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NUTRITIONAL ACCUMULATION FOR SALAD AND ITALIAN TOMATOES GROWN IN A PROTECTED ENVIRONMENT

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KEYWORDS

Solanum lycopersicum L., nutrient extraction, plant nutrition, greenhouse.

ABSTRACT

Tomato cultivation in a protected environment is an important tool for increasing yield, quality, and regularity of production. However, nutrient imbalance in this production system can lead to short-and long-term losses. This study aimed to characterize plant growth and nutrient accumulation and export of two tomato hybrids of the Salad ('Stella TY') and Italian ('HS 1188') groups in a protected environment and determine the accumulated thermal sum. The treatments consisted of evaluation times. Dry mass and nutrient accumulation could be determined by a sigmoidal non-linear model for both hybrids grown in the protected environment. The cumulative nutrient order was K > Ca > N > S > Mg > P > Mn > Zn > Fe > Cu > B for 'Stella TY' and K > N > Ca > S > P > Mg > Mn > Fe > Zn > Cu > B for 'HS1188', with yields of 105.7 and 103.4 t ha^{-1}, respectively. The accumulated thermal sum was 1851.7 degree days at 126 days after transplanting (DAT).

INTRODUCTION

Tomato production systems vary according to the region, purchasing power of producers, type (Santa Cruz, Persimmon, Salad, Italian, and Mini-Tomato), growth habit (determinate or indeterminate), cultivation in open or protected environments (greenhouse), and use or not of soil (Alvarenga, 2022).

Most tomatoes consumed freshly in Brazil have an indeterminate growth habit and are grown using soil as substrate in open environments. However, high air temperatures and precipitation, common in tropical countries, affect this type of cultivation throughout the year in certain regions.

Thus, cultivation in a protected environment is an important tool for increasing yield, quality, and regularity of production. The absence of precipitation in this production system favors less nutrient loss. Therefore, nutritional management needs to be different from that carried out in conventional open-field cultivation to be sustainable (Cesar et al., 2023).

In addition to the production system, the continuous launch of new hybrids, with a higher yield, ranging from 98 to 159 t ha^{-1} (Fayad et al., 2002; Purquerio et al., 2016; Moraes et al., 2018; Alvarenga, 2022), changes the nutritional requirements of plants.

Some information on nutrient accumulation for tomatoes in field cultivation has been reported in recent years (Purquerio et al., 2016; Diógenes et al., 2018; Moraes et al., 2018). However, cultivations carried out in a protected environment with a yield above 100 t ha^{-1} have no published information. The little existing information reports yields and nutrient accumulation lower than current market and plant demand, respectively, requiring update (Fayad et al., 2002; Prado et al., 2011; Betancourt & Pierre, 2013; Omaña & Peña, 2015).

Dry mass and nutrient accumulation by tomato plants grown in a protected environment could help to understand the specific nutritional requirements of new hybrids to refine their nutrition and fertilization, avoiding possible deficiencies or superfluous intake of some

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nutrients (Dezordi 2015; Moraes et al., 2018; Purquerio et al., 2019).

Physiological processes are affected by temperature and, consequently, the phenological stages of tomatoes. Thus, the thermal sum, which expresses the amount of energy that the plant needed to accumulate to complete each phenological stage, can be used to characterize the plant development (Ometto, 1981).

This research aimed to characterize the dry mass and nutrient accumulation and export of tomato hybrids of the Salad and Italian groups, grown in an agricultural greenhouse, and determine the accumulated thermal sum.

MATERIAL AND METHODS

Experimental site, periods, and meteorological elements

Two independent and simultaneous experiments were carried out on March 16 on July 20, 2017, at the Horticeres experimental station, Campinas, SP (22°46′14″ S, 47°4′1″ W, 600.0 m altitude). The regional climate is classified as Cwa (tropical with a dry winter season), according to the Köppen climate classification. The agricultural greenhouses had dimensions of 30.0 x 7.0 x 2.0 m (length, width, and floor-to-ceiling height), covered with a 150-µm low-density polyethylene plastic film, and closed laterally with a shading screen (30%), without climate control. Daily mean, minimum, and maximum air temperatures were recorded throughout the tomato crop cycle with an AK-28 digital thermometer. The equipment was installed in a shelter, with the sensor positioned at a height of 1.6 m, in the center of the protected environment. The mean air temperature during the experimental period was 23.9 °C, while the maximum and minimum mean values were 33.5 and 14.3 °C, respectively.

The tomato hybrids of indeterminate growth habit Stella TY and HS1188 (Horticeres), of the Salad and Italian groups, respectively, were used.

