Accumulation of nutrients during the formation of star fruit cultivars under different irrigation regimes

Acumulación de nutrientes durante la formación de cultivares de carambola en formación bajo regímenes de irrigación

ABSTRACT

Nutrient accumulation during the formation of star fruit (Averrhoa carambola) trees can be affected by the water regime and by the cultivar, but the details are not yet known for this species. The aim of this study was to evaluate the nutrient uptake of two star fruit cultivars in the formation phase under two irrigation regimes. The experiment was developed with a completely randomized design, with subdivided plots, with two irrigation levels (with and without irrigation) as plots, and two star fruit cultivars as subplots (‘B-10’ and ‘Golden Star’) and seven collection times from 0 to 720 days after transplanting (DAT) into the field as sub-subplots with six replicates. Nutrient uptake was evaluated in stem and leaves, and it was possible to observe that nutrient uptake and the average accumulation rate followed the dry matter mass accumulation of star fruit trees in formation. Nutrient uptake by shoots at 720 DAT differed for the Golden Star cultivar in the rainfed regime and for the B-10 cultivar in both irrigation regimes. There was no difference and followed the sequence Ca > K > N > Mg > S > P > Mn > Fe > Zn > B > Cu, and for Golden Star cultivar in the irrigated regime, the accumulation sequence was Ca > K > N > Mg > Mn > P > S > Fe > Zn > B > Cu.

1 São Paulo State University (UNESP), Department of Agronomy, Registro (Brazil). ORCID Rozane, D.E.: 0000-0003-0518-3689; ORCID Santos, E.M.H.: 0000-0003-1585-3500
2 São Paulo State University (UNESP), Department of Soil, Jaboticabal (Brazil). ORCID Prado, R.M.: 0000-0003-1998-6343
3 Federal University of Santa Maria (UFSM), Department of Soil Science, Santa Maria (Brazil). ORCID Paula, B.V.: 0000-0002-2348-1527
4 Federal University of Ceara (UFC), Department of Fitotecnia, Fortaleza (Brazil). ORCID Natale, W.: 0000-0001-9572-4463
5 Agricultural Research Company of Minas Gerais (EPAMIG), Experimental Farm of Caldas, Uberaba (Brazil). ORCID Amorim, D.A.: 0000-0003-4921-5080
6 Coordination of Integral Technical Assistance (CATI), Batatais Agriculture House, Batatais (Brazil). ORCID Hernandes, A: 0000-0002-8545-7581
7 Corresponding autor: danilo.rozane@unesp.br
The proper management of liming and fertilization is almost an imposition for fruit trees grown in sustainable systems and with high productivity, since it is necessary to supply the nutritional demand of the plants and to compensate the poverty of tropical soils due to the large amounts of nutrients immobilized by the vegetation or exported by each crop (Brunetto et al., 2020; Etienne Parent et al., 2021).

Nutrient uptake curves allow inferring the amount and period of greatest demand for each evaluated nutrient, thus it is possible to establish a balance between nutrient supply and plant demand, in order to obtain high yields with fruits of excellent quality (Brunetto et al., 2016; Stefanello et al., 2020). The nutrient concentrations in the first-stage of fruit growth require a nutritional balance to guarantee successful development and establishment at the definitive growing site (Orduz-Ríos et al., 2020).

Studies of nutrient uptake are more common in the international literature for annual crops such as vegetables (Adiele et al., 2021) and cereals (Silva et al., 2021), but they are very rare for fruit crops (Buitrago et al., 2021), especially star fruit. This is due to high added value and increasing demand of the international fruit markets. But the fruit is still underexploited due to the lack of scientific information on mineral nutrition of the fruit. Nutrient uptake by plants depends on several environmental factors with emphasis on water availability, climate variability, and genetics (Alva et al., 2002; Adiele et al., 2021).

Rozane et al. (2011) reported for seedlings of star fruit that the uptake of nutrients followed a linear accumulation of dry matter of star fruit seedlings with the time of cultivation being greater in leaves > stem > roots. The greatest accumulation and nutrients in the leaves at the beginning of development are also

Additional key words: Averrhoa carambola; nutritional requirement; water deficit; nutrient uptake.

RESUMEN

La acumulación de nutrientes durante la formación de árboles de carambola (Averrhoa carambola) puede ser afectado por el régimen de agua y por el cultivar, sin embargo, esto aún no es conocida para esta especie. El propósito de este estudio fue evaluar la acumulación de nutrientes de dos cultivares de carambola en fase de formación, bajo dos regímenes de irrigación. El experimento fue realizado en campo, mediante diseño completamente al azar, con parcelas divididas, siendo estas parcelas dos niveles de irrigación (con y sin irrigación) y, como subparcelas, dos cultivares de carambola (B-10 y Golden Star) y siete épocas de recogida de plantas, entre 0 a 720 días después del transplante (DAT), con seis réplicas. La acumulación de nutrientes fue evaluada en el tallo y las hojas, y fue posible observar que la toma de nutrientes y la tasa promedio de acumulación siguió la acumulación de masa seca de los árboles de carambola en formación. La acumulación de nutrientes por la parte aérea a los 720 DAT fue diferente, siendo que para la ‘Golden Star’ en el régimen seco y para la ‘B-10’ en ambos regímenes de irrigación no hubo diferencia, siguiendo la secuencia Ca > K > N > Mg > S > P > Mn > Fe > Zn > B > Cu, y para el cultivar Golden Star en el régimen irrigado, la secuencia de acumulación fue Ca > K > N > Mg > Mn > P > S > Fe > Zn > B > Cu. La más alta acumulación ocurrió en el régimen irrigado, independientemente del cultivar. El cultivar Golden Star acumuló, en promedio, cantidades mayores de N, P, K, Mg, S, Fe y Mn.

