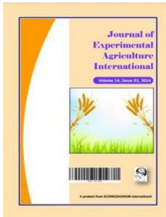

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Nutrient Solution for Production and Quality of Strawberry Grown in Substrate

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Authors' contributions

This work was carried out in collaboration between all authors. Authors DP and AS designed the study and wrote the first draft of the manuscript. Authors ICZ and DP performed the experiments. Authors ICZ, DP and FR participated in fieldwork and laboratory analysis. Authors ICZ and FR managed the analyses of the study. Author AS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study determined a nutritive solution and evaluated the performance in the development, production and quality of strawberry cultivated in the substrate.
Study Design: The treatments were commercial and recommended nutritional solutions for strawberry using the methods of Castelane and Araújo (C.A.), Furlani and Fernandes Junior (F.F.J.) and the proposed solution with seven replicates.
Place and Duration of Study: The experiment was carried out in the experimental area of the Federal Technological University of Paraná, Brazil, in the period between May and December 2014.
Methodology: Agronomic variables such as yield, number of fruits, nutrient content, physiological indicators, physical and chemical characteristics of fruits were analysed.
Results: The proposed nutrient solution resulted in larger masses of fresh and dry matter (225.4 g $plant^{-1}$ and 27.5 g $plant^{-1}$), number of fruits (40.1) and fresh fruit mass (750.4 g $plant^{-1}$), in relation to the other evaluated solutions. The proposed solution resulted in better physical and chemical characteristics such as soluble solids, reducing and total sugars, anthocyanins, flavonoids, phenolic compounds and ascorbic acid and the strawberry fruits presented an attractive colour and met the

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quality standards for the consumer. The highest levels of nitrogen (33.7 g kg^{-1}), phosphorus (9.3 g kg^{-1}), and potassium (28.2 g kg^{-1}) in the leaf tissue were found in the proposed solution and contributed to productivity and fruit quality gains of a strawberry.

Conclusion: These results provide a nutrient base and can be adapted to other cultivars in different locations.

Keywords: Fragaria x ananassa Duch; nutrients; colour; physical and chemical characteristics.

1. INTRODUCTION

The strawberry (*Fragaria x ananassa* Duch) is one of the fruits most appreciated by consumers in different regions of the world, highlighting its color, aroma, flavor and versatility in cooking and gastronomy. For this reason, strawberries are in great demand both in the natura and industrial processings [1].

Strawberry fruits with better physicochemical characteristics guarantee acceptance by the consumer market and increase yield in processing and industrialization. In this sense, the nutritional solution concentration, together with the use of processing techniques have been important factors taken into account to improve the productivity and physicochemical properties of the fruit [2].

Strawberry cultivation in the substrate is a production technique used in several regions of Brazil and around the world, allowing to obtain high production and greater ergonomics in crop management [3]. The main problem faced by producers in this production system is with regard to composition and management of the concentration of the nutrient solution.

In the literature Paranjpe et al. [4], reported that concentrations of nutrient solution with values of electrical conductivity (EC) between 1.4 and 1.8 dS m^{-1} and up to 2.0 dS m^{-1} [5] are proposed to obtain quality and productivity of strawberry fruits, but the great difficulty with most nutrient solutions is to adjust the amount of nutrients for substrate cultivation.

In this sense, the need arises for studies with nutritive solutions with the determination of ionic balance of nutrients and their relationship with yield and quality of strawberry fruits in substrate cultivation. In this study we determined a nutrient solution for strawberry and evaluated the agronomic characteristics and fruit quality. The results provide nutrient content information extracted by the plants with the proposed solution, production data and physiological indicators of fruit quality, which contribute to meet the demands of the consumer market and make the production system more sustainable.

2. MATERIALS AND METHODS

2.1 Plant Material and Growing Conditions

The experiment was carried out in the experimental area of the Federal University of Technology - Paraná, Brazil (25º42'52 "S, 53º03'94" W, 530 m altitude), in the period between May and December 2014, covered with a 150-micron plastic film.

The seedlings of the cultivar Camino Real were purchased from a suitable nurseryman of varietal quality, from Maxxi Mudas®, from Patagonia, Argentina. These were transplanted in plastic pots with a capacity of 8 L in dimensions 24 × 23 cm, placed in lines, on the soil of the protected environment, filled with sand of medium granulometry, being transplanted one plant per pot, distributed with a density of eight plants per square meter.

