Engenharia Agrícola

ISSN: 1809-4430 (on-line)

www.engenhariaagricola.org.br

Scientific Paper
Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v43n1e20220019/2023

ANALYSIS OF FERTIGATION EFFLUENTS FROM MINI-TOMATO GREENHOUSES AND THE NEED FOR DETECTION OF CONTROL POINTS

Thais Q. Z. Cesar[1*], Ariovaldo J. da Silva[1], Luis F. V. Purquerio[2], Agatha dos Santos[1]

[1*]Corresponding author. University of Campinas - UNICAMP, School of Agricultural Engineering/Campinas - SP, Brazil.
E-mail: thaisqzc@unicamp.br | ORCID ID: https://orcid.org/0000-0001-6959-7990

KEYWORDS

Solanum lycopersicum L., chemical analysis, effluent reuse, nutrient solution, phosphorus, potential environmental pollutant.

ABSTRACT

Water supply quality, nutrient availability in irrigation solutions, and discharge water or effluents must be monitored for protected cultivation to achieve sustainable management of food production. This study aimed to evaluate whether effluent solution from mini-tomato-protected crops can be recycled in an irrigation system based on plant nutritional demands. The experiment was carried out on a farm with mini-tomato protected-cropping. Water supply, as well as nutrient and effluent solutions, were analyzed in the experiment. Water supply was within the Brazilian limits established by CONAMA, except for nitrite, phosphorus, and sulfide. The effluent solution showed significant concentrations of macro- and micronutrients, highlighting phosphorus (220 to 395 mg L^{-1}). The replacement of nutrient solution in the central fertigation tank, excess of elements applied in the nutrient solution, and accumulation of effluent solution in the disposal tank kept the effluent solution enriched when compared to the nutrient solution initially applied. Water quality monitoring showed that effluent solution can be reused in the irrigation system based on its physicochemical parameters and mini-tomato tomato nutritional demands. The analyses also allowed us to detect control points to achieve food production sustainability.

INTRODUCTION

In recent years, protected cultivation techniques have been increasingly used for growing mini-tomatoes due to many reasons. These tools can increase productivity and control environmental factors, besides being sustainable practices. However, improper fertigation management in greenhouses has promoted negative environmental impacts as a result of excessive use of water and fertilizers. Unfortunately, this scenario opposes the goals set in the 2030 Agenda for Sustainable Development.

Cultivation in protected environments is promising since it allows controlling environmental factors such as solar radiation, air temperature, relative humidity, and carbon dioxide concentration. This system, therefore, enables plants to be grown throughout an entire year, promoting higher yields and product quality. The use of protected environments can also result in water, fertilizer, and pesticide savings, thus making production more sustainable.

Tomato is one of the main horticultural crops grown in the world. Brazil is currently the ninth largest tomato producer, contributing 2.25% of the world's production (FAOSTAT, 2020). In the country, mini-tomato cultivation is mainly performed in soilless pots in greenhouses. In Uruguay, over the last 10 years, in-field tomato production has decreased by 78%, while the greenhouse area occupied by tomatoes increased by 70%. The potential for efficient control of environmental factors is one of the main drivers of these changes, as it allows the cultivation of crops for longer periods during the year and increases production (Berrueta et al., 2020).

Protected cultivation systems may reduce environmental negative impacts by recirculating nutrient solutions, which has been a mandatory practice in some European countries (Van Os, 2017; Raviv et al., 2019). The use of closed systems is required by law, particularly in environmentally protected areas or regions with limited

[1] University of Campinas - UNICAMP, School of Agricultural Engineering/Campinas - SP, Brazil.
[2] Agronomic Institute - IAC, Horticulture Center/Campinas - SP, Brazil.

Area Editor: Fernando França da Cunha
Received in: 2-11-2022
Accepted in: 10-18-2022

water resources (Rufí-Salís et al., 2020). In the Netherlands, growers must reduce discharges of wastewater with nitrogen and phosphate to almost zero by 2027 (Van Os et al., 2019). Still, Brazil lacks a regulation for nutrient solution effluents, but current research has yet approached the subject.

Due to leaching, it is common practice to apply 10 to 20% more water via irrigation than is required by the crop (Alvarenga, 2013). This is because nutrient solution is not reused after passing through the crop root system. As tomato plants require high amounts of water, pressure on water resources and environmental impacts increase (Ghannem et al., 2021).

Fertilizers to be used to supply crop nutrients are dissolved at suitable concentrations in irrigation water, producing a nutrient solution (Nichols, 2019). However, improper fertigation management in greenhouses has produced negative environmental impacts as a result of excessive use of water, and fertilizers (Bonetta et al., 2019; Muñoz et al., 2017; Van Os et al., 2019). Therefore, in these systems, irrigation water salinity is also a limiting factor and water quality is essential to determine its potential for reuse (Haldar et al., 2020).

In an agricultural context, targets proposed by the 2030 Agenda for Sustainable Development include ensuring "availability and sustainable management of water and sanitation for all, as well as sustainable consumption and production patterns" (UN, 2015). Accordingly, food production in greenhouses can increase productivity and product quality, besides effective management of the resource, minimizing negative environmental impacts (Medeiros et al., 2018; Van Os et al., 2019; Vieira & Clemente, 2018).

A rapid increase in population and per capita water use has promoted the intensification of economic activities and climate changes. These arguments are held to be responsible for restrictions on the availability of fresh and potable water (UNESCO, 2021). It has been estimated that 40% of the world population will face water stress or scarcity conditions by 2056; therefore, sustainable water resource management options have become essential (WHO, 2013).

In this context, this study aimed to evaluate whether the fertigation solution effluent from mini-tomato-protected crops can be reused in the irrigation system based on plant nutritional demands.

