International Journal of Recycling of Organic Waste in Agriculture (2021)10: 353-362
Doi: 10.30486/IJROWA.2021.1903049.1093

ORIGINAL RESEARCH

Treated domestic sewage as a nutrient source for strawberry under hydroponic cultivation

Caroline Goulart Figueiredo[1], Fernando Cesar Sala[2], Claudinei Fonseca Souza[1*]

Received: 25 June 2020 / Accepted: 30 May 2021 / Published online: 16 October 2021

Abstract

Purpose This study aimed to compare the hydroponic strawberry production using the conventional nutrient solution and treated domestic sewage, seeking fertilizer savings and identifying its nutritional status and physicochemical and microbiological attributes of fruits.

Method The experiment was carried out in a greenhouse under the nutrient film technique (NTF) hydroponic system, with three treatments: DW – drinking water and chemical fertilizers, TDSS – treated domestic sewage supplemented with chemical fertilizers, and TDS– only treated domestic sewage. Each treatment consisted of four cultivation benches, a motor pump system, a timer, and a 500-L container to store nutrient solution. Four hydroponic profiles with a capacity for 12 plants were used on each bench, totaling 48 plants per bench and 192 plants per treatment. These benches were divided into four randomized blocks. We compared the nutrient content of treated domestic sewage to the conventional nutrient solution, amount of nutrients used in treatments, microbiological quality and quantitative and qualitative aspects of fruits, nutritional status of plants.

Results The TDS treatment showed a significant difference compared to the others, with visual symptoms of nutritional imbalance in plants, lower productivity, and fruits more acid with a smaller diameter. Soluble solids content showed no statistical difference between treatments and the microbiological quality of fruits, which showed no presence of *Escherichia coli*.

Conclusion The use of treated domestic sewage to compose the nutrient solution allowed obtaining savings of 33% in chemical fertilizers in the TDSS treatment compared to DW.

Keywords *Fragaria* × *ananassa* Duch., NFT hydroponic system, Water reuse, Sustainability

Introduction

The use of unconventional water resources, such as treated wastewater, assists in relieving the pressure on natural resources. World population growth, the search for advances in living standards, and impacts resulting from climate change will gradually increase the importance of water reuse (Schacht et al. 2016).

There are several possibilities for reuse, with agricultural, urban, and industrial being the most effective forms of use. The adoption of reuse in the agricultural environment can be advantageous, citing as an example the use of treated domestic sewage, which is composed of 99.93% of water and still contains nutrients and organic matter that are beneficial to plants. The prospects and forms of reuse depend on local climatic conditions, public policies, technical availability, and economic, social, and cultural factors (Mendonça 2017).

The search for complementary water sources shows a growing demand for production systems that allow efficient water use. According to Santos et al. (2013), hydroponic systems can make water use more efficient. Strawberry (*Fragaria* × *ananassa* Duch.) is among the crops that have shown a tendency to migrate from the conventional to hydroponic cultivation systems due to their ergonomic ease, with no need for crop rotation, and a decrease in pesticide use (Gonçalves et al. 2016; Paulus et al. 2018).

✉ Claudinei Fonseca Souza
cfsouza@ufscar.br

[1] Agriculture and Environment Graduate Program, Federal University of São Carlos, UFSCar, Araras, SP, Brazil
[2] Center for Agricultural Sciences, Federal University of São Carlos, Araras, SP, Brazil

In Brazil, strawberry production is centered in the states of Rio Grande do Sul, São Paulo, and Minas Gerais, but it has been expanding to other states and has already reached a production of 105 thousand tons per year. Strawberry has socioeconomic importance for Brazil because its cultivation is carried out by family farming, contributing to income and employment for families (Antunes et al. 2016).

Several flowers and vegetables of economic importance can be cultivated under hydroponic systems and obtain the required nitrogen and phosphorus from water reuse, resulting in a reduction in fertilizers and the costs of wastewater treatment (Rana et al. 2011).

Another advantage of hydroponic cultivation using reused water is the low risk to the health of workers and consumers, since, according to Cuba et al. (2012), in this type of cultivation, only the root system of plants is in direct contact with water, reducing the chance of microbiological contamination. In addition, Magwaza et al. (2020) also report a 60 to 87% reduction in the pathogenic load present in wastewater after circulation in hydroponic systems. According to the authors, several mechanisms are linked to this reduction, among them that of antibiosis. The microorganisms present in the root system of plants interact with the pathogenic organisms and result in their removal.

However, the environmental impacts caused by using wastewater in agriculture can be harmful. Among the concerns about reuse of treated wastewater are damages to soil quality and crop development (Urbano et al. 2017), salinity increase and, consequently the soil degradation; and the risk to public health due to the presence of pathogens in the water (Bichai et al. 2012).

According to Carvalho et al. (2013), attempting efficient planning and implementing well-defined policies, the practice of agricultural reuse can transform the polluting and aggressive problem of domestic sewage into an economic resource. The authors also emphasize that developing the course following the appropriate technical principles can make it economically viable, environmentally sustainable, and socially safe and accepted.