The replenishment of nutrients was carried out daily by means of a drip irrigation system, with drippers of the brand netafim®, with a spacing of 0.20 m and a flow of 3.2 L $hour^{-1}$, with a dripper per vessel, thus maintaining the sand in the field capacity. The total fertigated volume was 535.7 mm and the total irrigation time was 47.5 hours for all treatments.

The meteorological data (temperature, relative air humidity and solar radiation) were obtained every 15 minutes using Akso® brand AK 172 dataloggers installed in meteorological shelters, located in the center of the protected environment.

The fertilisers used to compose the evaluated nutrient solutions were potassium nitrate (KNO_3), calcium nitrate $Ca(NO_3)_2$, monoammonium phosphate ($NH_4H_2PO_4$) and magnesium sulfate ($MgSO_4$). For micronutrients the amount of 25 g per 1000 L of water of the commercial product Conmicros Standard® was used in all the nutrient solutions, which presented the concentrations of B (2.0%), CuEDTA (2.0%), FeEDTA (7.9%), MnEDTA (2.0%), Mo (0.4%) and ZnEDTA (0.8%).

The nutrient solutions after addition of the nutrients presented the following values of electrical conductivity and pH 2.0 and 6.0 mS cm^{-1} for the commercial solution (F.F.J.) [6], 1.7 and 6.2 mS cm^{-1} for the commercial solution (C.A.) [7], and 1.8 and 5.8 mS cm^{-1} for the proposed solution.

In relation to the management of nutrient solutions, the fertigations were done daily, and at each application of the fertirrigation, a new solution for each treatment was prepared. Also, twice-a-week irrigations were carried out only with water to avoid salinisation of the substrate. Electrical conductivity and pH were measured with conductivity and portable HI 98130 Hanna® brand portable pH meters each time the solution was prepared. pH values between 5 and 6, and electrical conductivity greater than 1.5 mS cm^{-1} were maintained during the experiment [8].

2.2 Treatments and Experimental Design

The treatments were commercial and recommended nutritional solutions for strawberry using the methods (C.A.) [7], (F.F.J.) [6] and proposed solution, with seven replicates. The amounts of nutrients used for each solution are shown in Table 1. The calculation of the proposed solution was based on ionic nutrient balance [9].

2.3 Evaluated Parameters

The content of macronutrients and micronutrients in leaf tissue was determined and four leaves per plant were completely expanded in the flowering period [10].

During the full flowering period (120 days after transplanting [DAT]) and at 190 DAT, measurements of the relative index of total chlorophyll in the abaxial and adaxial parts of the last two expanded leaves of each plant were performed at 11:00 AM using the chlorophyllometer model Clorofilog Falker® brand. The fresh matter mass of fruits and number of fruits per plant was determined by adding all the harvests during the evaluated period (fifteen harvests).

The average mass of fruits was obtained by dividing the fresh matter mass of fruits by the number of fruits per plant. The fruits were harvested when they presented more than 75% of the epidermis with pink colouration [11].

The fruit colour was determined in 10 fruits randomly selected from each nutrient solution, using a digital colourimeter (Minolta model, Cr 200 b), where the values of luminosity ("L") were determined, ranging from light to dark. The value 100 corresponds to white colour and value 0 (zero), the black colour, and component "c" which expresses chroma degree of the fruits, where, by the proposed classification, more colourful fruits present smaller values and less colourful fruits present higher values [12].

The soluble solids (SS) content was obtained by direct reading in Hanna® bench refractometer model HI 96801, using the homogenized pulp and filtered at room temperature, obtaining the values in degrees (Brix). The determination of the titratable acidity (T.A.) was by titration with 0.1N NaOH until it reaches pH 8.1. The ratio (SS/TA) was determined by dividing the soluble solids content by the titratable acidity.

Total sugar concentrations were determined by the method described by Dubois et al. [13] those of reducing sugars were obtained by the method described by Miller [14].

