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Accumulation of dry matter and macronutrients by the *Caeté* tomato under field conditions

Talita Barbosa Abreu Diógenes, Fábio Henrique Tavares de Oliveira, Fábio Martins de Queiroga, Anderson Cley Costa Moura, Simplicio Lyra de Carvalho & Hernane Arllen Medeiros Tavares

Universidade Federal Rural do Semiárido, Mossoró, Brasil. talita@ufersa.edu.br, fabio@ufersa.edu.br, fmartinsubi@gmail.com, andersontuf_15@hotmail.com, simpliciolyra@gmail.com, hernanearllen@hotmail.com.

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Abstract
New cultivation techniques associated with the use of genetic materials with high productive potential have provided the need for studies related to the accumulation of dry matter and nutrients by tomato plants. The objective of this study was to evaluate the accumulation of dry matter and macronutrients by the tomato 'Caeté' in Chapada do Apodi-CE. The accumulation of dry matter and nutrients in the vegetative part (stems and leaves) and in the fruits was quantified by sampling the plants at 14, 28, 42, 56, 70, 84 and 99 days after the transplant (DAT). The total accumulation of macronutrients in the plant followed the accumulation of dry matter, with greater demands in the fruiting phase. The accumulation of macronutrients at 99 DAT followed by the following decreasing order: K> N> Ca> S> Mg> P.

Keywords: Solanum lycopersicum L.; growth; fertigation; alkaline soil; Semiarid.

Acumulación de materia seca y macronutrientes por el tomate *Caeté* bajo condiciones de campo

Resumen
Nuevas técnicas de cultivo asociadas al uso de materiales genéticos de alto potencial productivo han proporcionado la necesidad de estudios relacionados con la acumulación de materia seca y nutrientes por las plantas de tomate. El objetivo de este estudio fue evaluar la acumulación de materia seca y macronutrientes por el tomate 'Caeté' en Chapada do Apodi-CE. La acumulación de materia seca y nutrientes en la parte vegetative (tallos y hojas) y en los frutos se cuantificó mediante el muestreo de las plantas a los 14, 28, 42, 56, 70, 84 y 99 días después del trasplante (DAT). La acumulación total de macronutrientes en la planta siguió a la acumulación de materia seca, con mayores demandas en la fase de fructificación. La acumulación de macronutrientes a 99 DAT seguido por el siguiente orden decreciente: K> N> Ca> S> Mg> P.

Palabras clave: Solanum lycopersicum L; crecimiento; fertirrigación; suelo alcalino; Semiárido.

1. Introduction

The tomato cultivars of the Italian Group, such as the Caeté tomato, are the most cultivated in the state of Rio Grande do Norte due to the consumption habits of the population and the lower cost of production because the tomatoes of this group show a fixed growth that ends after flowering, not requiring cultivation practices such as thinning, in addition to presenting a shorter cycle [10].

The use of new cultivation techniques (drip irrigation, mulching, fertigation, among others) when associated with the use of tomato cultivars of high productive potential highlights the need for studies focused on dry matter accumulation and nutrient absorption curves by the crop conducted according to the current cultivation practices.

Nutrient absorption curves and dry matter accumulation as a function of the age of the plant enable knowing the periods of greater nutrient requirement and dry matter production, obtaining reliable information on the most convenient times for applying fertilizers [6,15]. This

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information can help estimate the amount of nutrients needed to supply the plants through fertilization [20], thus providing better synchrony between the nutrient demand of the plant and the supply of these nutrients via fertigation [4,17].

However, it is necessary to take into account factors related to the genotype and the growing environment which can generate differences in the amount of nutrients required and absorbed when comparing data from different studies on the progress of dry matter and nutrient accumulation by tomato plants [6].

For most tomato cultivars, the plant absorbs less than 10% of the total nutrients accumulated during the cycle until the beginning of flowering [25, 6]. During flowering and fruiting (the phases of higher absorption intensity), the tomato accumulates high amounts of nutrients [11]. In this period the N, P, and K concentrations are higher in the fruits, and those of Ca, Mg and S are higher in the vegetative parts [25,5].

