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Growth and accumulation of nutrients of ‘Top Gun’ watermelon

Crescimento e acúmulo de nutrientes de melancia 'Top Gun'

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Abstract

An experiment was carried out in the city of Itápolis (SP), from October 2007 to January 2008, in a Red-Yellow Distrophic Argissolo (loamy soil), in order to evaluate growth, accumulation and exportation of macro and micro-nutrients in *Top Gun* hybrid watermelon. The experimental design took place in randomized blocks, having six different treatments corresponding to the sampling stages of plants: elongation of the main branch; presence of tertiary branches; early flowering; fruit with a diameter of 8 cm; fruit with a mass of between 4 and 5kg; and end of the cycle. The accumulation of dry mass was slow up to 35 DAS, increasing from this point on, reaching 1528 g plant^{-1} at the end of the cycle. The total accumulated dry mass was made up of 11.6% stems, 19.5% leaves, and 68.9% fruit. In terms of nutrient accumulation, this was also slow up to 35 DAS. With fruiting, came an increase in the demand for nutrients with 45 to 59 DAS being the period of greater nutritional demand. The order of decreasing nutrients was: K> N> Ca> Mg> P> S> Mn> Fe> B> Zn> Cu. The export of macronutrients (in kg ha^{-1}) was 36.4; 4.3; 62.7; 5.0; 6.5; and 2.3 for N, P, K, Ca, Mg and S, respectively. For Mn, Fe, B, Zn and Cu, the values exported in g ha^{-1} were 137.0; 157.7; 120.4; 60.4 and 22.1, respectively.

Additional keywords: *Citrullus lanatus* L.; dry mass; macronutrients; micronutrients; plant nutrition.

Resumo

Com o objetivo de avaliar crescimento, acúmulo e exportação de macro e micronutrientes em melancia, híbrido Top Gun, realizou-se um experimento no município de Itápolis (SP), de outubro de 2007 a janeiro de 2008, em um Argissolo Vermelho-Amarelo distrófico. O delineamento experimental foi o em blocos casualizados, com seis tratamentos, correspondentes às épocas de amostragem de plantas: alongamento da rama principal; presença de ramos terciários; início do florescimento; fruto de 8 cm de diâmetro; fruto com massa entre 4 e 5 kg e final do ciclo. O acúmulo de massa seca foi lento até 35 DAS, incrementando-se a partir deste ponto, atingindo no final do ciclo 1.528 g planta^{-1}. Do total de massa seca acumulada, as contribuições das hastes, das folhas e dos frutos foram, respectivamente, de 11,6%; 19,5% e 68,9%. Em relação ao acúmulo de nutrientes, este também foi lento até 35 DAS. Com a frutificação, ocorreu incremento na demanda por nutrientes, sendo de 45 a 59 DAS o período de maior demanda nutricional. A ordem decrescente dos nutrientes foi: K>N>Ca>Mg>P>S>Mn>Fe>B>Zn>Cu. A exportação de macronutrientes (em kg ha^{-1}) foi de 36,4; 4,3; 62,7; 5,0; 6,5 e 2,3 para N, P, K, Ca, Mg e S, respectivamente. Para Mn, Fe, B, Zn e Cu, os valores exportados em g ha^{-1} foram, respectivamente de 137,0; 157,7; 120,4; 60,4 e 22,1.

Palavras-chave adicionais: *Citrullus lanatus* L.; massa seca; macronutrientes; micronutrientes; nutrição de plantas.

Introduction

The total area dedicated to watermelon production in Brazil covers 90,447 ha and produces 2,090,432 tons, with a production value of R$1,351,434.00 (IBGE, 2016). This fruit is cultivated in every region of the country, especially in the states of Bahia, Rio Grande do Norte, Tocantins, Rio Grande do Sul, Goiás and São Paulo, with an average Brazilian productivity of 22.11 t ha^{-1} (IGBE , 2016), well below the crop potential, which is close to 100 t ha^{-1}.

Barros et al. (2012) reported that the inadequate management of mineral nutrition was among the main limitations in obtaining higher productivity. Fertilization may represent around 16.6% of the watermelon production costs (Sandri et al., 2014), and is essential, not only to achieve high productivity, but also to obtain high quality fruit (Nogueira et al. 2014). According to

Cecílio Filho & Peixoto (2013), an adequate fertilization strategy can be constructed by taking into account the process of nutrient accumulation, which gives the amounts of nutrients at each stage of development, as well as the stages when they are in most demand.

