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Macro and micronutrient accumulation in watermelon

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Abstract

The expansion of crop productivity such as watermelon can be reached by providing adequate nutrition in quantity and when plants need it most. It is known that well-nourished plants better resist biotic and abiotic stresses, being determinants for more sustainable management. In this sense, the objective of the present study was to evaluate the plant growth, the rate of nutrient absorption, the proportion of absorption, and estimate the quantity of exported nutrients by watermelon fruits. The experiment was implemented in randomized block design with eight treatments (phenological phases) - 33 and 40 (growth), 47 and 54 (flowering), 61 and 68 (filling), 75 and 82 (maturation) days after planting (DAP). Each evaluation consisted of plant collection for dry mass, macro, and micronutrient analysis in the shoot (leaves and stems), fruits, and the entire plant. The period between 61 and 68 DAP was the one with the highest plant dry matter increment. The accumulation of macronutrients in the plant shoot showed the following decreasing order: Ca>N>K>Mg>P>S, in the fruits: K>N>P>Ca>Mg>S and in the whole plant: K>N>Ca>P>Mg>S. For micronutrients, the decreasing order of accumulation for the shoot and the entire plant were Fe>Mn>Zn>B>Cu, and for fruits were Fe>B>Zn>Mn>Cu.

Keywords: *Citrullus lanatus*, nutrient exporting, plant nutrient accumulation

Introduction

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) is an annual vine plant that produces one of the most widely grown and consumed fruit. The watermelon fruit is an excellent source of vitamins, minerals, and antioxidants such as lycopene and carotenoids. These antioxidants are responsible for the red color and are related to protection against chronic health problems like cancer insurgence and cardiovascular disorders (Ali et al., 2017, Torun et al., 2018).

The findings of the functional benefits of watermelon tend to increase its consumption over the years (Kyriacou et al., 2018). The watermelon crop is relevant in Brazil to both the economic and social aspects and involves services, transportation and storage throughout the production cycle and in the post-harvest phase (Lund et al., 2015).

According to Rocha et al. (2020), one of the major obstacles to expanding the watermelon crop is the scarcity of technical information, especially mineral nutrition, which directly interferes with fruit productivity and quality (Nogueira et al., 2014).

To increase production, producers have used the extensive applications of mineral fertilizers, raising the production costs. However, the amounts of fertilizer applied are not always aligned with the absorption capacity of the plants. This situation causes losses to the environment by leaching, wasting nutrients, causing environmental contamination, and reducing energy efficiency (Greer et al., 2020).

The fertilization recommendations are made according to the nutrient contents in the soil, the extraction needs for the crop, and the relationship with the expected productivity. However, it is known that there are variations in the need for nutrients in each phase of the plant development; thus, the knowledge

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of the plant phases are of great need and a driver to improve the management of the dose and time of nutrient application, which increases the efficiency of the fertilization (Pereira et al., 2018).

The nutrient absorption march, expressed in response curves as a function of plant age, informs the periods of high nutrient absorption correlated with the plant metabolism in different plant development stages (Vidigal et al., 2009). Information such as the absorption march and the nutrient extraction and export curves help improve fertilizers' recommendations, which are necessary to promote effective integrated management (Xua et al., 2016).

The technological advances of agriculture, the pressure for more rational and sustainable production, added to the increase of the fertilizer costs, bring new requirements regarding the efficient use of nutrients, generally non-renewable resources (Silva et al., 2015). Thus, the objective of this study was to evaluate the nutrient absorption march of watermelon to improve the fertilizer recommendations for this crop.

Material and Methods

The experiment was conducted in the district of Martinésia (18°54'41'' S; 48°15'21'' W), located in Uberlândia (Brazil), between August and November (Winter-Spring). According to Koppen's classification, the region's climate is considered an 'Aw' (tropical savanna, with hot humid summer and dry cold winter) with an average temperature of 22.3 °C and average precipitation of 1,479 mm per year.

The soil of the experimental area has inclined relief (5%) and is classified as Yellow Red Latosol (Oxisol). Before the installation of the experiment, soil sampling was carried out in the 0-0.2 cm soil layer. Soil analysis was performed according to the method described by EMBRAPA (2013). The chemical components of 0-20 cm soil layer were: pH in water = 6.9; P = 190.3 mg dm^{-3}; K = 4 mmolc dm^{-3}; Ca = 34 mmolc dm^{-3}; Mg = 9 mmolc dm^{-3}; Al = 0 mmolc dm^{-3}; CTC = 63 mmolc dm^{-3}, and base saturation (V) = 74.6%.