Seedlings were produced in 128-cell plastic trays and transplanted at a spacing of 1.5 x 0.5 m between rows and plants, respectively (13,333 plants ha^{-1}). The plants were grown on a double stem, staked with a plastic fastener, and pruned at the maximum staking system height (1.8 m).

Soil chemical and physical characterization and tillage

Soil chemical analyses (0–0.2 m) indicated for the experiments with ‘Stella TY’ and ‘HS1188’, respectively: OM = 23.0 and 19.0 g dm^{-3}; pH in $CaCl_2$ = 5.8 and 6.0; P = 115.0 and 95.0 mg dm^{-3}; K = 4.2 and 2.8 $mmol_c$ dm^{-3}; Ca = 164.0 and 143.0 $mmol_c$ dm^{-3}; Mg = 32.0 and 22.0 $mmol_c$ dm^{-3}; S = 56.0 and 32.0 $mmol_c$ dm^{-3}; H+Al = 19.0 and 18.0 $mmol_c$ dm^{-3}; SB = 220.2 and 167.8 $mmol_c$ dm^{-3}; V = 91 and 90%; B = 2.8 and 2.4 mg dm^{-3}; Cu = 11.5 and 11.5 mg dm^{-3}; Fe = 44.0 and 39.0 mg dm^{-3}; Mn = 7.2 and 5.6 mg dm^{-3}; and Zn = 14.7 and 12.1 mg dm^{-3}. Soil physical analysis indicated 387, 97, and 516 g kg^{-1} of clay, silt, and sand, respectively.

The soil was tilled with a power tiller and, subsequently, beds were built. Double-sided plastic film (black/white) mulching was used to control invasive plants and conserve soil moisture.

Experimental design and fertilization

The experiment was conducted in randomized blocks, with four replications. Each cultivation row, composed of 55 tomato plants, characterized a block. Treatments consisted of the evaluation times (0, 14, 28, 42, 56, 70, 84, 98, 112, and 126 days after transplanting – DAT).

Planting fertilization was not carried out. Topdressing fertilizations were carried out via fertigation, using a localized drip irrigation system, in which two drip lines (30 cm between emitters) were used per tomato planting row.

Throughout the crop cycle, N (232.1 and 271.4 kg ha^{-1}), K_2O (304.8 and 362.7 kg ha^{-1}), Ca (125.5 and 150.3 kg ha^{-1}), P_2O_5 (192.2 and 197.0 kg ha^{-1}), Mg (31.6 and 32.9 kg ha^{-1}), S (4.8 and 4.6 kg ha^{-1}), B (623.6 g ha^{-1}), Cu (106.9 g ha^{-1}), Fe (1808.1 g ha^{-1}), Mo (736.5 g ha^{-1}), Mn (10.7 g ha^{-1}), and Zn (1003.7 g ha^{-1}) were applied for ‘Stella TY’ and ‘HS1188’, respectively, in both experiments in the form of KNO_3, $Ca(NO_3)_2$, MAP, $MgSO_4$, Reloxin BRA (11.6% K_2O; 1.3% S; 0.9% Mg; 2.1% B; 0.4% Cu; 2.7% Fe; 2.5% Mn; 0.04% Mo; and 3.4% Zn), and Reloxin X60 (6.0% Fe).

Evaluated and calculated characteristics

The plants were analyzed at 14-day intervals, when data on plant height, number of leaves and racemes, fresh and dry mass of the plant (roots, leaves, stems, and fruits), and nutrient contents in the roots, leaves and stem, and fruits were collected. The roots were collected using a shovel, totaling a soil volume of 0.027 m^3 (0.3 x 0.3 x 0.3 m). After collection, the plant parts were weighed to determine the fresh mass, and, subsequently, all the material was washed in water and neutral detergent and dried in a forced-air circulation oven (60 °C) to determine the dry mass and nutrient contents (N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn).

The degree days (DD) were calculated according to Ometto (1981): $DD = (Tmean - Tb)$ if TB > TM > Tm > Tb or $DD = \frac{2(TM-Tm)\,(Tm-\quad)+(TM-Tm)^2-(TM-TB)^2}{2(TM)}$ if TM > TB > Tm > Tb, where Tmean is the mean temperature, TB is the upper basal temperature (34 °C), Tb is the lower basal temperature (10 °C), TM is the maximum observed temperature, and Tm is the minimum observed temperature. The accumulated thermal sum (ATS) was obtained by adding the degree days up at each phenological stage, which corresponded to I (transplanting until the beginning of flowering), II (beginning of flowering until the beginning of fruit ripening), and III (beginning of fruit ripening until the end of harvesting) (adapted from Alvarenga, 2022).

Nutrient accumulation was calculated by multiplying the content of each nutrient in the plant tissue and the dry matter of each part. The total accumulation in the plant was determined by the sum of the accumulation of the plant parts for each nutrient.