In view of the above, we can verify that the present study is innovative for the region where the soils are alkaline derived from calcareous (one of the few found in Brazil), in which studies on accumulation of dry matter and nutrients are scarce. Moreover, the tomato is a crop that demands high technological level due to its improved genetic development with new cultivars and hybrids frequently being inserted in the market which require large investment in its production, thereby justifying these experiments to be carried out regularly.

Thus, the objective of this study was to evaluate the accumulation of dry matter and nutrients by the tomato cultivar '*Caeté*' cultivated under field conditions.

2. Material and methods

The experiment was conducted under field conditions at Fazenda Terra Santa, Quixeré-CE, in an area of 0.2 ha planted according to a single-row system with 2.0 x 0.62 m spacing. The farm is located at Chapada do Apodi at 5°05'18" South latitude, 37°47'30" West longitude, at 123 m altitude, in a Haplic Cambisol soil derived from calcareous. The chemical characteristics evaluated before implanting the experiment in the 0-20 cm layer were: pH (H_2O) = 7.2; OM = 18.12 g kg^{-1}; Ca^{2+}, Mg^{2+}, K^+ and Al^{3+} = 8.3; 2.1; 0.493 and 0.0 cmol$_c$ dm^{-3}, respectively; P = 4.02 mg dm^{-3}; Cu, Fe, Mn and Zn = 0.63; 2.05; 28.5 and 2.4 mg dm^{-3}, respectively.

The region's climate according to the Köppen classification is BSwh; dry, very hot and with rainy season in the summer delaying towards autumn.

Soil preparation consisted of subsoiling, plowing and two crossed harrows followed by row grooving, in which the planting fertilization was carried out with 15kg ha-1 of nitrogen (N), 30 kg ha-1 of phosphorus (P2O5) and 12 kg ha-1 of potassium chloride (KCl).

Ridges with 0.20 m height and 0.60 m wide were raised over the planting furrows where a drip irrigation system was installed using 16 mm flexible tape and emitters with a flow rate of 1.7L h^{-1}, spaced 0.30 m apart. The soil was then covered with 1.40 m wide and 0.25 microns thick black polyethylene plastic with the aid of a feeder machine. The planting holes were subsequently spaced 0.62 m apart with a 60 mm diameter nozzle.

Sowing the *Caeté*® hybrid was performed with 200-cell expanded polystyrene trays using the Golden Mix® commercial substrate. The seedlings were transplanted on June 10, 2013, at the stage of five definitive leaves, 25 days after sowing.

The cover fertilizations were carried out weekly via fertigation based on the soil chemical analysis performed prior to installing the experiment and the fertilization recommendation tables of the states of Minas Gerais, São Paulo and Pernambuco, in which 485 kg ha^{-1} of N, 600 kg ha^{-1} of P_2O_5, 690 kg ha^{-1} of (KCl), 118 kg ha^{-1} of Ca, 11 kg ha^{-1} of Mn and 20 kg ha^{-1} of Zn were applied.

Pest and disease control was carried out in accordance with technical recommendations adopted in the region. Control of invasive plants was performed between the rows using a hoe and manually between plants.

The plants were tutored using tutors and ropes. A 2.0 m height tutor was placed at the end of each row and at every meter at a depth of 0.30m.

For evaluating the accumulation of dry matter and nutrients in the crop, plants in good phytosanitary status were sampled at intervals of 14 days to 99 (DAT), thus totaling seven samplings in 4 replicates, and harvested in the morning. Two plants were collected in the first two samplings, while only one was collected in the others. The plants were cut at the stem, placed in properly identified bags and sent to the laboratory. The fruits of the sampled plants that fell due to senescence were used in the sampling.

At the laboratory, the plants were weighed (total weight) and then fractionated into vegetative part (stems and leaves) and fruits. The vegetative part was crushed in a forage machine and then a sub-sample of about 500 g was taken. A sub-sample of about 500 g was also collected from the fruits after they were cut into small pieces in order to accelerate the drying process.