Palabras claves adicionales: Averrhoa carambola; requerimiento nutricional; déficit de agua; absorción de nutrientes.

Received: 13-12-2021 Accepted: 20-04-2022 Published: 26-08-2022
reported by Franco et al. (2007), Freitas et al. (2011) and Adiele et al. (2021). The concepts of a critical dilution curve (Silva et al., 2021) and decrease as a function of the age and development of the plants was not observed in this study, which is believed to be due to the young characteristics of the plants, confirming Rozane et al. (2011) and Brunetto et al. (2020).

We hypothesize that the nutrient uptake behavior during star fruit formation is dependent on the water regime and the selected cultivar. Thus, the aim of this study was to evaluate the growth and nutrient uptake of star fruit trees in the formation phase under two water regimes.

**MATERIAL AND METHODS**

The experiment was conducted under field conditions with coordinates 21°15′22″ S and 48°18′58″ W at 615 m a.s.l. According to the Köppen classification, the local climate is of Aw type tropical megathermal with dry winter and average annual rainfall of 1,420 mm.

The soil is classified as typical eutrophic Red Latosol with clayey texture, kaolinite, hypoferric, and smooth undulating relief (Eutrustox) (Embrapa, 2018). Samples collected from 0-0.20 and 0.20-0.40 m layers are characterized in chemical terms with the following results: 4.5 and 4.1; 23 and 14; 196 and 159; 0.41 and 0.38; 1.4 and 1.0; 57 and 26; 16.8 and 8.7; 4.8 and 0.9; 7 and 2; 19 and 7; 7 and 3; 42 and 38; 30.9 and 13.3; 73 and 51; 3 and 6; 42 and 26, respectively, for pH (CaCl₂); OM (g dm⁻³); P; B; Cu; Fe; Mn; Zn; S-SO₄ (mg dm⁻³); K; Ca; Mg; SB; H + Al; T; Al (mmolc dm⁻³) and V (%)(Raij et al., 2001).

Plant nursery seedlings were used to establish the orchard according to propagation techniques recommended by Donadio et al. (2001). The grafting of B-10 and Golden Star cultivars was carried out in hypobiotes from sexual propagation.

The experiment was carried out in sub-subdivided plots with two irrigation levels as plots (with and without irrigation), two cultivars (B-10 and Golden Star) as subplots, and seven plant collection times as sub-subplots; the first one was carried out with seedlings from the nursery at the time of trial implementation; and the others at 120, 240, 360, 480, 600 and 720 days after transplanting (DAT) in the field. The design was completely randomized with six replicates and totaled 168 experimental units.

With the aid of a furrow opener coupled to a tractor, a furrow of 0.40 m in the upper base and 0.40 m in depth was opened, making a planting hole of approximately 0.064 m³ (0.40 × 0.40 × 0.40 m). Spacing between plants was 5 × 5 m. Each hole received 20 L of organic compound based on bovine manure. Phosphorus was used at a dose of 180 g of P₂O₅ per hole in the form of simple superphosphate (Natale et al., 2008) and 2 g of Zn and 1 g of B (Donadio et al., 2001), with zinc sulfate and boric acid as sources.

After the planting of seedlings, crowning was performed, irrigating plants in the first 33 days after installation with the aid of a tank drawn by a tractor, applying 15 - 20 L of water per star fruit tree, establishing a watering shift of 2-3 d. Then, the micro-sprinkler irrigation system was installed, placing a ‘balletina’ type micro-sprinkler per plant with a flow rate of 30 L h⁻¹, 0.20 m from the trunk of each plant with a radius of approximately 2.0 m.

Irrigation management was performed with the aid of tensiometers installed at 0.20 m, 0.30 m, and 0.40 m of depth, with 0.20 m being used for irrigation decision-making, while the other two controled the applied water depth (Libardi, 1992), triggering the system when 30% of the water available in the soil was consumed. Three tensiometer batteries were installed, and irrigation decision-making was performed using the mean of the readings.

Up to 180 DAT, all the plants were irrigated so that seedlings and an orchard were established. After this period, irrigation was stopped in half of star fruit trees in order to characterize the statistical design treatments (with and without irrigation).

Covering fertilizations were carried out as suggested by Natale et al. (2008), beginning at 36 DAT. The recommended doses (140 g of N and 112 g of K₂O per plant) were divided into four applications, with urea and potassium chloride as sources. At 270 DAT, new fertilization was performed, applying 200 g of N and 50 g of K₂O per plant in the form of ammonium sulfate and potassium chloride, also divided into four applications.

Up to 360 d, control of invasive plants in the canopy projection area was carried out when necessary with manual weeding. After this period, contact chemical
desiccants were used. For weed management between rows, brush cutter mowers were used throughout the experimental period.