Table 1. Quantities of nutrients used in the preparation of nutrient solutions for strawberry cultivation on the substrate

Nutrients (mg L^{-1})	Commercial solution C.A.	Commercial solution F.F.J.	Proposed solution
N-NO_3^-	124.6	116.2	166.9
N-NH_4^-	5.6	5.6	31.92
P - $H_2PO_4^-$	46.5	49.6	78.12
K^+	195.0	234.0	182.13
Ca^{++}	124.0	104.0	68.0
Mg^{++}	24.60	36.0	13.7
S-SO_4^{--}	43.20	48.0	16.6

The quantification of total phenolic compounds (mg gallic acid 100 g pulp^{-1}) was carried out according to the spectrophotometric method of Follin-Ciocauteau, proposed by Woisky and Salatino [15]. The ascorbic acid content (Vitamin C) was determined by standard titration method of AOAC modified by Benassi and Antunes [16]. Vitamin C content was calculated based on titration values of a standard solution of ascorbic acid and the results expressed in mg of 10 g of ascorbic acid 100 g pulp^{-1}.

In the quantification of anthocyanins and flavonoids, the procedure described by Mazaro et al. [17] was used. All the physicochemical analyses were determined in a single crop, at 150 DAT, which corresponded to the peak of production. A composite sample of 100 fruits per treatment was used for all the analyses, taking seven subsamples of approximately 50 g each.

At 190 DAT, which corresponded to end of the experiment, the mass of fresh matter in a precision scale (0.001 g) of all the plants of the experiment was determined. After the plants were placed to dry in a forced circulation air oven at 65°C until reaching constant mass to determine the mass of dry matter.

2.4 Statistical Analysis

The data of experiment were submitted for analysis of variance (Test F), when the F test was significant the means were compared by Tukey's test (P=0.05), using “SAS Studio” [18].

3. RESULTS AND DISCUSSION

During the conduction of experiment, the average temperature, relative humidity and average daily radiation were 19.2°C, 75% and 949.7 kJ m^{-2}. The temperature conditions during the experiment were found to be within the ranges suitable for the crop. Temperatures that range between 18°C and 24°C are considered adequate for the development of the crop [19].

The electrical conductivity (EC) in the solutions tested ranged from 1.5 to 2.1 dS m^{-1}, with an average of 1.8 dS m^{-1}. The mean conductivity is at the upper limit of the recommended range of 1.4 to 1.8 dS m^{-1} [6]. The pH variations of the solutions were between 5.0 and 7.0, with an average of 6.2. pH ranges between 5.5 and 6.5 are most indicated for the culture [6].

It was observed that the EC in the evaluated solutions improved fruit quality by increasing the solids content and sugars. It was found that evaluated solutions were within the recommended pH range for strawberry.

Nutrient solutions significantly influenced nutrient content in leaf tissue. The highest levels of nitrogen (33.7 g kg^{-1}), phosphorus (9.3 g kg^{-1}) and potassium (28.2 g kg^{-1}) in the leaf tissue were found in the proposed solution (Table 2). The other macronutrients did not differ significantly. For micronutrients, there were significant differences for the boron content in F.F.J. solution and higher iron and manganese contents in the proposed solution.

The macronutrients, in descending order, nitrogen (N), potassium (K), calcium (Ca), phosphorus (P), magnesium (Mg), and sulphur (S) were the nutrients extracted in greater quantity by the strawberry. The following ranges are recommended: N, 15-25 g kg^{-1}; P, 2-4 g kg^{-1}; K, 20-40 g kg^{-1}; Ca, 10-25 g kg^{-1}; Mg, 6-10 g kg^{-1}; and S, 1-5 g kg^{-1}. For boron (B), iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn) are 35-100, 50-300, 30-300, 5-20, and 20-50 mg kg^{-1}, respectively [20]. The contents found in the foliar tissue for the studied solutions are superior to those suitable for N and P, within the recommended range for K, Ca, Mg, B, Fe, Mn, Zn, and Cu. No visual symptoms of nutritional deficiency were observed in the strawberry plants during the experiment.

The proposed solution resulted in the highest relative indices of total chlorophyll in the flowering phase and at the end of the crop cycle (Table 3). There was also a decrease in the relative index of total chlorophyll in final phase of the cycle in all evaluated solutions.