In Brazil, the process of nutrient accumulation in watermelon involving various hybrids was carried out by a number of researchers including: Grangeiro & Cecílio Filho (2004) who worked with the Tide hybrid and Grangeiro & Cecílio Filho (2005a, b) worked with the seedless hybrids, Shadow and Nova; Vidigal et al. (2009) worked with the cultivar Crimson Sweet; Lucena et al. (2011) worked with the Quetzale hybrid; Aguiar Neto et al. (2016) worked with the Quetzale and Shadow hybrids; and Schiavon Júnior et al. (2017) worked with the Master hybrid. Similarity was found only in the decreasing order of accumulated nutrients of the watermelon, those being K, N, Ca. Secondary macronutrients as well as micronutrients did not present a pattern for the order of accumulation by the plant. Quantities of dry mass and nutrients accumulated by the watermelon, as well as periods of greater accumulation and export percentages were variable according to cultivar, season and region. Thus, it is important to know the growth and nutrient accumulation of the cultivar in the planting region.

The objective was to evaluate the growth, accumulation and exportation of nutrients by the 'Top Gun' watermelon.

Material and methods

The experiment was set up and conducted in a rural property in Itápolis, SP, from October 26, 2007 to January 5, 2008, which is located at 21º 35' 35'' S and 48º 48' 42'' W at an altitude of 481 m. The soil was classified as Dystrophic Red-Yellow Argisol, medium texture (Embrapa, 2013). The precipitation during the time of the experiment was 423.5 mm.

In the experimental area, samples of soil were removed from the top layer at a depth of 0-20 cm for chemical analysis and the observed results were pH $_{(CaCl2)}$ 4.8, 19 g dm^{-3} of organic matter, 5 mg dm^{-3} of P; 2.1; 15.0; 9.0 and 18.0 mmol$_c$ dm^{-3} of K, Ca, Mg and H+Al, respectively; 60% base saturation; 0.6; 29.0; 1.0; 0.6 and 24 mg dm^{-3} of B, Fe, Zn, Cu and Mn, respectively.

The experiment was set up in a randomized block design with six treatments (stages of plant sampling) and six replications. Samples were taken at six moments in the plant’s development: main branch elongation; presence of tertiary branches; early flowering; fruit at 8 cm in diameter; fruit with mass of between 4 and 5 kg; and end of the cycle.

Soil preparation consisted of plowing and harvesting. Liming was performed with calcite limestone, with 60% PRNT, to raise the base saturation to 80%. Fertilization consisted of the application of 580 kg ha^{-1} of N-P_2O_5-K_2O in the ratio 4-30-16. The sowing of the Top Gun hybrid was performed at a spacing of 3.0 x x 1.5 m. Crop practices (weeding, pest and diseas e control) were carried out. At 40 days after sowing (DAS) the plants, 150 kg ha^{-1} of N-P_2O_5-K_2O was applied in the proportion of 20-00-20.

At 35 DAS, the evaluation of the nutritional state of the watermelon plant was carried out, by collecting the fifth leaf from the tip of the branch, disregarding the apical tuft, as recommended by Trani & Raij (1997).

In order to evaluate the accumulations of mass and nutrients, six plants were collected per season, one per experimental unit. The plants were collected without the roots, and the cut was made in the hypocotyl region. Then, they were separated into leaf (petiole + leaf blade), stem and fruit, washed with running water and then with deionized water. Afterwards, the leaves, fruit and stems were placed in paper bags and dried in an oven with forced air circulation at 65 ºC. The fruit was sliced to facilitate drying. The dried samples were weighed on a precision scale of 0.01 g. To obtain the total mass of the fruit, the mass of fruit obtained at 64 DAS (first harvest) and 71 DAS (last harvest and at the end of the cycle) were added. Milling was done in Wiley type stainless steel mill with a 20 mesh sieve. The samples were prepared for digestion in the laboratory and then the macro and micronutrient contents were determined (N, P, K, Ca, Mg, S, Cu, Fe, Mn, Zn and B), according to procedures described by Bataglia et al. (1983).