MATERIAL AND METHODS

This experiment was carried out on a farm located at 22° 48' 56" S, 47° 03' 28" W, 664-m altitude, between 2018 and 2019. The farm had eight commercial greenhouses and covered 8,924 m². The water system studied was divided into three main points: (1) water supply points, where samples were collected from one rainwater tank (P1) and one deep well (P2); (2) nutrient solution point, where samples were collected from a nutrient solution tank at a central fertigation unit; and (3) effluent solution point, where samples were collected from an effluent tank and corresponded to the accumulated solution from seven fertigation days (FIGURE 1).

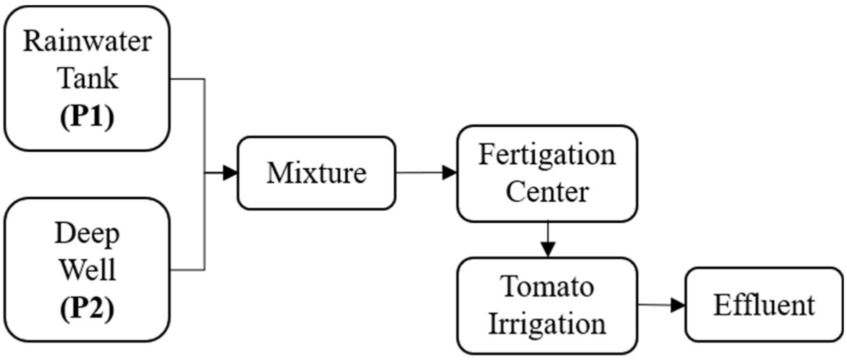

FIGURE 1. Schematic diagram of the water system studied, showing the main collection points in an open cycle: water supply (rainwater tank and deep well), nutrient solution at fertigation center, and effluent solution.

The water supply system consisted of a rainwater tank (P1) that stores 4 million L of rainwater from all greenhouse covers, and a 350-m deep well (P2). The rainwater tank was exposed to bird and fish droppings and used for non-commercial fish farming.

The nutrient solution was prepared with water from the tank and deep well added with $Ca(NO_3)_2$, KNO_3, $NH_4H_2PO_4$, KH_2PO_4, $MgSO_4$, K_2SO_4, $MnSO_4$, $ZnSO_4$, H_3-BO_3, and iron chelate. It was formulated according to the agronomic recommendations adopted by the grower and did not follow the literature.

Effluent solution consisted of excess fertigation from one of the greenhouses under open-cycle irrigation. It was accumulated in a tank throughout the week and discharged thereafter. The production system comprised 1,580 pots filled with granulated coconut fiber, with two drippers per pot operating at a flow of 4 L h^{-1} each, totaling a flow rate of 12,640 L h^{-1}. The mini-tomato varieties 'Coquetel DRC564' and 'SweetGrape' were used and corresponded to an average of 300 t $year^{-1}$ for both tomato varieties.

Samples were collected according to the National Sample Collection and Preservation Guide (CETESB & ANA, 2011). It was performed monthly for water supply points and weekly for nutrient and effluent solution points. The analyses were carried out in triplicates.

At the water supply points, samples were analyzed for physical-chemical and biological properties. For P1, CONAMA Resolution nº 357, of 03/17/2005 (for surface reservoirs), was followed. And, for P2, CONAMA Resolution nº 396, of 04/03/2008 (for groundwater), was followed.

At the nutrient solution point, concentrations of nitrate (NO_3^-), ammoniacal nitrogen (NH_4^+), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), and iron (Fe) were evaluated as a function of the nutrient demand at each tomato stage (A – from sowing to 30 days after transplanting [DAT], B – from 30 to 60 DAT, C – from 60 DAT to the last harvest). Descriptive analysis was used to compare the suitability of solutions with the limits recommended in the literature. These standards were obtained through a bibliographic survey on the nutritional requirement of tomato crops (Fernandes et al., 2002; Moraes, 1997; Pires et al., 2009; Santos et al., 2017; Takahashi et al., 2018), as shown in Table 1. These limits correspond to the maximum and minimum absolute values among the recommendations found.

At the effluent solution point, concentrations of ions and elements (NO_3^-, NH_4^+, P, K, Ca, Mg, S, and Fe) were analyzed as a function of the nutrient demand at each tomato stage (A, B, and C) to evaluate its reuse potential to supply the need for fertilizers or solution dilution.

The experiment was based on deterministic variables (characterizations of water supply at P1 and P2; nutrient solution; and effluent solution), dependent variables (physicochemical properties), and independent variables (crop stages).

TABLE 1. Threshold concentrations (mg L^{-1}) of elements in nutrient solution for each tomato crop stage (A – from sowing to 30 DAT, B – from 30 to 60 DAT, C – from 60 DAT to the last harvest).

Element	Stage A		Stage B		Stage C	
	Min	Max	Min	Max	Min	Max
	mg L^{-1}					
$NO3^-$	135.0	200.0	150.0	396.0	164.0	396.0
$NH4^+$	30.0	35.0	30.0	37.0	19.0	38.0
P	43.6	60.0	43.6	60.0	43.6	87.2
K	152.0	350.0	152.0	350.0	268.0	409.0
Ca	143.0	233.0	143.0	233.0	143.0	466.0
Mg	27.0	60.0	27.0	60.0	36.0	60.0
S	39.0	150.0	39.0	150.0	70.0	150.0
Fe	1.8	2.7	1.8	2.7	1.8	5.5

For water supply at P1 and P2, physicochemical (pH, color, turbidity, dissolved oxygen, total solids, NO_2^-, NO_3^-, NH_4^+, S, P, and Cl) and biological (thermotolerant coliforms) properties were evaluated. The nutrient and effluent solutions were characterized in terms of their physicochemical properties (pH, electrical conductivity, NO_2^-, NO_3^-, NH_4^+) and metals (Ca, K, Mg, P, Fe, and S). All physicochemical analyses followed the methods recommended in the Standard Methods for Examination of Water and Wastewater, while metals were analyzed by atomic absorption spectrophotometry with a plasma source (ICP-OES) according to the 3120B Method (APHA, 2017).