The following biometric variables were evaluated in all plots: height (from plant top to the end of the last expanded leaf); and stem diameter (0.10 and 0.40 m from plant top), determined with the aid of a digital caliper. Plants were then divided into stems and leaves, washed in distilled water and dried in an oven with forced air circulation at a temperature of 65°C until reaching constant mass. The dry mass of the different parts was determined after determination of the dry mass of the stems and leaves. The material was ground and analyzed for nutrient content of plant tissues using a methodology described by Bataglia et al. (1983).

Nutrient uptake was obtained by multiplying the content of the element in the plant organ by the mass of dry matter corresponding to each part of the star fruit tree at the time of evaluation. The accumulation of nutrients in the shoots was obtained by the sum of the amounts present in the stems and leaves.

Based on the results, analyses of variance (F test) were performed for the several characteristics studied, as well as an regression study for the culture time. The regression model was used for all variables, resulting in significance by the F test, representing the evaluated characteristic.

For the exponential model, the adjustment equation is represented by:

\[ Y = Y_0 + A_1 e^{(x/t_1)} \]

where \( Y_0 \) is the lower asymptote, \( A_1 \) is the growth amplitude, \( e \) is the inverse of the neperian logarithm, \( x \) are the days after transplanting, and \( t_1 \) is the growth rate.

RESULTS AND DISCUSSION

There was similarity in the adjustment of nutrient uptake equations with the dry matter mass (Fig. 1), resulting in greater occurrence of adjustments to the exponential model that can be explained by star fruit trees in the present experimental conditions at 720 d of cultivation having on average 5.0 (4.7%) for B-10 and 5.3 (4.9%) for Golden Star cultivars and on the weight of nutrients evaluated in the total dry matter mass for irrigated and rainfed regimes. Of the total accumulated nutrients, 57 (73%) for B-10 and 48 (67%) for Golden Star cultivars occurred in relation to the last evaluation at 600 DAT for irrigated and rainfed regimes (Fig. 2 to 9). Rozane et al. (2011) observed similarities in nutrient uptake in the same star fruit genotypes cultivated under hydroponics.

Nutrient uptake by shoots at 720 DAT differed. For the Golden Star cultivar under rainfed regime and for B-10 cultivar under both irrigation regimes no difference was observed. They followed the sequence Ca > K > N > Mg > Mn > Fe > Zn > B > Cu, and for Golden Star cultivar in the irrigated regime, the accumulation sequence was Ca > K > N > Mg > Mn > P > S > Fe > Zn > B > Cu.

The mean percentage values in relation to the dry matter mass of shoots for both cultivars in both water regimes was 0.90, 0.07, 1.12, 1.90, 0.83, 0.08, 0.0016, 0.0004, 0.0095, 0.0516, and 0.0032 for N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn (Fig. 2 to 9). 95.05% remained for the dry matter mass of shoots (Tab. 1, 2).
Figure 1. Equations, F value, significance, and determination coefficient ($R^2$) obtained in regression studies on the effects of cultivation time (d) on the dry mass of shoots (◇), leaves (▲) and stems (●) of ‘B-10’ cultivar grown under an irrigated regime (a) and non-irrigated regime (A) and non-irrigated regime (B) under field conditions and of ‘Golden Star’ cultivar grown under irrigated regime (C) and non-irrigated regime (D) under field conditions.
| Cultivation time (days) | Accumulation (g/plant) | Equation | F value | P value | R² value |
|--------------------------|------------------------|----------|---------|---------|----------|
| A                        | N                      | $\hat{y} = 0.154 + 1.770e^{(x/175.11)}$ | 59.00   | 0.02    | 0.98     |
| B                        | P                      | $\hat{y} = 0.026 + 0.133e^{(x/246.56)}$ | 31.26   | 0.03    | 0.97     |
| C                        | K                      | $\hat{y} = 0.144 + 0.258e^{(x/145.53)}$ | 17.59   | 0.05    | 0.95     |
| D                        | Ca                     | $\hat{y} = 0.128 + 0.001e^{(x/65.82)}$ | 76.22   | 0.01    | 0.99     |
| E                        | Mg                     | $\hat{y} = 0.048 + 0.0007e^{(x/231.35)}$ | 75.16   | 0.01    | 0.99     |
| F                        | S                      | $\hat{y} = 0.020 + 0.142e^{(x/231.35)}$ | 180.50  | 0.01    | 0.99     |