As quantidades dos nutrientes foram calculadas mediante o produto entre o teor e a massa seca correspondente a cada parte da planta e época avaliada. Para obter a quantidade total de nutrientes no fruto, foram somadas as quantidades de nutrientes nos frutos das duas colheitas. O total acumulado pela planta correspondeu à soma das quantidades presentes nas folhas, hastes e frutos. A exportação dos nutrientes correspondeu às quantidades presentes nos frutos.

The quantities of nutrients were calculated by the product of the content and the dry mass corresponding to each part of the plant and the evaluated period. To obtain the total amount of nutrients in the fruit, the amounts of nutrients in the fruit of the two harvests were added. The total accumulated by the plant corresponded to the sum of the quantities present in the leaves, stems and fruit. The nutrients exported corresponded to the quantities present in the fruits.

To obtain the equations of nutrient accumulation during the cycle, the Origin 6.0 program was used. The equations were fitted to the nonlinear logistic model: $y = a/(1 = e^{-k(x - xc)})$; where: y = the mean value of the evaluated characteristic; a = maximum asymptotic (maximum quantity); k = average rate of increment of accumulated quantity; x = time (days); xc = time required to reach half the maximum quantity.

Results and discussion

Growth and development

According to the proposed harvest of plants, based on morphological characteristics, the development of the watermelon plant was divided into five phenological phases that corresponded to two vegetative stages and three reproductive stages (Figure 1).

The watermelon plant cycle was 71 days and the yield was 31 t ha^{-1}. Nutrient content at 35 DAS was 35.6; 3.0; 27.0; 47.0; 5.0 and 1.9 g kg^{-1} of N, P, K, Ca, Mg, S and 42; 13.9; 181; 430 and 42 mg kg^{-1} of B, Cu, Fe, Mn and Zn, respectively. The levels are within the ranges considered adequate for watermelon plants, according to Trani & Raij (1997), with the exception of Mn, which was above the values of reference.

Phase V_1, which corresponded to the period between sowing and elongation of the main stem (before the appearance of secondary stems) lasted 23 days. During this period, the plant accumulated 2.5% and 2.6% of the total dry mass accumulated at the end of the cycle in the stems and leaves, respectively.

Phase V_2 started with the emission of the secondary and tertiary stems and ended when flowering began (24 to 35 DAS) (Figure 1). By then, it had accumulated 3.8% of the total dry mass obtained at the end of the cycle, similar to that reported by Vidigal et al. (2009) and Aguiar Neto et al. (2016) with Crimson Sweet and Shadow watermelon.