The deterministic variables were tested by descriptive analysis to characterize water supply at P1 and P2 (suitable or not for irrigation), nutrient solution (suitable or not for irrigation), and effluent solution (reusable for irrigation or disposable). The dependent response variables (D) were subjected to analysis of variance (ANOVA) for correlation between nutrient and effluent solutions with crop stages.

RESULTS AND DISCUSSION

Evaluation of water supply for irrigation use

The results of physicochemical and biological analyses for both water supply points (P1 and P2) were following several parameters of the CONAMA Resolutions n. 357 of 3/17/2005 and n. 396 of 4/3/2008 (Table 2).

The pH values of the rainwater tank (P1) and deep well (P2) samples were within the minimum and maximum limits established by legislation (6 and 9, respectively). Color (C), turbidity (T), dissolved oxygen (DO), total solids (TS), nitrate (NO_3^-), ammoniacal nitrogen (NH_4^+), and sulfate (SO_4^{-2}) in both P1 and P2 also followed the legislation recommendations.

However, the results of total chlorine (Cl) showed non-compliance with the maximum established by legislation (0.01 mg Cl L^{-1}) at both P1 and P2, ranging from 0.02 to 0.09 mg Cl L^{-1}. At P1, nitrite (NO_2^-), phosphorus (P), and sulfide (S^{2-}) showed values above the maximum established by legislation for a lentic environment (1.0 mg N L^{-1}; 0.020 mg P L^{-1}; and 0.002 mg S L^{-1}). The concentrations of NO_2^-, P, and S were eight, 28, and 25 times higher than the maximum allowed. The use of a nutrient film technique for tomato hydroponic production promotes excess Cl and S accumulations in the rhizosphere of plants, interfering with other ion concentrations. An adequate Cl concentration in the rhizosphere ranges from 22 to 143 mg L^{-1}, with a maximum of 426 mg L^{-1}; for sulfate, the maximum is 20.8 mmol L^{-1} (Minami & Mello, 2017).

Thermotolerant coliforms were positive at P1 due to contamination by bird droppings and the use of the tank for non-commercial fish farming. Monitoring water quality for use in irrigation allows the detection of control points to achieve sustainable food production.

TABLE 2. Physicochemical and biological properties for water supply at rainwater tank (P1) and deep well (P2) for 11 months.

	Month 1		Month 2		Month 3		Month 4		Month 5		Month 6		Month 7		Month 8		Month 9		Month 10		Month 11	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
pH	6.7	8.7	6.7	8.9	6.2	8.7	5.8 *	8.6	5.4 *	8.6	6.2	8.7	8.9	8.6	7.6	9.2 *	6.8	8.7	7.1	8.6	6.8	8.5
C (PTCo)	48	<LD	41	<LD	38	5	29	<LD	23	10	<LD	22	15	<LD	26	<LD	24	1	58	2	25	<LD
T (NTU)	3.25	0.20	0.35	0.44	6.90	0.26	2.77	0.24	1.02	0.02	2.00	0.20	2.50	0.21	4.65	4.60	3.67	0.18	5.00	3.50	4.80	0.25
DO (mg L^{-1})	8.11	7.69	6.63	6.96	7.82	6.92	6.49	6.32	8.06	6.80	7.60	6.60	9.55	6.83	8.50	8.07	6.62	6.68	28.00	15.00	7.26	6.47
TS (mg L^{-1})	96	231	88	209	232	120	313	75	37	50	150	147	62	111	54	157	107	277	153	134	125	169
NO3- (mg L^{-1})	0.1	0.1	0.1	0.1	<LD	<LD	<LD	<LD	<LD	<LD	0.5	<LD	0.01	0.6	0.6	0.1	<LD	<LD	1	0.7	0.6	0.2
NH4+ (mg L^{-1})	0.56	<LD	<LD	<LD	<LD	<LD	<LD	<LD	0.28	<LD	0.30	<LD	<LD	<LD	<LD	<LD	<LD	<LD	1.4	<LD	0.2	<LD
SO4 (mg L^{-1})	0	1.0	<LD	2.1	0	2.0	<LD	1.18	1.5	2.8	1.0	1.0	1.0	1.6	<LD	3.0	<LD	2.0	1.0	1.0	<LD	<LD
Cl (mg L^{-1})	<LD	<LD	<LD	0.02*	0.01	0.04*	<LD	<LD	0.03*	0.09*	<LD	<LD	0.07*	0.01	0.02*	<LD	0.01	0.03*	<LD	<LD	0.02*	<LD
NO2- (mg L^{-1})	3.00*	1.00	4.00*	1.00	3.35*	0.70	<LD	<LD	1.00	1.00	2.50*	1.00	8.00*	1.33*	1.00	1.00	1.00	1.00	1.00	<LD	<LD	<LD
P (mg L^{-1})	0.56*	<LD	<LD	<LD	<LD	<LD	<LD	<LD	0.56*	<LD	<LD	<LD	0.01	0.02	0.01	<LD	0.30*	<LD	0.2*	<LD	<LD	<LD
S (mg L^{-1})	0.05*	0.001	0.03*	0.001	0.03*	0.002	0.04*	0.001	0.03*	0.001	0.03*	0.001	0.05*	0.001	0.05*	0.002	0.04*	0.002	0.04*	0.001	0.04*	0.001
TTC	P	A	P	A	A	A	P	A	P	A	P	A	A	A	P	A	P	A	P	A	P	A

<LD: lower than detection limit; pH: hydrogen potential; C: color; T: turbidity; DO: dissolved oxygen; TS: total solids; NO_3^-: nitrate; NH_4^+: ammoniacal nitrogen; SO_4^{2-}: sulfate; Cl: total chlorine; NO_2^-: nitrite; P: phosphorus; S^{2-}: sulfide; TTC: thermotolerant coliforms; P: present; A: absent.
*: non-compliance with the limits established by the CONAMA nº 357 17/3/2005 (Annex1).