These subsamples were placed in a forced circulation air oven at 65°C until reaching constant mass. The material was subsequently weighed, ground in a Willey mill and then packaged into collection flasks for further chemical analysis.

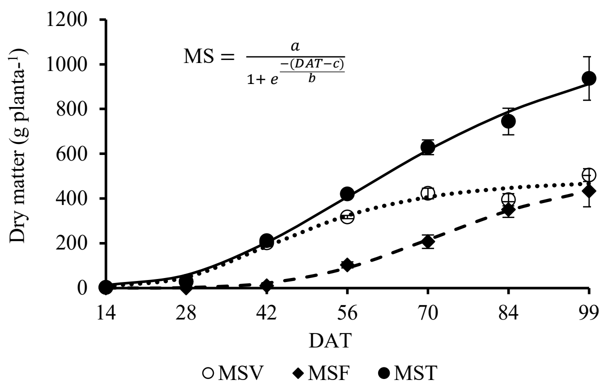
The chemical analyzes for determining the macronutrient accumulations in the vegetative part and the fruits were carried out according to the methodological procedures suggested by [22]. The accumulation of nutrients was estimated for each sampling period of the plants based on the results of the macronutrient concentrations obtained in each of these parts and according to the dry matter contents of the samples.

The data were then submitted to non-linear regression analysis.

3. Results and discussion

3.1. Accumulation of dry matter

Continuous accumulation of dry matter in the aerial part of the tomato was observed throughout the cycle, which was slow up to approximately 30 DAT (Fig. 1). A similar behavior was also observed by [13], using a SM-16 hybrid of determined growth conducted under field conditions in a Haplic Cambisol soil in the same region as the present study.



Equations	Coefficients			R^2
	A	b	c	
MSV	492.56	-4.08	48.58	0.96
MSF	540.38	-5.45	76.53	0.99
MST	1211.47	-3.25	70.23	0.99

Figure 1. Accumulation of dry matter in the vegetative part (MSV), fruits (MSF) and total (MST) in 'Caeté' cultivar grown under field conditions as a function of days after transplant (DAT).
Source: The authors.

According to [16], the initial slow growth of the plants is because they use much of their energy for soil fixation, since the roots at this stage are the preferential drainage for photoassimilates.

After 30 DAT, the dry matter accumulation was higher, especially when the plant enters the reproductive phase around 43 DAT, and which intensified until the end of the cycle at 99 DAT reaching the estimated maximum total dry matter (TDM) of 912.84 g plant^{-1} (Fig. 1). This result is higher than the 717.37 g plant^{-1} found by [23] with the SM-16 hybrid of determined growth cultivated under field conditions in a Haplic Cambisol soil derived from calcareous. It is also superior to the results obtained by [3], who found 406.3 g plant^{-1} in evaluating the cultivar *Santa Clara* of undetermined growth cultivated under field conditions, and 397 g plant^{-1} with the EF-50 hybrid of determined growth.

Of the total dry matter accumulated estimated at 99 DAT, 467.02 g plant^{-1} (52%) accumulated in the vegetative part (VDM), while 433.82 g plant^{-1} (48%) accumulated in the fruit (FDM). The fruits behaved as the main drain, since they were responsible for 48% of the total dry matter accumulated by the plant. The rest of the dry matter (52%) was distributed among the other drain parts such as leaves, stems and inflorescences (Table 1).

Table 1.
Dry matter accumulated in the vegetative part, in the fruits and total, in 'Caeté' tomato cultivated under field conditions as a function of days after transplant (DAT)

DAT	Dry matter (g plant $^{-1}$)		
	Vegetative	**Fruits**	**Total**
17	6.67	0.14	11.85
28	46.95	2.33	57.82
43	186.12	22.33	204.01
57	323.86	90.25	407.48
71	406.24	215.67	616.42
85	447.01	345.47	788.02
99	467.02 (52%)	433.82 (48%)	912.84 (100%)

Source: The authors

Similar results to those obtained in this study have also been observed by other authors [9,23,19] in evaluating the growth of the Italian type tomato of determined growth in the same soil and climatic conditions as the present study, and also verified that the fruits behaved as the main drain.