The periods of maximum dry mass and nutrient accumulation were calculated according to Moraes et al. (2018), determined through the points of minimum (PCmin) and maximum (PCmax) curvature in the sigmoidal models.

Nutrient extraction and export were calculated by multiplying the total and fruit nutrient accumulation values, respectively, by the total number of plants in a hectare. The yield was calculated by multiplying the mean mass of fresh fruits per plant and the number of plants per hectare. The relationship between nutrient extraction (N, P, K, Ca, Mg, S, B, Fe, Mn, and Zn) and yield (N/Y) was calculated by dividing the nutrient extraction value in kg ha^{-1} by fruit yield in t ha^{-1}.

Data analysis

A three-parameter sigmoidal non-linear regression model, defined according to the best coefficient of determination (R^2) and built in the SigmaPlot 12.5 program, was used for analyzing dry mass and nutrient accumulation.

RESULTS AND DISCUSSION

Thermal requirement

The mean air temperature during the experimental period was 23.9 °C, while the maximum and minimum mean values were 33.5 and 14.3 °C, respectively. The mean temperature throughout the cultivation cycle was within the extreme ranges of lower (10.0 °C) and higher (34.0 °C) basal temperatures for tomatoes (Alvarenga, 2022).

The duration of phenological stages and accumulated thermal sum (ATS) varied between the hybrids Stella TY and HS1188 (Table 1). Both hybrids accumulated 1815.7 degree days (DD) at the end of their cycles. Schmidt *et al.* (2017) observed ATS values close to that of the present study, with values of 1749.4 and 1717.5 DD for Netuno and San Vito tomatoes, respectively. Palaretti et al. (2012) verified a lower thermal requirement for F1 Scheila, grown in an open field (1548.0 DD for 148 days), which was sufficient for crop development. Importantly, ATS varies according to the genotype and has been widely tested and used for different crops, as it is a measure that represents the plant development time, regardless of the time of year.

TABLE 1. Duration of Stages I (transplanting until the beginning of flowering), II (beginning of flowering until the beginning of fruit ripening), and III (beginning of fruit ripening until the end of harvesting) in days after transplanting (DAT) and accumulated thermal sum (ATS) by the tomato hybrids Stella TY and HS1188. Campinas, Instituto Agronômico, 2017.

Stage	Stella TY		HS1188	
	DAT	ATS	DAT	ATS
I	0 - 29	461.6	0 - 29	461.6
II	30 - 70	572.4	30 -77	670.1
III	71 - 126	781.7	78 - 126	684.0
∑		1815.7		1815.7

ATS can be used to implement crop fertilization management strategies to the detriment of days after transplanting (DAT). The mathematical model ATS = 56.7256 + 13.9599x, with an $R^2 = 0.99$, allows adapting the data presented in DAT to ATS. Thus, the farmer or extension agent can decide which is the best strategy to be used according to the available resources.

Growth and mass accumulation

'Stella TY' and 'HS1188' reached the staking system height (1.8 m) at 84 days after transplanting (DAT), when they had 38 and 39 leaves and 13 and 14 racemes, respectively. Importantly, the pruning height was lower than that usually used in protected cultivation (2.2 m), as the structure used in the experiment had a floor-to-ceiling height of 2.0 m.

Modeling showed that the intensification of the total dry mass (TDM) accumulation occurred when 'Stella TY' had 33 leaves and 'HS1188' had 48 leaves, which represent a vegetative canopy with 82 and 76% of total leaves observed at 126 DAT, respectively. The number of leaves is a phenological characteristic used to monitor the plant development to the detriment of DAT and help in planning the distribution of nutrients in growing seasons and regions where environmental differences interfere with the crop cycle duration (Moraes et al., 2016; Moraes et al., 2018).

The partition of the total dry mass was different between the development stages. Dry accumulation in stage I was lower (36.6 and 22.2 g), being composed mainly of leaves and stems. Intense growth and mass accumulation (233.4 and 194.8 g) were observed from stage II, while stage III showed stabilization of the leaf and stem dry mass (LSDM) and a significant increase in fruit dry mass (FDM), totaling 687.0 and 606.9 g of TDM at the end of the production cycle.

The significant increase in leaf area in the first stages of plant development is important to increase solar radiation interception, with the obtained assimilates used in the formation of new leaves at this stage, also behaving as a drain (Peil & Galvez, 2005). The photoassimilates are translocated to the fruits at the beginning of fruiting, becoming the main drains of the plant (Purquerio et al., 2016). FDM became higher than LSDM at 118 and 113 DAT for 'Stella TY' (Figure 1a) and 'HS1188' (Figure 1b), respectively, with FDM representing 52 and 51% of TDM at 126 DAT. These results were higher than the value of 45% observed by Prado et al. (2011) but lower than the 66 and 71% observed by Moraes et al. (2018) in field cultivation.