Thus, for the reasons explained above, strawberry was the crop chosen in this study because of its microbiological quality requirement for safe consumption in nature. Therefore, this knowledge can provide recommendations that make the practice of water and nutrients reuse in agriculture feasible for non-edible crops (ornamentals and seedlings for reforestation, e.g.). Consequently, environmental impacts through the eutrophication process resulting from inadequate sewage disposal and the exploitation of the natural resources for the chemical fertilizers production could be reduced.

In recognition of the importance of studies about using treated wastewater safely in agriculture, the goal of this study was to compare the hydroponic strawberry production using the conventional nutrient solution and treated domestic sewage, seeking fertilizer savings and the identification of its nutritional status and physicochemical and microbiological aspects of the fruits.

Material and methods

The experiment was carried out in a greenhouse belonging to the Department of Natural Resources and Environmental Protection (DRNPA) of the Center for Agricultural Sciences (CCA) of the Federal University of São Carlos (UFSCar), Araras, São Paulo State, Brazil (22°18′53.23″ S and 47°23′0.91″ W). The temperature and day length were monitored throughout the experimental period through a weather station.

The day-neutral strawberry cultivar PRA Estiva (Brazilian origin) was used under the nutrient film technique (NFT) hydroponic system. Strawberry seedlings were transplanted on February 15th and conducted until June 15th, 2019. A nutrient solution adapted from Paulus et al. (2018), varying according to the vegetative and fruiting stages of strawberry, was used in this study (Table 1).

The cultivation system was composed of twelve workbenches (plots), each 3-m in length, and four polypropylene hydroponic profiles (75 mm) per workbench. The adopted spacing was 0.25 m between plants in the hydroponic profiles and 0.30 m between plants of the different shapes, totaling 12 plants per profile, 48 plants per bench, and 192 plants per treatment. However, only 74 plants per treatment were considered for the analysis, which corresponded to the experimental net plot area, Fig. 1.

The hydroponic system contained a tank with 500 L, a pumping system, four workbenches (repetitions), and a solution return system to the tank. A flow rate of 1.5 L m^{-1} was used to keep the nutrient solution circulating by gravity with the profiles in the slope of 10%, using a timer to start the pumping system at intermittent intervals of 15 minutes during the day and for 15 minutes every hour during the night (Carvalho et al. 2018).

The experimental design was randomized in blocks with three treatments and four replications. Treatments

Table 1 Nutrient solutions adapted from Paulus et al. (2018) for hydroponic strawberry cultivation

Fertilizer	Concentration at the vegetative stage (g m^{-3})	Concentration at the fruiting stage (g m^{-3})
Calcium nitrate	600	550
Potassium nitrate	200	200
Monoammonium phosphate	50	0
Monopotassium phosphate	140	200
Potassium sulfate	200	150
Magnesium sulfate	350	350
Conmicros Standard*: B (2.0%), CuEDTA (2.0%), FeEDTA (7.9%), MnEDTA (2.0%), Mo (0.4%), and ZnEDTA (0.8%)	30	30

*References to the registered trademark do not constitute an endorsement by the authors.