Evaluation of nutrient solution for irrigation use

The concentrations of ions and elements in nutrient solution were compared with the thresholds in the specialized bibliography for the nutritional requirement of tomato crops (Table 1). Only magnesium concentrations (Figure 2g) were under the threshold for all tomato crop stages.

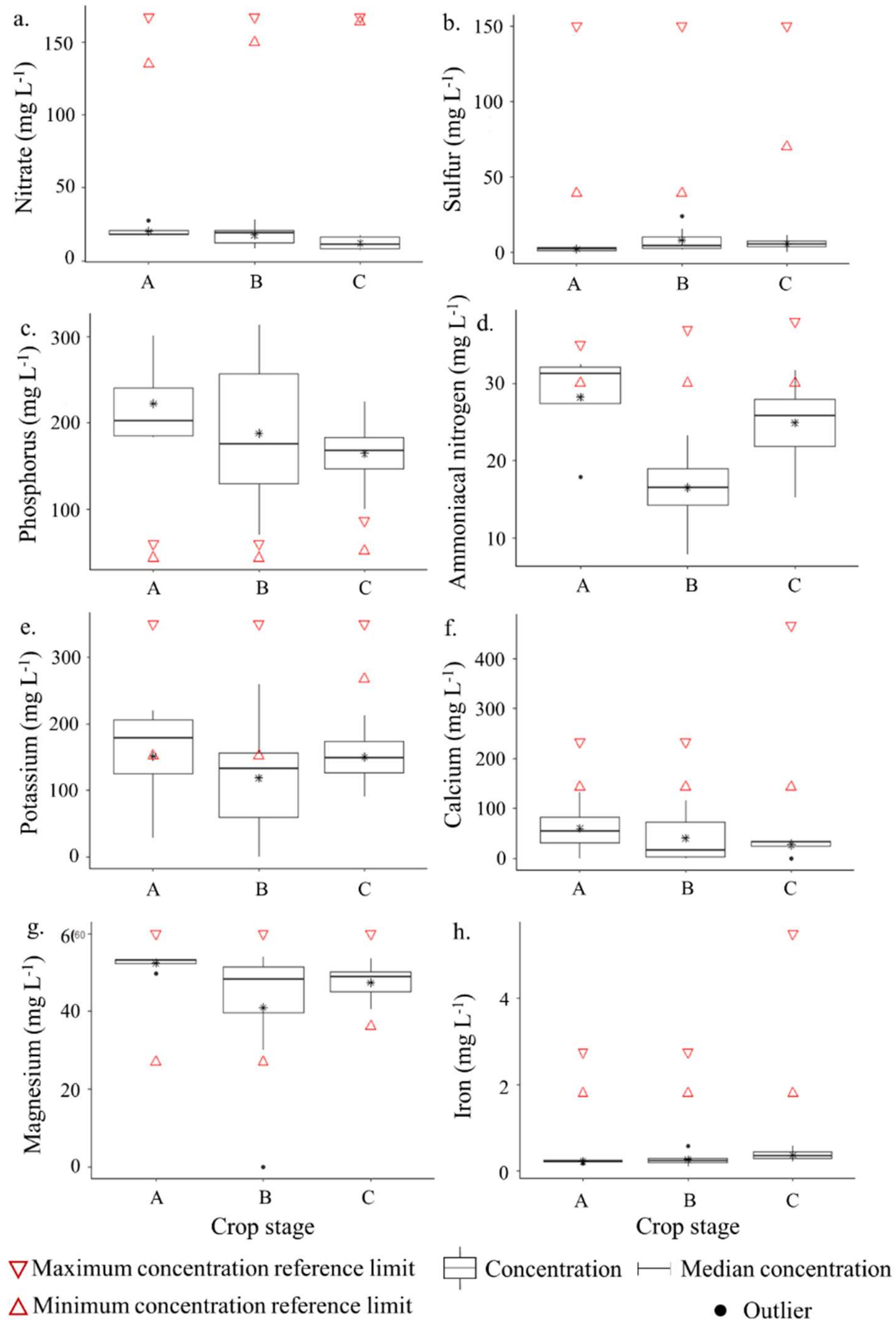

FIGURE 2. Concentrations of nitrate (a), sulfur (b), phosphorus (c), ammoniacal nitrogen (d), potassium (e), calcium (f), magnesium (g), and iron (h) in nutrient solution for different tomato stages, values compared with the maximum and minimum reference limits.

The concentrations of nitrate (Figure 2a), sulfur (Figure 2b), ammoniacal nitrogen (Figure 2d), potassium (Figure 2e; for stages B and C), calcium (Figure 2f), and iron (Figure 2h) in nutrient solution was lower than the minimum reference limits. Therefore, these elements were applied at concentrations below those demanded by plants for proper development, especially for tomatoes. This crop is nutrient-demanding to reach high yields, and the amounts in the water supply are usually insufficient.

