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March of nutrient absorption and growth of fertigated melon 'Gladial®'

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Abstract

The use of fertigation in melon cultivation is becoming increasingly common, and there is a need to optimize the doses of applied fertilizers. Knowledge of the nutritional demands of the crop and its rate of uptake is essential for determining the amount of nutrients required at different phenological stages. The objective of this study was to determine the rate of macronutrient and micronutrient uptake in fertigated melons, as well as the accumulation of fresh and dry matter in leaves, stems, and fruits. This study was performed in Petrolina-PE, in an entirely randomized experimental design with nine evaluation periods and six repetitions. Plants were collected at 7, 14, 21, 28, 36, 43, 50, 57, and 64 days after emergence (DAE). The accumulation of N, P, K, Ca, Mg, Fe, Mn, Zn, Cu, dry matter, and fresh matter in the leaves, stems, fruits, and total matter accumulation throughout the cycle was analyzed. Dry matter increases at 64 DAE. Nutrient accumulation was in the following order of micronutrients: K>Ca>N>Mg>P and Fe>Mn>Zn>Cu.

Keywords: dry matter, nutrient accumulation, nutrient demand

Introduction

Melon (*Cucumis melo* L.) is a vegetable of great economic importance in Brazil and worldwide, with Brazil being the 13th largest melon producer in the world (FAO, 2017). Its cultivation in the country is prominent in the Northeast region, which contributes to approximately 91% of the country's total production, with Rio Grande do Norte being the state with the highest production with 338,665 tons produced annually (IBGE, 2017).

This is due to the soil and climate characteristics of the region, which are favorable for melon production. In addition, rainfall is concentrated in a few months of the year, thus leading to a low incidence of disease and better-quality fruit (Oliveira et al., 2020). Aside from the favorable climate, the region has technological subsidies for irrigated crops, being a productive center for domestic and foreign markets, and thus requires a production system that ensures good productivity and fruit quality.

However, conventional fertilizers are based on outdated technical bulletins and manuals with general information about the melon crop and do not consider the specificity of each soil, thus hindering the proper recommendation for the demonstration of the productive potential of the crop (Oliveira, 2017). Furthermore, they lack information regarding the growth of the hybrid melon 'Gladial®' grown in the region, especially in the irrigated perimeters of the San Francisco Valley.

Through irrigated production, the San Francisco Valley has adopted technologies such as fertigation. This method has enabled fertilizers to be spread throughout the crop cycle, thereby reducing fertilizer losses and ensuring better use of nutrients and higher yields. Therefore, the San Francisco Valley stands out in the cultivation of yellow varieties and accounts for approximately one-eighth of national production (Lima, 2015).

However, to quantify the amount of nutrients

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needed to meet the nutritional demands of melons, it is necessary to utilize crop information, especially the growth of the 'Gladial®' variety cultivated in the Valley. As few studies have investigated the nutritional deficiency of melons throughout the cycle, addressing this knowledge gap will require an understanding of the amount of each nutrient extracted by plants, given by the march of nutrient uptake.

The nutrient uptake march provides information that allows the producer to determine the correct quantities and times to fertilize each nutrient via fertigation, as well as knowledge of when the nutrient demand is greatest and the quantities extracted by the crop, thus notifying them of the importance of nutrition at that time for obtaining satisfactory yields (Oliveira et al., 2020).

This study aimed to determine the absorption rate of macronutrients and micronutrients, as well as the accumulation of fresh and dry matter in the leaves, stems, and fruits of melon trees.

Material and Methods

This study was conducted in the experimental area of the Federal Institute of Sertão Pernambucano, Petrolina campus Rural Zone, latitude 9°20'13'' S, longitude 40°42'01'' W, and altitude 413 m (1354 ft.), in yellow Ultisols under climate BSh'. According to Kõppen's classification, the climate is very hot and semi-arid with a rainy season in summer extending to the beginning of autumn INMET (2020).