At 71 DAT in full fruiting and ripening stages, the dry matter accumulation in the fruits was 215.67 g plant^{-1} (Table 1). This value is more than twice that observed at 57 DAT during the fruiting phase, evidencing that the plant requires higher amounts of nutrients during the fruit maturation phase. According to [13], when the plant begins to produce fruits, carbohydrates and other photoassimilates are translocated from the leaves to the fruits as a result of the predominance of the reproductive phase over the vegetative phase, so that the fruits begin to act as the main drain of the plants.

3.2. *Accumulation of macronutrients*

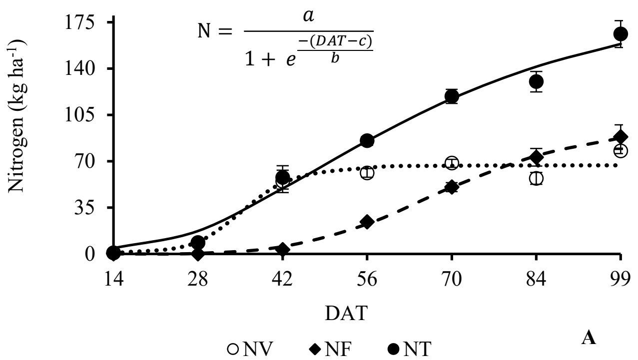
The accumulation of macronutrients by the tomato follows plant growth, being smaller in the initial phase and greater after 30 DAT. With the plant's entry into the reproductive phase at approximately 43 DAT, the accumulation of macronutrients becomes even more marked (Figs. 2A to F). After 70 DAT, N, P and K macronutrients were more intensely translocated from the vegetative part to the fruits, resulting in greater accumulation of these nutrients in the fruits in detriment to the vegetative part.

The accumulation of nutrients in the plant's organs varies depending on the plant's metabolic and physiological activities and on the nutrients themselves. In this study we found that the leaves of the tomato plants were the organs that presented the highest concentration of nutrients in the initial phase of development, and there was an increase in the absorption of these nutrients by the plants as the fruiting phase started, in which N, P and K gradually accumulated in greater quantities in the fruits, while Ca, Mg and S nutrients remained more accumulated in the vegetative part.

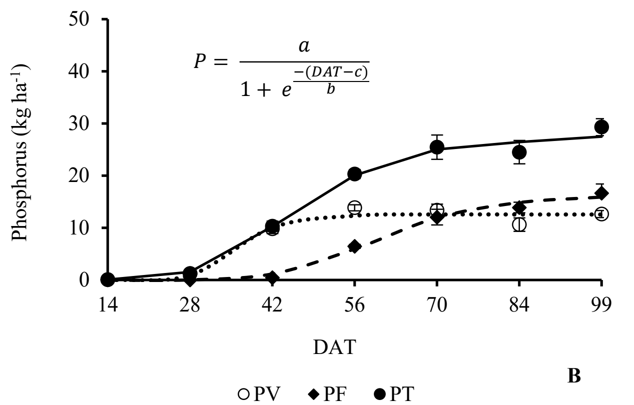
The accumulation of N was low in the initial stages, however this accumulation increased after 30 DAT, reaching even higher values at the end of the crop cycle when an estimated total of 158.6 kg ha^{-1} was recorded at 99 DAT (Fig. 2A). We observed that the behavior of this nutrient's accumulation curve (Fig. 2A) was similar to that of dry matter accumulation (Fig. 1).

Close to 85 DAT there was an increase of N accumulation in the fruits, which was superior to that accumulated by the vegetative part. At 99 DAT, the estimated maximum accumulation of 87.59 kg ha^{-1} of N (Fig. 2A) was reached. This total accumulation was higher than the 23.5kg ha^{-1} found by [17] in an experiment carried out with *Raisa* tomatos of undetermined growth in a hydroponic system, and inferior to the 133.72 kg ha^{-1} found by [10].