Figure 2. Equations, F value, significance, and determination coefficient (R²) obtained in regression studies on the effects of cultivation time on N (A), P (B), K (C), Ca (D), Mg (E) and S (F) uptake in shoots (◊), leaves (■) and stems (▲) of ‘B-10’ cultivar in irrigated regime under field conditions.
Figure 3. Equations, F value, significance, and determination coefficient ($R^2$) obtained in regression studies on the effects of cultivation time on B (A), Cu (B), Fe (C), Mn (D) and Zn (E) uptake in shoots (◊), leaves (■) and stems (▲) of ‘B-10’ cultivar in irrigated regime under field conditions.
Figure 4. Equations, F value, significance, and determination coefficient ($R^2$) obtained in regression studies on the effects of cultivation time on N (A), P (B), K (C), Ca (D), Mg (E) and S (F) uptake in shoots (◊), leaves (■) and stems (▲) of 'B-10' cultivar in non-irrigated regime under field conditions.
Figure 5. Equations, F value, significance, and determination coefficient ($R^2$) obtained in regression studies on the effects of cultivation time on B (A), Cu (B), F (C), Mn (D), and Zn (E) uptake in shoots (◊), leaves (■) and stems (▲) of ‘B-10’ cultivar in non-irrigated regime under field conditions.
Figure 6. Equations, F value, significance, and determination coefficient ($R^2$) obtained in regression studies on the effects of cultivation time on N (A), P (B), K (C), Ca (D), Mg (E) and S (F) uptake in shoots (○), leaves (■) and stems (▲) of ‘Golden Star’ cultivar in irrigated regime under field conditions.
Figure 7. Equations, F value, significance, and determination coefficient ($R^2$) obtained in regression studies on the effects of cultivation time on B (A), Cu (B), Fe (C), Mn (D), and Zn (E) uptake in shoots (○), leaves (■) and stems (▲) of ‘Golden Star’ cultivar in irrigated regime under field conditions.
Figure 8. Equations, F value, significance, and determination coefficient ($R^2$) obtained in regression studies on the effects of cultivation time on N (A), P (B), K (C), Ca (D), Mg (E) and S (F) uptake in shoots (◇), leaves ( ■) and stems (▲) of ‘Golden Star’ cultivar in non-irrigated regime under field conditions.
Figure 9. Equations, F value, significance, and determination coefficient ($R^2$) obtained in regression studies on the effects of cultivation time on B (A), Cu (B), Fe (C), Mn (D) and Zn (E) uptake in shoots (◊), leaves (■) and stems (▲) of ‘Golden Star’ cultivar in non-irrigated regime under field conditions.
Table 1. F value and variation coefficients of the factors cultivar, irrigation, cultivation time, and their interaction on the nutrient uptake in the different organs of B-10 and Golden Star cultivars.

| Factors        | N      | P      | K      | Ca     | Mg     | S      | B      | Cu     | Fe     | Mn     | Zn     |
|----------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| **Stem**       |        |        |        |        |        |        |        |        |        |        |        |        |
| Cultivation time (T) | 1369.45** | 417.71** | 1166.18** | 3043.75** | 3655.69** | 591.85** | 1496.43** | 228.68** | 1079.64** | 4291.45** | 530.16** |
| Irrigated (I)  | 22.844** | 26.38** | 8.46*  | 51.50** | 48.12** | 5.43*  | 124.24** | 23.53** | 345.73** | 176.85** | 0.77**  |
| Cultivars (C)  | 4.39**  | 65.30** | 5.87*  | 0.24**  | 19.13** | 85.56** | 8.06*  | 21.80** | 3.53ns  | 284.83** | 0.66**  |
| Interaction (I x C) | 0.92**  | 0.26**  | 1.70** | 0.61**  | 0.63**  | 34.96** | 0.02** | 9.69*  | 11.30** | 526.58** | 0.30**  |
| Interaction (I x T) | 16.69** | 17.83** | 9.51** | 4.21**  | 48.99** | 24.18** | 3.87** | 119.43** | 1152.80** | 4.79**  |
| Interaction (C x T) | 13.27** | 24.72** | 5.13** | 2.82**  | 12.76** | 49.55** | 22.49** | 10.00** | 7.06**  | 435.19** | 5.65**  |
| Interaction (I x C x T) | 2.23*   | 2.59*   | 2.29*  | 7.43**  | 0.68**  | 36.82** | 7.28** | 1.33** | 10.31** | 633.73** | 2.86**  |
| CV (%)(1)       | 10.6   | 24.2   | 27.2   | 14.1   | 9.85   | 26.7   | 14.7   | 43.9   | 18.2   | 13.5   | 17.6   |
| CV (%)(2)       | 19.7   | 24.0   | 20.1   | 18.2   | 19.1   | 22.7   | 17.2   | 34.3   | 18.3   | 13.9   | 27.5   |
| CV (%)(3)       | 14.3   | 22.4   | 20.4   | 17.0   | 16.4   | 23.2   | 14.7   | 43.3   | 21.6   | 12.8   | 20.7   |
| **Leaves**      |        |        |        |        |        |        |        |        |        |        |        |        |
| Cultivation time (T) | 1504.08** | 1800.30** | 1337.75** | 2421.35** | 3607.64** | 829.28** | 1521.88** | 619.08** | 1476.01** | 1036.77** | 679.56** |
| Irrigated (I)  | 190.47** | 182.56** | 57.11** | 107.84** | 107.77** | 213.64** | 306.24** | 67.98** | 605.62** | 172.65** | 33.45** |
| Cultivars (C)  | 44.97**  | 65.81** | 76.09** | 0.35**  | 0.35**  | 13.77** | 0.01**  | 0.77**  | 14.33** | 23.00** |
| Interaction (I x C) | 31.99** | 4.75**  | 14.80** | 13.29** | 1.23**  | 5.31**  | 18.92** | 27.01** | 10.58** | 15.05** | 29.49** |
| Interaction (I x T) | 126.96** | 87.12** | 49.40** | 21.29** | 32.30** | 134.12** | 131.91** | 24.82** | 283.32** | 119.88** | 116.94** |
| Interaction (C x T) | 24.83** | 39.15** | 44.67** | 5.17**  | 18.20** | 35.77** | 18.69** | 5.75**  | 72.85** | 28.31** |
| Interaction (I x C x T) | 5.01**  | 4.25**  | 4.39**  | 3.40**  | 2.46**  | 2.90**  | 8.34**  | 22.61** | 6.62**  | 12.01** | 18.20** |
| CV (%)(1)       | 10.6   | 11.1   | 20.1   | 14.4   | 14.9   | 20.3   | 15.9   | 23.1   | 17.6   | 18.6   | 16.9   |
| CV (%)(2)       | 7.3    | 11.5   | 17.9   | 15.9   | 19.0   | 13.1   | 15.2   | 23.6   | 15.2   | 21.6   | 14.1   |
| CV (%)(3)       | 13.0   | 12.2   | 17.2   | 18.3   | 14.4   | 16.4   | 15.2   | 22.6   | 15.8   | 15.6   | 16.8   |

