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# Growth and macronutrient accumulation in tomato cultivated in an organic system

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## ABSTRACT

The aim of this study was to characterize the growth and nutrient absorption of 'Debora Victory' tomato grown in organic system. The treatments consisted of nine sampling dates, at 2, 32, 46, 60, 77, 91, 109, 122 and 137 days after transplantation (DAT). In the last sampling, plants reached an estimated accumulation of dry and fresh weight in plant shoots of 550 and 9,528 g/plant, respectively. At the end of the cycle, the distribution of dry matter was 73% in the fruits, 16% in the leaves and 11% in the stem. The yield of total fresh fruits was estimated at 154.7 t/ha. The decreasing order of nutrient accumulation in plant shoots was K>N>Ca>P>S>Mg, with estimated values of 22.6; 10.4; 5.0; 2.3; 2.1 and 1.6 g/plant, respectively, corresponding to 431; 198; 95; 44; 40 and 30 kg/ha of K, N, Ca, P, S and Mg, respectively. The decreasing order of nutrient accumulation in the fruits was K>N>P>S>Mg>Ca, with estimated values of 16.6; 8.4; 1.7; 0.8; 0.7 and 0.2 g/plant, respectively, which corresponded to an estimated total extraction of 315; 153; 32; 16; 14 and 3 kg/ha of K, N, P, S, Mg and Ca, respectively. In the last sampling, the greatest accumulation of N, P and K occurred in the fruits and Ca, S and Mg in the vegetative organs (stem + leaves).

**Keywords:** *Solanum lycopersicum*, dry matter, nutrient accumulation, organic agriculture.

## RESUMO

**Crescimento e acúmulo de macronutrientes em tomateiro cultivado em sistema orgânico**

O objetivo desta pesquisa foi caracterizar o crescimento e absorção de nutrientes pelo tomateiro 'Debora Victory' cultivado em sistema orgânico. Os tratamentos constituíram-se por nove épocas de amostragem, aos 2, 32, 46, 60, 77, 91, 109, 122 e 137 dias após o transplante (DAT). As plantas atingiram acúmulo estimado de massa seca e fresca na parte aérea na última amostragem de 550 e 9528 g/planta, respectivamente. Ao final do ciclo, a distribuição da massa seca foi de 73% nos frutos, 16% nas folhas e 11% no caule. A produtividade de frutos frescos totais foi estimada em 154,7 t/ha. A ordem decrescente do acúmulo de nutrientes na parte aérea das plantas foi K>N>Ca>P>S>Mg, com valores estimados de 22,6; 10,4; 5,0; 2,3; 2,1 e 1,6 g/planta, respectivamente, correspondendo a 431; 198; 95; 44; 40 e 30 kg/ha de K, N, Ca, P, S e Mg, respectivamente. A ordem decrescente do acúmulo de nutrientes nos frutos foi K>N>P>S>Mg>Ca, com valores estimados de 16,6; 8,4; 1,7; 0,8; 0,7 e 0,2 g/planta, respectivamente, o que correspondeu a uma extração estimada total de 315; 153; 32; 16; 14 e 3 kg/ha de K, N, P, S, Mg e Ca, respectivamente. Na última amostragem, o maior acúmulo de N, P e K ocorreu nos frutos e de Ca, S e Mg na parte vegetativa (caule + folhas).

**Palavras-chave:** *Solanum lycopersicum*, massa seca, acúmulo de nutrientes, agricultura orgânica.

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The cultivation of tomatoes in organic systems has advantages over the conventional system due to the greater economic return to the farmer (Melo & Silva, 2012; Souza & Garcia, 2013), protection of the environment (Mazzei *et al*., 2021) and production of fruits with better quality, bringing flavor, health, food and nutritional security to the consumer (Nascimento *et al*., 2013; Vieira *et al*., 2014).

One of the bases of organic systems is a fertilization that leads to the nutritional balance of the plants and results in the maximum yield with the balanced use of inputs for the management of fertilization, pests, and diseases (Khatounian, 2001). The "Trophobiosis Theory" (Chaboussou, 1987) underlies the management practices used to obtain the nutritional balance of the plants. Experiments based on this theory showed that, in excess, fertilization with N, K, Ca and Mg, as well as pesticides, can cause metabolic imbalances in plants, making them susceptible to pests and diseases.

Nutrient accumulation patterns show the need for nutrients at each stage of plant development, being important for recommending fertilization (Bastos *et al*., 2013). It is noteworthy that these patterns reflect what the plant needs according to its characteristics and not what should be applied directly, since the efficiency of the use of nutrients

must be considered, which also varies according to climatic conditions, soil type, irrigation system, cultural management, the nutrient considered, among other factors (Fageria, 1998).

Fertilization for plants, according to the patterns of nutrient absorption, will lead to the nutritional balance of the plant, without scarcity or excesses of nutrients, which is recommended according to the "Trophobiosis Theory", thus reducing the susceptibility of plants to pests and diseases (Almeida, 2011; Queiroz, 2011). This is important for greater sustainability, efficiency, and cost reduction for both conventional and organic production systems. However, these informations are still limited, mainly in organic production systems, being found only under conventional cultivation conditions (Purquerio *et al*., 2016).

The aim of this study was to characterize the growth and macronutrient absorption of 'Debora Victory' hybrid tomato, grown in an organic open field system.

## MATERIAL AND METHODS

The plants used in this study were grown at Sítio Paraíso, which has been organic certified by IBD since the year 2000. This is located in the municipality of Itápolis-SP, Brazil (21°21'S, 48°28'W, 485 m altitude), characterized by a tropical climate with dry winter (Cepagri, 2014). During the period plants were in the field, the average maximum temperatures were 31.7, 29.4, 29.4, 27.6 and 32.2ºC, the minimum were 19, 17, 15, 15 and 16ºC, the monthly rainfall were 28.2, 31.6, 2.4, 25.6, and 10.6 mm, and the average relative humidity were 72, 66, 68, 65, and 59% on April, May, June, July, and August, respectively.