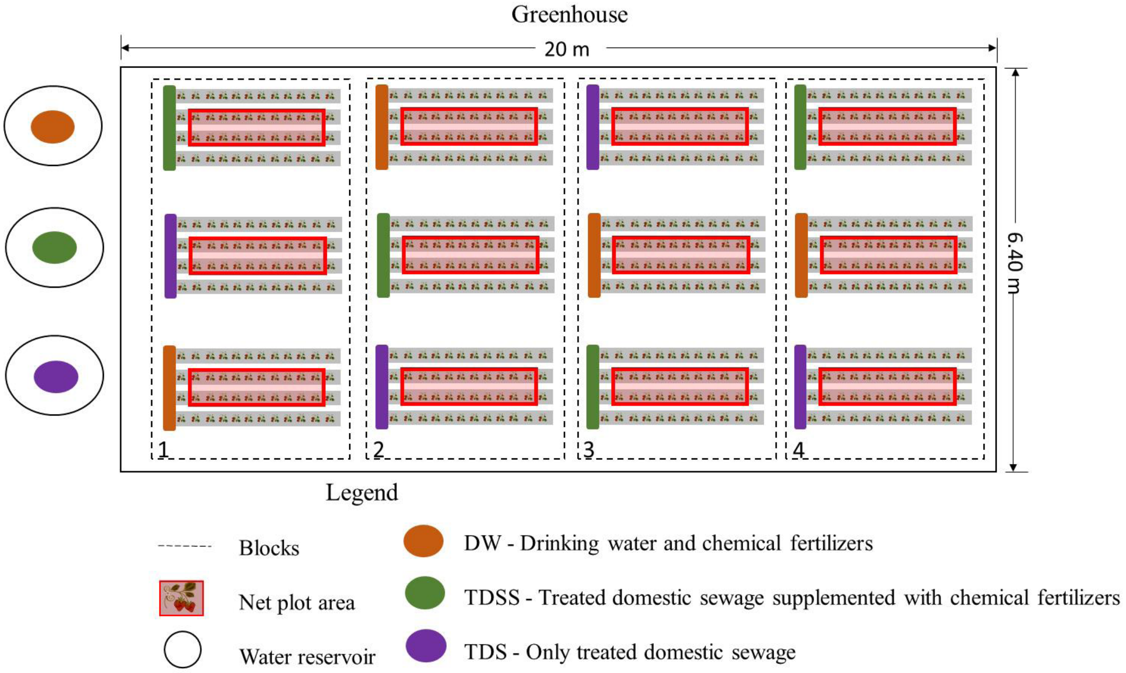

Fig. 1 Experimental design of the greenhouse for strawberry cultivation using three treatments for hydroponic DW: drinking water and chemical fertilizers (orange line), TDSS: treated domestic sewage with the addition of chemical fertilizers (green line), and TDS: only treated domestic sewage (purple line).

consisted of drinking water and chemical fertilizers (DW), which corresponded to a nutritional solution adapted from Paulus et al. (2018); treated domestic sewage with the addition of chemical fertilizers (TDSS) to reach the concentration adopted in DW after its chemical analysis; and only treated domestic sewage (TDS), which also underwent chemical examination.

Treated domestic sewage was collected at the exit of a pilot sewage treatment plant located at CCA, Fig. 2. This pilot plant treated sewage from the bathrooms and restaurant of the university and was monitored for one year by Oliveira et al. (2019). The sewage treatment plant is divided into four units, in which the raw effluent is received in a fat box, goes to a septic tank through PVC piping, passes through a wetland unit, and reaches the tertiary treatment, which corresponds to physical disinfection of the effluent using an ultraviolet system. Upon entering the sewage treatment station, the grease box separated the coarse materials present in the effluent. At the same time, in the septic tank, the sedimentation of the solids occurred and digestion by anaerobic bacteria, followed by the wetlands unit, the effluent received the polishing and finally, followed the tertiary treatment with the reduction of the pathogenic load. After all these treatment steps, the effluent was stored in an equalization tank.

After evaluating all treatment units, the station presents removal efficiency of: 96.9% turbidity, 30.6% electrical conductivity, 68.2% potassium, 54.1% total nitrogen, 36.1% total phosphorus, 14.6% magnesium, 60.6% total organic carbon, 99.98% total coliforms, and more than 99.99% *Escherichia coli* (Oliveira et al. 2019).

Treated domestic sewage from the equalization tank was analyzed before each nutrient solution preparation to calculate the chemical complementation of the TDSS treatment by analyzing the pH, turbidity, dissolved oxygen (DO), electrical conductivity (EC), total phosphorus (TP), total nitrogen (TN), potassium (K), calcium

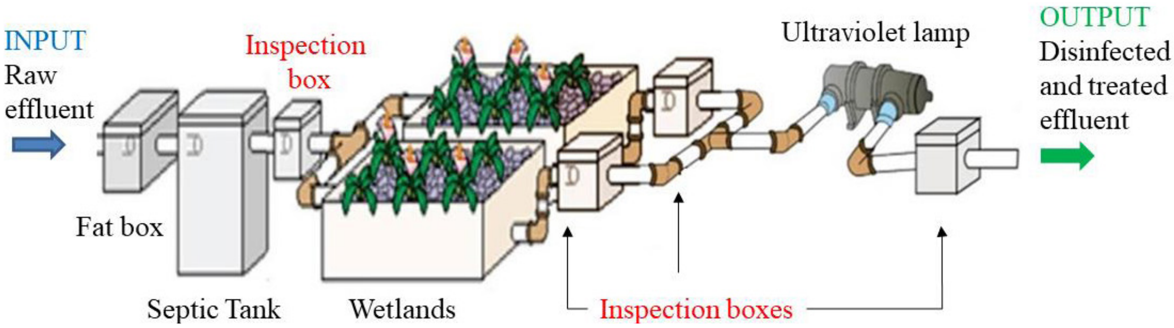

Fig. 2 Schematic of the sewage treatment plant units Source: Adapted from Oliveira et al. (2019)

(Ca), magnesium (Mg), and total and thermotolerant coliforms (*Escherichia coli*).

The analytical methodology used in the analyses followed the Standard Methods for the Examination of Water and Wastewater (APHA 2012).

Electrical conductivity (EC) of nutrient solutions was monitored and maintained between 1.3 and 1.5 dS m^{-1} to ensure ideal conditions for plant development; pH was only monitored. EC was corrected by adding water or nutrients whenever it deviated 20% from the initial value. The complete replacement of the nutrient solution was carried out when values below 1.3 dS m^{-1} were reached (Fernandes-Junior et al. 2002).

Plant nutritional status was assessed by chemical leaf analyses performed at 30 and 60 days after transplanting (DAT). For this, three plants were taken at random from each treatment. The methodology proposed by Passos and Trani (2013) was used to determine the leaf content of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn).