The mass of the fresh and dry matter presented significant differences, being largest accumulation of fresh (225.4 g plant^{-1}) and dry (27.5 g plant^{-1}) mass obtained in the proposed solution (Table 3). The fresh mass of the proposed solution was 6.74% higher than the Castelane and Araújo commercial solution.

The highest relative chlorophyll index in the proposed solution is justified by higher nitrogen content present in the leaf tissue. The content of chlorophyll in the leaf is used to predict the nutritional level of N in plants, due to the fact that the amount of this pigment correlates positively with N content in the plant [21]. This relationship is attributed mainly to the fact that 50% to 70% of total N of the leaves is integral with enzymes, which are associated with chloroplasts [22].

Table 2. Nutrient content in leaf tissue of fertigated strawberry with different nutrient solutions

Nutrients	N g kg^{-1}	P g kg^{-1}	K g kg^{-1}	Ca g kg^{-1}	Mg g kg^{-1}	S g kg^{-1}	B mg kg^{-1}	Cu mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Zn mg kg^{-1}
Sol. C.A.	31.1 b*	7.8 b	21.8 b	11.1 ^{ns}	6.9 ^{ns}	1.1 ^{ns}	100.5 b	5.3 ^{ns}	82.6 b	194.0 b	30.0 ^{ns}
Sol. F.F.J.	30.4 b	8.0 b	23.4 b	10.9	6.8	1.2	103.0 a	5.7	81.7 b	216.5 b	29.5
P. solution	33.7 a	9.3 a	28.2 a	10.5	7.0	1.2	98.4 b	5.5	86.5 a	222.0 a	31.6
Mean	31.7	8.4	24.5	10.8	6.9	1.2	100.6	5.5	83.6	210.8	30.4
C.V. (%)	3.9	9.2	3.3	3.1	5.6	4.3	1.2	2.3	3.5	2.6	2.2

**Means followed by the same letter in the column do not differ significantly by Tukey test, at P=0.05; ns: no significant; C.V.: Coefficient of variance*

Table 3. Relative index (I.R.) of total chlorophyll phases full flowering and the end, masses of fresh and dry matter of shoot (M.F. and M.S.) of fertigated strawberry plants with different nutrient solutions

Solutions	Full Flowering I. R. of total chlorophyll	End of cycle I. R. of total chlorophyll	M.F. (g $planta^{-1}$)	M.S. (g $planta^{-1}$)
Sol. C. A.	54.4 b*	50.2 b	210.2 b	21.0 b
Sol. F. F.J.	57.1 b	52.9 b	208.7 b	20.7 b
P. solution	62.2 a	59.4 a	225.4 a	27.5 a
Mean	57.9	54.17	215.0	23.1
C.V. (%)	9.3	8.4	20.4	22.0

**Means followed by the same letter in the column do not differ significantly by Tukey test, at P=0.05; C.V.: Coefficient of variance*

Table 4. Number of fruits $plant^{-1}$ (N.F.P.), mean fruit mass (M.F.M), fresh fruit mass (F.F.M.), luminosity of the epidermis, the colour of the epidermis (Chroma) of fertigated strawberry with nutritive solutions

Solution	N.F.P.	M.F.M. (g)	F.F.M. (g $plant^{-1}$)	Luminosity	Chroma
Sol. C.A.	30.3 b*	12.5 b	690.8 b	28.7 ^{ns}	35.1 a
Sol. F.F.J.	32.5 b	13.3 b	704.6 b	27.8	34.93 a
P. solution	40.1 a	15.7 a	750.4 a	26.0	32.10 b
Mean	34.3	13.83	715.3	27.8	34.0
C.V. (%)	22.4	13.7	27.8	3.81	3.87

**Means followed by the same letter in the column do not differ significantly by Tukey test, at P=0.05; ns: no significant; C.V.: Coefficient of variance*

The decrease of relative index of chlorophyll in the final phase of crop cycle can be explained by the advancing age of the leaf because in this phase, there is a decline of photosynthetic capacity. The photosynthetic efficiency is linked to the amount of chlorophyll and consequently, to the growth phase of the plant [23].

The results of mass of the fresh and dry matter obtained with the proposed solution may be related to higher nutrient intake, especially the nitrogen present in the foliar tissue of the proposed solution (Table 2). Plant development, productivity and strawberry fruit quality are strongly influenced by nitrogen fertilization [24].