The soil of the experimental area was subsoiled, plowed and the seedbed was formed. The enchanter was used twice to lift and then to shape the seedbeds. Each seedbed had 50 meters long, 0.4 meters wide, and 0.15 meters high.

Fertilizers were applied manually to the planting furrow. About 7.5 g of N, 45 g of P, and 22.5 g of K were applied as 4-14-8 (N, P_2O_5, K_2O) and Yoorin (18% P_2O_5 total, 18% Ca, 7% Mg, 10% Si). The cover fertilization was 150 grams per plant of 20-0-20 (N, P_2O_5, K_2O), 70 grams of potassium sulfate and 12.5 grams of super simple phosphate (18% P_2O_5 total, 16% Ca, 8% S), divided in applications at 20, 40 and 60 days after the transplanting the watermelon seedlings.

Mulching (black-silver) was placed on each seedbed to facilitate the crop management and to reduce the occurrence of invading plants (weeds). Weeds were also managed in pre-emergence and post-emergence (4 L ha^{-1} of oxydiazon and 2 L ha^{-1} of paraquat). Phytosanitary control was performed only when necessary with products registered for culture and at a recommended dose. The seedling planting occurred in lines spaced by 2.5 meters and 1 meter between plants, with a total population of 4,000 plants per hectare. The watermelon hybrid YWM14 was used.

Although part of the conduction period of the experiment coincided with the rainy season in the region, the water needed for plant development was complemented with irrigation. A drip system was installed, and the drippers were placed 0.5 m apart from each other. The water flow was about 4 L $hour^{-1}$ delivering 35 liters of water per turn, twice a week, totaling 400 mm by the end of the crop cycle. The water from rains was discounted from the water blade that needed to be applied.

The experimental design was set as randomized blocks, with eight treatments and three replications. The treatments were the sampling dates, which occurred with an interval of 7 days between each sampling. Sampling started at 33 days after planting (DAP) (treatment 1) and ended at 81 DAP (treatment 8).

Each replication corresponded to 3 plants, in which all analyses were done. From one collection to another, care was always taken to pick up plants between two other plants. The collected plant did not present a competitive advantage if it was next to a plant position that was removed in the previous collections.

The eight samplings (treatments) were grouped into following pairs to designate the formation of 4 phases of phenological development, 'growth' (collections 1 and 2), 'flowering' (collections 3 and 4), 'filling' (collections 5 and 6) and 'maturation' (collections 7 and 8). Initially, a cut was made at about 1 cm above the soil level, the roots were discarded, and the top was considered the "whole plant". The plants were then separated into leaves (leaf limb and petiole), stems (main stem and its branches), and fruits (without the peduncle).

The fresh biomasses (FM) of each of the three plant divisions were weighed separately on an analytical scale. A sample of 200 grams of each material was destined to dry in a forced air circulation oven to obtain the moisture content and dry biomass (DM). Plant dry was performed at 65 °C until it reached constant mass.

The dry biomass of the whole plant was calculated by extrapolating the fresh and dry biomass content contained in the dry biomass and the total fresh biomass obtained in the initial weighing. The dry biomass was intended to quantify the macro and micronutrient contents (g kg^{-1}), according to EMBRAPA (2013). The content of the nutrients was also extrapolated to total quantities accumulated by the plants during the development cycle (g plant^{-1}).

The accumulated dry mass, the relationship between the absorbed nutrients, and the nutrient absorption march were used to trace a behavioral parameter of the nutritional need of the watermelon plants. The data were previously submitted to analysis of variance (ANOVA) and analysis of regressions using the statistical software SISVAR®.

Results and Discussion

The accumulation of dry matter in shoot (leaves and stem), fruits, and whole watermelon showed a linear increase, according to the data set, with maximum at the end of the cycle (82 DAP) (Table 1). The maximum accumulated of DM was

619.5; 587 and 1115.5 g plant^{-1} in shoot, fruits, and whole plant, respectively.

The N accumulation in the watermelon shoot (leaves and stems) increased up to 76 DAP, with a maximum of 14.5 g plant^{-1}. The accumulation was increasing for fruits and whole plant until the end of the cycle (82 DAP) with maximums of 14.6 and 29.5 g plant^{-1} (Table 1).