The root dry mass (RDM) was not very expressive when compared to the other plant parts, representing between 1 and 2% of the total.

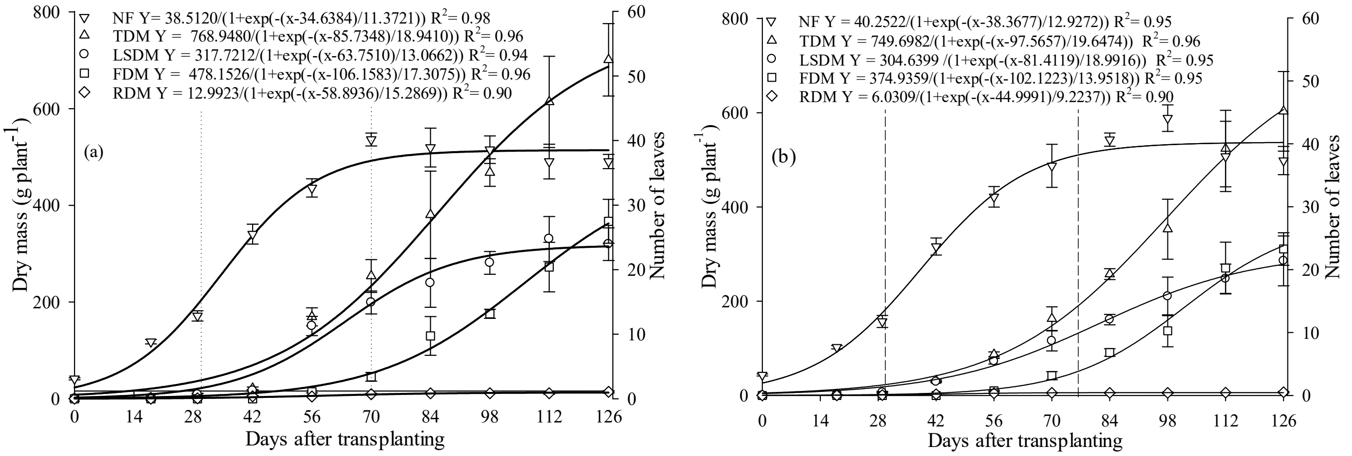

FIGURE 1. Total (TDM), leaf and stem (LSDM), fruit (FDM), and root dry mass (RDM) accumulation and number of leaves (NF) of ‘Stella TY’ (a) and ‘HS1188’ (b) tomatoes as a function of days after transplanting. Dashed vertical lines indicate 29 (461.5 degree days, Stage I) and 70 DAT (1033.9 degree days, Stage II) (a) and 29 (461.5 degree days, Stage I) and 77 DAT (1131.6 degree days, Stage II) (b).

Nutrient accumulation

Mathematical models allowed estimating the amount of nutrients (K, N, Ca, S, Mg, P, Mn, Zn, Fe, Cu, and B) accumulated by ‘Stella TY’ and ‘HS1188’ tomatoes throughout the crop cycle (Figures 2a-d).