Before planting, the soil was collected for chemical analysis by taking representative composite samples in the 0.00–0.20 m (0–8 in) and 0.20–0.40 m (8 in-1.3 ft) layers and sent to the soil laboratory of IF Sertão PE (Table 1). After analysis, the necessary fertilization was calculated using the nutrient uptake rate of melon as obtained by Damasceno et al. (2012), with the addition of 15% as an index of the loss of efficiency of nutrient use. The soil was also prepared by plowing, harrowing, constructing ridges, and by covering the soil with *mulching*.

Table 1. Chemical attributes of the soil in the experimental area.

Depth	pH	EC	$P_{disp.}$	K	Na	Ca	Mg	H+Al	BS	CEC	V
cm	H_2O	dS m^{-1}	mg kg^{-1}	------------------------cmol$_c$ kg^{-1}-------------------							%
0–20	7.54	0.292	4.89	0.21	0.08	2.42	0.19	0.17	2.9	3.06	94.6
20–40	7.57	0.289	37.46	0.18	0.08	1.66	0.05	0.17	2.0	2.14	92.3

The experiment was set up in an entirely randomized design with nine treatments corresponding to nine evaluation periods and six repetitions. The experiment consisted of four 30 meter (98 ft)-long ridges. Seeds were sown in two of these and the other two acted as borders.

The planting was performed by directly sowing seeds of the hybrid melon 'Gladial F1' at a spacing of 0.3 × 2 m (11.8 in x 6 ft 7 in) (16,666 plants ha^{-1}); plant collection for analysis was started at seven days after emergence (DAE). The plants were irrigated with 16 mm (0.6 in) driplines spaced at 0.40 m (1.3 ft) and an average flow rate of 1.75 L h^{-1}, which was also used for fertilization via fertigation by fertilizer injector.

The irrigation blade was managed using the Reference Evapotranspiration (ETo) of the previous day, which was provided by an automatic Davis agrometeorological station, model vantage pro-2, located approximately 900 m (2952 ft 9 in) from the experimental area, which, together with the crop coefficient (kc) of 0.90, 1.05, and 0.75 corresponding to initial, medium, and final kc, respectively (Allen et al., 1998), was calculated for the daily crop water requirement.

The fertilizers used were 200 kg (440.5 lb) ha^{-1} of potassium chloride, 98 kg (215.8 lb) ha^{-1} of monoammonium phosphate, 350 kg (770.9 lb) ha^{-1} of calcium nitrate, 15 kg (33 lb) ha^{-1} of zinc sulfate, 10 kg (22 lb) ha^{-1} of boric acid, and 200 kg (440.5 lb) ha^{-1} of magnesium sulfate. All fertilizers were applied in tranches until 55 DAE, except for boric acid and zinc sulfate, which were applied until 35 DAE. In addition, *Lithothamnium calcareum* was applied twice: the first at 30 DAE with 0.64 kg (1.4 lb) ha^{-1} by fertigation and the second at 41 DAE with 0.32 kg (0.7 lb) ha^{-1} by foliar application.

During the melon cycle, the maximum temperature ranged between 28.40 °C (83.12 °F) and 37.30 °C (99.14 °F) and the minimum temperature between 17.40 °C (63.32 °F) and 24.70 °C (76.46 °F), with an average temperature of 27.30 °C (81.14 °F). The plants were collected at 7, 14, 21, 28, 36, 43, 50, 57, and 64 DAE, separating the stems, leaves, and fruits when present. Each part obtained in each evaluated period was weighed fresh and later dried in an oven with forced air circulation at 65 °C (149 °F) until a constant weight was achieved.

After drying, the material was weighed and crushed in a Willey mill for sulfur digestion according to the methodology described by Carmo et al. (2000) to determine the contents of N, P, K, Ca, Mg, Fe, Mn, Zn, and Cu. Accumulation in each plant part was quantified by multiplying the nutrient content by the respective dry mass of the organ, and the accumulated percentage was calculated (Equation 1).

$$PA: \frac{TN}{TMN}\ x\ 100 \quad (1)$$

where PA= accumulated percentage, TN= nutrient content, and TMN= maximum accumulated nutrient content.