The study was performed with the 'Debora Victory' (Sakata) tomato hybrid, of indeterminate growth, cultivated in open field, conducted with one stem per plant. Seeds were sown on February 26, 2014 and transplanted on April 01, 2014, with one row per bed, spaced 1.50 x 0.35 m apart, corresponding to a plant population density of 19,047 plants/ha. Before the tomato, sorghum was grown as green manure (October, 2013 to January, 2014). A soil sample was collected on January 20, 2014, at 0-20 cm depth, after the incorporation of sorghum, with the following results: $pH_{(CaCl2)}$ = 6.9; organic matter content = 22 g/dm$^3$; H+Al = 11 mmol$_c$/dm$^3$; K = 2.8 mmol$_c$/dm$^3$; $P_{resin}$ = 271 mg/dm$^3$; Ca = 52 mmol$_c$/dm$^3$; Mg = 11 mmol$_c$/dm$^3$; SB = 65.8 mmol$_c$/dm$^3$; CEC = 76.8 mmol$_c$/dm$^3$ and V = 86%.

Planting fertilization consisted of 20 t/ha of biodynamic compost produced with grasses from clearing and dairy cattle manure, 15 days before transplanting the seedlings. The organic compost used contained (% of dry matter), 39,6% of organic carbon (C), 1.40% of N, 3.51% of $P_2O_5$, 1.23% of $K_2O$, 7.58% of Ca, 0.46% of Mg, 0.35% of S, humidity of 41.9% and C/N = 28.3. The biodynamic horn-manure preparation (500) was also applied to the beds (100 g/100 L of water) one week before transplanting the seedlings.

The irrigation system consisted of 2 lines of drippers per bed, one on each side of the tomato line. Double-sided plastic film (black/silver) was used to cover the beds and mulch from the grass clearing was distributed between the beds.

Plants were fertigated with the following biofertilizers: Bio K (6 kg of bone meal, 13.5 kg of potassium sulphate, 6 kg of shell limestone, 12 kg of rice bran, 6 liters of molasses, 3 L of milk, 1.5 L of microorganism solution were placed in a 200 L vat and the volume was filled to 200 L with water); Bio N-TM (27 kg of castor bean cake, 3 L of molasses, 3 L of microorganism solution were placed in a vat and the volume was filled to 200 L with water); Bio N-EG (27 kg of chicken manure, 3 L of molasses, 3 L of microorganism solution and the volume was filled to 200 L with water); Bio N-FS (27 kg of blood meal, 3 L of molasses, 3 L of microorganism solution were placed in a 200 L vat and the volume was filled to 200 L with water).

These biofertilizers were analyzed according to the procedures describe by the Brazilian Ministry of Agriculture and Livestock (Brasil, 2014), with the following results of N, P, K, Ca, Mg and S, respectively: Bio K: 0.5; 7.0; 16.0; 0.6; 0.4; 7.0 g/L; Bio N-TM: 1.0; 0.5; 1.3; 0.5; 0.4; 0.1 g/L; Bio N-EG: 1.4; 1.3; 2.0; 0.6; 0.2; 0.2 g/L; Bio N-FS: 1.4; 0.4; 0.3; 0.3; 0.0 (not detected), 0.1 g/L. In the period from 32 to 60 days after transplantation (DAT) 2,971 L/ha of Bio K were applied; from 46 to 109 DAT, 5,143 L/ha of Bio N-TM were applied; from 91 to 109 DAT, 3,331 L/ha of Bio N-EG were applied and from 109 to 137 DAT, 4,078.91 L/ha of Bio N-FS were applied, which corresponded to the total application of 17, 29, 62, 8, 4 and 22 kg/ha of N, P, K, Ca, Mg and S, respectively, through fertigation.

In order to characterize the growth and macronutrient absorption, the treatments consisted of nine sampling dates of the plants at 2, 32, 46, 60, 77, 91, 109, 122, and 137 DAT. At 2 DAT, 14 plants were collected to assess the fresh and dry weight of shoots and macronutrient contents. On the other dates, 4 replications of 1 plant were collected. At 32 DAT, fresh weight, dry weight, and macronutrient contents of leaves and stem were assessed. At 46, 60, 77, 91, 109, 122, and 137 DAT, fresh weight, dry weight, and macronutrient contents of leaves, stem, and fruits were assessed.

After determining the fresh weight on a digital scale (0.1 g precision), the samples were washed with running water, then left for 1 minute to soak in filtered water, and then left to soak for another 1 minute in distilled water. Then they were dried on paper towels, placed in paper bags, and dried in an oven with forced air circulation at 65°C for 3 to 5 days, until a constant weight was reached. The dry weight of each plant's organ was determined on a digital scale. Then, the dried samples were stored in paper bags in a dry chamber (20ºC and 40% relative humidity).

At the end of plants sampling of all dates, samples of leaves, stem, and fruits were sent to the Laboratory of Mineral Nutrition of Plants of UNESP/FCA, to analyze the contents of macronutrients. The determination of the N content was carried out by the sulfuric digestion method, while P, K, Ca, Mg and S were

determined by the nitric-perchloric digestion method, both methods as described by Malavolta *et al.* (1997). The amounts of accumulated nutrients were obtained by the multiplication of the content of each nutrient by the dry weight of the sample.

With the averages of fresh weight of fruits and dry weight of leaves, stem and fruits, and the amounts of macronutrients, the growth and absorption of macronutrients were adjusted over the time by using the Origin Pro 8 software.

## RESULTS AND DISCUSSION

### Growth

At 32 DAT the first flower buds were already observed in the plants, while at 46 DAT there were fruits starting to develop. At 77 DAT the fruits of the first bunch were already red, ready to harvest. At 109 DAT, apical pruning of the plant was carried out, when the crop was in full harvest, and the cycle was finalized at 137 DAT.

There was a continuous increase in dry weight of the stem throughout the cycle, with the maximum estimated value of 63.4 g/plant at 137 DAT (Figure 1B). The daily rate of accumulation of dry weight in the stem was almost constant throughout the cycle, varying from 0.4 to 0.5 g/plant/day (Table 1).

There was an increase in dry weight of the leaves up to 116 DAT, with an estimated maximum of 90.1 g/plant (Figure 1B), which remained nearly constant until the end of the cycle.

The daily accumulation of dry weight of leaves decreased throughout the cycle, from 1.4 g/plant/day in the first period (2 to 32 DAT) to -0.2 g/plant/day in the last period (123 to 137 DAT) (Table 1). The negative value in the last 14 days for dry weight, is probably due to the translocation of nutrients from the leaves (source) to the fruits (sink), as well as the fact that apical pruning was performed at 109 DAT, preventing the formation of new leaves.

There was an increase of dry and fresh weight of fruits throughout the cycle, reaching an estimated maximum of 402.1 and 8,123.0 g/plant, respectively, at the end of the cycle at 137 DAT (Figure 1A and 1B). There was also an increasing in daily accumulation of dry and fresh weight, from 0.8 and 12 g/plant/day in the first assessment period (33 to 46 DAT) to 6.1 and 126.8 g/plant/day in the last period (123 to 137 DAT), respectively (Table 1).