The accumulation of P and K also presented a quadratic adjustment for the watermelon shoot, with maximum accumulations observed at 63 and 72 DAP, corresponding to 1.8 and 13.4 g plant^{-1}, respectively. Fruits and the whole plant accumulated 2.6 and 4.2 g plant^{-1} of P and 18.3 and 31.3 g plant^{-1} of K, respectively.

Table 1. Accumulation of macronutrients (g plant^{-1}) in the shoot (leaves and stem), fruits, and whole watermelon plant along its crop cycle.

Plant part	Equation	R^2	$X_{maximum}$	$Y_{maximum}$
	Dry biomass			
Shoot	12.269x – 386.58	84.95	82	619.48
Fruit	20.366x - 1083	94.77	82	587.01
Whole plant	24.818x – 919.53	94.28	82	1115.54
	Nitrogen			
Shoot	$-0.0082x^2 + 1.2544x - 33.526$	95.53	76	14.45
Fruit	0.5164x - 27.777	96.92	82	14.57
Whole plant	0.6263x - 21.896	97.91	82	29.46
	Phosphorus			
Shoot	$-0.0024x^2 + 0.3026x - 7.7177$	76.39	63	1.82
Fruit	0.0843x - 4.3454	92.92	82	2.57
Whole plant	0.0852x - 2.8055	89.33	82	4.18
	Potassium			
Shoot	$-0.0096x^2 + 1.3783x - 36.068$	91.87	72	13.40
Fruit	0.6304x - 33.413	94.06	82	18.28
Whole plant	0.6679x - 23.45	98.12	82	31.31
	Calcium			
Shoot	0.3487x - 12.097	88.50	82	16.50
Fruit	$-0.0044x^2 + 0.6443x - 21.992$	42.14	73	1.59
Whole plant	0.3926x - 13.848	85.89	82	18.35
	Magnesium			
Shoot	0.0643x - 2.0524	85.33	82	3.22
Fruit	0.0347x - 1.8506	77.11	82	0.99
Whole plant	0.0856x - 2.957	94.22	82	4.06
	Sulfur			
Shoot	0.0101x - 0.3177	73.24	82	0.51
Fruit	0.0189x - 1.0043	84.71	82	0.55
Whole plant	0.0217x - 0.8099	87.46	82	0.97

Calcium accumulation in fruits increased up to 73 DAP and then decreased, with a maximum accumulation of 1.6 g plant^{-1}. The maximum accumulation (82 DAP) observed in the shoot, and the whole plant were 16.5 and 18.4 g plant^{-1}, respectively (Table 1). The accumulation of Mg and S increased in all plant parts, shoot, fruit and the whole plant, and the maximum accumulation of Mg was 3.2, 1.0, and 4.1 g plant^{-1}, while for S the accumulation was 0.5, 0.6 and 1.0 g plant^{-1}, respectively (Table 1).

Considering the accumulation of macronutrients the decreasing order for the watermelon shoot was Ca > N > K > Mg > P > S, for fruits was K > N > P > Ca > Mg > S, and for the whole plant was K > N > Ca > P > Mg > S (Table 1).

The nutrient accumulation rate in the first 33 DAP was little. Grangeiro & Cecílio Filho (2004, 2005) also observed this reduced accumulation at the beginning of the watermelon cycle. This result was expected since the accumulation of nutrients tends to follow the pattern of the dry matter curve, which, likewise, is characterized by slow growth in the initial phases (Vidigal et al., 2009).

Almeida et al. (2012) detected that the change of the preferential drain occurred from 44 to 64 DAP. In cucurbitaceous, absorption pattern tends to be similar for species (Araújo et al., 2001). The time differences in the preferential drain can be explained by differences in crop management (e.g., fertilization) and the differences in the crop cycle between the varieties or hybrids.

Nitrogen, K, and Ca were the most absorbed macronutrients by the watermelon plants, according to Santos et al. (2016) and Pereira et al. (2018), which differed from the present study. Here K was the most absorbed and accumulated nutrient, which can be justified by the divergences between the nutrient contents in the soil and the amount of fertilizers applied (upon the recommendation of fertilization), that is, the amount of available K for absorption and the accumulation capacity of each variety or hybrid.

The divergences in the order and quantity of nutrients absorbed in relation to the varieties can be understood by the variations in the morphology, anatomy, and physiology of the plants, especially regarding the root system. Variations in root diameter, for example, can make roots more absorbing and more adaptive to environments (Kong et al., 2017).