Moreover, the increase of K in the plant causes an increase in the production of photoassimilates and consequently, a greater mobilization of leaf N in the synthesis of macromolecules, which in turn are used in vegetative growth and fruit production [25].

The number of fruits per plant, average fruit mass, and fresh fruit mass was influenced by evaluated treatments, obtaining best results in the proposed solution (Table 4). There were gains of 6.1% and 7.94% in the fresh fruit mass in relation to commercial solutions F.F.J. and C.A, which can be attributed to ionic balance of the proposed solution, which met the nutritional demand of strawberry with nutrient amounts without excesses or deficiencies, contributing to fruit quality and sustainable management of fertilizers in agriculture.

For the luminosity (L) of the epidermis, the nutrient solutions evaluated did not present significant influence (Table 4). The values of luminosity of the evaluated solutions were below the value 29.24 and according to Conti et al. [12] indicate dark colour. The dark colour of strawberry fruits in the evaluated solutions is a desirable characteristic for both industry and consumers because dark red fruits are more attractive in the eyes of consumers.

For the colour component or chroma value of the epidermis, the proposed solution presented darker and more colourful fruits. The "C" component expresses the colour of fruits, where values less than 24.92 have more colour of the epidermis, values between 24.92 and 36.08 have intermediate colour, and values above 36.08 have less colourful fruits [12]. It is of great importance that the external aspect of the fruit in commercialisation is mainly in natura, the proposed solution resulted in fruits being more attractive for commercialization.

The superiority in the number of fruits and fresh fruit mass in proposed solution can be attributed to the ionic balance of the solution, which favoured the absorption of some ions, such as potassium (28.2 g kg^{-1}) (Table 2), which improved productivity and fruit quality [26]. The increase in mean mass of fruits, influenced by potassium present in the proposed solution, can be attributed to the important role that this nutrient plays in the translocation of photoassimilates from leaves to the fruits and the role it exerts in cell extension [25].

The number of fruits found in the proposed solution was 33.9% higher than that observed by Vignolo et al. [27], where 26.5 fruits per plant with the cultivar Camino Real in cultivation were carried out in the soil. The fresh fruit mass transformed into yield results in 60 t ha^{-1}, which is higher than the yield obtained from 9.07 and 10.55 t ha^{-1}, with the same cultivar in conventional and organic systems, respectively [28].

The proposed solution resulted in more colourful fruits, with a higher content of soluble solids and of total and reducing sugars, possibly due to the higher content of potassium. Potassium is one of the nutrients most used by strawberry, considered the "element of quality" in plant nutrition, to improve physical-chemical characteristics and to increase production [10].

The SS/TA were not influenced by the evaluated nutrient solutions, the average value being 0.90 g.100 g $pulp^{-1}$ and 9.33, respectively (Table 5). It was verified that the proposed nutrient solution resulted in a higher content of soluble solids and concentration of total and reducing sugars, anthocyanins, flavonoids, phenolic compounds and ascorbic acid (Table 5).

The soluble solids content in the proposed solution was 25.3% higher than the results obtained by Andriolo et al. [26] of 6.65 °Brix. The minimum values of soluble solids should be higher than 7.0 °Brix, guaranteeing acceptable taste [11], all nutritional solutions presented values above 7.0 °Brix, considered acceptable for consumers.

Table 5. Soluble solids (S.S.) (°Brix), total sugars (T.S.) (mg.g^{-1} fresh fruit mass), reducing sugars (R.S.) (mg.g^{-1} fresh fruit mass), flavonoids (F.) (mg.100 g^{-1} fresh fruit mass), anthocyanins (A.) (mg.100 g^{-1} fresh fruit mass), phenolic compounds (P.C.) (mg of galic acid 100 g^{-1} fresh fruit mass) and ascorbic acid (A.A.) (mg.100 g^{-1} pulp) of fertigated strawberry fruits with different nutrient solutions