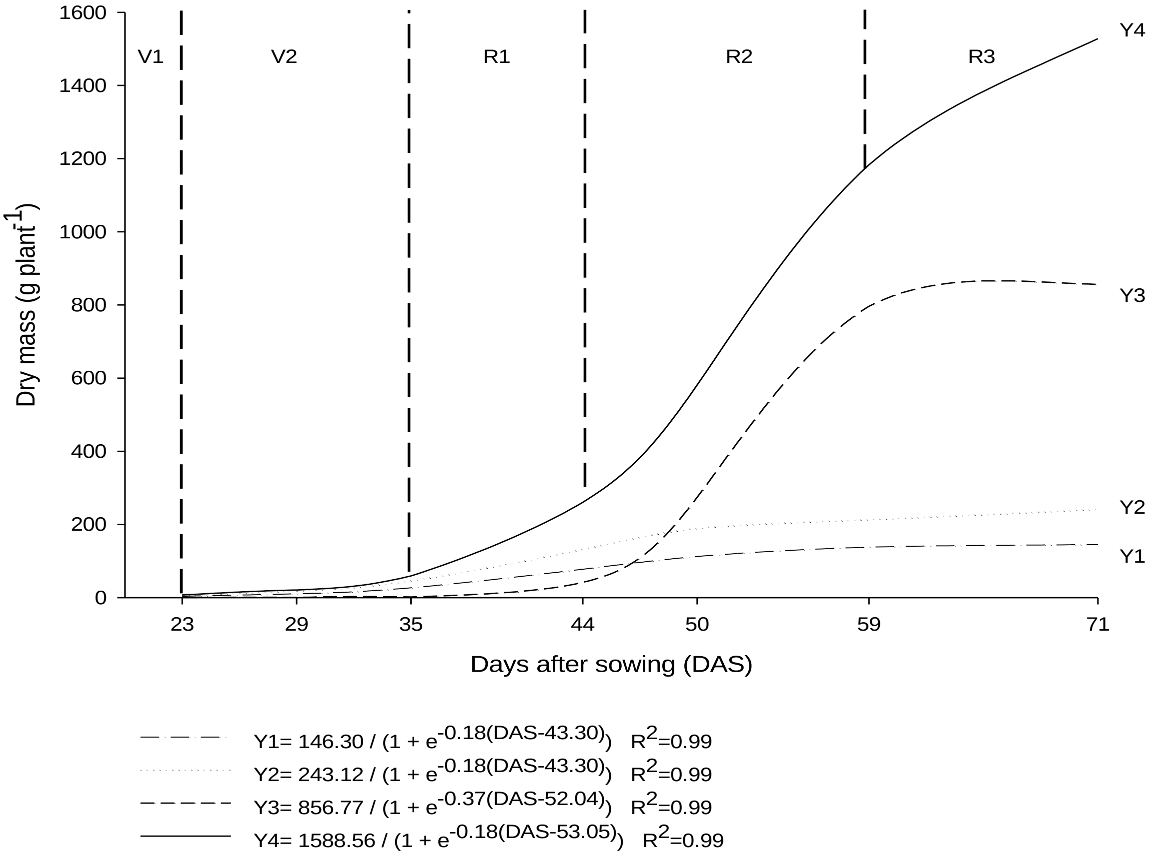

Figure 1 - Accumulation of dry mass in stems (Y1), leaves (Y2), fruits (Y3) and plant without root (Y4), of watermelon 'Top Gun'.

Phase R_1 started with flowering and went up until 44 DAS when the first fruit was 8 cm in diameter (Figure 1). During this period, there was a great accumulation of dry mass in the stems and leaves, with increments rates of 5.6 and 9.53 g day^{-1}, respectively.

Phase R_2 started at 45 DAS and closed at 59 DAS. It was characterized by a great accumulation of dry mass of the fruit, with an average incremental rate of 50 g day^{-1}. In this period, the fruit reached 754.53 grams, equivalent to 66% of the maximum accumulated dry mass of the fruit (1,136.77g) (Figure 1). At the end of the period, there was a slowdown in the rate of increase of dry mass, with a tendency whereby fruit growth stabilized. The aerial part, at this stage, also continued to grow, but with smaller increments and by the end reached 94% and 95% of the total for stems and leaves, respectively.

Phase R_3 was characterized by the maturation of fruit and ended with the harvest and lasted from 54 to 71 DAS. When the harvesters came to harvest the crop at 64 DAS (first harvest) which, consequently, ran over on the stems, there was an accelerated senescence of the aerial part and the second harvest, at 71 DAS, ended the cultivation.

In the reproductive phase, the accumulation of dry mass in the stems and leaves was 118 and 195g, respectively; corresponding to 81 and 80% of the total dry mass accumulated. The continuous accumulation of dry mass in leaves and stems during the reproductive phase characterized the habit of indeterminate growth of the watermelon plant. This result is in accordance with that reported by Vidigal et al. (2009), in Crimson Sweet, and Aguiar Neto et al. (2016) in Shadow and Quetzale, which observed increases in the accumulation of dry mass in the aerial part of the plant up until the harvest of the fruit.

At the end of the cycle, stems, leaves and fruit accumulated 145.0; 241.5 and 856.0 g plant^{-1}, which corresponded to 11.6%, 19.5% and 68.9% of the total dry mass of the plant, respectively. In Quetzale and Shadow watermelons, the fruit and the aerial part (leaves and stems) were 48% and 51%, respectively (Aguiar Neto et al., 2016). Grangeiro & Cecílio Filho (2004) verified that the 'Tide' watermelon plant presented a proportion of the vegetative part of 31% and for fruit 69% of the accumulated dry mass, values close to those observed in this study. The higher rates of accumulation of dry mass in the fruit suggest that these organs are the main drains of the plant after the beginning of the reproductive period, due to the greater translocation of carbohydrates from the leaves to the fruits, as a consequence of the predominance of the reproductive phase over the vegetative phase (Marschner, 2011).