The data were subjected to analysis of variance and the degrees of freedom, when significant, relative to the time after emergence, were unfolded in regression analysis and fitted by polynomial models using SISVAR 5.6 statistical program (Ferreira, 2011).

Results and Discussion

The accumulation of dry matter until 21 DAE exhibited slow behavior. This behavior was similar to that observed by Mendoza-Cortez et al. (2014) in a study with melons of the cultivars 'Olympic express' and 'Iracema', where the plants showed slow dry matter accumulation until 28 days after transplanting, and greater increases with the beginning of the fruiting phase.

The melon 'Gladial®' reached the maximum estimated value of dry matter at 64 DAE with 474.26 g (1.04 lb) plant^{-1} dry matter of the aerial part (Figure 1A), higher than what was observed by Aguiar Neto et al. (2014) in a test with the hybrids 'Iracema' and 'Grand Prix' in Petrolina-PE, where they reached values of 341.19 (0.75 lb) and 403.28 g (0.88 lb) plant^{-1} at 55 days after transplanting, respectively. This may be attributed to the genetic factors of each hybrid and the soil conditions, nutrition, irrigation, and plant health, among other factors, that corroborate in the development of the culture.

Regarding the distribution of dry matter in each organ of the plant, the fruits showed the greatest increase in quantity, followed by the leaves and stems with lower values. This is similar to the findings of Oliveira (2017), wherein the fruit stood out in the accumulation of dry matter compared to the vegetative part (leaf + stem).

The total fresh matter showed linear adjustment, and reached a value of 6669.70 g (14 lb) plant^{-1} at the 64th DAE. This result can be attributed to the high productivity of the crop in the experimental condition with about 90 t ha^{-1}, with an estimated 5418.14 g (11.9 lb) plant^{-1} fresh matter being observed in the fruits, the organ with a higher increment of fresh matter in the period from 40 to 64 DAE (Figure 1B).

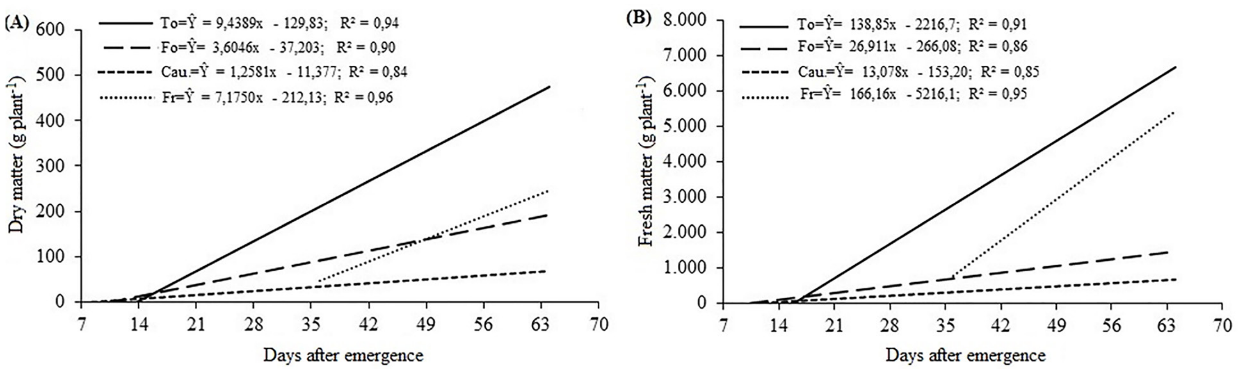

Figure 1. (A) Increments of dry matter; (B) fresh matter, of the aerial part in leaf (Fo), stem (Cau), fruit (Fr), and total (To) in 'Gladial®' melons with the days after emergence.