Solution	S.S.	T.S.	R.S.	F.	A.	P.C.	A.A.
Sol. C. A.	8.0 b*	8.7 b	1.1 b	3.3 b	34.0 b	75.1 b	45.1 b
Sol. F. F. J.	8.2 b	9.0 b	1.3 b	3.1 b	35.0 b	76.4 b	47.0 b
P. solution	8.9 a	10.1 a	1.9 a	4.0 a	40.4 a	80.6 a	52.5 a
Mean	8.4	9.3	1.4	3.5	36.1	77.4	48.2
C.V. (%)	8.1	7.7	19.3	17.9	20.2	10.3	12.7

**Means followed by the same letter in the column do not differ significantly by Tukey test, at P=0.05; C.V.: Coefficient of variance*

In the relationship between sugar content and acidity (SS/TA) there was no statistically significant difference between the evaluated solutions, with a mean value of 9.33. This value meets the minimum relationship patterns for strawberry fruits of 8.75 [11]. The strawberry fruits of the cultivar Camino Real presented an adequate SS/TA ratio, with a degree of maturation and fruit quality. The SS/TA ratio is an important parameter to determine fruit maturation, and fruit taste evaluation, as well as an indicator of fruit palatability, being directly linked to the preference and acceptance of the fruits by the consumer [29].

Commercially, the colour of the fruits can be influenced by the anthocyanins, which contributes greatly to quality evaluation, since the consumers correlate between the colour and total quality of specific products [30]. The anthocyanin content in the proposed solution was higher than that reported in the literature (20.93 mg 100 g^{-1} fresh fruit mass) by Calvete et al. [31] with the same cultivar, on different commercial substrates. According to Clifford [32] the anthocyanin levels may present variations related to climatic factors, seasonality, the degree of maturation, nutrition and type of cultivar.

The results of the present study indicate that fruits of the proposed solution presented an attractive colour and fruits with higher concentrations of anthocyanins, allowing greater benefits to the consumer due to the antioxidant effect.

As the anthocyanins content may be a criterion of choice at the time of feeding, due to the health benefits [31], the consumer will be eating higher anthocyanin content when consuming strawberries of the Camino real proposed solution. For humans, the intake of foods rich in anthocyanins, such as red fruits, is related to health benefits, as these components have high antioxidant and antitumor activity, as well as acting as an anti-inflammatory and preventing the formation of edemas [33].

The phenolic compounds and ascorbic acid contents presented significant differences for the evaluated solutions. The proposed solution resulted in an increase in phenolic compounds and ascorbic acid. In the literature, it is reported that potassium fertilisation exerts a beneficial effect on vitamin C levels [34].

Furthermore, the phenolic contents found in this study are lower than those verified by Pineli et al. [35] with the same cultivar (174.3 mg 100 g^{-1} pulp). Phenolic compounds are significantly influenced by the genetic factors of the cultivar [36]. In addition, the "open" culture system provides a higher content of phenolic compounds than the protected environment system [37].

Another factor that possibly influenced the content of phenolic compounds was the temperature. It is known that the synthesis of phenolic substances is favoured by the milder temperatures, especially the nocturnal ones and also the temperature variation from day to night, affects pigment deposition [38]. The average temperature of 19.2°C favoured the deposition of phenolic compounds, anthocyanins and flavonoids in fruits.

Potassium exerts influence on phenolic content, as it is related to photosynthesis and to biosynthesis of starch and proteins. With the increase of K doses in the plant, the production of photosynthates increases, which may increase the targeting of excess carbon fixed to the pathway of shikimic acid, which is the pathway for the formation of phenolic compounds, which may increase the concentration of phenolics in the plant [39].

The ascorbic acid (Vitamin C) in strawberry may vary according to the cultivar, stage of ripening and fertilisation. It is one of the most important nutritional components in fruits and human food and its content can be used as an index of food quality [11]. In addition to mineral nutrition, the intensity of solar radiation (949.7 kJ m^{-2}) associated with the time of year (summer) contributed to the increase in ascorbic acid content. The intensity and duration of fruit exposure to sunrays during growth influence the amount of ascorbic acid formed is synthesised from sugars supplied by photosynthesis, which increases with the highest incidence of radiation [38].

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4. CONCLUSION

In this study, the proposed nutrient solution contributed to productivity gains, fruit quality and comes as an option of adequate nutrient content for the strawberry, with ionic balance, without excess nutrients. These results provide a nutrient base and can be adapted to other cultivars in different locations.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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