Progression of nutrient accumulation

Nitrogen was the second most accumulated nutrient by the 'Top Gun' watermelon hybrid, with a maximum estimate of 23.23 g plant^{-1}, at 71 DAS, with 59% of the nitrogen accumulated in the R_2 stage, a period of intense accumulation of dry mass by the plant (Figure 2). According to Teixeira et al. (2014), the coincidence between the higher N absorption and the period with the greatest accumulation of dry mass is due to the close relationship between the two parameters.

The accumulation of nitrogen in the stems and leaves was small during the initial stages, from 0.015 and 0.23 g plant^{-1} at 23 DAS, to 2.36 and 5.20 g plant^{-1} at 71 DAS, respectively. In the R_1 period, a greater demand for nitrogen by the stems and leaves was observed, with an estimated accumulation of 1.42 and 4.3 g plant^{-1}, respectively, corresponding to 20% and 61% of the total nitrogen accumulated by the plant during this period. In the following phases, the increase in the amount of nitrogen accumulated in the leaves and stems was lower, as a consequence of the beginning of fructification, suggesting that there was translocation of the nutrient from the leaves and stems to the fruit (Teixeira et al., 2014). In the fruit, over 27 days (from 45 to 71 DAS) the accumulation of N increased from 1.31 to 16.37 g plant^{-1} at a mean rate of 557 mg N day^{-1}, a much higher value than that reported by Grangeiro & Cecílio Filho (2005a), in the 'Nova' watermelon, which presented an accumulation rate of 347.6 mg N day^{-1}, during the period of higher nitrogen demand in the fruit.

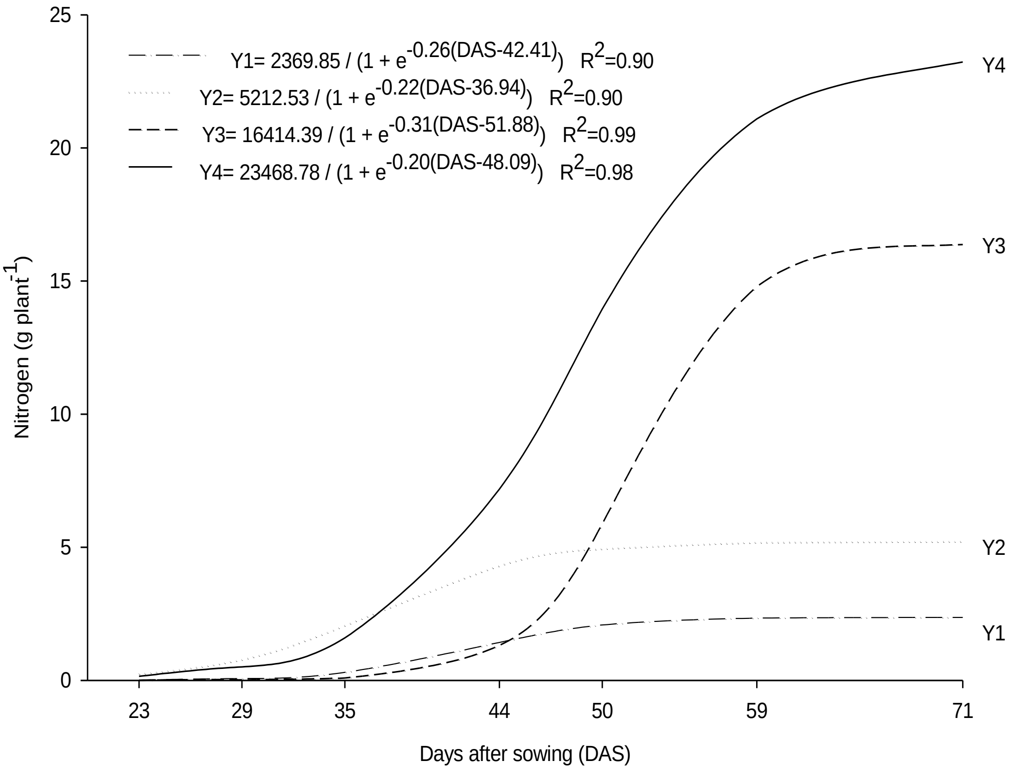

Figure 2 - Accumulation of nitrogen in stems (Y1), leaves (Y2), fruits (Y3) and plant without root (Y4), of watermelon 'Top Gun'.