to be continued
### Table 1. F value and variation coefficients of the factors cultivar, irrigation, cultivation time, and their interaction on the nutrient uptake in the different organs of B-10 and Golden Star cultivars.

| Factors | N    | P    | K    | Ca   | Mg   | S    | B    | Cu   | Fe   | Mn   | Zn   |
|---------|------|------|------|------|------|------|------|------|------|------|------|
|         |      |      |      |      |      |      |      |      |      |      |      |
| Aerial parts |      |      |      |      |      |      |      |      |      |      |      |
| Cultivation time (T) | 2589.25** | 1318.70** | 2068.08* | 6181.11** | 6895.87** | 1285.18** | 2038.72** | 466.64** | 2449.63** | 3648.38** | 788.40** |
| Irrigated (I) | 161.15** | 79.59** | 48.27** | 111.28** | 169.54** | 54.93** | 274.16** | 51.93** | 9.27.46** | 662.65** | 8.33* |
| Cultivars (C) | 22.91** | 80.16** | 51.66** | 0.49NS | 11.69** | 30.14** | 1.27** | 9.10* | 59.37** | 12.35** | 3.60NS |
| Interaction (I x C) | 11.55** | 0.18NS | 10.74** | 0.65NS | 1.47** | 12.60** | 9.35** | 0.06NS | 0.02NS | 33.93** | 0.91NS |
| Interaction (I x T) | 83.43** | 49.72** | 43.67** | 27.62** | 19.25** | 53.11** | 113.97** | 9.44** | 315.93** | 578.46** | 34.02** |
| Interaction (C x T) | 34.19** | 47.13** | 32.28** | 7.07** | 7.56** | 25.13** | 23.50** | 4.85** | 20.13** | 42.96** | 15.57** |
| Interaction (I x C x T) | 5.50** | 3.78** | 5.14** | 6.67** | 2.06** | 25.04** | 7.27** | 4.21** | 13.20** | 148.91** | 7.94** |
| CV (%)(1) | 9.8  | 15.4 | 18.0 | 11.2 | 19.4 | 14.6 | 28.2 | 12.9 | 13.1 | 16.1 |
| CV (%)(2) | 9.6  | 15.9 | 16.2 | 13.0 | 12.2 | 14.6 | 27.0 | 11.9 | 15.0 | 20.4 |
| CV (%)(3) | 10.0 | 13.4 | 14.4 | 11.8 | 14.3 | 12.9 | 27.9 | 13.1 | 10.1 | 16.2 |

Notes: NS, *, **: non-significant and significant at P<0.05 and P<0.01, respectively. 
(1), (2) and (3) Variation coefficients for plot, subplot and sub-subplot, respectively.

### Table 2. Analysis of variance and average results of the dry matter mass (g/plant) of stem and leaves of growing star fruit trees, cultivated in irrigated and non-irrigated regimes under field conditions.

| Cultivation time (T) days | Stem | Leaves | Aerial parts |
|---------------------------|------|--------|-------------|
| 0                         | 9.05 | 4.91   | 13.97       |
| 120                       | 38.98| 36.13  | 75.11       |
| 240                       | 59.17| 68.85  | 128.02      |
| 360                       | 320.32| 236.57| 556.89      |
| 480                       | 538.96| 499.98| 1038.94     |
| 600                       | 1026.63| 447.81| 1474.45     |
| 720                       | 2299.25| 1169.71| 3468.96    |
| Test F                    | 6337.41** | 3785.41** | 7647.20** |

| Irrigated (I)             |       |        |            |
|---------------------------|-------|--------|------------|
| Irrigated                 | 665.38| 399.56| 1064.94    |
| Non-irrigated              | 561.01| 304.43| 865.44     |
| Test F                    | 132.23** | 315.14** | 238.07** |

| Cultivars (C)             |       |        |            |
|---------------------------|-------|--------|------------|
| B-10                      | 634.72| 348.40| 940.07     |
| Golden Star               | 591.67| 355.59| 990.31     |
| Test F                    | 22.83**| 2.79ns| 18.36**    |
| Irrigated (I x C)         | 20.50** | 27.20** | 28.47**    |

Notes: ** to be continued
The order of nutrient uptake differs from that verified by Rozane et al. (2011) for the same genotypes, since they observed that N and K were required, as well as from that reported by Freitas et al. (2011) for Nota-10 star fruit cultivar, with N and K being the most required, both studies were conducted under hydroponics. However, Ondo et al. (2012) observed that Ca, followed by potassium, are the most exported nutrients in fruit plants in general. Variations in the order of nutrient uptake in fruit trees are commonly reported in the literature, when different genetic materials and cultivation techniques are used, in addition to the cultivation time such as for guava (Augustinho et al., 2008; Franco et al., 2007).