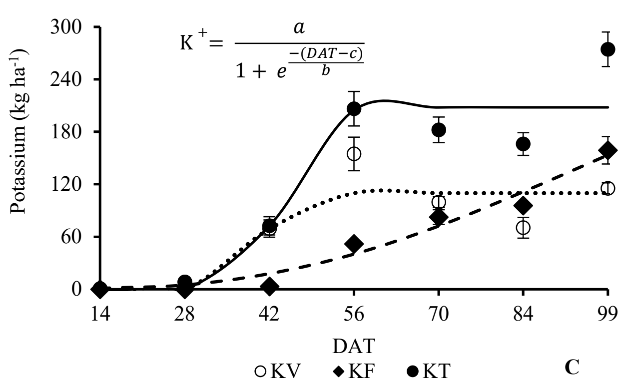
N has greater implication on the plant's growth rate as it favors vegetative development and increases the leaf area, hence the similarity with the dry matter accumulation curve. This nutrient also exerts an effect on the production of photoassimilates, having implication in the source-drain ratio, changing the distribution of assimilates between vegetative and reproductive parts.



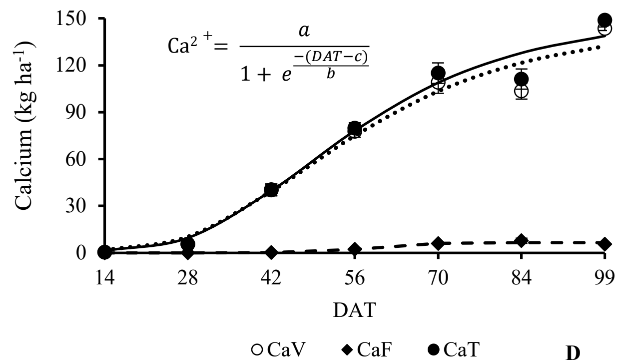
Equations	Coefficients			R^2
	a	b	c	
NV	66.94	-7.54	35.75	0.97
NF	101.21	-5.63	71.10	0.99
NT	203.37	-2.87	63.78	0.99



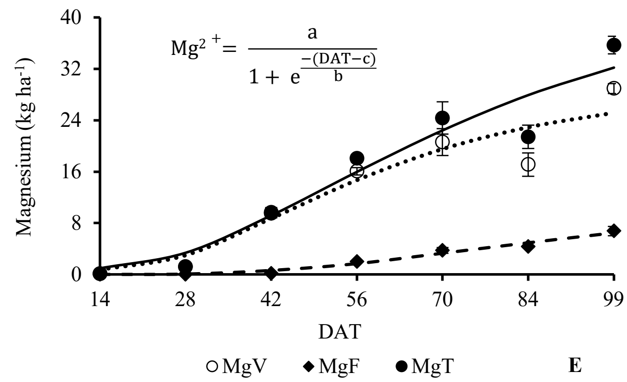
Equations	Coeficientes			R^2
	a	b	c	
PV	12.64	-9.00	36.85	0.98
PF	16.50	-6.89	61.71	0.99
PT	28.14	-5.24	47.79	0.99



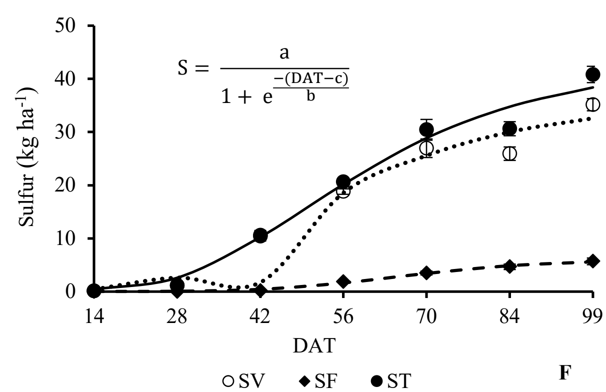
Equations	Coefficients			R^2
	a	b	c	
KV	110.01	-72.02	42.69	0.89
KF	411.23	-3.09	117.03	0.98
KT	208.14	-16.85	44.62	0.94