The accumulation of dry weight in the whole plant followed the fruit trend, with an estimated maximum of 550.2 g/plant at the end of the cycle at 137 DAT (Figure 1B). As observed for the fruits, the daily accumulation of total dry weight increased, going from 1.7 g/plant/day in the first assessment period (2 to 32 DAT) to 6.8 g/plant/day in the last period (123 to 137 DAT, Table 1).

The increasing accumulation of fresh and dry fruit weight and total weight throughout the cycle was also reported by Fayad *et al.* (2001), in the Santa Clara cultivar and by Purquerio *et al.* (2016), in the 'Dominador' and 'Serato' hybrids, with a total dry weight of 406.3; 773.8 and 871.4 g/plant, respectively. However, these authors worked with two stems per plant, which favors obtaining greater weight per plant.

In the studies of Purquerio *et al*. (2016), the accumulation of fresh fruit weight in the 'Dominador' and 'Serato' hybrids started at 42 DAT and reached a maximum value of 9,891 and 11,938 g/plant, respectively, and maximum dry weight values of 415.4 and 537.2 g/plant, respectively, at 154 DAT. In the present study, the value of total fresh weight of fruits was lower: 5,764 g/plant. However, the plants were conducted with only one stem. Considering that the plant population was higher in this study (19,047 plants/ha) than in the studies by those authors (13,333 plants/ha), total yield was similar: 154.7 t/ha in this study and 131, 9 and 158.7 t/ha for the 'Dominador' and 'Serato' hybrids, respectively, reported by Purquerio *et al*. (2016) for cultivation in the conventional system.

The fruits constituted the main sink of the plant, corresponding to 73% of dry matter at the end of the cycle (137 DAT). They were followed by leaves, with 16%, and stem, with 11%. Fayad *et al*. (2001) reported that the fruits constituted 51% of the total dry weight produced by the plant at 120 DAT, followed by 35% of the leaves and 14% on the stem, studying the Santa Clara cultivar. Purquerio *et al*. (2016) obtained a distribution of 61.7 and 53.7% of dry matter in the fruits and 38.3 and 46.3% in the vegetative parts (leaves + stem), in the 'Dominador' and 'Serato' hybrids, respectively, at 154 DAT, showing the importance of genotype in the dry matter accumulation in plants. Prado *et al*. (2011), at the end of the 'Raísa' tomato cycle, obtained 45% of the total dry matter in the fruits, followed by 27% in the leaves, 24% in the stem, and 3% in the roots.

Therefore, there is a consensus that fruits are the main drains in a tomato plant, regardless of the genetic material and the production system and that the greatest increase in fresh and dry weight of the plant occurs after the beginning of fruiting, increasing even more throughout the cycle (Figure 1A and 1B, Table 1).

However, in this research, the fruits represented a higher value of shoot dry matter (73%) compared to the mentioned authors. There are several possible reasons, including the genotype and cultivation conditions. The Debora Victory hybrid is used by the producer after tests carried out over the last few years and it was the one that presented the greatest productive potential for the system adopted by this producer, resulting in greater accumulation of dry matter in fruits. The longer harvest time also favors a higher concentration of dry matter in the fruits. For example, Prado *et al*. (2011) were the authors who reported a lower rate of dry matter accumulation in fruits (45%), probably because they had a shorter productive period, with harvests up to 85 DAT. The second lowest accumulation in fruits (51%) was reported by Fayad *et al*. (2001) with harvests up to 120 DAT, that is, at least two weeks less with harvestings. Also the supply of nutrients affects the distribution of dry matter. For example, excess nitrogen can favor greater accumulation in the vegetative part (leaves and stem). In the present

**Table 1.** Estimated accumulation of dry and fresh matter (g/plant/day) by stem, leaves, fruits and shoots of tomato plants 'Débora Victory' in the period from March 4, 2014 to August 16, 2014, in each interval between plant samplings. Itápolis, UNESP, 2014.

| Interval (DAT*) | Stem | | Leaves | | Fruits | | Shoots | |
|---|---|---|---|---|---|---|---|---|
| | Dry matter | Fresh matter | Dry matter | Fresh matter | Dry matter | Fresh matter | Dry matter | Fresh matter |
| 2 - 32 | 0.4 | 6.0 | 1.4 | 13.1 | - | | 1.7 | 15.1 |
| 33 - 46 | 0.5 | 4.8 | 1.1 | 9.5 | 0.8 | 12.0 | 2.7 | 38.3 |
| 47 - 60 | 0.5 | 3.9 | 0.8 | 7.2 | 2.5 | 47.6 | 3.3 | 53.1 |
| 61 - 77 | 0.5 | 3.1 | 0.7 | 4.6 | 3.2 | 63.6 | 4.0 | 69.5 |
| 78 - 91 | 0.5 | 2.2 | 0.5 | 2.0 | 4.0 | 79.7 | 4.7 | 85.9 |
| 92 - 109 | 0.5 | 1.2 | 0.2 | -0.6 | 4.7 | 96.2 | 5.5 | 102.8 |
| 110 - 122 | 0.5 | 0.4 | 0.0 | -3.2 | 5.4 | 112.3 | 6.2 | 119.2 |
| 123 - 137 | 0.5 | -0.5 | -0.2 | -5.5 | 6.1 | 126.8 | 6.8 | 134.0 |

*DAT = days after transplantation.

study, only 17 kg/ha of N was supplied in fertigation throughout the cycle and the sources used before planting (green manure with sorghum and fertilization with organic compost) are of slower release of nutrients compared to those used by other authors in a conventional system using sources that rapidly release nutrients to plants. Fayad *et al.* (2001), for example, applied a greater amount of N in top dressing: 240 kg/ha, using urea. So, this high N supply can favor greater accumulation of dry matter in leaves and stem, compared to fruits.

**Macronutrient absorption**

Although the data fit the quadratic model, an increase in the accumulation of N was observed in the stem throughout the cycle, with a maximum accumulation of 0.6 g/plant at 137 DAT (Figure 1C). However, the daily accumulation decreased throughout the cycle, being higher in the first 30 DAT, with a daily accumulation rate of 0.008 g/plant/day (Table 2). In the last period (123 to 137 DAT), an accumulation of only 0.001 g/plant/day of N in the stem was estimated.