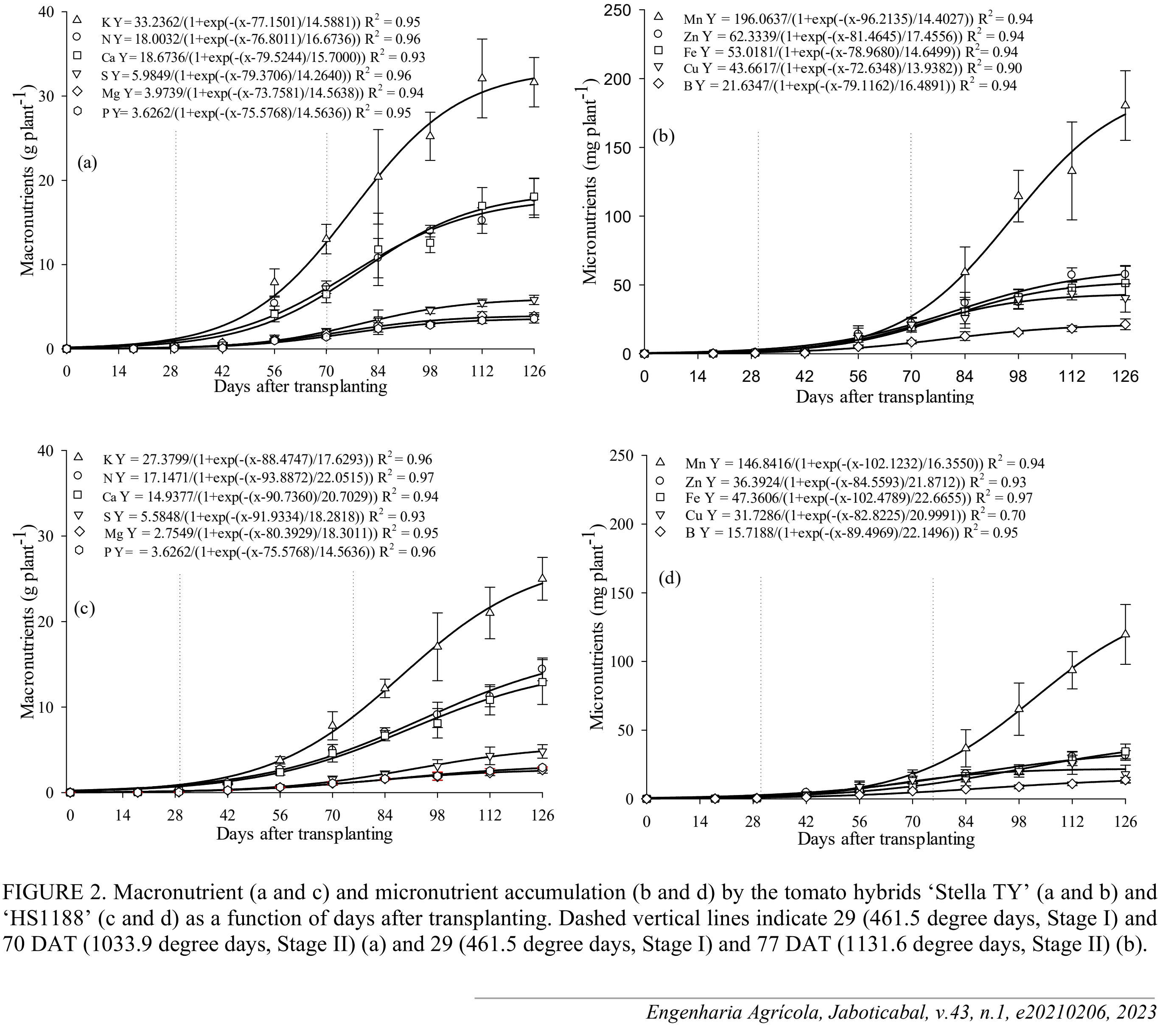

FIGURE 2. Macronutrient (a and c) and micronutrient accumulation (b and d) by the tomato hybrids ‘Stella TY’ (a and b) and ‘HS1188’ (c and d) as a function of days after transplanting. Dashed vertical lines indicate 29 (461.5 degree days, Stage I) and 70 DAT (1033.9 degree days, Stage II) (a) and 29 (461.5 degree days, Stage I) and 77 DAT (1131.6 degree days, Stage II) (b).

The maximum macronutrient (g plant^{-1}) and micronutrient (mg plant^{-1}) accumulation observed at the end of the cultivation cycle for 'Stella TY' followed the order K (32.1) > Ca (17.7) > N (17.1) > S (5.8) > Mg (3.9) > P (3.5) and Mn (174.1) > Zn (57.8) > Fe (51.0) > Cu (42.7) > B (20.4) (Figures 2a and b). The other for 'HS1188' was K > (24.5) > N (13.9) > Ca (12.6) > S (4.8) > P (2.9) > Mg (2.5) and Mn (119.2) > Fe (35.0) > Zn (31.6) > Cu (28.1) > B (13.2) (Figures 2a and b).

K was the nutrient most accumulated by tomato plants (Figures 2a and c), as also observed by other authors (Fayad et al., 2002; Purquerio et al., 2016). K accumulation for 'Stella TY' and 'HS1188' represented approximately 40% of the total amount of accumulated macronutrients. The hybrids presented K accumulation at least 79% higher than genotypes studied in a protected environment by Fayad et al. (2002), Prado et al. (2011), and Omaña & Peña (2015).

In Brazil, studies that address K accumulation in a protected environment are outdated, showing low mass production, which makes their use difficult for the currently cultivated genotypes. Purquerio et al. (2016) and Moraes et al. (2018) reported the accumulation of 27.8 and 33.0 g K plant^{-1} in field cultivation for Dominador and Serato tomatoes and 30.2 and 29.8 g K plant^{-1} for Gault and Pomerano.

A total of 79 and 86% of all K was accumulated by 'Stella TY' and 'HS1188' tomatoes in a period of 61 and 71 days, respectively (Table 2). K is involved in physiological processes that control plant growth, flowering, fruiting, and fruit quality (Alvarenga, 2022). Therefore, it has increasing accumulation at the three phenological stages.