The 'Gladial®' melon accumulated the highest levels of K (322.54 kg or 710.4 lb ha^{-1}), followed by Ca (177.09 kg or 390 lb) ha^{-1}), N (130.99 kg or 288.5 lb ha^{-1}), Mg (39.07 kg or 86 lb ha^{-1}), and P (28.60 kg or 62.9 lb ha^{-1}). Thus, the requirement of macronutrients by melons followed the order K>Ca>N>Mg>P. These results are consistent with those of Kano et al. (2002), in which the average accumulation in the aerial part followed the same sequence with 7.016 (0.24 oz), 5.560 (0.19 oz), 5.064 (0.17 oz), 2.059 (0.07 oz), 1.40 (0.05 oz), and 0.708 g (0.02 oz) plant^{-1} of K, Ca, N, Mg, S, and P, respectively.

Potassium was the nutrient most required by 'Gladial®' melon, reaching a maximum estimated value of 322.54 kg (710.4 lb) ha^{-1} at the 40th and 50th DAE (Figure 2A). These results corroborate those obtained by Aguiar Neto et al. (2014) with the hybrids 'Iracema' and 'Grand Prix' in Petrolina-PE, in which K was the most required macronutrient in both cultivars, reaching maximum values of 17.27 (0.60 oz) and 19.24 g (0.67 oz) plant^{-1}(287.82 and 320.67 kg ha^{-1} or 633.9 lb and 706.3 lb ha^{-1}). Oliveira et al. (2020) also observed that K was the most assimilated nutrient, similar to what was observed in this study; however, the melon 'Gladial®' extracted twice as much in terms of magnitude.

In the period between the 28th and 43rd DAE, high K-accumulation rates were observed, accumulating approximately 55% of all K in the cycle, demonstrating that fertilization with K sources is essential for satisfactory yields.

The second most required macronutrient by the 'Gladial®' melon was Ca, with linear accumulations observed throughout the cycle, with approximately 58% of the total accumulated in the period between the 13th and 43rd DAE and the maximum value of 177.09 kg (390 lb) ha^{-1} observed at the 64th DAE (Figure 2B). Results were different from those found by Oliveira et al. (2020) in the yellow melon cultivar 'Goldex', in which the maximum accumulated value was observed at 35 days after transplanting. In a study performed by Oliveira (2017) on 'Goldex' yellow melon, the maximum value was observed 58 days after transplanting.

The Ca in the leaves of 'Gladial®' melon accounted for 84.25% of the total accumulated, similar to what was observed by Melo et al. (2013) and Oliveira (2017) where the leaves accumulated >90% of the quantitative Ca in melon plants.

The accumulation of Mg was linear until the 64th DAE, reaching a maximum estimated value of 39.07 kg (86 lb) ha^{-1} (Figure 2C). The same behavior was observed by Kano et al. (2002) in the lacy melon plant that was obtained in the last evaluation at 97 days after transplanting and showed a value of 2.6 g (0.09 oz) $plant^{-1}$ (34.32 kg or 75.5 lb ha^{-1}). However, in a study by Aguiar Neto et al. (2014) with the hybrids 'Grand Prix and 'Iracema', the values obtained were <1.00 g (0.03 oz) $plant^{-1}$ (16.67 kg or 36.7 lb ha^{-1}).

This is due to the genetic potential of each cultivar and the supply of this nutrient in the soil solution as Mg is behaviorally similar to Ca. Although it is redistributed to a greater extent in the plant, Mg^{+} has the xylematic pathway as the predominant pathway, and its availability in the soil influences its distribution to the reproductive organs of the plant (Araújo et al., 2017). However, the dynamics of accumulation in each part of the plant were similar to those found by Mendoza-Cortez et al. (2014), with the leaves having the highest amounts observed, followed by the fruits and the stem with the lowest values.