Gargantini & Blanco (1963) observed an increasing accumulation of N in the stem of tomato 'Santa Cruz 1639' until 100 days after germination (DAG), decreasing from this point on until the end of the cycle at 140 DAG. Prado *et al*. (2011) found an increase in the accumulation of N in the stem up to 85 DAT, in a study carried out with the 'Raísa' tomato.

In the leaves data fit the quadratic model also, with an increase in the accumulation of N observed up to 87 DAT, with an estimated maximum of 2.4 g/plant (Figure 1C), with a decrease from that date on. Gargantini & Blanco (1963), in the conventional system, also observed uptake of N in the leaves increasing up to 90 DAG, decreasing from this point on until the end of the cycle.

As for the stem, the period of greatest daily accumulation in the leaves was during the first 30 DAT, with a rate of 0.046 g/plant/day, being negative in the last 3 periods analyzed (Table 2). It is estimated that the decrease in accumulation of N by the leaves after 87 DAT is due to translocation to the fruits, which is in accordance with Gargantini & Blanco (1963) and Lucena *et al*. (2013). In the plant, N, P and K are highly mobile, with redistribution of these nutrients by the phloem, moving from the leaves to other organs of the plant, mainly the fruits (Malavolta, 2006).

Assessment of N accumulation in fruits started at 46 DAT and increased throughout the cycle, reaching a maximum value of 8.0 g/plant at 137 DAT (Figure 1C). The rate of accumulation increased in each assessment period, from 0.018 g/plant/day in the first period (33 to 46 DAT) to 0.116 g/plant/day in the last period (123 to 137 DAT, Table 2). Gargantini & Blanco (1963) also observed that the accumulation of N in the fruits increased continually, following the development of the plant. Prado *et al*. (2011) also found an increase in the accumulation of N in the fruits up to 85 DAT, in the conventional system.

There was a continuous increase of the N accumulation in plant shoots, from 0.057 g/plant/day in the first period (2 to 32 DAT) to 0.101 g/plant/day in the last period (123 to 137 DAT, Table 2), reaching 10.4 g of N/plant at the end of the cycle (137 DAT, Figure 1), showing the importance of the availability of this nutrient throughout the cycle.

The N extraction of plant shoots was estimate in 198 kg/ha, slightly lower than the results obtained by Fayad *et al*. (2002) and Purquerio *et al*. (2016), who estimated N extractions of 206 to 209 kg/ha. Despite the high fruit production in the present research, the accumulation of N in plant shoots was not so great compared to these authors, probably due to the low application of N throughout the cycle (only 17 kg/ha in fertigation). Fayad *et al*. (2002) applied 240 kg/ha of N in top dressing, which favored the plant to accumulate more N, even with a lower production cycle.

Concerning P in the stem, a linear increase in accumulation was observed throughout the cycle, with a total accumulation of 0.3 g/plant at 137 DAT (Figure 1D). Accumulation remained relatively constant throughout the cycle, with a daily rate close to 0.002 g/plant/

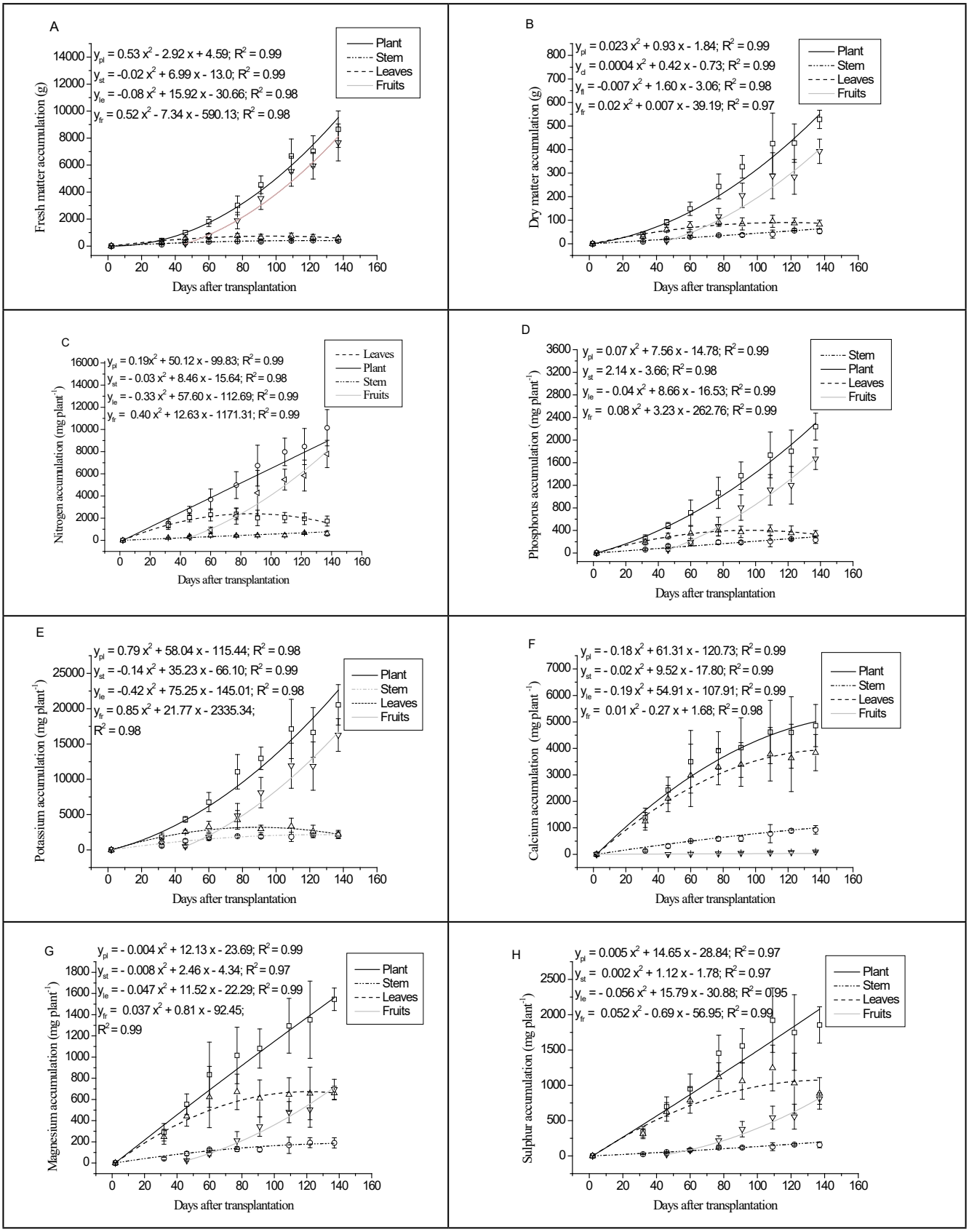


**Figure 1.** Fresh (A) and dry (B) matter, nitrogen (C), phosphorus (D), potassium (E), calcium (F), magnesium (G) and sulphur (H) accumulation in stem, leaves, fruits and shoots of 'Débora Victory' tomato plants, at 2, 32, 46, 60, 77, 91, 109, 122 and 137 days after transplantation. Itápolis, UNESP, 2014.

day (Table 2). However, Gargantini & Blanco (1963) observed that the absorption of P in the stem increased until 90 DAG, with a subsequent decrease until the end of the cycle at 140 DAG. Prado *et al.* (2011), in turn, found an increase in the accumulation of P in the stem up to 85 DAT.