TABLE 2. Beginning (PCmin), end (PCmax), and duration of the period (DP) of highest nutrient, total (TDM), leaf and stem (LSDM), and fruit dry mass (FDM) accumulation, amount of accumulated nutrients in the period (AC), and the ratio between AC and total accumulation (AC/TA) in days after transplanting (DAT) for the tomato hybrids Stella TY and HS1188. Campinas, Instituto Agronômico, 2017.

	'Stella TY'					'HS1188'				
	PCmin[1]	PCmax[2]	DP[3]	AC	AC/TA	PCmin	PCmax	DP	AC	AC/TA
	---- DAT ----		Days	g plant^{-1}	%	--- DAT ---		Days	g plant^{-1}	%
N	43	110	67	13.7	80	50	126	76	11.8	85
P	46	105	59	2.8	79	46	126	80	2.5	87
K	48	106	61	25.2	79	53	124	71	20.9	86
Ca	48	111	63	14.2	80	49	126	77	10.9	86
Mg	45	103	58	3.0	78	44	117	73	2.1	82
S	50	108	57	4.6	79	55	126	71	4.2	86
TDM	48	124	76	609.5	-	58	126	68	518.6	-
LSDM	38	90	52	227.1	-	43	119	76	232.1	-
FDM	72	126	54	304.5	-	74	126	52	273.5	-
	---- DAT ----		Days	mg plant^{-1}	%	--- DAT ---		Days	mg plant^{-1}	%
B	46	112	66	16.5	81	45	126	81	11.3	86
Cu	45	101	56	33.3	78	41	125	84	24.2	86
Fe	50	108	58	40.1	79	57	126	69	29.4	84
Mn	67	125	58	149.9	86	69	126	57	102.0	86
Zn	46	112	66	45.9	79	41	126	85	27.3	86

[1]Point of minimum curvature (PCmin = x0-2b) and [2]Point of maximum curvature (PCmax = x0+2b), calculated from parameters of the sigmoidal equation used to adjust the nutrient accumulation data; [3]DP = PCmax − PCmin.

N and Ca showed the same accumulation trend and similar values. However, the second most accumulated nutrient at 126 DAT was Ca for 'Stella TY' and N for 'HS1188' (Figures 2a and c). The difference in the order of N and Ca accumulation corroborates other studies (Fayad et al., 2002; Betancourt & Pierre, 2013; Omaña & Peña, 2015).

N is the nutrient that acts most significantly in the formation of the photosynthetic canopy of tomato plants (Alvarenga, 2022). The hybrids Stella TY and HS1188 showed the beginning of PCmin for TDM 5 and 8 days after PCmin for N, respectively (Table 2). Its importance continues during the fruiting stage for the photosynthetic complex maintenance and the relationship with other nutrients.

S was the fourth most accumulated nutrient (Figures 2a and c), corroborating with the study of Fayad et al. (2002) in a protected environment. P was little accumulated but even lower values were found in a protected environment by Omaña & Peña (2015), in the hydroponics system by Prado et al. (2011), and in the field by Fayad et al. (2002).

In both tomato hybrids, PCmin for P occurred at 46 DAT. However, 'HS1188' had a DP 21 days longer than 'Stella TY' (Table 2). Importantly, the accumulated P in the periods of highest demand was very close between the hybrids (Table 2) even with the 21-day difference in the duration of these periods, indicating the need for different management practices to supply this nutrient, depending on the genotype.

Mg is the central element of the chlorophyll molecule (Rengel et al., 2022) and its availability is fundamental during the vegetative and reproductive stages. PCmin, PCmax, and DP for Mg were similar to those observed for P in the hybrid Stella TY, but this ratio was non-representative for HS1188, as well as for Gault and Pomerano (Moraes et al., 2018) (Table 2).

The highest increase in micronutrient accumulation occurred at fruiting. Mn was accumulated in higher amounts, corroborating Fayad et al. (2002) and Moraes et al. (2018). PCmin for Mn was the latest among the evaluated micronutrients, close to the PCmin for fruit dry mass and with increasing accumulation until the end of the tomato cycle.

Fe was the third most accumulated micronutrient for ‘Stella TY’ (51.0 mg $plant^{-1}$) while ‘HS1188’ accumulated 35.0 mg $plant^{-1}$, being the second most accumulated for this hybrid (Figures 2b and d). Thus, it was more requested by ‘HS1188’ than ‘Stella TY’ despite its smaller total accumulated amount.

Zn plays an important role in the metabolism of carbohydrates, proteins, auxins, and membrane integrity (Rengel et al., 2022). Fayad et al. (2002) and Purquerio et al. (2016) observed that Zn accumulation ranged from 25.0 to 33.9 mg $plant^{-1}$, values lower than those of Stella TY and HS1188.