At the end of the cycle, the contribution of stems, leaves and fruits was 9.8%; 21.8% and 68.4% of the total nitrogen accumulated in the plant, respectively. In the Quetzale and Shadow watermelons, Aguiar Neto et al. (2016), reported that the greatest nitrogen demand occurred during the period from 45 to 55 DAT and that the fruit contributed with 35% and 41% of the total nitrogen accumulated, respectively. Santos et al. (2016) in Precious Petite and BGCIA 941 watermelons found the highest demands for nitrogen, 15.0 and 20.9 g plant^{-1}, were from 20 to 70 DAS and from 32 to 60 DAS, respectively.

Phosphorus was among the macronutrients that accumulated in less quantity. The estimated maximum value of phosphorus was 2.32 g plant^{-1}, obtained at 71 DAS (Figure 3). Considering the whole plant, the period of greatest accumulation of P (65%) occurred from 44 to 59 DAS (R_2), with an average accumulation rate of 100 mg day^{-1} of P.

In the leaves and stems, the accumulation of phosphorus increased up until 71 DAS, but had higher demand during the period 35 to 44 DAS (R_1). At the end of the cycle, the amounts of phosphorus in the stems and leaves were 0.17 and 0.35 g plant^{-1}, respectively, corresponding to 7.1% and 14.4% of total phosphorus accumulated. In the fruit, the estimated maximum accumulation of phosphorus occurred at 71 DAS (1.92 g plant^{-1}). The higher demand by the fruit coincided with that of the whole plant, from 44 to 59 DAS, with an average rate of 111.5 mg day^{-1}. The contribution of the fruit to the total accumulation of phosphorus was 78.5%, similar to that reported by Schiavon Júnior et al. (2017) in the Master hybrid.

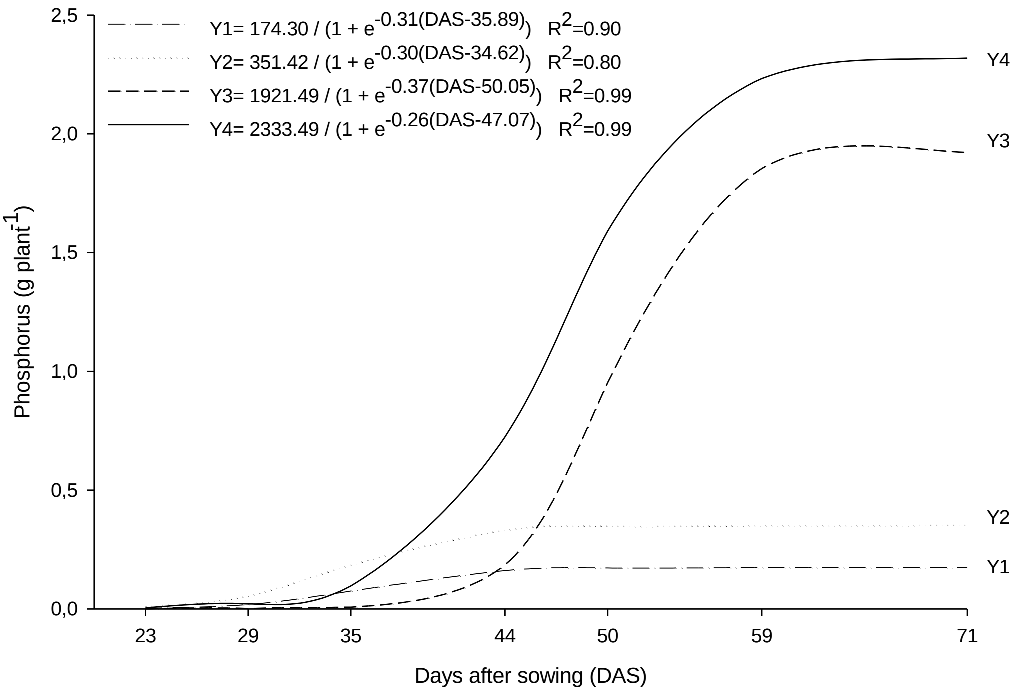

Figure 3 - Accumulation of phosphorus in stems (Y1), leaves (Y2), fruits (Y3) and plant without root (Y4), of watermelon 'Top Gun'.