In the leaves, the accumulation of P fit to a quadratic model, there was an increase up to 97 DAT, with an estimated maximum of 0.4 g/plant (Figure 1D) and decreased from that date. Gargantini & Blanco (1963) also observed that the absorption of P increased in the leaves until 90 DAG, then decreasing until the end of the test at 140 DAG.

The period of greatest daily accumulation of P in the leaves was in the first 30 DAT, with a rate of 0.007 g/plant/day, being negative in the last 3 periods analyzed (Table 2). It is estimated that the reduction in the accumulation of P in the leaves after 97 DAT is due to translocation to the fruits, which is in accordance with Gargantini & Blanco (1963) and Lucena *et al*. (2013), as it is a highly mobile nutrient, with redistribution to other organs of the plant, mainly fruits (Malavolta, 2006).

Assessment of P accumulation in fruits started at 46 DAT and increased continuously reaching a maximum value of 1.7 g/plant at 137 DAT (Figure 1D). The rate of increase grew in each assessment period, going from 0.004 g/plant/day in the first period (33 to 46 DAT) to 0.024 g/plant/day in the last period (123 to 137 DAT, Table 2). Also, Gargantini & Blanco (1963) and Prado *et al*. (2011) reported that the accumulation of P in the fruits increased continuously during the development of the plant.

As with fruits, there was continuous increase in the accumulation of P by the plant shoots, going from 0.010 g/plant/day in the first period with fruits (33 to 46 DAT) to 0.025 g/plant/day in the last period (123 to 137 DAT, Table 2), reaching 2.3 g/plant at the end of the cycle (137 DAT), which shows the importance of the availability of this nutrient throughout the whole cycle.

The estimated extraction of 44 kg/ha of P by the 'Debora Victory' tomato plant was greater than the results obtained by Fayad *et al*. (2002) and Purquerio *et al*. (2016), which ranged from 31 to 35 kg/ha of P. The greater P accumulation in tomato plants in the present research is probably due to the high P content in the soil (271 mg/dm$^3$) compared to other researches, such as in Fayad *et al*. (2002) where the P content in soil was only 30.2 mg/dm$^3$.

The accumulation of K in the stem fit the quadratic model, with an increase observed up to 126 DAT, with a maximum estimated accumulation of 2.2 g/plant, which remained stable until the end of the cycle: 2.1 g/plant (137 DAT, Figure 1E). However, the daily accumulation decreased throughout the cycle, being higher in the first 30 DAT, with a rate of 0.031 g/plant/day (Table 2) and decreasing progressively until a negative daily accumulation of K (-0.001 g/plant/day) was estimated in the last period (123 to 137 DAT). This was probably due to translocation of this nutrient from stem to the fruits. Gargantini & Blanco (1963) observed that potassium accumulation in the stem grew up to 100 DAG, decreasing until the end of the test at 140 DAG.

The accumulation of K in the leaves also fit the quadratic model, with an increasing until 89 DAT, with an estimated maximum of 3.2 g/plant (Figure 1E), followed by a decrease from that date on. Similar results were reported by other authors (Gargantini & Blanco, 1963; Prado *et al*., 2011). The period of highest K accumulation was in the first 30 DAT, with a daily rate of 0.061 g/plant/day, this being negative in the last 3 periods analyzed (Table 2). It is estimated that the reduction in the accumulation of K in the leaves after 89 DAT is due to its translocation to the fruits, which is in accordance with Gargantini & Blanco (1963) and Lucena *et al*. (2013), and probably is a pattern in tomato plants. In the plant, N, P and K are highly mobile, with the redistribution of these nutrients by the phloem, moving from the leaves to other plant organs, mainly the fruits (Malavolta, 2006).

Assessment of K accumulation in fruits started at 46 DAT and increased continuously reaching a maximum value of 16.6 g/plant at 137 DAT (Figure 1E). The rate of this increase grew in each assessment period, from 0.033 g/plant/day in the first period (33 to 46 DAT)

**Table 2.** Estimated accumulation (g/plant/day) of nitrogen (N), phosphorus (P) and potassium (K) by stem, leaves, fruits and shoots of tomato plants 'Débora Victory' in the period from March 4, 2014, to August 16, 2014, in each interval between plant samplings. Itápolis, UNESP, 2014.

| Interval (DAT*) | Stem | | | Leaves | | | Fruits | | | Shoots | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | N | P | K | N | P | K | N | P | K |
| 2 - 32 | 0.008 | 0.002 | 0.031 | 0.046 | 0.007 | 0.061 | - | - | - | 0.057 | 0.010 | 0.085 |
| 33 - 46 | 0.006 | 0.002 | 0.024 | 0.032 | 0.005 | 0.042 | 0.018 | 0.004 | 0.033 | 0.065 | 0.013 | 0.119 |
| 47 - 60 | 0.006 | 0.002 | 0.020 | 0.023 | 0.004 | 0.030 | 0.055 | 0.012 | 0.111 | 0.071 | 0.015 | 0.142 |
| 61 - 77 | 0.005 | 0.003 | 0.016 | 0.012 | 0.003 | 0.017 | 0.067 | 0.014 | 0.138 | 0.077 | 0.017 | 0.166 |
| 78 - 91 | 0.004 | 0.002 | 0.012 | 0.002 | 0.001 | 0.004 | 0.080 | 0.017 | 0.164 | 0.083 | 0.019 | 0.190 |
| 92 - 109 | 0.003 | 0.003 | 0.007 | -0.009 | 0.000 | -0.009 | 0.092 | 0.019 | 0.191 | 0.089 | 0.021 | 0.216 |
| 110 - 122 | 0.002 | 0.002 | 0.003 | -0.019 | -0.003 | -0.023 | 0.105 | 0.022 | 0.218 | 0.095 | 0.023 | 0.240 |
| 123 - 137 | 0.001 | 0.002 | -0.001 | -0.028 | -0.003 | -0.034 | 0.116 | 0.024 | 0.241 | 0.100 | 0.025 | 0.262 |

*DAT = days after transplantation.

to 0.241 g/plant/day in the last period (123 to 137 DAT, Table 2), showing the importance of the availability of this nutrient throughout the cycle. Prado *et al*. (2011) found an increase in the accumulation of K in the fruits until the last assessment carried out at 85 DAT. However, Gargantini & Blanco (1963) observed that the accumulation of K in the fruits increased until 110 DAG, decreasing from that date until 140 DAG.

