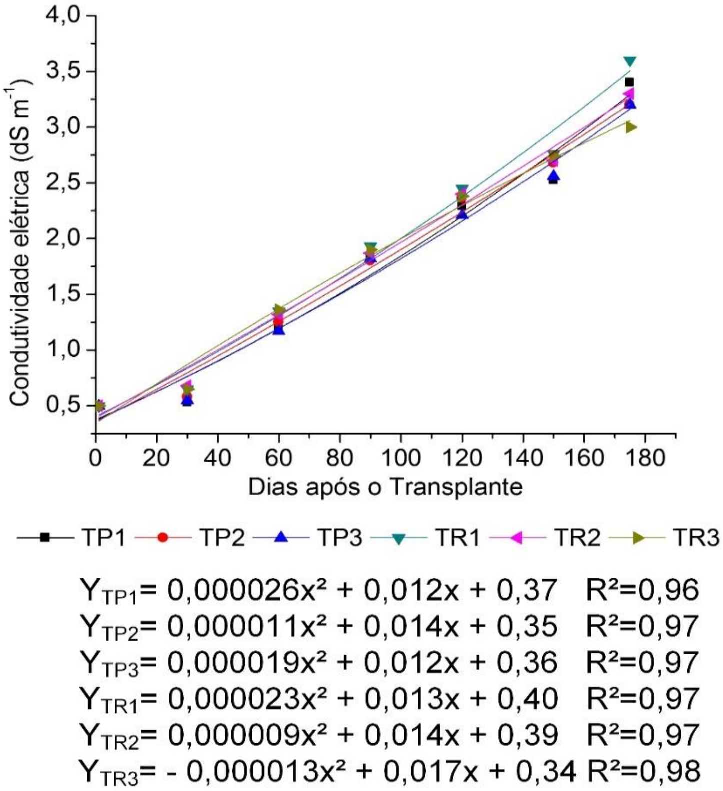
Table 4. Analysis of variance of the average electrical conductivity and pH of coconut fiber throughout the development of the crop according to the types of water, potable and reused, and the percentages of replacement of the measured Etc (100, 75 and 50%).

Electrical Conductivity			
Types of Water	Evapotranspiration (Etc) 100%	75%	50%
Drinkable	1.72 ± 1.03 Ba	1.77 ± 1.04 Ba	1.76 ± 1.08 Ba
Reuse	1.79 ± 0.99 Aa	1.82 ± 1.05 Aa	1.89 ± 1.14 Aa
pH			
Types of Water	Evapotranspiration 100%	75%	50%
Drinkable	5.73 ± 0.16 Aa	5.64 ± 0.14 Aa	5.74 ± 0.18 Aa
Reuse	5.64 ± 0.18 Aa	5.66 ± 0.17 Aa	5.77 ± 0.24 Aa

Different capital letters in the columns indicate a significant difference between water types according to the Tukey test ($p < 0.05$). Different lowercase letters in the rows indicate a significant difference between crop evapotranspiration replacement percentages according to the Tukey test ($p < 0.05$).

The gradual increase in the electrical conductivity of the substrates during the crop cycle was represented by a quadratic function (Figure 1). Although this increase represents an accumulation of salts in the substrate, the values found were within the recommended range for plant cultivation, which ranges from 1.5 to 4 mS m^{-1}, as proposed by Lasaridi et al. (2006). The pepper crop is classified as moderately sensitive to salinity (1.5 dS m^{-1}) (NICK; BORÉM, 2016); however, according to Soares et al. (2007), plants grown in hydroponic systems have greater tolerance to salinity than those grown in soil because of the greater and more constant availability of water to the crop.

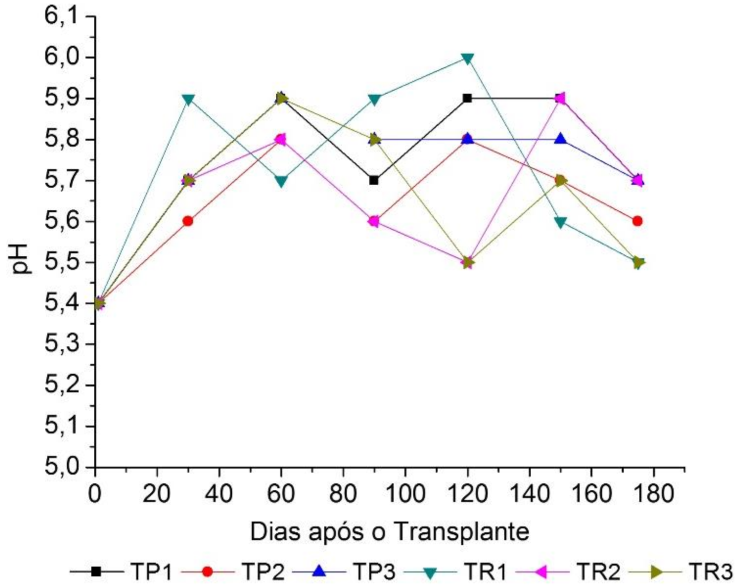
Figure 1. Electrical conductivity of the coconut husk fiber substrate throughout pepper cultivation for the different treatments: TP1 drinking water and 100% crop evapotranspiration (ETc); TP2 drinking water and 75% ETc; TP3 drinking water and 50% ETc; TR1 reused water and 100% ETc; TR2 reused water and 75% ETc; TR3 reused water and 50% ETc.