Harvest started on March 15, 2019, totaling 19 operations. The harvested fruits were 70% red or fully ripe (Fernandes-Junior et al. 2002).

Fruit mass (g $plant^{-1}$) was determined by weighing and summing the total production of each treatment divided by the number of plants in the useful area.

The mean size (transverse and equatorial diameter) of fruits was determined using a caliper. Soluble solids content (°Brix) was determined using a manual refractometer, and pH through the pulp juice diluted to 10%, following the methodology of Instituto Adolfo Lutz (2008). The microbiological fruits analysis aimed at the presence or absence of *E. coli* and was based on an adaptation of the Colilert enzymatic method from IDEXX (2019). The Colilert test detects total coliforms and *E. coli* at one organism/100 mL.

Microbiological analysis is an indication of contamination during fruit cultivation and management. To compare the parameter, Resolution RDC No. 12, of January 2nd, 2001, was used as a reference. This proposal was approved by the National Health Surveillance Agency (ANVISA) and stipulated the microbiological quality criteria for different food groups suitable for consumption.

The results were submitted to the Kruskal Wallis test, with means compared by the Dunn test at a 5% probability level using the software R Core Team (2019).

Results and discussion

Several environmental factors influence strawberry growth and development, with temperature and photoperiod being the most relevant. In this way, temperature and day-length data are shown in Fig. 3 for the experimental period.

The interaction between temperature and day length is evident in the floral induction of strawberries (Antunes et al. 2016). In Fig. 3, it is possible to observe that as winter approaches, the days become shorter, and the temperature declines, stimulating flowering and fruiting. In general, the longer the day, the lower the temperature required for floral induction to occur. The production of stolons, in most varieties, starts when the length of the day is longer than 12 hours and temperatures are above 22 ºC (Fachinello et al. 1994). The experimental period was suitable for floral induction, which presented an average of 11.2 hours of day length and an average temperature of 22.2 ºC.

Treated domestic sewage analysis

The studied treated domestic sewage showed low nutrient contents to be used as a nutrient solution (Table 2), taking into account the recommendation of Paulus et al. (2018) for strawberry cultivation in a hydroponic system. These results are related to the effluent source and treatment processes. Oliveira et al. (2019) monitored the same sewage treatment plant. They found that the efficiency in removing nitrogen and phosphorus was attributed to the wetland unit, with a removal rate of 74.6% of nitrogen and 82.7% of phosphorus.

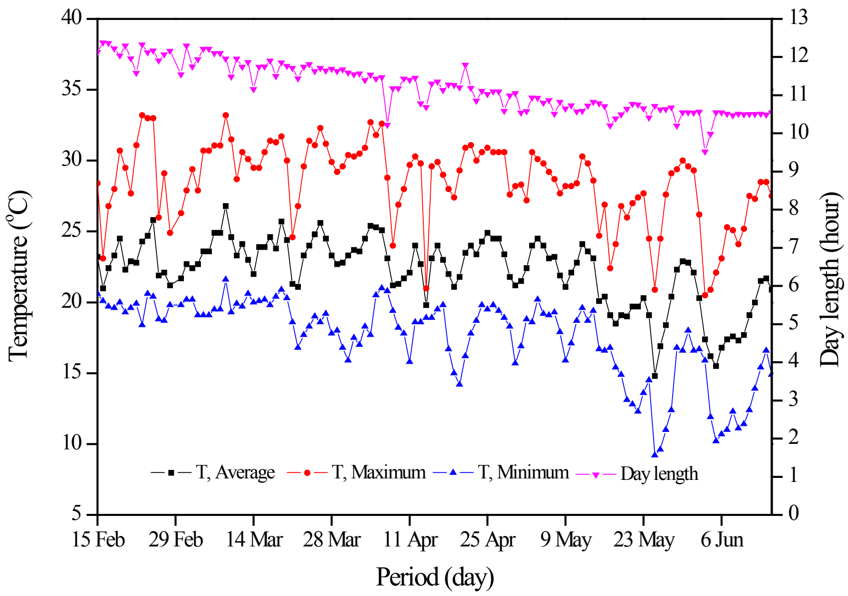

Fig. 3 The air temperature (average, maximum and minimum) and day length (hours) monitored during the strawberry cultivation

Electrical conductivity remained below 0.75 dS m^{-1} in all analyses, which is the value proposed by Martinez and Silva-Filho 2004 as a parameter of water quality for nutrient solution preparation.

The pH value was higher than the ideal for plant development. According to Wang et al. (2017), this value should be maintained within a range from 5.5 to 6.5. Although plants support pH values between 4.5 and 7.5 without the natural occurrence of physiological damage, a pH value above 6.5 under hydroponic cultivation favors the formation of insoluble complexes, reducing the availability of manganese, copper, zinc, boron, and phosphorus, indirectly affecting plant growth (Cometti et al. 2006).

Calcium, sodium, and magnesium contents were average compared to the results from the analyses necessary to verify irrigation water quality (Ayers and Westcot 1994). However, potassium contents presented restrictions, as the authors established that the limit is up to 2 mg L^{-1}, with the final effluent showing a mean of 20.6 mg L^{-1}.