Considering that the fruits are the main sinks of the plants, total K accumulation in the plants followed accumulation in the fruits, being continuous throughout the cycle and reaching greater daily demand (0.262 g/plant/day) in the last period (123 to 137 DAT, Table 2) with total accumulation of 22.6 g/plant (Figure 1E). In the conventional system, Gargantini & Blanco (1963) found that the accumulation of K was increasing in the plant of tomato 'Santa Cruz 1639' until 110 DAG, when there was a reduction until 140 DAG.

The rate of extraction per area, estimated at 431 kg/ha of K, was greater than the result of 360 kg/ha, obtained by Fayad *et al*. (2002) for the 'Santa Clara' tomato. All fertilization was made with organic materials and, usually, the K is the nutrient most readily available to plants with organic fertilization similar to inorganic fertilizers (Magro *et al*., 2010), and this allowed great extraction and accumulation of this nutrient in tomato plants grown in the organic system. Besides this, probably the greater yield in the present study, compared to Fayad *et al*. (2002), also favored greater extraction and accumulation of K in plants and, also, it cannot be discarded that 'Debora Victory' tomato possibly is more exigent in K than 'Santa Clara'.

There was an increase in the accumulation of Ca in the stem throughout the cycle, with maximum accumulation estimated at 1.0 g/plant at 137 DAT (Figure 1F). Gargantini & Blanco (1963) also observed Ca accumulation in the stem until the end of the test at 140 DAG. In addition, Prado *et al*. (2011) found an increase in the accumulation of Ca in the stem up to 85 DAT. However, daily accumulation decreased over the cycle, being higher in the first 30 DAT, with a rate of 0.009 g/plant/day, decreasing in the last period (123 to 137 DAT) to 0.006 g/plant/day (Table 3).

There was also an increase in the accumulation of Ca in the leaves throughout the cycle, with an accumulation of 3.9 g/plant at 137 DAT (Figure 1F). Gargantini & Blanco (1963) and Prado *et al*. (2011) also found Ca accumulation in the leaves throughout the cycle. However, the daily accumulation decreased over the cycle (Table 3), being higher in the first 30 DAT, with a rate of 0.049 g/plant/day, decreasing until the last period (123 to 137 DAT) to only 0.007 g/plant/day.

The assessment of Ca accumulation in fruits started at 46 DAT and a continuous increase was observed, reaching a maximum of 0.2 g/plant at 137 DAT (Figure 1F). The increase of this rate was higher at each assessment period, going from 0.001 g/plant/day in the first period (33 to 46 DAT) to 0.002 g/plant/day in the last period (123 to 137 DAT, Table 3). For the total accumulation of Ca in the plant, greater daily accumulations were observed in the first sampling periods (Table 3), with a total accumulation of 5.0 g/plant at the end of the cycle (137 DAT, Figure 1F). Gargantini & Blanco (1963) and Prado *et al*. (2011) observed an increasing Ca accumulation in fruits and plants throughout the cycle.

In studies by Prado *et al*. (2011), the accumulation of Ca in the plant was 2.3 g/plant at 85 DAT. In the present study, Ca accumulation was higher, with an estimated value of 3.8 g/plant (Figure 1F), but it was lower than those reported by Fayad *et al*. (2002) and Purquerio *et al*. (2016). Calcium accumulates mainly in the leaves because they have a greater transpiration surface (Malavolta, 2006). As in this research the plants showed less accumulation of leaf dry matter compared to the researches by Fayad *et al*. (2002) and Purquerio *et al*. (2016), it is to be expected that there was less extraction and accumulation of Ca in the plants. It is noteworthy that the base saturation was adequate, as well as the calcium content in the soil, and there was no water deficit throughout the cycle, which allows deducing that there was no restriction for the absorption and accumulation of Ca in the tomato plants, and fruits with calcium deficiency were not observed, showing that the Ca supply was sufficient, without lack.

There was an increase in the accumulation of Mg in the stem throughout the cycle, with an estimated accumulation of 0.2 g/plant at 137 DAT (Figure 1G). However, daily accumulation decreased over the cycle, being higher in the first 30 DAT, with a rate of 0.002 g/plant/day, reducing to less than 0.001 g/plant/day in the last period (123 to 137 DAT, Table 3). Gargantini & Blanco (1963), however, observed increasing accumulation of Mg in the stem up to 100 DAG, decreasing until the end of the test at 140 DAG.

The accumulation of Mg in the leaves fit the quadratic model, with an increase up to 121 DAT with a maximum of 0.7 g/plant and this rate remained practically constant until 137 DAT (Figure 1G). Daily accumulation decreased over the cycle, being higher in the first 30 DAT, with a rate of 0.010 g/plant/day (Table 3), decreasing progressively until the last period (123 to 137 DAT), when a negative daily accumulation of Mg (-0.001 g/plant/day) was estimated, probably due to the translocation of this nutrient to the fruits. Gargantini & Blanco (1963) observed that the accumulation of Mg by the leaves increased up to 90 DAG, decreasing up to 140 DAG, when they also observed the translocation of Mg from the vegetative parts to the fruits. Mg is also mobile in the phloem, being translocated from older leaves to newer or growing leaves and fruits (Malavolta, 2006; Bastos *et al*., 2013).

Assessment of Mg accumulation in the fruits started at 46 DAT and increased continuously reaching a maximum value of 0.7 g/plant at 137 DAT (Figure 1G). The daily rate increased with each assessment period, from 0.002 g/plant/day in the first period (33 to 46 DAT) to 0.010 g/plant/day in the last period (123 to 137 DAT, Table 3). Gargantini & Blanco (1963) and Prado *et al*. (2011) also observed an increasing rate of Mg

accumulation in the fruits throughout the cycle.