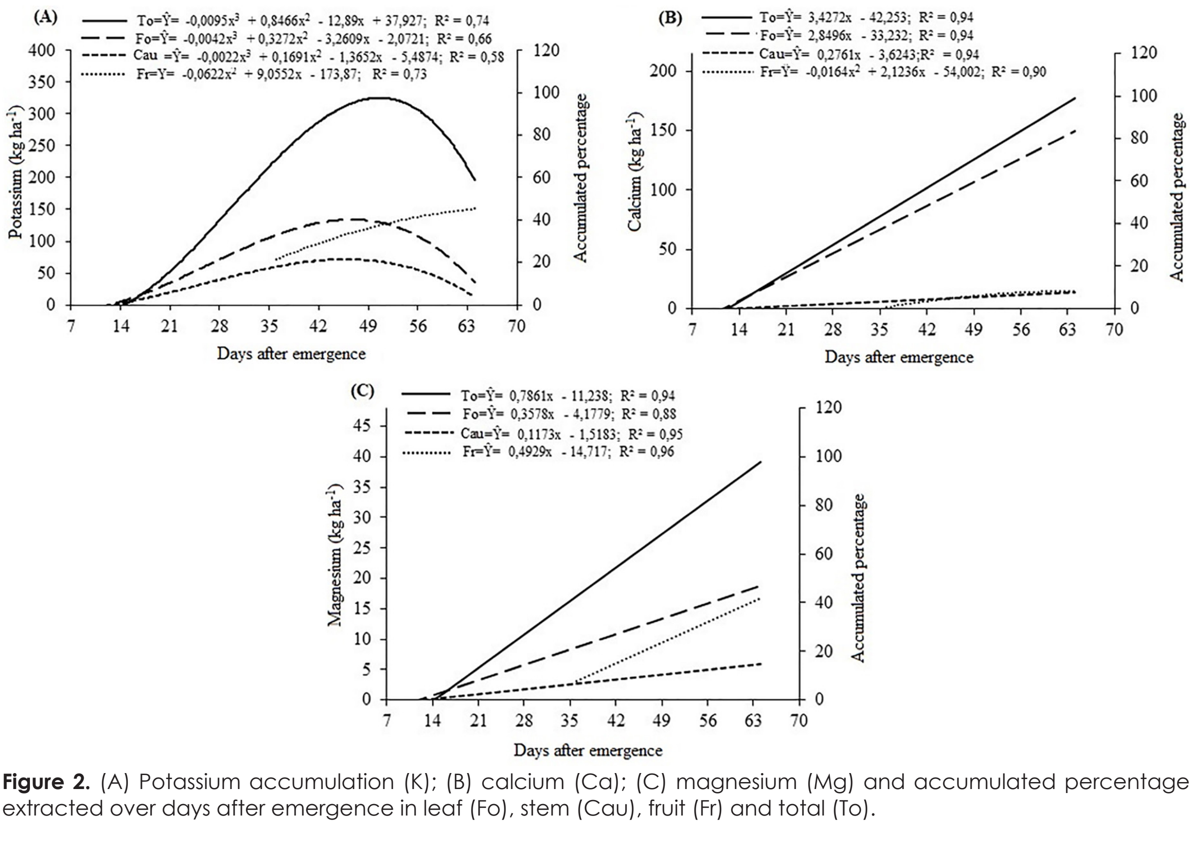

Figure 2. (A) Potassium accumulation (K); (B) calcium (Ca); (C) magnesium (Mg) and accumulated percentage extracted over days after emergence in leaf (Fo), stem (Cau), fruit (Fr) and total (To).

The third most extracted nutrient in the plants was N, with increasing accumulation until the 55.34th DAE when the maximum estimated value of 130.99 kg (288.5 lb) ha^{-1} was reached, and decreasing until the 64th DAE (Figure 3A). This is similar to what was observed by Oliveira (2017) with 'Goldex' melon, wherein the highest value of N was reached 57 days after transplanting and declined until the 70th day. However, most of this accumulation was due to the fruits that obtained higher increments of N reaching 79.26 kg (174.5 lb) ha^{-1} at the 52.34th DAE, followed by the leaves and stem. The same result was observed by Melo et al. (2013) in a lacy melon plant, in which the fruits stood out in the accumulation of N compared to the leaves and stems.

At the 50.40th DAE, 100% of N was accumulated, with 88% of this value being observed at the 14th and 45th DAE. This fact highlights the importance of N application, following the recommendations for each field condition to reduce the rates of fertilizer losses and aiming to meet the demand of the crop.