The values recommended by Ayers and Westcot (1994) for irrigation water represent a standard for application to the soil. However, these values are considered low for use as a nutrient solution, according to the recommendation of Paulus et al. (2018) for strawberry cultivation under a hydroponic system.

Variations observed in nutrient contents between samplings are due to the sewage source, which is domestic and comes from the university center, being subject to seasonal changes, such as school holidays.

Cuba et al. (2012), when discussing the water reuse potential in agriculture, comment that the Environmental Company of São Paulo State establishes the conditions for water reuse regarding its

Table 2 Results of the physical, chemical, and microbiological characterization of treated domestic sewage used in the experiment over the cultivation period

Parameter	Results of effluent analysis over the cultivation period						
	Days after transplanting					Mean	Standard deviation
	0	23	52	75	103		
pH	6.63	8	6.54	7.04	7.06	7.05	0.57
EC (dS m^{-1})	0.36	0.25	0.40	0.60	0.69	0.46	0.18
TOC (mg L^{-1})	7.5	21.7	46.59	37.58	33.89	29.45	15.17
DO (mg L^{-1})	1.22	1.28	1.24	1.18	1.52	1.28	0.13
Turbidity (NTU)	13.7	13.7	9.3	9.3	9.3	9.3	2.40
TN (mg L^{-1})	10.32	10	10	16	22	13.66	5.31
TP (mg L^{-1})	0.3	0.84	0	0	0.1	0.24	0.35
K (mg L^{-1})	34	5	6	46.6	11.5	20.62	18.67
Ca (mg L^{-1})	32	29	47	43	38	37.8	7.46
Mg (mg L^{-1})	6	5.6	13	15	11	10.12	4.19
Na (mg L^{-1})	42	32.5	36	11.4	41.8	32.74	12.58
SAR ($mmol_c$ L^{-1})	1.79	1.42	1.20	0.38	1.54	1.26	0.54
Total coliforms MLN** 100 mL^{-1}	NP	NP	NP	NP	1.7×10^3	–	–
Escherichia coli MLN** 100 mL^{-1}	NP	NP	NP	NP	17	–	–

EC: electrical conductivity; TOC: total organic carbon; DO: dissolved oxygen; TN: total nitrogen; TP: total phosphorus; K: potassium; Ca: calcium; Mg: magnesium; Na: sodium; SAR: sodium adsorption ratio. MLN: Most likely number. NP: Not performed. **There is no standard deviation for this parameter.

microbiological characteristics, allowing the irrigation using wastewater only on fields, lawns, parks, and planting forages, forestry, and crops for the industry. In Brazil, reusing water in the cultivation of leafy or fruit vegetables is not yet allowed regardless of the quality standards of water reuse and *E. coli* count.

Nutrient solution

The monitoring of pH and electrical conductivity of treatments allowed verifying fluctuations in pH values throughout the cultivation. However, according to Backes et al. (2004), this behavior is expected in soilless cultivation systems, as nutrient solutions have no buffering capacity. The mean pH values were 7.09 (±0.71), 6.50 (±0.97), and 7.64 (±0.40) in the DW, TDSS, and TDS treatments, respectively.

Thus, the mean pH value in the TDSS treatment is on the limit of the ideal range for nutrient absorption in hydroponic solution but above the recommended in the DW and TDS treatments.

A nutrient solution with a pH higher than 6.5 indirectly affects plant development, favoring the formation of precipitates and reducing the availability of micronutrients (Cometti et al. 2006).

The mean electrical conductivity was 1.59 dS m^{-1} (±0.22) in the DW treatment and 1.64 dS m^{-1} (±0.20) in the TDSS treatment, which is within the recommendation of Paulus et al. (2018). According to these authors, nutrient solution concentrations with electrical conductivity values between 1.2 and 2.0 dS m^{-1} are the most indicated for strawberry cultivation under hydroponic systems aiming at the productivity and quality of fruits.

The mean electrical conductivity in the TDS treatment was 0.29 dS m^{-1} (±0.13). This low conductivity value and solution stability reflect the effluent source and the used treatment.

In the experimental conditions adopted in this work, the use of treated effluent as a water and nutrients source for the nutrient solution preparation reduces the use of some fertilizers in the TDSS treatment without prejudice to the culture concerning DW (Table 3).

Agronomic assessment

Plants from the DW treatment showed no visual symptoms of nutritional deficiency even under high pH conditions. On the other hand, the TDS treatment presented a pH above the recommended value of 6.5 during the entire growing period despite few fluctuations, leading

Table 3 Comparing the number of fertilizers used in treatments consisting of drinking water plus chemical fertilizers (DW) and treated domestic sewage plus chemical fertilizers (TDSS)

Fertilizer	Total amount		Percentage of saving (%)
	DW (g)	TDSS (g)	
Calcium nitrate	1332	922	31
Potassium nitrate	470	273	42
Monopotassium phosphate	419	355	15
Potassium sulfate	392	265	32
Magnesium sulfate	819	472	42

to the low development of plants' shoot and root systems compared to other treatments.