The greatest variations in the accumulation of nutrients in the shoots at 720 DAT between the genotypes occurred in the micronutrients, for both cultivars the accumulation was on average 36% lower when there was no irrigation, an outstanding observation for Mn which had the lowest accumulation 68 and 62%, respectively for ‘B-10’ and ‘Golden Star’ (Fig. 3, 5, 7 and 9). For macronutrients, the highest accumulation also occurred in irrigated areas that had on average 13% more in relation to non-irrigated areas (Fig. 2, 4, 6 and 8). This confirmed the observations of Medyouni et al. (2021), who indicated a reduction in the size of tomato leaves and fruits when subjected to water stress. The fundamental role of water in the nutritional stability of fruit trees was reported by Rozane et al. (2009) due to its more expressive relative importance in the supply of nutrients due to transport via mass flow (Epstein and Bloom, 2006). Jiménez-Suancha et al. (2015) agree that water participates in
most of the physiological processes that occur in the growth and productivity of plants that includes the transport and assimilation of nutrients.

During cultivation, there were differences in nutrient uptake in leaves, stems, and shoots (Tab. 1). At the end of the experimental period, during the irrigated regime, there was greater Ca, Mg, Cu and Mn uptake in the stems in relation to the leaves in both cultivars, in addition to greater Fe and Zn uptake for B-10 cultivar (Fig. 2, 3, 6 and 7). For the non-irrigated system in both cultivars under study, at 600 DAT the greatest nutrient uptake occurred in the stems in relation to the leaves, due to a reduction in the dry matter mass of the latter organ (Tab. 2) because of the abscission caused by water deficit. However, for the non-irrigated regime at 720 DAT, the greater nutrient uptake in leaves in relation to the stems of B-10 cultivar followed the order: K, N, P, S, Mn, Fe, and B; in the Golden Star cultivar, the sequence was K, N, P, Mn, Fe, and Cu (Fig. 4, 5, 8 and 9), indicating that stems were important reserve organs for Ca and Mg.

The period of greatest nutritional requirement of star fruit trees was between 600 and 720 DAT, a period that also corresponded to greater dry matter mass accumulation (Fig. 1). Nutrient uptake in both cultivars, at different cultivation times, presented variable behaviors as a function of water regime, organ analyzed, and nutrient (Tab. 1). For all nutrients the largest accumulations occurred in the irrigated regime, with values higher than those obtained for the non-irrigated regime of 8.4; 7.4; 7.3; 13.7; 3.4 and 5.0 for N, P, K, Ca, Mg, S macronutrients, and 27.7; 26.1; 45.5; 19.7; for B, Cu, Fe, Mn and Zn micronutrients (Fig. 2 to 9). These data agreed with Aquino et al. (2012).

It seems reasonable to expect that the greatest nutrient uptake occurs in plants managed under irrigation, given the fundamental role of water in the absorption of elements, as well as the changes it causes in soil and plants. Epstein and Bloom (2006) indicate that water is essential for plant growth because it plays a role in the transport of mineral elements in the plant and suggest that an ideal water potential in the zone of root absorption facilitates contact, absorption, and stabilization of plant nutrients. Amijee et al. (1991) suggest that water directly and indirectly affects mechanistic models that simulate nutrient uptake, such as the diffusion coefficient of an element in water, as well as the volumetric content of water in soil and the inflow rate of water by roots, the latter having an important role in the transport of nutrients by mass flow.

The lower accumulation of nutrients in the aerial part of star fruit plants at 720 DAT when they were submitted to the non-irrigated regime (Fig. 2 to 9) was not reflected in the decrease in the accumulation of dry matter of the cultivars (Fig. 1). Small variations in water availability may allow the maintenance of an adequate photosynthetic rate and the maintenance of production in some species (Molina-Montenegro et al., 2011). Mahouachi, (2009) indicates that magnesium may be the element that would best protect the photosynthetic machine from water stress. In the present study, for the conditions and cultivars evaluated, no damage was observed in the accumulation of magnesium that could contribute to the explanation that the water deficit was not sufficiently severe and thus did not affect the accumulation of dry matter between treatments with and without irrigation. at 720 DAT (Fig. 1).

Regarding the cultivar factor, considering shoots (stem + leaves), the Golden Star cultivar had the highest accumulations in higher amounts of macronutrients (g/plant) at 720 d of N (2.4); P (1.0); K (16.2); Mg (0.1), and S (0.7); and for micronutrients (mg/plant), Fe (99.9) and Mn (761.9) while Cu accumulated 8.7 mg/plant, higher in the B-10 cultivar (Fig. 2 to 9). Ca, B and Zn nutrients were not significant (Tab. 1).