The treatments irrigated with a nutrient solution prepared with reused water presented the highest electrical conductivity at the end of the cultivation. This result is related to the greater electrical conductivity of the nutrient solution compared with that of the drinking water because of the higher amounts of calcium, magnesium, sulfate and sodium.

pH is a fundamental chemical characteristic of the substrate, as it is associated with the availability of nutrients for plants (LUDWIG et al. 2014). The variations observed for pH were within the level considered optimal for substrates, between 5 and 6.5, according to Abad, Noguera and Carrión (2004) (Figure 2).

Figure 2. Results of pH measurements of the coconut husk fiber substrate throughout pepper cultivation for the different treatments: TP1 drinking water and 100% crop evapotranspiration (ETc); TP2 drinking water and 75% ETc; TP3 drinking water and 50% ETc; TR1 reused water and 100% evapotranspiration; TR2 reused water and 75% ETc; TR3 reused water and 50% ETc.



The oscillations in pH values shown in Figure 2 are common due to the absorption of cations and anions by the roots, in addition to the release of organic acids through the roots (MARSCHNER, 2011).

The cation exchange capacity of a substrate is related to the amount of cations present on its surface, which can be exchanged until equilibrium is reached with the cations in the nutrient solution (ZORZETO, 2011). The initial CEC of coconut fiber is considered medium according to Martínez and Roca (2011), who defined a CEC < 75 mmolc kg $^{-1}$ = low, between 75 and 100 mmolc kg $^{-1}$ = medium, and > 100 mmolc kg $^{-1}$ = high. At the end of cultivation, an increase in the CEC of the substrates in all the treatments was observed due to the increase in and accumulation of nutrients provided by the frequent application of nutrient solutions.

The soluble contents of macro- and micronutrients, sodium and chloride present in the substrate after cultivation also increased in all the treatments (Table 5). The initial values of coconut fiber agreed with the average contents reported by Carrijo, Liz and Makishima (2002) for this type of substrate. Similar results were reported by Melo et al. (2013), who reported an increase in the nutrient contents present in the coconut fiber substrate after the cultivation of lace melon.

Table 5. The soluble nutrients present in the coconut husk fiber substrate initially and after cultivation for the different treatments .

Substrate	Nitrate	Match	Chloride	Sulfur	N-Ammoniacal	Potassium	Sodium
	mg L $^{-1}$						
Home	61.7	52	15.3	11.7	1.7	97.7	16.3
TP1 (final)	152.6	105.1	47.9	96.5	6.8	361.3	48.9
TP2 (final)	153.9	101.7	37.6	95.4	6.1	321.6	36.5
TP3 (final)	128.2	110.1	38.9	105.8	5.5	236	39.1
TR1 (final)	224.8	125.8	50.3	123.3	6.1	334.4	60.3
TR2 (final)	237.3	133.4	66	98.2	7.5	334.1	56
TR3 (final)	204.4	99.7	37	83.2	6.1	244.4	47

Substrate	Calcium	Magnesium	Boron	Copper	Iron	Manganese	Zinc
	mg L $^{-1}$						
Home	16	1.3	0.2	0.1	0.1	0.1	0.3
TP1 (final)	125.3	73.6	1.1	0.7	0.6	0.4	0.7
TP2 (final)	107	55.1	1,2	0.3	0.1	0.2	0.4
TP3 (final)	121.6	80	2.5	1	0.7	0.9	1.4
TR1 (final)	153.8	161.1	2.4	0.7	1.6	1,2	1,2
TR2 (final)	156.7	106.5	1.8	0.3	0.7	0.7	1
TR3 (final)	140.9	137.8	0.9	0.2	0.3	0.2	0.4

TP1 (final): Treatment with drinking water and 100% crop evapotranspiration (ETc) depth; TP2 (final): drinking water and 75% ETc depth; TP3 (final): drinking water and 50% ETc depth; TR1 (final): reused water and 100% ETc replacement; TR2 (final): reused water and 75% ETc depth; TR3 (final): reused water and 50% ETc depth.
Source: Soil and Plant Analysis Laboratory of the Agronomic Institute of Campinas, IAC

Nitrate increased in the substrate at the end of cultivation by 147, 150, 110, 263, 284 and 231% for treatments TP1, TP2, TP3, TR1, TR2 and TR3, respectively. This nutrient, when available in large quantities in the substrate, can lead to excessive absorption by the crop, accumulating in the edible parts, and thus being harmful to health (CHARLO et al., 2012).