The results of leaf analysis of strawberry plants at 30 and 60 DAT (Table 4) were compared to the macro-and micronutrient sufficiency range recommended by Passos and Trani (2013).

The leaf analysis carried out at 30 DAT showed phosphorus, potassium, and magnesium contents below the range recommended by Passos and Trani (2013) in all treatments, while calcium, copper, iron, and zinc contents were above the ideal coverage for the crop. However, no visual symptoms of nutritional deficiency

Table 4 Results of leaf chemical analysis of strawberry plants from different treatments at 30 and 60 days after transplanting

Nutrient	Analysis at 30 DAT			Analysis at 60 DAT			Sufficiency range*
	Treatment			Treatment			
	DW	TDSS	TDS	DW	TDSS	TDS	
	----------------------- g kg^{-1} -----------------------						
Nitrogen	21	18	21.50	20	21	18	25–15
Phosphorus	1.01	1.17	1.01	4.38	4.67	2.21	4–2
Potassium	9.08	15.26	10.08	26.31	27.5	17.52	40–20
Calcium	40.15	33.13	36.37	12.14	9.85	7.78	25–10
Magnesium	3.90	3.64	3.12	3.9	3.85	3.17	10–6
Sulfur	1.66	1.70	1.30	1.02	3.37	1.48	5–1
	----------------------- mg kg^{-1} -----------------------						
Boron	67	67	34	56	63	7	100–35
Copper	215	253	282	21	17	17	20–5
Iron	321	332	321	237	282	404	300–50
Manganese	82	97	96	124	238	185	300–30
Zinc	54	62	65	32	44	114	50–20

*Sufficiency range recommended by Passos and Trani (2013).

or toxicity due to excess nutrients were observed until this period.

The TDS treatment was different from the others after 38 DAT, allowing observing a reduced growth of the plant shoot. The leaf analysis carried out at 60 DAT showed magnesium deficiency in all treatments but without visual symptoms, which, according to Barreto et al. (2018), are characterized by crinkling and leaf necrosis.

The TDS treatment showed characteristics of nutritional imbalance, which could be observed in the leaf analysis carried out at 60 DAT. Plant tissues showed potassium, calcium, and boron deficiencies, and iron and zinc contents were above the recommended range.

The low growth and darkening of roots and a reduction in shoot growth were due to these deficiencies, also observed by Barreto et al. (2017) due to the unavailability of calcium, potassium, and boron.

No statistical differences were found in the mean productivity of the DW and TDSS treatments (Table 5), but with a significant difference between them and the TDS treatment, with productivity of 72% lower. The low productivity in TDS reinforces the fact that the treated domestic sewage without complementing chemical fertilizers does not have the necessary nutrients to supply the demand for the strawberry.

The means of production obtained in the DW and TDSS treatments were similar to the standards observed by Fernandes-Junior et al. (2002). These authors assessed the production of fruits and stolons of strawberries under different cultivation systems in a protected environment from September to December 2000. They found that the mean fruit production under the NFT hydroponic system was 91.1 g plant^{-1}.

The physicochemical characterization of fruits indicated that their quality varied depending on the treatment (Table 5).

Table 5 Means of production and physicochemical characterization of strawberry fruits under different treatments

Parameter	DW	TDSS	TDS	P-value
Mass (g plant^{-1})	89.55a	81.82a	23.76b	0
pH	3.49a	3.46a	3.38b	0
Soluble solids (°Brix %)	6.29a	6.40a	6.61a	0.27
Transverse diameter (mm)	25.8a	24.6a	20.6b	0
Equatorial diameter (mm)	34.3a	34.1a	26.6b	0

DW: treatment using potable water and chemical fertilizers; TDSS: treatment using treated domestic sewage supplemented with chemical fertilizers; TDS: treatment with treated domestic sewage. Means followed by the same letter in the row do not differ statistically from each other by the Dunn test at a 5% probability level.

Fruits from the TDS treatment showed a higher acidity and smaller diameter than fruits from the DW and TDSS treatments (Table 5). It may be due to the low availability of nutrients in the treated domestic sewage, which led to the nutritional deficiencies of the crop.

Valentinuzzi et al. (2018) observed that potassium is an essential macronutrient for the quality parameters of strawberry fruits. Its absence can reduce fruit size, besides interfering with its nutraceutical properties, including sugar content, organic acids, and antioxidants.

Moreover, Calvete et al. (2016) pointed out that soilless strawberry fruits have a pH ranging from 2.70 to 3.05 depending on the cultivar, being more acid than fruits produced under the conventional system mean pH of 5.3.

Soluble solids content (°Brix) had no difference between treatments, indicating that the nutritional crop aspects showed no influence on this parameter. However, the values were below the mean sugar content currently observed in strawberry cultivars, which vary from 8 to 9 °Brix for fruits grown under a protected environment (Calvete et al. 2016).