Equations	Coefficients			R^2
	a	b	c	
CaV	150.16	-3.63	57.05	0.98
CaF	6.51	-15.46	59.74	0.97
CaT	155.45	-3.82	56.82	0.98



Equations	Coefficients			R^2
	a	b	c	
MgV	30.41	-2.99	58.3	0.95
MgF	10.78	-3.74	88.61	0.98
MgT	546.30	-2.65	72.52	0.96



Equations	Coefficients			R^2
	a	b	c	
SV	36.97	-3.63	56.85	0.98
SF	6.30	-5.55	68.51	0.99
ST	44.71	-3.62	60.10	0.99

Figure 2. Accumulation in the vegetative part, of fruits and total of nitrogen (A), phosphorus (B), potassium (C), calcium (D), magnesium (E) and sulfur (F) by Caeté tomato cultivated under field conditions, in function days after transplantation (DAT). V, F and T after each nutrient = accumulation of the respective nutrient in the vegetative part (V), in the fruits (F) and total (T).
Source: The authors

In addition, taking into account the physiological processes of plants compared to other nutrients, N has a greater effect on the growth and absorption rates of elements and is therefore more important in terms of optimum crop nutrition control [7, 8].

Phosphorus was the least accumulated macronutrient by the crop. Its total estimated accumulation at 99 DAT was 27.5kg ha-1, of which 16.6 kg ha-1 of this total was accumulated in the fruits (Fig. 2B).

These values are lower than the 24.9 kg ha-1 (total) and the 14.83 kg ha-1 (fruit) found by [10] in SM-16 tomatoes, and superior to the 7 kg ha-1 accumulated in the tomato fruits observed by Prado et al. (2011).

Only about 10% of the total P applied to the soil via fertilizer is absorbed by the plants [18,12]. For this reason, according to the authors, P is considered a low-utilization nutrient by the plants in the fertilization due to its low values of soil extraction, especially when compared to N and K [10]. However, phosphate fertilization is usually the one that most favors production in Brazilian soils even though the P accumulation is low; one of the reasons is the fact that P is absorbed by the plants from the first stages until senescence.

The lack of phosphorus in Brazilian soils associated with its low mobility and high affinity for iron and aluminum minerals turns the soil into a "plant competitor" for this element, making it the most used macronutrient in fertilization in Brazil [21].

K was the nutrient accumulated in the greatest quantity by the crop, reaching the total estimated amount of 208.08 kg ha-1 at 99 DAT, of which 153.56 kg ha-1 was accumulated in the fruits. The amount of K in the vegetative part stabilized close to 71 DAT in the fruit maturation stage and with an increase in the fruits (Fig. 3B). K is the most abundant cation in plant tissues; it is absorbed from the soil solution in large quantities by the roots in the form of the K+ ion [24]. However and also according to the authors, this nutrient is not part of any organic structure or molecule and it can be found as free or adsorbed cations, which makes it easily exchangeable between cells or tissues with high intracellular mobility.

The applied K is used by the plant in large quantities. However, in soils that present medium or high levels of this nutrient, naturally fertile soils or those derived from previous fertilizations, the application of this macronutrient in high doses favors luxury consumption, which is when the plant absorbs more potassium than it needs and this extra amount has no reflection on productivity.

[17] found that that the total K accumulated by the Raisa tomato in a hydroponic system was 41 kg ha-1. [10] obtained higher values of total K (305.83 kg ha-1) and in the fruit (178.63 kg ha-1).

The estimated total Ca accumulation at 99 DAT was 138.8 kg ha-1. This is also a nutrient that is accumulated in large quantity by the tomato. The fruit (an organ with low accumulation of Ca) accumulated the maximum estimated amount of 6.5 kg ha-1 (4.7%) at 99 DAT (Fig. 2D). After being transported to the leaves, Ca becomes immobile and does not translocate into fruit [1]. In this sense, the low content of this nutrient found in the fruit is due to the concentration dilution resulting from the fruit growth and the precipitation of Ca in the phloem [14].