**CONCLUSIONS**

The nutrient uptake curve and the mean accumulation rate followed the dry matter mass accumulation of growing star fruit trees.

Nutrient uptake by shoots at 720 DAT differed, and for Golden Star cultivar in the rainfed regime and for B-10 cultivar in both irrigation regimes no difference was observed and followed the sequence: Ca> K> N> Mg> S> P> Mn> Fe> Zn> B> Cu, for Golden Star cultivar in the irrigated regime, the accumulation sequence was: Ca> K> N> Mg> Mn> P> S> Fe> Zn> B> Cu.

The highest nutrient uptake occurred in the irrigated regime regardless of cultivar. The ‘Golden Star’ accumulated, on average, larger amounts of N, P, K, Mg, S, Fe and Mn than ‘B-10’.
Acknowledgments

To FAPESP, for granting the financial aid (2006 / 55570-2 and 2006 / 55569-4). Part of the doctoral thesis of the first author.

Conflict of interests: The authors declare that this article was conducted in the absence of any commercial, financial, professional or personal relationship that could be interpreted as a potential conflict of interest.

BIBLIOGRAPHIC REFERENCES

Adiele, J.G., A.G.T. Schut, K.S. Ezui, P. Pypers, and K.E. Gille. 2021. Dynamics of N-P-K demand and uptake in cassava. Agron. Sustain. Dev. 41, 1. Doi: https://doi.org/10.1007/s13593-020-00649-w

Alva, A.K., T. Hodges, R.A. Boydston, and H.P. Collins. 2002. Dry matter and nitrogen accumulations and partitioning in two potato cultivars. J. Plant. Nutr. 25(8), 1621-1630. Doi: https://doi.org/10.1081/PLN-12006047

Amijee, F., P.B. Barraclough, and P.B. Tinker. 1991. Modeling phosphorus uptake and utilization by plants. pp. 63-75. In: Johansen, C., K.K. Lee, and K.L. Sahrawat (eds.). Phosphorus nutrition of grain legumes in the semi-arid tropics. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.

Aquino, L.A., R.F.B.A. Aquino, T.C. Silva, D.F. Santos, and P.G. Berger. 2012. Aplicação do fósforo e da irrigação na absorção e exportação de nutrientes pelo algodoêro. Rev. Bras. Eng. Agríc. Ambient. 16(4), 355-361. Doi: https://https://doi.org/10.1590/S1415-43662012000400004

Augustinho, L.M.D., R.M. Prado, D.E. Rozane, and N. Freitas. 2008. Acúmulo de massa seca e marcha de absorção de nutrientes em mudas de goiabeira “Pedro Sato”. Bragantia 67, 577-585. Doi: https://doi.org/10.1590/S0006-87052008000300004

Bataglia, O.C., A.M.C. Furlani, J.F.P. Teixeira, P.R. Furlani, and J.R. Gallo. 1983. Métodos de análise química de plantas. Instituto Agronômico Campinas, Campinas, Brazil.

Brunetto, G., C.A. Ceretta, G.W.B. Melo, E. Girotto, P.A.A. Ferreira, C.R. Lourenzi, R. Rosa Couto, A. Tassinaria, R.K. Hammerschmitt, L.O.S. Silva, B.P. Lazzaretti, M.S. Souza Kulmann, and C. Carranca. 2016. Contribution of nitrogen from urea applied at different rates and times on grapevine nutrition. Sci. Hortic. 207, 1-6. Doi: https://doi.org/10.1016/j.scienta.2016.05.002

Brunetto, G., E.K. Ricchenevsky, L.O. Stefanello, B.V. Paula, M.S. Souza Kulmann, A. Tassinaria, G.W.B. Melo, W. Natale, D.E. Rozane, M.N. Ciotta, A.F. Brighenti, J.J. Comin, C.R. Lourenzi, A. Loss, D.E. Schmitt, J. Zalamena, L. De Conti, T.L. Tiecher, A.L.K. Souza, and B.P. Bem. 2020. Diagnosis and management of nutrient constraints in grape. pp. 693-710. In: Srivastava, A.K. and C. Hu (eds.). Fruit crops: Diagnosis and management of nutrient constraints. Elsevier. Doi: https://https://doi.org/10.1016/B978-0-12-818732-6.00047-2

Buitrago, S., M. Leandro, and G. Fischer. 2021. Symptoms and growth components of feijoa (Acca sellowiana [O. Berg] Burret) plants in response to the missing elements N, P, and K. Rev. Colomb. Cienc. Hortic. 15(3), e15159. Doi: https://doi.org/10.17584/rcch.2021v15is3.15159

Donadio, L.C.R.M., J.A.A. Silva, and F.S.R. Araújo Prado. 2001. Carambola (Averrhoa carambola L.). Sociedade Brasileira de Fruticultura, Jaboticabal, Brazil.

Embrapa. 2018. Sistema Brasileiro de Classificação de Solos. 5th ed. Brasília.

Epstein, E. and A.J. Bloom. 2006. Nutrição mineral de plantas: princípios e perspectivas. 2nd ed. Londrina, Brazil.