Furthermore, P concentrations in nutrient solution were on average three times higher than the reference limits for all stages (Figure 2c). In practice, the first challenge of formulating a nutrient solution arises from the mineral composition of irrigation water. This is because, most of the time, irrigation water contains macro- and micronutrients and other non-nutrient ions at high concentrations (Mendoza-Grimón et al., 2021). Besides, natural resources such as phosphorous are not endless and can negatively impact the environment; therefore, its extraction must be restricted for sustainable use of this element (Marcelis & Heuvelink, 2019).

Comparison between nutrient and effluent solutions

The pH values reached a minimum and maximum of 4.4 and 6.1 for effluent and nutrient solutions, respectively (Figure 3a). For most hydroponic crops, the ideal pH in the root zone ranges from 5.5 to 6.5, while values between 5.0-5.5 and 6.5-7.0 may not cause problems for most of them. However, when exposed to pH above 7 or lower than 5, plant growth is restricted (Trani et al., 2022).

Regarding electrical conductivity (EC), averages of effluent solution were higher than those of nutrient solution in stages B and C (Figure 3b). In this type of system, EC gradually increases due to the accumulation of non-essential ions, for which the apparent absorption concentration (i.e., the ratio between nutrient and water absorptions) is lower than its concentration in irrigation water (Carmassi et al., 2005).

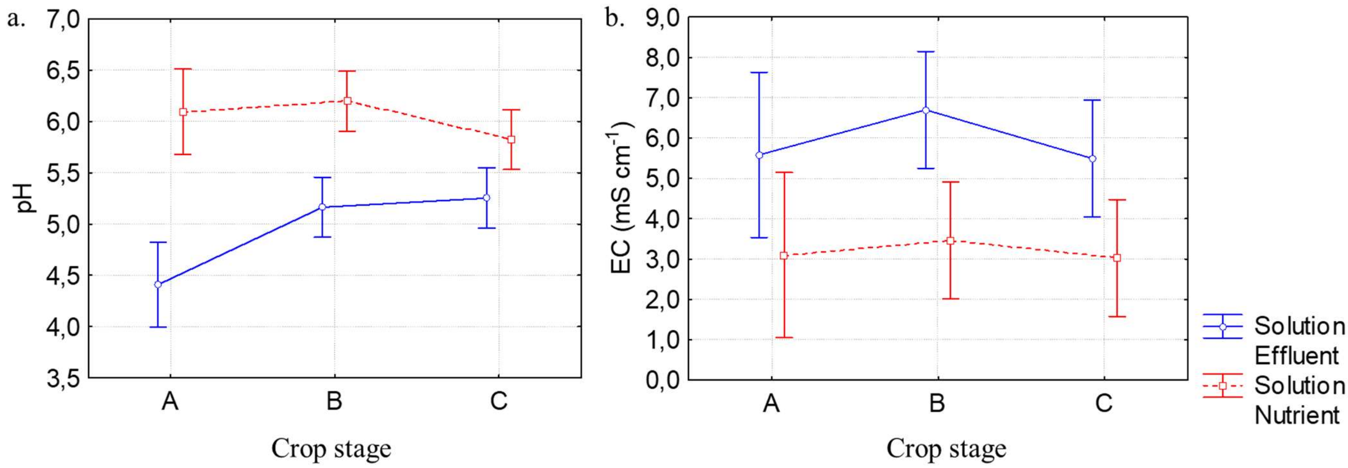

FIGURE 3. Monthly averages of pH and electrical conductivity (EC) in nutrient and effluent solutions at different tomato crop stages (A – from sowing to 30 DAT, B – from 30 to 60 DAT, C – from 60 DAT to the last harvest).

For concentrations of nitrogen forms, such as nitrite, nutrient solution showed higher averages than effluent solution only at stage A (Figure 4a). It can be explained by nitrite oxidation, in which NO_2^- is oxidized to NO_3^- by nitrite-oxidizing bacteria (NOB). NOB is widely distributed in the soil and includes the genera *Nitrobacter*, *Nitrotoga*, *Nitrococcus*, *Nitrospina,* and *Nitrospira* (Attard et al., 2010). As for nitrate form, no significant differences were found between nutrient and effluent solutions, regardless of the stage (Figure 4b). However, the concentration of its ammoniacal form was significantly lower in the effluent solution than in the nutrient solution for all stages (Figure 4d). In the effluent solution accumulated, ammoniacal nitrogen was converted into nitrite form. Ammonia-oxidizing bacteria (AOB) and ammonia-oxidizing archaea are found in the soil and are responsible for the conversion of ammonia (NH_4^+) into nitrite (NO_2^-) (Attard et al., 2010). Most of all, in solution, nitrite derived from ammonia is oxidized and results in nitrate (Vieira, 2017).