The micronutrients B and Cu were the two less accumulated by plants of both hybrids (Figures 2b and d) and also by ‘Dominador’ and ‘Serato’ in the study by Purquerio et al. (2016). These nutrients are involved in reproductive growth, flowering induction, pollination, and fruit establishment (Rengel et al., 2022).

Yield, extraction, export, and amount of nutrients required per ton of fruit produced

Yields of the tomato group Salad ‘Stella TY’ and Italian ‘HS1188’ (105.7 and 103.4 t ha^{-1}, respectively) were considered adequate and above the national mean of 70.1 t ha^{-1} (IBGE, 2019).

The order of nutrient extraction differed between genotypes for N, Ca, P, Mg, Fe, and Zn (Table 3). K was the most extracted nutrient, with a value approximately 42% higher than the second place, which was Ca for ‘Stella TY’ and N for ‘HS1188’. K was also the nutrient most exported by hybrids, with values, respectively, 39.5 and 47.0% higher than N export and 89.1 and 88.2% higher than P export. However, K was the second largest in the N/Y ratio, behind N in ‘Stella TY’ and P in ‘HS1188’.

TABLE 3. Nutrient extraction by plants (ET), export by fruits (EP), the ratio between export and extraction (EP/ET), and amount of nutrients required per ton of fruit produced (N/Y) by the tomato hybrids Stella TY and HS1188 at the end of the cultivation cycle. Campinas, Instituto Agronômico, 2017.

	‘Stella TY'				‘HS1188'			
	ET	EP	EP/ET	N/Y	ET	EP	EP/ET	N/Y
	----- kg ha^{-1} -----		%	kg t^{-1}	----- kg ha^{-1} -----		%	kg t^{-1}
N	238.59	139.35	58.40	2.26	192.08	107.66	56.05	1.86
P	47.60	25.06	52.62	0.45	39.10	23.88	61.07	0.38
K	421.90	230.27	54.58	3.99	333.38	203.07	60.91	3.22
Ca	241.13	11.69	4.85	2.28	172.25	10.94	6.35	1.67
Mg	51.89	12.58	24.23	0.49	35.15	10.57	30.07	0.34
S	77.38	12.62	16.30	0.73	64.20	11.74	18.28	0.62
B	0.29	0.06	20.77	0.00	0.18	0.05	29.73	0.00
Cu	0.54	0.03	5.59	0.01	0.24	0.03	12.62	0.00
Fe	0.69	0.23	33.92	0.01	0.46	0.18	38.30	0.00
Mn	2.41	0.08	3.51	0.02	1.60	0.06	3.76	0.01
Zn	0.77	0.14	18.16	0.01	0.42	0.11	25.23	0.00

K overuse and misuse are not uncommon in commercial crops due to its importance (Alvarenga, 2022). High K concentrations can induce negative effects on fruit production and quality due to competition with Ca and Mg for the absorption site, nutritional imbalance, and difficulty in absorbing water by the plant (Rengel et al., 2022).

N and Ca were extracted in similar amounts, corroborating Fayad et al. (2002) and differing from Purquerio et al. (2016) and Moraes et al. (2018) in field cultivation. The export was different between the two nutrients. N was exported in higher amounts (58.4 and 56.0%) (Table 3), as it is a mobile nutrient with important biochemical functions. In contrast, only 4.8 and 6.3% of the extracted amount of Ca were exported due to its low mobility in the plant, thus consisting of the least exported macronutrient, as also observed by Moraes et al. (2018).

S was the fourth most extracted and exported macronutrient by both hybrids (Table 3). It is a nutrient of little importance in fertilization programs and there is no official recommendation for its application in the state of São Paulo. However, the fact that it is present in other fertilizer sources and/or sulfur fungicides alleviates situations of deficiency.

Mg extraction for ‘Stella TY’ was 32.0% higher than for ‘HS1188’, being the fifth and sixth most extracted nutrients, respectively. Fayad et al. (2002) observed that 21.0% of the extracted Mg was exported and higher values were found for ‘Stella TY’ (24.2%) and ‘HS1188’ (30.1%).

P was the macronutrient with the lowest amount extracted and exported, but it presented the highest EP/ET ratio (Table 3), as also observed by Moraes et al. (2018).

The most exported micronutrient for both hybrids was Fe (Table 3), as also observed for the cultivars Santa Clara and EF-50 (Fayad et al., 2002) and Dominador and Serato (Purquerio et al., 2016). In contrast, Cu was the least exported micronutrient, corroborating with Moraes et al. (2018).