Microbiological analysis

The results of the analysis of fruits from all treatments (Table 6) were within the parameters established in the resolution RDC No. 12 of January 2, 2001, for the group of foods that include fresh, in nature, whole, selected, or non-selected strawberries and similar, the resolution allows up to 2x10^3 NMP of thermotolerant coliforms, and the result was below the detectable limit.

Table 6 Microbiological analysis of strawberry fruits grown under domestic sewage effluent treated at the sewage treatment plant located at CCA of UFSCar, Araras, SP, Brazil

Treatment	*Escherichia coli* (MLN*)
DW	BDL**
TDSS	BDL
TDS	BDL

DW: treatment using drinking water and chemical fertilizers; TDSS: treatment using treated domestic sewage supplemented with chemical fertilizers; TDS: treatment with treated domestic sewage. *MLN: most likely number; **BDL: below the detection limit.

According to Cuba et al. (2015), hydroponic profiles act as a barrier, restricting the contact of the effluent only to the plant root. Thus, although *E. coli* was present in the treated domestic sewage used in the TDSS and TDS treatments, its absence in fruits indicates no direct contact with the effluent and hence no microbiological contamination. Reis and Olivares (2006) reported that, unlike fungi, bacteria have, in general, no active structures that allow them to penetrate intact plant tissues.

These results show that treated domestic sewage could be used to cultivate vegetables, guaranteeing their microbiological quality, even though it is not allowed by the Brazilian legislation. The careful choice of cultivation and irrigation methods, in addition to the proper analysis and treatment of effluents, are essential measures to ensure the health security of crops produced from treated domestic sewage. Unfortunately, the best practices and regulations to use TDSS and guarantee good agricultural practices that ensure human health and safe cultivation concerning pathogens risk has still not been identified.

Conclusion

Given the results obtained, it is concluded that, in the experimental conditions in which this work took place, reused water as a source of nutrients in the hydroponic cultivation of strawberries presented advantages, highlighting the global saving of 33% of chemical fertilizers. Using reused water as a nutritional solution without additional nutrients does not meet the crop's needs, causing a nutritional deficiency, reduced productivity, and quality of strawberry fruits. However, when supplemented, it meets all the parameters of strawberry cultivation, equating to cultivation with conventional nutrient solution. The application of reused water did not result in microbiological contamination by *E. coli* in any treatments. Future research using the same conditions of this study is encouraged.

Acknowledgment The authors gratefully acknowledge Coordination for the Improvement of Higher Education Personnel (CAPES) for the scholarship granted to C.G. Figueiredo. Financial support was provided by FAPESP (2013/14893-7) and National Council for Scientific and Technological Development (CNPq).

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

References

American Public Health Association (APHA) (2012) Standards methods for the examination of water and wastewater. APHA, Washington

Antunes LEC, Reisser Jr C, Schwengber JE (2016) Morangueiro. Embrapa, Brasília. http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1092843

Ayers RS, Westcot DW (1994) Water quality for agriculture. FAO, Roma

Backes FAAL, Santos OSS, Pilau FG, Bonnecarrere RAG, Medeiros SLP, Fagan EB (2004) Nutrients replacement in nutrient solution for lettuce hydroponic cultivation. Cienc Rural 34: 1407-1414. http://dx.doi.org/10.1590/S0103-84782004000500013

Barreto CF, Silva PS, Navroski R, Benati JA, Nava G, Antunes LEC (2017) Nutrients deficiency with effects on the strawberries development. Sci Agr 18: 63-71. http://dx.doi.org/10.5380/rsa.v18i4.53470

Barreto CF, Silva PS, Navroski R, Benati JA, Nava G, Antunes LEC (2018) Sintomas visuais de deficiência nutricional em morangueiro. Boletim de Pesquisa e Desenvolvimento. Embrapa, Brasília. http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1097888

Bichai F, Polo-López MI, Ibañez PF (2012) Solar disinfection of wastewater to reduce contamination of lettuce crops by *Escherichia coli* in reclaimed water irrigation. Water Res 46: 6040-6050. https://doi.org/10.1016/j.watres.2012.08.024

Calvete EO, Costa RC, Mendonça HFC, Cecatto AP (2016) Sistemas de produção fora do solo. In: Antunes LEC, Reisser Jr C, Schwengber JE (eds) Morangueiro, First ed. Embrapa, Brasília, pp 219-259

Carvalho RS, Santos Filho JS, Santana LOG, Gomes DA, Mendonça LC, Faccioli GG (2013) Influence of wastewater reuse on the microbiological quality of sunflowers for animal feed. Rev Amb Água 8: 157-167. https://doi.org/10.4136/ambi-agua.1116

Carvalho RSC, Bastos RG, Souza CF (2018) Influence of the use of wastewater on nutrient absorption and production of lettuce grown in a hydroponic system. Agr Water Manage 203: 311-321. https://doi.org/10.1016/j.agwat.2018.03.028

Cometti NN, Furlani PR, Ruiz PR, Fernandes EIF (2006) Soluções nutritivas: Formulação e Aplicações. In: Fernandes MS (ed) Nutrição Mineral de Plantas, Second ed. SBCS, Viçosa, pp 89-114