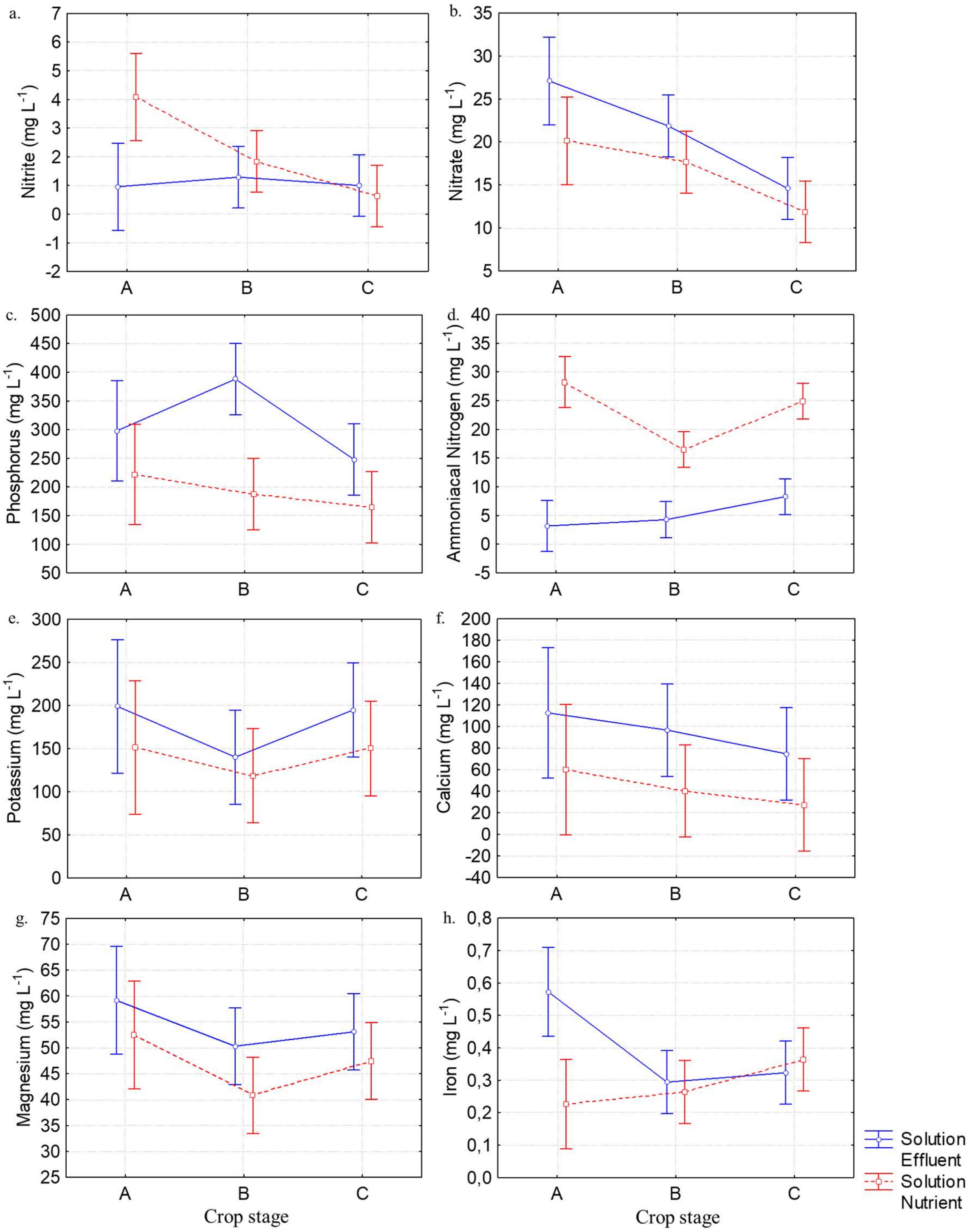

FIGURE 4. Monthly averages of nitrite (a), nitrate (b), phosphorus (c), ammoniacal nitrogen (d), potassium (e), calcium (f), magnesium (g), and iron (h) concentrations in nutrient and effluent solutions at different tomato stages (A – from sowing to 30 DAT, B – from 30 to 60 DAT, C – from 60 DAT to the last harvest).

The concentrations of metallic elements [potassium (Figure 4e), calcium (Figure 4f), and magnesium (Figure 4g)] in the effluent solution were not significantly different from those in the nutrient solution, regardless of the crop stage. However, on average, all these elements had surpluses in effluent solution. The concentrations found in effluent solution were 1.2 to 1.5, 1.7 to 2.9, and 1.1 to 1.2 times higher for potassium, calcium, and magnesium, respectively, representing surpluses throughout the crop cycle.

The averages of iron concentration at stage A (Figure 4h) and phosphorus concentration at stage B (Figure 4c) were higher in the effluent solution than in the nutrient solution. This difference ranged from 0.9 to 2.8 for iron, while for phosphorus it was 1.3 to 2.0, regardless of the cycle. Nutrient surpluses represent what plants have not used throughout the growing cycle. Among the macronutrients, phosphorus is less required (Moraes et al., 2018). For example, the hybrids ‘Gault’ and ‘Pomerano’ require 2.0 and 2.2 g plant^{-1} at the end of the growing cycle. In soilless systems, phosphorus efficiency is higher than in crops grown in soil systems. Moreover, phosphorus amounts remaining in nutrient solution effluent are higher than those of the other nutrients, as seen in our study.

Furthermore, higher concentrations in effluent solution were related to solution accumulation and replacement of nutrient solution in the fertigation tank. Considering how nutrients were replaced throughout the cultivation cycle, the effluent solution improved when compared to the initial solution. Such enrichment was also supported by the higher EC value in effluent solution (Figure 3b), which is characterized by the presence of metallic elements at high concentrations.

Evaluation of effluent solution for reuse

Table 3 shows the limit concentrations of elements (i.e., minimum, and maximum) in the nutrient solution, considering the agronomic recommendations practiced by the grower. When comparing the literature values (Table 1) with the practiced by the grower (Table 3), differences were observed, except for magnesium, whose content practiced by the grower was, on average, within the literature recommendation.

In general, the literature recommendations were higher than those practiced on the farm. Considering concentration averages and all crop stages, differences varied from 1.7 to 2.2 for potassium, from 2.9 to 12.2 for calcium, and from 8.2 to 11.0 for iron. Therefore, the nutrient solution used by the grower had concentrations of these elements below those recommended by the literature. For phosphorus, however, the concentration applied by the grower was 2.5 to 4.7 times higher than the recommended in the literature.