The accumulation of P increased until the 64th DAE, reaching 28.60 kg (62.9 lb) ha^{-1}, for which the fruits were responsible for the greatest increases, with more than 75% of the total P accumulated in the plant, followed by the leaves and stem (Figure 3B). Similar results were obtained by Melo et al. (2013), where P had the maximum increment at harvest with 0.91 g (0.03 oz) plant^{-1} and the fruits stood out in the accumulation of this nutrient, with more than 58% of the total extracted.

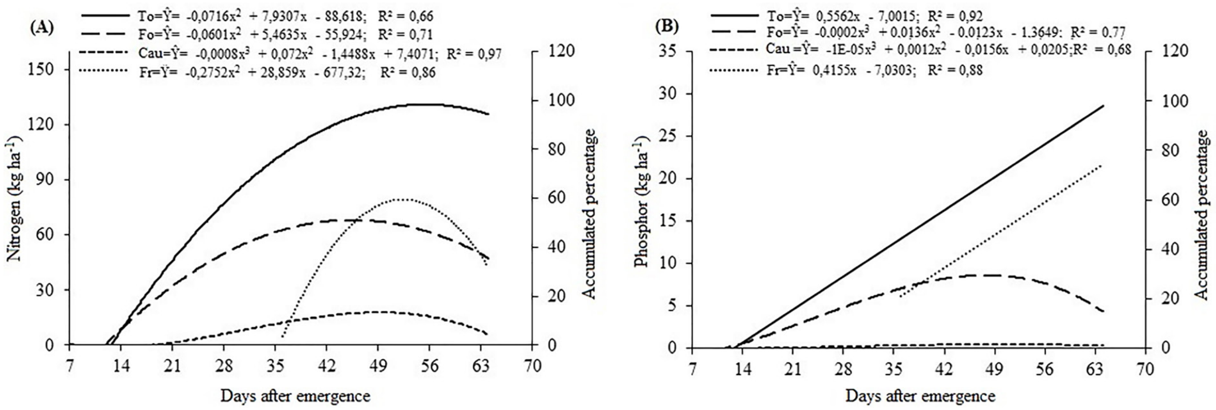

Figure 3. (A) Nitrogen accumulation (N); (B) phosphorus (P) and percentage extracted over days after emergence in leaf (Fo), stem (Cau), fruit (Fr), and total (To).

The macronutrients N and K increased until the 55th and 50th DAE, respectively, and decreased until the end of the cycle. Thus, fertilization with sources of N and K in the 'Gladial®' melon should meet the behavior presented to promote better utilization of the nutrients in question and provide greater productivity and fruit quality.

In contrast, P, Ca, and Mg linearly increased over time, reaching values of 28.60 (62.9), 177.09 (390), and 39.07 (86) kg (lb.) ha^{-1} at the 64th DAE. Based on these results, new studies with a greater experimental interval are recommended to define the maximum accumulation of these nutrients in the plant. However, since then, the parceled supply at the maximum until the 64th DAE allowed the melon plant to demonstrate its productive potential and simultaneously reduce the rate of loss of these nutrients.

Concerning the micronutrients (Figure 4) accumulated by the 'Gladial®' melon, it was possible to observe that Fe was the one that stood out the most with 1166.92 g (2.57 lb) ha^{-1}, followed by Mn (249.43 g or 0.54 lb ha^{-1}), Zn (239.33 g or 0.52 lb ha^{-1}), and finally Cu (60.33 g or 2.12 oz ha^{-1}). Oliveira et al. (2020) evaluated the increment of micronutrients in hybrid 'Goldex' and obtained the sequence of extraction in the following order: Fe > Mn > Zn > B > Cu.

This is higher than what was found by Melo et al. (2013) in a lacy melon plant where it showed at harvest 18.01 mg plant^{-1} (300.15 g or 0.66 lb ha^{-1}), a value attributed to the genetic potential of each cultivar, soil, and climatic conditions of each study.