As with fruits and stems, there was an increasing accumulation of total Mg by the plant, at a daily rate that practically remained stable throughout the cycle, starting with 0.012 g/plant/day reaching 0.011 g/plant/day in the last period (123 to 137 DAT, Table 3), reaching 1.6 g/plant at the end of the cycle (137 DAT).

Extraction per area, estimated at 30 kg/ha of Mg by the 'Debora Victory' tomato, was similar to the results obtained by Fayad *et al*. (2002) and lower than those of Purquerio *et al*. (2016): 34 kg/ha of Mg.

There was an increasing accumulation of S in the stem throughout the cycle, with an estimated accumulation of 0.2 g/plant at 137 DAT (Figure 1H). The accumulation rate increased during the cycle, with an initial daily rate of 0.001 g/plant/day, which increased until the last period (123 to 137 DAT), when it was estimated 0.002 g/plant/day (Table 3). Gargantini & Blanco (1963) observed increasing accumulation of S in the stem up to 100 DAG and decreasing thereafter.

There was also accumulation of S in the leaves throughout the cycle, with a rate of 1.1 g/plant at 137 DAT (Figure 1H). However, the daily rate of accumulation decreased during the cycle (Table 3), being higher in the first 30 DAT, with a rate of 0.014 g/plant/day and decreasing until the last period (123 to 137 DAT), when the daily accumulation rate of S in leaves was estimated at only 0.001 g/plant/day. Gargantini & Blanco (1963) observed increasing accumulation of S in the leaves until 130 DAG, decreasing afterward.

Assessment of S accumulation in fruits started at 46 DAT, with a continuous increase up to 137 DAT, reaching a maximum value of 0.8 g/plant (Figure 1H). The rate of increase was higher at each assessment period, going from 0.002 g/plant/day in the first period (33 to 46 DAT) to 0.013 g/plant/day in the last period (123 to 137 DAT, Table 3). Gargantini & Blanco (1963) and Prado *et al*. (2011) also observed an increasing accumulation rate of S in the fruits throughout the cycle.

There was a continuous increase in the rate of total S accumulation by the plant, at a practically constant daily rate, starting with 0.015 g/plant/day and reaching 0.016 g/plant/day in the last period (123 to 137 DAT, Table 3), reaching 2.1 g/plant at the end of the cycle (137 DAT).

The extraction per area by the 'Debora Victory' tomato, estimated at 40 kg/ha of S, was lower than the results obtained by Fayad *et al*. (2002) and by Purquerio *et al*. (2016), which ranged from 46 to 49 kg/ha.

At 137 DAT, when the plant reached the maximum dry matter accumulation, the highest N accumulation occurred in the fruits (79%, 8.0 g/plant), followed by the leaves (15%, 1.6 g/plant) and stem (6%, 0.6 g/plant, Figure 1C). A similar result was observed for P with higher accumulation in fruits (73%, 1.7 g/plant), followed by leaves (14%, 0.3 g/plant) and stem (13%, 0.3 g/plant, Figure 1D), as well as for K: fruits (79%, 16.6 g/plant) followed by leaves (11%, 2.2 g/plant) and stem (10%, 2,1 g/plant, Figure 1E). Other authors also found greater accumulation of N, P, and K in the fruits than in the vegetative parts of the plants (Gargantini & Blanco, 1963; Fayad *et al*., 2002; Lucena *et al.*, 2013; Purquerio *et al.*, 2016).

As for Mg, the highest accumulation also occurred in fruits (46%, 0.7 g/plant), but it was only slightly higher than that found in leaves (42%, 0.7 g/plant), with less accumulation on the stem (12%, 0.2 g/plant), therefore, the highest concentration of Mg was in the vegetative parts (sum of the leaves + stem), rather than in the fruits (Figure 1G). Other authors have also found greater Mg accumulation in the vegetative part than in the tomato fruits (Gargantini & Blanco, 1963; Fayad *et al.*, 2002; Lucena *et al.*, 2013; Purquerio *et al*., 2016). This is probably due to the best-known role of Mg in the plant being related to its presence in chlorophyll, with 10% of the total Mg of the leaf in chlorophyll (Malavolta, 2006). For S, the highest accumulation occurred in leaves (51%, 1.1 g/plant), followed by fruits (39%, 0.8 g/plant) and stem (9%, 0.2 g/plant, Figure 1H). S is an essential nutrient for plant growth, as it forms amino acids, vitamins, cofactors and secondary products, such

**Table 3.** Estimated accumulation (g/plant/day) of calcium (Ca), magnesium (Mg) and sulphur (S) by stem, leaves, fruits and total in tomato plants 'Débora Victory' in the period from March 4, 2014 to August 16, 2014, in each interval between plant samplings. Itápolis, UNESP, 2014.

| Interval (DAT*) | Stem | | | Leaves | | | Fruits | | | Shoots | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | S | Ca | Mg | S | Ca | Mg | S | Ca | Mg | S |
| 2 - 32 | 0.009 | 0.002 | 0.001 | 0.049 | 0.010 | 0.014 | - | - | - | 0.055 | 0.012 | 0.015 |
| 33 - 46 | 0.008 | 0.002 | 0.001 | 0.040 | 0.008 | 0.011 | 0.001 | 0.002 | 0.001 | 0.048 | 0.012 | 0.015 |
| 47 - 60 | 0.008 | 0.002 | 0.001 | 0.035 | 0.007 | 0.010 | 0.001 | 0.005 | 0.005 | 0.043 | 0.012 | 0.015 |
| 61 - 77 | 0.007 | 0.001 | 0.001 | 0.029 | 0.005 | 0.008 | 0.001 | 0.006 | 0.006 | 0.037 | 0.012 | 0.015 |
| 78 - 91 | 0.007 | 0.001 | 0.002 | 0.024 | 0.004 | 0.006 | 0.001 | 0.007 | 0.008 | 0.032 | 0.011 | 0.016 |
| 92 - 109 | 0.006 | 0.001 | 0.002 | 0.018 | 0.002 | 0.005 | 0.002 | 0.008 | 0.010 | 0.026 | 0.011 | 0.016 |
| 110 - 122 | 0.006 | 0.001 | 0.002 | 0.012 | 0.001 | 0.003 | 0.002 | 0.009 | 0.011 | 0.021 | 0.011 | 0.016 |
| 123 - 137 | 0.006 | 0.000 | 0.002 | 0.007 | -0.001 | 0.001 | 0.002 | 0.010 | 0.013 | 0.016 | 0.011 | 0.016 |

*DAT = days after transplantation.

as glucosinolates, and usually is not a nutrient that is most accumulated in fruits or seeds, except for brassicas (Cardoso *et al*., 2016; Corrêa *et al.*, 2017).