The amounts of nutrients per ton of fruit produced (N/Y) indicate the nutritional requirements of the plant, isolating the factors yield and crop cycle duration. ‘Stella

TY' required K > N = Ca > S > Mg = P and 'HS1188' demanded K > N > Ca > S > P > Mg (Table 3). Among all nutrients, the hybrid Stella TY, from the Salad group, was more nutritionally demanding than the hybrid HS1188, from the Italian group, and the hybrids Pomerano and Gault, also from the Salad type (Moraes et al., 2018) in the field cultivation. The required amount of nutrients per ton of fruit can be useful in recommending fertilization, as it allows adjustments to be made according to the expected tomato yield.

CONCLUSIONS

Dry mass and nutrient accumulation could be determined by a sigmoidal non-linear model for both hybrids grown in a protected environment. The cumulative nutrient order was K > Ca > N > S > Mg > P > Mn > Zn > Fe > Cu > B for 'Stella TY' and K > N > Ca > S > P > Mg > Mn > Fe > Zn > Cu > B for 'HS1188'. The accumulated thermal sum was 1851.7 degree days at 126 days after transplanting (DAT).

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REFERENCES

Alvarenga MAR (2022) Tomate: Produção em campo, em casa-de-vegetação e em hidroponia. Lavras, Universitária de Lavras. 517p.

Cesar TQZ, Silva AJ, Purquerio LFV, Santos A (2023) Analysis of fertigation effluents from mini-tomato greenhouses and the need for detection of control points. Engenharia Agrícola 43(1):e20220019.

Betancourt P, Pierre F (2013) Extracción de macronutrientes por el cultivo de tomate (*Solanum lycopersicum* Mill. Var. Alba) em casas de cultivo em Quíbor, estado Lara. Bioagro 25: 181-188.

Dezordi LR, Aquino LA de, Novais RF, Aquino PM de, Santos LPD dos (2015) Nutrient recommendation model for carrot crop – FERTICALC Carrot. Revista Brasileira de Ciência do Solo 39:1714-1722.

Diógenes TBA, Oliveira FHT de, Queiroga FM de, Moura ACC, Carvalho SL de, Tavares HAM (2018) Accumulation of dry mass and macronutrients by the Caeté tomato cultivar under field conditions. Dyna 85: 101-106.

Fayad JÁ, Fontes PCR, Cardoso AA, Finger FL, Ferreira FA (2002) Absorção de nutrientes pelo tomateiro cultivado sob condições de campo e de ambiente protegido. Horticultura Brasileira 20: 90-94.

IBGE - Instituto Brasileiro de Geografia e Estatística (2019) Levantamento sistemático da produção agrícola. Available: https://sidra.ibge.gov.br/home/lspa/brasil. Accessed Feb 04, 2020.

Moraes CC de, Araújo HS, Factor TL, Purquerio LFV (2016) Fenologia e acumulação de nutrientes por cebola de dia curto em semeadura direta. Revista de Ciências Agrárias 36: 281-290.

Moraes CC de, Factor TL, Araujo HS, Purquerio LFV (2018) Plant growth and nutrient accumulation in two tomato hybrids under tropical conditions. Australian Journal of Crop Science 12: 1419-1425.

Omaña HG, Peña H (2015) Acumulación de materia seca y balance de nutrientes en tomate Solanum lycopersicum L. cultivado en ambiente protegido. Bioagro 27: 111-120.

Ometto JC (1981) Bioclimatologia vegetal. São Paulo, Agronômica Ceres. 425p.

Palaretti LF, Mantovani EC, Silva DJH, Cecon PR (2012) Soma térmica para o desenvolvimento dos estádios do tomateiro. Revista Brasileira de Agricultura Irrigada 6: 240-246.

Peil R, Gálvez J (2005) Reparto de materia seca como factor determinante de la producción de las hortalizas de fruto cultivadas en invernadero. Revista Brasileira de Agrociência 11: 5-11.

Prado R de M, Santos VHG, Gondim AR de O, Alves AV, Cecílio Filho AB, Correia MAR (2011) Crescimento e marcha de absorção de nutrientes em tomateiro cultivar Raísa cultivado em sistema hidropônico. Semina: Ciências Agrária 32: 19-30.

Purquerio LFV, Mattar GS, Duart AM, Moraes CC, Araújo HS, Santos FF (2019) Growth, yield, nutrient accumulation and export and thermal sum of Italian zucchini. Horticultura Brasileira 37: 221-227.

Purquerio LFV, Santos FFB, Factor TL (2016) Nutrient uptake by tomatoes 'Dominador' and 'Serato' grown in São Paulo State, Brazil. Acta Horticulturae 1123: 35-40.

Rengel Z, Cakmak I, White P (2022) Marschner's Mineral Nutrition of Plants. London, Academic Press. 816p.