The increase in each plant organ occurred in a quadratic manner, where the leaf alone accumulated approximately 75% of the total (903.88 g or 1.99 lb ha^{-1}) at the 64th DAE. This greater demand can be attributed to the role of Fe in the synthesis of chlorophyll and consequently in photosynthesis (Araújo et., 2017). However, the fruits only accumulated 264.33 g (0.58 lb) ha^{-1} at the 64th DAE, which was 20% of the total Fe, in contrast to the findings of Melo et al. (2013), where the fruits at 70 days after transplanting obtained a value of 8.48 mg plant^{-1} (141.33 g or 0.31 lb ha^{-1}). Moreover, concerning the total Fe accumulated by the 'Gladial®' melon, it was observed that this occurred linearly and that this micronutrient had a slow accumulation until 14 DAE and intensified after 21 days, which was also noted by Oliveira (2017).

The Mn in the leaves, stem, and whole plant increased linearly over the DAE, reaching values of 168.46 (0.37), 22.81 (0.05), and 249.83 (0.55) g (lb.) ha^{-1}, respectively, which simultaneously corresponds to approximately 67.38%, 9.14%, and 100% of the total absorbed (Figure 4B). Melo et al. (2013) found a total accumulation of 14.9 mg plant^{-1}, which is equivalent to that found in the present study.

The fruit showed a quadratic response, with the maximum accumulation (58.48 g or 2.06 oz ha^{-1}) observed at the 56.19th DAE. The high Mn increment in leaves was also observed by Oliveira et al. (2020), where 67% of this nutrient was found to be accumulated in the leaves. According to Dubberstein et al. (2017), Mn plays an important role in the activation of enzymes, water photolysis reactions, chlorophyll formation, and in the formation, multiplication, and functioning of chloroplasts. In addition, it also plays a role in nitrogen metabolism and cyclic compounds, and acts as a precursor of amino acids, hormones, phenols, and lignin (Conducta et al., 2020).

The accumulation of Zn in the plant occurred continuously until the 64th DAE where the plant absorbed 239.33 g (0.52 lb) ha^{-1} (Figure 4C), which is consistent with the findings of Melo et al. (2013), with a maximum amount of 10.37 mg $plant^{-1}$ (177.83 g or 0.39 lb ha^{-1}) verified at harvest. The accumulation of this micronutrient in the leaf and stem fitted a third-order polynomial model, with maximum values of 91.66 (3.23) and 33.33 (1.17) g(oz.) ha^{-1}, respectively.

The fruits were the main organs of Zn storage, linearly reaching the maximum of 116.66 g (0.25 lb ha^{-1}) or 55% of the total accumulated at the 64th DAE, followed by the leaves with 36% and the stem with 9%. The total accumulated by the 'Gladial®' melon was similar to what was verified by Melo et al. (2013), wherein the maximum amount accumulated by the fruits of the lacy melon was 6.07 mg $plant^{-1}$ (101.16 g or 0.22 lb ha^{-1}) at the end of the cycle. Furthermore, Oliveira et al. (2020) observed that fruits of the 'Goldex' melon were the main nutrient compartment at the end of the cycle, storing approximately 52% of the total accumulated nutrients, followed by leaves (41%) and stem (7%), equivalent to that observed in this study.

Among the micronutrients studied, Cu was the least accumulated by the melon plants throughout the cycle (Figure 4D), which is consistent with other studies on nutrient uptake in the melon crop, where this nutrient was the least accumulated by the crop (Melo et al., 2011; Terceiro Neto et al., 2012). At the 64th DAE, the plant accumulated 60.33 g (2.12 oz) ha^{-1} and the fruits were the main compartments of accumulation of this micronutrient, containing approximately 56% of the total extracted by the plant (30.87 g or 1.08 oz ha^{-1}), which contrasts with what was observed in 'Goldex' melon, where 80% of Cu was accumulated in the fruits (Oliveira et al., 2020). This is because of its importance in carbohydrate, protein, and cell wall metabolism, N metabolism, and plant reproduction (Araújo et al., 2017).