Cuba RS, Carmo JR, Bastos RG, Souza CF (2015) Potential of domestic sewage effluent treated as a source of water and nutrients in hydroponic lettuce. Rev Amb Água 10: 574-586. http://dx.doi.org/10.4136/ambi-agua.1575

Fachinello JC, Hoffmann A, Nachtigal JC, Kersten E, Fortes GRL (1994) Propagação de plantas frutíferas de clima temperado. UFPEL, Pelotas

Fernandes-Junior F, Furlani PR, Ribeiro IJA, Carvalho CRL (2002) Fruit and runner tips production of strawberry plants grown on different cropping systems under protected cultivation. Bragantia 61: 25-34. http://dx.doi.org/10.1590/S0006-87052002000100005

Gonçalves MA, Vignolo GK, Antunes LEC, Reisser Jr C (2016) Produção de morango fora do solo. Documentos. Embrapa, Pelotas. http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1048342

IDEXX Laboratories (2019) Colilert®. https://www.idexx.com.br/pt-br/water/water-products-services/colilert/ Accessed 11 may 2020

Instituto Adolfo Lutz (2008) Métodos físico-químicos para análise de alimentos. Instituto Adolfo Lutz, São Paulo. http://www.ial.sp.gov.br/ial/publicacoes/livros/metodos-fisico-quimicos-para-analise-de-alimentos

Magwaza ST, Magwaza LS, Odindo AO, Mditshwa A (2020) Hydroponic technology as decentralised system for domestic wastewater treatment and vegetable production in urban agriculture: A review. Sci Total Environ 698: 134154. https://doi.org/10.1016/j.scitotenv.2019.134154

Martinez HEP, Silva-Filho JB (2004) Introdução ao cultivo hidropônico de plantas. UFV, Viçosa

Mendonça LC (2017) A importância do reúso de efluentes de esgotos domésticos tratados na agricultura. In: Mendonça LC, Mendonça SR (eds) Sistemas sustentáveis de esgotos: orientações técnicas para projeto e dimensionamento de redes coletoras, emissários, canais, estações elevatórias, tratamento e reúso na agricultura, Blucher, São Paulo, pp 293 - 314

Oliveira AAS, Bastos RG, Souza CF (2019) Adaptation of domestic efluente for agricultural reuse by biological, physical treatment and disinfection by ultravioleta radiation. Rev Amb Água 14: e2292. https://doi.org/10.4136/ambi-agua.2292

Passos FA, Trani PE (2013) Calagem e adubação do morangueiro. IAC, Campinas. http://www.iac.sp.gov.br/imagem_informacoestecnologicas/89.pdf

Paulus D, Zorzzi IC, Santin A, Rankrape F (2018) Nutrient solution for production and quality of strawberry grown in substrate. J Exp Agric Int 28: 1-10. https://doi.org/10.9734/JEAI/2018/44763

R Core Team (2019) R: A language and environment for statistical computing. https://www.Rproject.org/ Accessed 16 september 2019

Rana S, Bag SK, Golder D, Roy SM, Pradhan C, Jana BB (2011) Reclamation of municipal domestic wastewater by aquaponics of tomato plants. Ecol Eng 37: 981-988. https://doi.org/10.1016/j.ecoleng.2011.01.009

Reis VM, Olivares FL (2006) Vias de penetração e infecção de plantas por bactérias. Embrapa, Seropédica. http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/629232

Santos JD, Silva ALL, Costa JL, Scheidt GN, Novak AC, Sydney EB, Soccol CR (2013) Development of a vinasse nutritive solution for hydroponics. J Environ Manage 114: 8-12. https://doi.org/10.1016/j.jenvman.2012.10.045

Schacht K, Chen Y, Tarchitzky J, Marschner B (2016) The use of treated wastewater for irrigation as a component of integrated water resources management: Reducing environmental implications on soil and groundwater by evaluating site-specific soil sensitivities. In: Borchardt D, Bogardi JJ, Ibisch RB (eds) Integrated water resources management: concept, research and implementation. Springer International Publishing, New York, pp 459-470

Urbano VR, Mendonça TG, Bastos RG, Souza CF (2017) Effects of treated wastewater irrigation on soil properties and lettuce yield. Agr Water Manage 181: 108-115. https://doi.org/10.1016/j.agwat.2016.12.001

Valentinuzzi F, Maver M, Fontanari S, Mott D, Savini G, Tiziani R, Cesco S (2018) Foliar application of potassium-based fertilizer improves strawberry fruit quality. Acta Hortic 1217: 379-384. https://doi.org/10.17660/ActaHortic.2018.1217.48

Wang L, Chen X, Guo W, Li Y, Yan H, Xue X (2017) Yield and nutritional quality of water spinach (*Ipomoea aquatica*) as influenced by hydroponic nutrient solutions with different pH adjustments. Int J Agric Biol 19: 635□642. https://doi.org/10.17957/IJAB/15.0311