The results obtained for the total accumulation of Ca in this study are similar to those found by [3] for the EF-50 hybrid (cultivated in a protected environment) and for the Santa Clara cultivar (cultivated in the field), finding total Ca accumulations of 195 and 202 kg ha-1, respectively. The authors also observed that the fruits accumulated only 5% of the total accumulated by the plant; these results are very similar to those found in the present study for nutrient accumulation in the fruit, which was 4.7% (Fig. 2D).

In situations where fruit growth occurs rapidly, dilution may lead to Ca concentrations below the required critical level, which can result in deficiency symptoms in fruits, known as blossom end rot, which is very common in tomatoes. Another factor that can accentuate this difference in the amounts of Ca accumulated in the vegetative part and in the fruits is the competition between K and Ca that occurs inside the plant [11]. The higher potassium flux contributes to decreasing the presence of Ca in fruits.

Total Mg accumulation at 99 DAT was 32.2 kg ha-1, in which the greatest accumulation was observed in the vegetative part. The estimated accumulation in the fruits was 6.5 kg ha-1 (Fig. 2E). Mg has a specific role in activating plant enzymes involved in respiration, photosynthesis and synthesis of DNA and RNA [2]. Moreover, according to [14], magnesium is also part of the chlorophyll molecule structure, being one of the reasons why this nutrient accumulates more in the vegetative part than in the fruits.

Similar amounts of total Mg accumulation and in the fruit were also observed by [10] in SM-16 tomatoes of 35.49 kg ha-1 and 8.68 kg ha-1, respectively, and by [3] in the Santa clara tomato cultivar, who found 40 kg ha-1 and 6 kg ha-1 for total accumulation and in the fruit, respectively.

The estimated total of S accumulated by the crop at 99 DAT was 38.4 kg ha-1. The fruit (the organ with the lowest amount of S) had the maximum accumulation of 5.6 kg ha-1 at 99 DAT (Fig. 2F). [3] reported that the EF-50 hybrid and the Santa clara cultivar accumulated 49 kg ha-1 of total S and 9 kg ha-1 in the fruit.

4. Conclusions

The total accumulation of macronutrients in the plant followed the dry matter accumulation, with higher demands found during the fruiting phase, indicating that it is the period of greatest need for fertilization.

The accumulation of macronutrients at 99 DAT maintained the following order: K>N>Ca>S>Mg>P, accumulating 208.08; 158.6; 138.8; 38.4; 32.2 and 27.5 kg ha^{-1}, respectively.

N, P and K accumulated in larger quantities in fruit, while the other macronutrients accumulated more in the vegetative part.

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T.B.A. Diógenes, is BSc. in Agronomist, MSc. in Soil Science and PhD.in Soil and Water Management by the Federal Rural Semi-Arid University (UFERSA), Brazil. Research line: soil fertility and fertilization.
ORCID: 0000-0002-1478-7508

F.H.T. de Oliveira, is PhD. in Agronomy (Soil and Plant Nutrition) by the Federal University of Viçosa, Brazil (2002). Associate professor IV of the Federal Rural University of the Semi-Arid, Brazil.
ORCID: 0000-0001-8581-8482

F.M. de Queiroga, is PhD in Phytotechnology from the Federal Rural University of the Semi-Arid, Brazil (2015). Production and Administrative Manager of Fazenda Terra Santa, Brazil.
ORCID: 0000-0001-9189-8036

A.C.C. Moura, is BSc. in Agronomy by the Federal Rural University of the Semi-Arid, Brazil (2016).
ORCID: 0000-0002-3629-734X

S.L. de Carvalho, is BSc. in Agronomy by the Federal Rural University of the Semi-Arid, Brazil (2016).
ORCID: 0000-0002-8106-2785

H.A.M. Tavares, is a undergraduate student in Agronomy at UFERSA, fellowship of the Institutional Scholarship Program of Scientific Initiation (PIBIC).
ORCID: 0000-0002-5044-2654