Daily management of nutrient solutions based on EC (electrical conductivity) made by the producer promoted successive increases in nutrient concentrations in an unbalanced way. The excess of elements applied in the nutrient solution and accumulation of effluent solution in the disposal tank during the seven days kept the effluent solution enriched compared to the initial nutrient solution.

According to the literature, improper fertigation management in greenhouses has produced negative environmental impacts as a result of excessive use of water and fertilizers (Bonetta et al., 2019; Muñoz et al., 2017; Van Os et al., 2019). Tomato crops demand high water quantity, and the addition of a 10 to 20% leaching fraction in water is a common practice (Alvarenga, 2013), increasing pressure on water resources and environmental impacts (Ghannem et al., 2021).

Given the above, particularly in environmentally protected areas or regions with limited water resources, the use of closed systems has been required by law (Rufí-Salís et al., 2020). In the Netherlands, for example, growers must reduce wastewater discharge with nitrogen and phosphate to almost zero by 2027 (Van Os et al., 2019). Still, one of our challenges associated with the Sustainable Development Goals (SDG) is within SDG 6, Subgoal 6.3, which focuses on substantially increasing water recycling and safe reuse globally by 2030. Aeroponic production systems, which are more efficient in water use and produce less effluent, are also an option (Calori et al., 2017; Calori et al., 2021). Then, to evaluate the reuse of effluent solutions in a closed system, regarding the need to add fertilizers or dilute solution, the reference adopted was the agronomic recommendations already practiced by the grower (Table 3). The nutrient concentrations in the effluent solution were then compared to the minimum and maximum reference limits (Figure 5).

TABLE 3. Concentration limits (mg L^{-1}) of elements in nutrient solution for different tomato stages (A – from sowing to 30 DAT, B – from 30 to 60 DAT, C – from 60 DAT to the last harvest).

Element	Stage A		Stage B		Stage C	
	Min	Max	Min	Max	Min	Max
	mg L^{-1}					
N	85.0	216.0	107.0	272.0	142.0	942.0
$NO3^-$	16.9	27.3	8.1	28.0	7.2	17.3
$NH4^+$	17.9	32.5	7.8	23.2	15.2	31.7
P	183.4	300.1	70.4	313.0	100.0	224.0
K	28.5	219.1	0.0	259.1	90.6	212.3
Ca	0.0	131.5	0.0	116.0	0.0	38.4
Mg	49.7	53.7	0.0	54.1	40.4	53.5
S	0.0	4.0	1.7	23.7	0.0	11.0
Fe	0.2	0.2	0.1	0.6	0.2	0.6

The concentrations of nitrate (Figure 5a), sulfur (Figure 5b), potassium (Figure 5e), calcium (Figure 5f; for stages A and B), magnesium (Figure 5g; for stages B and C), and iron (Figure 5h; for stages B and C) were within those established in the literature. Only ammoniacal nitrogen (Figure 5d) was below the minimum limits established by recommendations and those reviewed in the literature (stages A and B, 30 mg L^{-1}; and stage C, 19 mg L^{-1}), thus, supplementation is required.