The preparation of the nutrient solution with the treated effluent provided the greatest increase in nitrate in the substrate; this may be due to the initial concentration of nitrogen in the reused water (Table 2).

With respect to ammoniacal nitrogen, the increases were more significant, but the values found were within the range considered optimal for substrates, which varies from 0 to 20 mg L $^{-1}$, as proposed by Martínez and Roca (2011).

The phosphorus levels found at the end of cultivation in the substrates of the TP1, TP2, TP3, TR1, TR2, and TR3 treatments were 102, 96, 111, 142, 156, and 91.7% higher than the initial levels, respectively. For this nutrient, similar to what occurred with nitrogen, the highest levels were found in the treatments cultivated with reused water.

Potassium is the second most required element by crops (EPSTEIN; BLOOM, 2006), and in the substrate, it is the nutrient with the highest concentration compared with other nutrients. According to Abrahão, Boas and Bull (2014), one element can affect the absorption and distribution of another through competition, as occurs with K^{+}, Ca^{2+} and Mg^{2+}, with excess potassium competing with the absorption of calcium and magnesium.

The desired calcium content in the substrate for vegetable cultivation is up to 200 mg/L (MARTÍNEZ; ROCA, 2011), with the initial amount found in low fiber. Among all macronutrients, calcium was the second highest percentage increase, with values of 683, 568, 660, 861, 879, and 780% in treatments TP1, TP2, TP3, TR1, TR2, and TR3, respectively.

Compared with those of the other nutrients, the percentage of magnesium and sulfur accumulated in the substrates at the end of the cultivation period increased the most. Like the other nutrients, the highest levels were observed in the treatments cultivated with reused water (Table 5).

In terms of micronutrients, there was also an increase in micronutrient levels in coconut fiber; however, the quantities found were within the expected values for substrates, according to the levels considered ideal proposed by Martínez and Roca (2011).

Chlorine is absorbed in very low quantities in the form of Cl^{-} and is classified as a micronutrient (EPSTEIN; BLOON, 2006). Like those of the other elements, their levels increased in the substrate after pepper cultivation.

Sodium is classified as a beneficial element for plants and is required in low quantities, with the exception of halophytes, which benefit from relatively high levels of this element (TAIZ; ZEIGER, 2013). Sodium accumulation in the substrate at the end of the crop cycle was greater in the treatments irrigated with the nutrient solution prepared with reused water, possibly because of its higher sodium content than that of the drinking water. Coconut husks may also contain sodium and chloride in their composition, depending on the management, origin, and processing of these raw materials to obtain the substrate (CARRIJO; LIZ; MAKISHIMA, 2002).

When evaluating all the changes in the physical and chemical characteristics of the coconut fiber substrate used, adjustments in the management of the nutrient solution are clearly necessary to ensure the consumption of the nutrients accumulated throughout the crop cycle. Nick and Borém (2016) reported that in hydroponic systems with a substrate without nutrient solution recirculation, the nutrient solution is generally applied so that 20% drainage occurs to ensure the water necessary for crop development and to allow the leaching of nutrients accumulated in the substrate. This practice, in addition to increasing fertilizer costs, increases the risk of soil contamination due to excess leached nutrients if they are not collected.

Charlo et al. (2012) evaluated the accumulation of nutrients in a coconut husk fiber substrate during the pepper crop cycle in a hydroponic system without recirculation and with drainage of 20% of the applied nutrient solution and reported that nutrients accumulated in the fiber; the authors recommended changes in the management of the nutrient solution.

6 CONCLUSIONS

Among the characterized physical parameters, the density of coconut shell fibers increased in all the treatments.

The replacement of nutrient solution in the substrate through crop evapotranspiration increased the nutrient content, electrical conductivity and CEC of the substrate, with the highest values observed for treatments cultivated with nutrient solution prepared with reused water.

On the basis of these results, changing the management of nutrients in the nutrient solution, using reduced quantities, or alternating their supply with the application of water is recommended; however, further studies are needed for more efficient management.

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