The greatest accumulation of Ca occurred in the leaves (77%, 3.9 g/plant), followed by the stem (20%, 1.0 g/plant) and fruits (3%, 0.2 g/plant, Figure 1F). Other authors also found greater Ca accumulation in the vegetative part than in the tomato fruits (Gargantini & Blanco, 1963; Fayad *et al*., 2002; Lucena *et al*., 2013; Purquerio *et al*., 2016).

The decreasing order of the total accumulation of nutrients at the end of the cycle at 137 DAT was K>N>Ca>P>S>Mg, with estimated values of 22.6; 10.4; 5.0; 2.3; 2.1 and 1.6 g/plant, respectively (Table 3).

In the study carried out by Gargantini & Blanco (1963) with the Santa Cruz cultivar, absorption of macronutrients in a similar order was presented: K>N>Ca>S>P>Mg. Similar results were obtained by Fayad *et al*. (2002), with the Santa Clara cultivar, and Purquerio *et al*. (2016) with the Dominador and Serato hybrids, the only difference being the inversion of P and S which, in this study, presented very close accumulation values. In addition to the handling being different between surveys, there are also genetic differences, since a different cultivar/hybrid was used in each study.

On the other hand, the decreasing order of nutrient accumulation in the fruits was K>N>P>S>Mg>Ca, with estimated values of 16.6; 8.0; 1.7; 0.8; 0.7 and 0.2 g/plant, respectively. The low accumulation of Ca stands out in proportion to the others because it accumulates preferentially in the leaves, probably due to the low mobility of this nutrient in the plant by the phloem. The absorption of Ca is linked to transpiration and the leaves have a large surface to transpire and receive this nutrient throughout the cycle, without translocation to the reproductive organs (Araújo *et al*., 2015). This nutrient is, thus, practically immobile in the plant. According to Malavolta (2006), this is due to the fact that the transport of this nutrient occurs preferentially in the xylem, with little translocation of Ca to the fruits, with accumulation preferentially in the vegetative part of the plant. Gargantini & Blanco (1963) also observed that Ca showed low translocation from vegetative organs to tomato fruits.

Despite the genetic difference between the hybrids or cultivars studied by different authors, as well as differences in management, soil, and climate, it is clear that the trend in macronutrient absorption is not so different among the different authors, mainly the decreasing order of accumulation in the plant. Therefore, regardless of the management system, organic or conventional, there is a great need for nutrients by the plant and by the tomato fruits, and the important thing in order to obtain high productivity in sustainable systems is to balance the need for different nutrients, without any lack or excess, as recommended in the "Trophobiosis Theory". The choice of genotype is also of great importance, as genotypes less adapted to the management adopted by the producer and to the climatic conditions of the place and planting time will present lower fruit yield. In organic systems in which the soil is already stabilized and with good content of organic matter, as in the local where this research was set up, nutrients are released by the mineralization of organic matter throughout the cycle and with good management by the producer, mainly irrigation, the plants had nutrients available throughout the cycle.

Fageria (1998) states that several factors can affect the nutritional efficiency of plants, including environmental and soil conditions, such as temperature, solar radiation, precipitation, soil pH, aluminum toxicity, salinity, nutrient deficiency, and organic matter content, among others. In addition to these, other intrinsic factors of the plant such as genotype, growth of the root system, biological nitrogen fixation, mycorrhizae, allelopathy, diseases, pests, and competition with weeds also affect the nutritional efficiency of the plants.

According to the recommendations made by Fageria (1998), among the mechanisms for optimizing nutritional efficiency in crop production, which are advocated by organic production systems, are the maintenance of adequate soil moisture, the appropriate use of crop rotation, the maintenance of organic matter at the appropriate level, the use of green manure or animal manure, and the incorporation of crop remains for nutrient recycling. In this research, the importance of selecting a genotype with good adaptation to the growing conditions could be seen, combined with a soil whose fertility was "built" over time and the use of organic sources (green manure and compost) over the cycles, maintaining a high organic matter content in the soil. With this, it is possible to keep the plant well nourished throughout the cycle, without excesses, mainly of N, with less vegetative vigor and greater fruit production. The nutritional demands of tomato hybrid plants should not be different in conventional or organic systems. However, well managed organic system plants are nourished with the continuous and constant release of nutrients throughout the cycle, in addition to the organic matter contained in the soil improving the physical structure of the soil and reducing the loss of nutrients by leaching, mainly N and K, and by fixation, mainly P.

According to Khatounian (2001), organic agriculture seeks to obtain optimal productivity in long term instead of maximum productivity in short term. Optimal productivity is the one that reconciles the economics of agricultural exploitation with the preservation of natural resources and satisfactory product quality. Maximum productivity is usually associated with high levels of environmental impact due to the increase in the amounts of pesticides and chemical fertilizers. These generate externalities, meaning that the costs of correcting these damages are paid by society and not by the conventional agriculture that caused them.

In organic agriculture, the central idea is to produce while preserving the environment for as long as possible, ideally without any externalities. The productivity thus obtained is what has

been called optimal, not only in its short-term economic aspect, but also optimal in the sense that it encompasses environmental preservation, production quantity, and product quality, an optimum that unfolds over time and does not compromise other spaces (Khatounian, 2001).

A basic principle to obtain good results in organic systems is to perform fertilization that leads to the nutritional balance of the plants and results in optimal productivity, which is achieved through a better cost/benefit ratio, that is, obtaining a maximum possible productivity with the balanced use of inputs for the management of fertilization, pests, and diseases (Khatounian, 2001).

According to Aquino *et al*. (2015), the finding of differences in the efficiency of nutrient use between cultivars has great practical relevance as it allows the adoption of different fertilization regimes, and the use of efficient cultivars in the use of nutrients becomes an important factor in the current scenario, due to the demand for higher yields and reduced costs with the use of fertilizers. Fageria (1998) also recommends the use of cultivars with high productive potential and resistance to diseases, aiming at increasing nutritional efficiency.

It has been observed, as in the present research, that the Debora Victory hybrid has adapted well to the organic system, with good efficiency in the use of nutrients for fruit formation. However, there is a need to supply all the macronutrients throughout the tomato cycle and that are great extraction and accumulation of nutrients in plants, presenting the following descending order in the shoot K>N>Ca>P>S>Mg and in fruits K>N>P>S>Mg>Ca.

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