Authors report a trend of reduction in N, P, and K levels in the watermelon shoot at the end of the cycle (Almeida, 2012), an observation that also occurred in the present study. Possibly, the easy mobility of these nutrients in the plant allowed them to be readily translocated to the fruits.

Potassium was the first nutrient in the order of priority of absorption by the fruits and whole plant, indicating K as a nutrient of great relevance for forming and structuring the watermelon fruits. Thus, K was indicated as the most important nutrient for the stabilization of cucurbitaceous fruits, closely related to fruit quality and peel resistance to post-harvest (Mendes et al., 2010).

Regarding the micronutrients, a linear adjustment was observed for B, Fe, Mn, and Zn in all evaluated parts: shoot (leaves and stems), fruits, and whole plant. Therefore, there was a growing accumulation of these nutrients until the end of the watermelon crop cycle (82 DAP) (Table 2).

Table 2. Accumulation of micronutrients (g plant^{-1}) in the shoot (leaves and stem), fruits, and whole watermelon plant along its crop cycle.

Plant part	Equation	R^2	$X_{maximum}$	$Y_{maximum}$
		Boron		
Shoot	0.8389x - 31.154	93.03	82	37.64
Fruit	0.7161x - 39.216	91.12	82	19.50
Whole plant	1.2513x - 48.941	89.42	82	53.67
		Copper		
Shoot	$-0.0043x^2 + 0.6291x - 16.639$	94.70	73	6.37
Fruit	0.1566x - 7.8029	83.83	82	5.04
Whole plant	0.2445x - 8.0664	90.66	82	11.98
		Iron		
Shoot	8.8205x - 307.37	92.13	82	415.91
Fruit	3.783x - 205.37	82.33	82	105.16
Whole plant	11.044x - 402.83	96.49	82	502.78
		Manganese		
Shoot	1.4861x - 60.497	88.20	82	61.36
Fruit	0.6367x - 37.221	63.19	82	14.99
Whole plant	1.7927x - 74.329	84.35	82	72.67
		Zinc		
Shoot	0.8503x - 29.284	98.40	82	40.44
Fruit	0.7261x - 40.108	85.27	82	19.43
Whole plant	1.2597x - 47.029	94.83	82	56.27

The maximum accumulation of micronutrients in the shoot, fruits, and whole plant were 37.7, 19.5 and 53.7 g plant^{-1} of B, 415.9, 105.2 and 502.8 g plant^{-1} of Fe, 61.4, 15 and 72.7 g plant^{-1} of Mn, and 40.4, 19.4 and 56.3

g plant-1 of Zn, respectively (Table 2). However, the Cu accumulation increased up to 73 DAP (6.4 g plant-1), followed by an accumulation fall in the shoot (leaves and stems). Fruits and the whole plant showed increasing accumulation until the end of the cycle (82 DAP), with maximums of 5 and 12 g plant-1, respectively (Table 2).

The decreasing order of accumulation of micronutrients in watermelon shoot and whole plant were: Fe > Mn > Zn > B > Cu, and for fruits: Fe > B > Zn > Mn > Cu. Therefore, an inversion in the B and Mn accumulation was observed - fruits (commercial plant part) presented more B than Mn. Iron was the most absorbed micronutrient for both vegetative and reproductive phases, justified by its great importance in chlorophyll biosynthesis and possible relationship with the increase of sugars and soluble proteins (Wang et al., 2016).

The total amounts of nutrients accumulated at the end of each phenological phase (growth, flowering, filling, and maturation) are shown in Table 3. The growth phase (33 to 44 DAP) showed very small amounts accumulated, representing between 2.3% (Mn) to 9.3% (Cu) of the total absorbed throughout the cycle. In flowering (47 to 54 DAP) the accumulation of K (38%), Mg (49%), and Fe (38%) stood out. The most demanded nutrients in filling (61 to 68 DAT) were N (37%), P (56%), Ca (75%), and Cu (57%). The other nutrients, S (56%), B (43%), Mn (61%), and Zn (42%), had higher expression of accumulation in the maturation phase (75 to 82 DAT) (Table 3).

Table 3. The total amount of nutrients accumulated (g planta-1) by the end of each watermelon phase (hybrid YWM14).