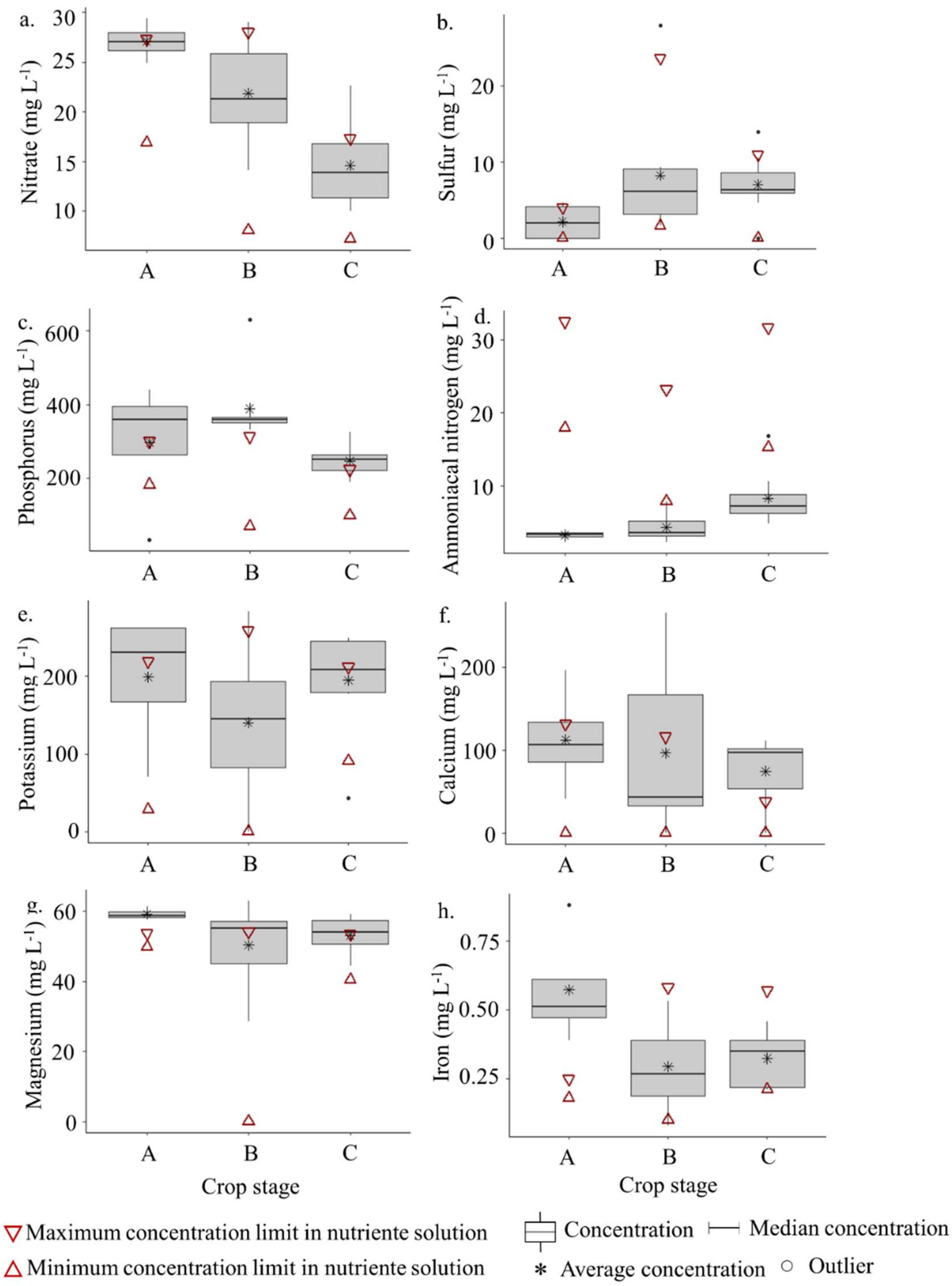

FIGURE 5. Comparison between concentrations of nitrate (a), sulfur (b), phosphorus (c), ammoniacal nitrogen (d), potassium (e), calcium (f), magnesium (g), and iron (h) in effluent solution for different tomato stages and the maximum and minimum limits in solution.

The concentrations of phosphorus (Figure 5c), calcium (Figure 5f; for stage C), magnesium (Figure 5g; for stage A), and iron (Figure 5h; for stage A) were higher than those established by both agronomic and practiced recommendations. In our study, phosphorus was critical and stood out, with concentrations ranging from 220 to 395 mg L^{-1}.

Recirculating water and non-used nutrients in a closed system maximizes water-use efficiency, such as for hydroponically grown tomatoes (Verdoliva et al., 2021), and reduces losses of nitrogen and total fertilizers, leading to a more sustainable greenhouse production (Savvas & Neocleous, 2019). Furthermore, a high P concentration in nutrient solution can make Zn less available (Minami & Mello, 2017), while a high Ca concentration reduces cation absorption, especially K^{+} and Mg^{2+}, besides increasing anions.

According to Helmecke et al. (2020), water reuse has been a common practice in several countries since 1912. However, these authors emphasized that there is a challenge in balancing adequate wastewater and nutrient loads in reclaimed water for specific crop requirements. Neocleous et al. (2021) also discussed that recycling effluent solutions depends much more on scientific knowledge and intelligent nutrition management than on the supply of a standard nutrient solution in open soilless systems. This is because the effluent solution has not had a constant composition over time, and nutrient concentrations are variable during the production cycle, as observed here.

Chemical analyses are essential to formulate efficient nutrient solutions. However, their costs make the process unfeasible and can be used only in less demanding crops, such as pastures and reforestation. Some commercial electrodes can measure nitrate (NO_3^-), potassium (K^+), calcium (Ca^{2+}), and sodium (Na^+) in real-time using leaf extract, which can help in determining control points. Moreover, Savvas et al. (2020) developed an online decision support to calculate and readjust automatically nutrient solutions for open and closed hydroponic cultivations, according to growth stage and environmental conditions.

Consideration for disposal of effluent solution

Awareness about the importance of rational use, control of losses and waste, and reuse of water has grown. Although it has been a practice for over a century, only recently has the technical and scientific basis for controlled reuse, understood as safe, sustainable, and viable from a sanitary, environmental, and economic point of view, been consolidated.

In Brazil, the CONAMA Resolution n. 430, of 5/13/2011, deals with the conditions for the disposal of effluents into surface water bodies. Indirect discharge of effluents into receiving bodies must comply with the provisions in the Resolution when there is no specific legislation or standards. The disposal of effluents into the soil, even if treated, is not subject to the parameters and discharge standards in this Resolution. However, it cannot cause pollution or contamination of surface and underground waters.

The effluent solution accumulated contains significant concentrations of macro- and micronutrients that may cause pollution to water bodies. Elements, such as phosphorus, are potential pollutants when released into rivers, lakes, or estuaries, affecting the quality of receiving water bodies, and even compromising biodiversity (Liu et al., 2022). Therefore, the reuse of effluent solution mitigates potential negative environmental impacts since it avoids inadequate effluent discharge into the soil, its salinization, leaching, and eutrophication of surface hydric bodies.

CONCLUSIONS

1. Based on the management practiced by the grower, nutritional replacement based on electrical conductivity made the effluent solution richer than the initial nutrient solution.
2. The effluent solution has the potential to be reused in the irrigation system, based on its physicochemical properties, tomato nutritional demands, and the need for fertilizers or solution dilution.
3. The water supply showed high concentrations of nitrite, phosphorus, and sulfide.
4. The nutrient solution was nutritionally unbalanced, with high phosphorus concentrations and low nitrate, sulfur, ammoniacal nitrogen, potassium, calcium, and iron concentrations.
5. The effluent solution was also nutritionally unbalanced, with ammoniacal nitrogen below the minimum limits, and phosphorus, calcium, magnesium, and iron above the maximum limits.
6. Monitoring the quality of irrigation water may allow for detecting control points, such as higher concentrations of phosphorous, which is a natural resource that is not endless and can negatively affect the environment.

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