Etienne Parent, L., W. Natale, and G. Brunetto. 2021. Machine learning, compositional and fractal models to diagnose soil quality and plant nutrition. pp. 1-23. In: Aide, M.T. and I. Braden (eds.). Soil science - emerging technologies, global perspectives and applications. IntechOpen. Doi: https://doi.org/10.5772/intechopen.98596

Franco, C.F., R.M. Prado, L.F. Brachirolli, and D.E. Rozane. 2007. Curva de crescimento e marcha de absorção de macronutrientes em mudas de goiabeira. Rev. Bras. Ciênc. Solo 31(6), 1429-1437. Doi: https://doi.org/10.1590/S0100-06832007000600020

Freitas, N., R.M. Prado, D.E. Rozane, M.H. Torres, and M.B. Arouca. 2011. Marcha de absorção de nutrientes e crescimento de mudas de carambola exvertida com a cultivar nota-10. Semin. Ciênc. Agr. 32(4), 1251-1242. Doi: https://https://doi.org/10.5453/1679-0359.2011v32n4p1231

Jiménez-Suancha, S.C., O.H. Alvarado, and H.E. Balaguera-López. 2015. Fluorescencia como indicador de estrés en Helianthus annuus L. Una revisión. Rev. Colomb. Cienc. Hortic. 9(1), 149-160. Doi: https://doi.org/10.17584/rcch.2015v9i1.3753

Libardi, S.A.M. 1992. Uso práctico do tensiômetro pelo agricultor irrigante. Instituto de Pesquisas Tecnológicas, Sao Paulo, Brazil.

Mahouachi, J. 2009. Changes in nutrient concentrations and leaf gas exchange parameters in banana plantlets under gradual soil moisture depletion. Sci. Hortic. 120(4), 460-466. Doi: https://doi.org/10.1016/j.scienta.2008.12.002

Medyouni, I., R. Zouaoui, E. Rubio, S. Serino, H.B. Ahmed, and N. Bertin. 2021. Effects of water deficit on leaves and fruit quality during the development period in tomato plant. Food Sci. Nutr. 9(4), 1949-1960. Doi: https://doi.org/10.1002/fsn3.2160
Molina-Montenegro, M.A., A. Zurita-Silva, and R. Oses. 2011. Efecto de la disponibilidad hídrica sobre el desempeño fisiológico y productivo de un cultivo de lechuga (Lactuca sativa). Cienc. Inv. Agr. 38(1), 65-74.

Natale, W., R.M. Prado, D.E. Rozane, L.M. Romualdo, H.A. Souza, and A. Hernandes. 2008. Resposta da caramboleira á calagem. Rev. Bras. Frutic. 30(4), 1136-1145. Doi: https://doi.org/10.1590/S0100-29452008000400046

Ondo, J.A., R.M. Biyogo, M. Ollui-Mboulou, E. Eba, and J. Omva-Zue. 2012. Macro-nutrients in edible parts of food crops in the region of Moanda, Gabon. Agric. Sci. 3(5), 697-701. Doi: https://doi.org/10.4236/as.2012.35084

Orduz-Ríos, F., K. Suárez-Parra, P.A. Serrano-Cely, P.C. Serrano-Agudelo, and N. Forero-Pineda. 2020. Evaluation of N-P-K-Ca-Mg dynamics in plum (Prunus salicina Lindl.) var. Horvin under nursery conditions. Rev. Colomb. Cienc. Hortic. 14(5), 384-391. Doi: https://doi.org/10.17584/rcch.2020v14i5.11941

Raij, B., J.C. Andrade, H. Cantarella, and J.A. Quaggio. 2001. Análise química para a avaliação da fertilidade de solos tropicais. Instituto Agronômico de Campinas, Campinas, Brazil.

Rozane, D.E., W. Natale, R.M. Prado, and J.C. Barbosa. 2009. Tamanho da amostra foliar para avaliação do estado nutricional de goiabeiras com e sem irrigação. Rev. Bras. Eng. Agríc. Ambient. 13(5), 233-239. Doi: https://doi.org/10.1590/S1415-45662009000300003

Rozane, D.E., R.M. Prado, W. Natale, L.M. Romualdo, H.A. Souza, and S.H.M.G. Silva. 2011. Produção de mudas de caramboleiras ‘B-10’ e ‘Golden Star’: II - marcha de absorção e acúmulo de nutrientes. Rev. Bras. Frutic. 33(4), 1508-1521. Doi: https://doi.org/10.1590/S0100-29452011000400032

Silva, A.O., B.R. Jaenisch, I.A. Ciampitti, and R.P. Lollato. 2021. Wheat nitrogen, phosphorus, potassium, and sulfur uptake dynamics under different management practices. Agron. J. 113(3), 2752-2769. Doi: https://doi.org/10.1002/agj2.20637

Stefanello, L.O., R. Schwalbert, R.A. Schwalbert, L. De Conti, M.S.S. Kulmann, L.P. Garlet, M.L.R. Silveira, C.K. Sautter, G.WB. Melo, D.E. Rozane, and G. Brunetto. 2020. Nitrogen supply method affects growth, yield and must composition of young grape vines (Vitis vinifera L. cv Alicante Bouschet) in southern Brazil. Sci. Hortic. 261, 108910. Doi: https://doi.org/10.1016/j.scienta.2019.108910