Fase	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Crescimento	2.0	0.2	2.2	1.2	0.2	0.3	2.7	0.9	26.4	2.2	2.3
Florescimento	11.9	1.7	14.1	7.1	2.0	0.3	14.5	5.4	205.7	10.2	18.2
Enchimento	22.2	3.7	23.8	18.8	3.3	0.4	37.8	10.9	347.1	36.6	37.7
Maturação	27.7	3.6	31.0	15.6	3.7	0.9	66.1	9.7	478.0	94.3	65.5

The amount of nutrients before the fruit-filling phase was low, highlighting the relevance of nutritional management regarding the time of fertilizer application and its portioning throughout the cultivation cycle. Commercial areas of watermelon crops with irrigation systems allow better control of the nutrients applied and the positioning of such according to the plant needs.

The knowledge about the plant stages more able to absorb and translocate the nutrients improves the sustainability of the agroecological system, especially in relation to the use and efficiency of the nutrients applied. Such management reduces the soil contaminations and nutrient loss, turning to more economically viable managements. The marches of nutrient absorption allow producers to establish more personalized fertilization, according to the variety and nutrient contents in the soil. Therefore, more rational recommendations, with nutrient applications following the plant age and the periods of greatest need for the nutrients (Morais et al., 2020).

Watermelon plants accumulated 124 kg ha-1 of K, 111 kg ha-1 of N, 75.2 kg ha-1 of Ca, 14.7 kg ha-1 of Mg, 14.6 kg ha-1 of P, and 4.3 kg ha-1 of S. Figure 1 shows the accumulated distribution between shoots and fruits. Therefore, a total of nutrients exported of 74.8 kg ha-1 (N) 57.8 kg ha-1 (P), 8.4 kg ha-1 (Ca), 4.8 kg ha-1 (Mg), 10.1 kg ha-1 (P), and 2.6 kg ha-1 (S) was observed. The amount of nutrient in the shoot (remained straw for decomposition and replacement of nutrients) in successive crops were 49.2 kg ha-1 (K), 53.1 kg ha-1 (N), 66.8 kg ha-1 (Ca), 9.9 kg ha-1 (Mg), 4.5 kg ha-1 (P), and 1.7 kg ha-1 (S).

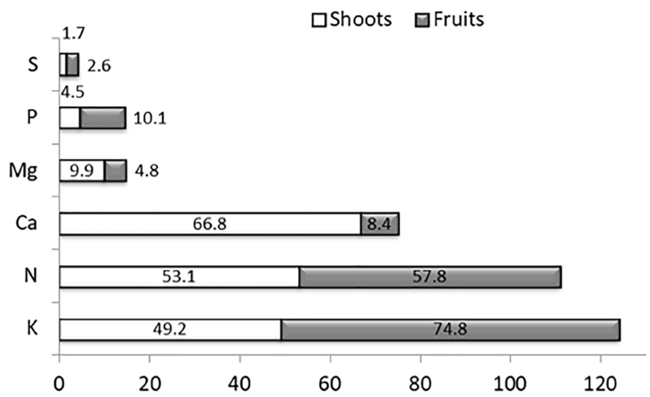

Figure 1. Accumulated (kg ha-1) macronutrients in watermelon shoot and fruit (hybrid YWM14).

Watermelon plants accumulated 1937 g ha-1 of Fe, 377 g ha-1 of Mn, 264 g ha-1 of B, 262 g ha-1 of Zn, and 45 g ha-1 of Cu. Figure 2 shows the distribution of the accumulated between the watermelon shoot and fruits. Therefore, a total of nutrients exported of 515 g ha-1 (Fe), 86.8 g ha-1 (Mn), 87.3 g ha-1 (B), 93.6 g ha-1 (Zn), 19.9 g ha-1 (Cu), and 2.6 kg ha-1 (S) was observed. The amount of nutrient in the shoot (remained straw for decomposition and replacement of nutrients) in successive crops were 1422 g ha-1 (Fe), 290 g ha-1 (Mn), 177 g ha-1 (B), 168 g ha-1 (Zn), and 25 g ha-1 (Cu) and 2.6 kg ha-1 (S).

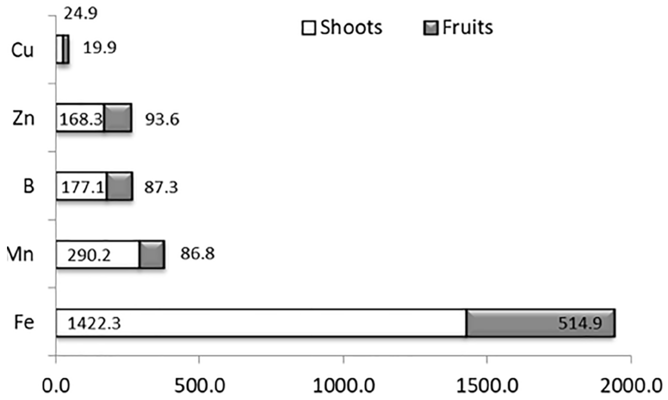

Figure 2. Accumulated (kg ha^{-1}) micronutrients in watermelon shoot and fruit (hybrid YWM14).