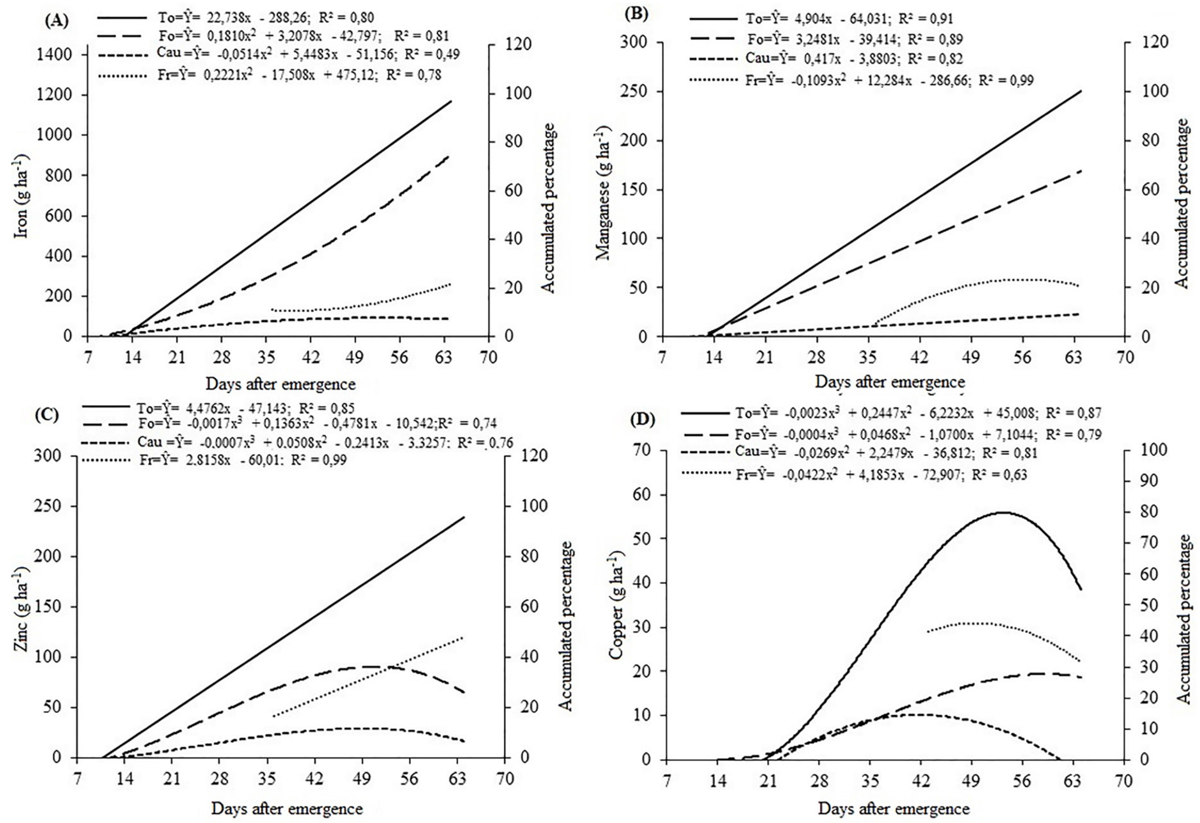

Figure 4. (A) Iron accumulation (Fe); (B) Manganese accumulation (Mn); (C) Zinc accumulation (Zn); (D) Copper accumulation (Cu) in leaf (Fo), stem (Cau), fruit (Fr) and total in yellow melon "Gladial F1" cultivated under fertigation as a function of evaluation periods (days after emergence).

Conclusions

Dry matter production increases until the 64th DAE.

The order of nutrient accumulation in yellow melon 'Gladial®' grown under fertigation is: K>Ca>N>Mg>P.

The period from the 14th to 43rd DAE was the period of highest demand for nitrogen and potassium by the 'Gladial®' melon.

Among the micronutrients analyzed, Fe was the most extracted by the crop, followed by Mn, Zn, and Cu.

The period between 36 and 64 DAE was the period of greatest demand for micronutrients by the plant.

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