The rate between what was exported (fruits) and what was left in the field (shoot), the most exported macronutrients were P (69.2%), S (61.1%), K (60.4%), and N (52.1%), and the most exported micronutrient was Cu (44.4%) (Figure 3). Interestingly, the micronutrients Mn, Fe, B and Zn presented a rate of return above 60%, staying in the shoot biomass for decomposition.

Considering that micronutrients are required in small amounts, special care should be allocated to this category of nutrients since the imbalance between micronutrients is as detrimental to productivity as the lack of a primary macronutrient (NPK).

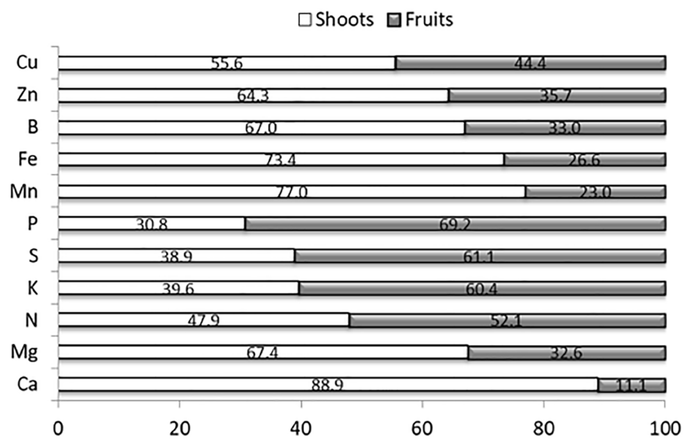

Figure 3. Percentage of each accumulated nutrient in watermelon shoot and fruit (hybrid YWM14

Balanced nutrition presents several benefits to plant development. In addition to culminating in better crop performance, actions that value the balance of nutrients applied are directly related to the maintenance of soil quality and the sustainability of agricultural systems (Changhui et al., 2014).

It is important to observe the rate of nutrients exported from the system to understand what needs to be reset in the face of the watermelon crop requirements. The quantity to be inserted in the system must be in accordance with soil analysis, crop requirements, and the biomass elements' replacement. The time to biomass to return a nutrient is variable and majorly depends on soil life (microbiota) diversity and quantity, C/N ratio of the crop residues, climatic conditions, and dynamic interactions among these factors. The nutrient reposition from the biomass decomposition is listed in the literature as a contribution that must be considered in fertilization programs (Grangeiro & Cecílio Filho, 2005).

The Ca in the present study presented a return rate of 88%, which deserves attention for the following fertilization regarding soil correction to avoid unbalances among other cations in soil due to excess of Ca. An unbalanced nutrient situation can generate difficulties for nutrient absorption; thus, the deficiency of some nutrients, excess doses or even applications in an unsynchronized way can result in limitations or a fall in productivity (Qiu et al., 2014).

The ideal balance among nutrients should be sought since imbalances reduce the plant vitality and increase the sensitivity to stress conditions that may occur during the crop cycle. Nutritional balance has a significant effect on reducing the occurrence and progress of phytopathogens (Hemmati & Mansoori, 2016). Also, it reduces the production costs and the environmental impact of the agricultural activity by applying rational doses in time. This, knowing the proportion between nutrients in the different phenological phases helps in the most appropriate nutritional management and with higher economic and ecological returns.

Conclusions

The decreasing order of macronutrient accumulation in the shoot (leaves and stems) were: Ca>N>K>Mg>P>S; fruits: K>N>P>Ca>Mg>S and whole plant: K>N>Ca>P>Mg>S.

The decreasing order micronutrient accumulation for the shoot and whole plant were: Fe>Mn>Zn>B>Cu, and for watermelon fruits were: Fe>B>Zn>Mn>Cu.

Calcium and K were the macronutrients with the highest accumulation by the plant shoot and watermelon fruits.

Iron was the micronutrient of the greatest accumulation by the plant and was also the most required element in all phenological phases of the crop.

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