According to Yetisir et al. (2013), each cultivar presents a specific requirement for phosphorus and, in turn, is related to the accumulation in the plant. Phosphorus accumulation in the Top Gun watermelon (2.32 g plant^{-1}) was lower than in 'Crimson Sweet' (Vidigal et al., 2009) and 'Nova' (Grangeiro & Cecílio Filho, 2005a); however, the performance was similar in relation to the periods of higher demand of the macronutrient, and the contribution of the vegetative part and the fruit part, in the total accumulation of phosphorus.

Potassium was the most accumulated nutrient by 'Top Gun' watermelon, with an estimated maximum of 38.12 g plant^{-1} (71 DAS). The highest nutrient demand by the plant occurred between 45 and 59 DAS (R_2) (Figure 4). During this period, the watermelon plant presented an accumulation of 1,729 mg day^{-1} of potassium, a result that was similar to those found by Aguiar Neto et al. (2016), which reported maximum accumulations of 25.61 and 20.51 g plant^{-1} in the Quetzale and Shadow watermelons, respectively, at 55 DAT. Schiavon Júnior et al. (2017), working with the Master watermelon hybrid, observed that the accumulated amount of potassium was 18.4 g plant^{-1}, at 45 DAT, and the greatest demand occurred during the period from 28 to 42 DAT.

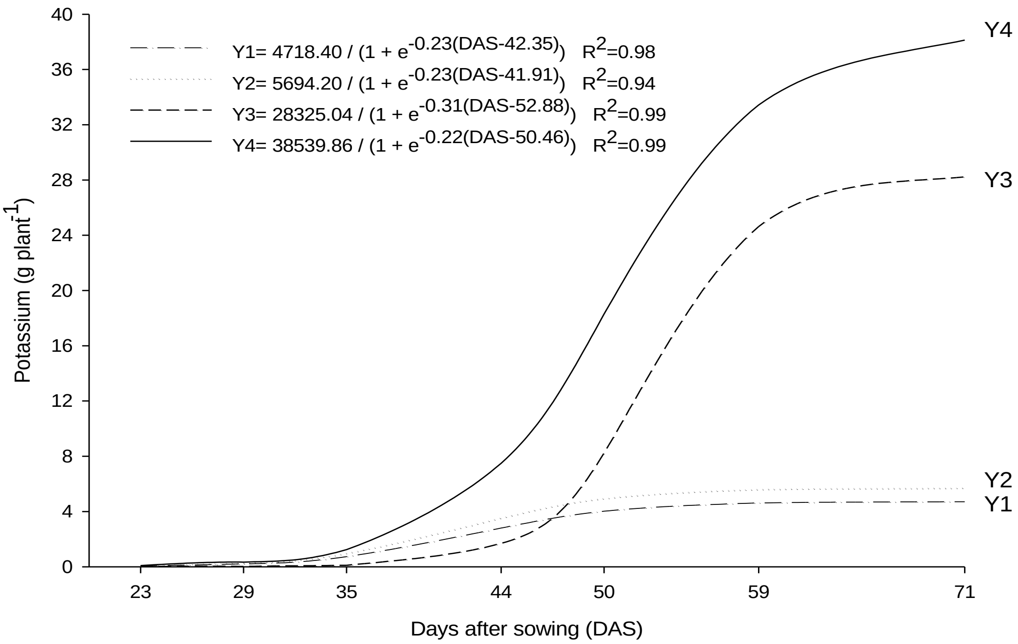

Figure 4 - Accumulation of potassium in stems (Y1), leaves (Y2), fruits (Y3) and plant without root (Y4), of watermelon 'Top Gun'.

At 44 DAS, it was observed that potassium was mainly accumulated in the stems and leaves; however, the increment was greater in the fruit. Similar results were found by Araújo et al. (2001), who observed reductions in the accumulation of potassium in the leaves after the development of the fruit, suggesting a strong redistribution of the macronutrient from the vegetative to the reproductive parts of the plant. In the fruit, high accumulation of potassium was observed until the harvest, with 73.1% of total potassium accumulated, while the contribution of stems and leaves was 12.2% and 14.7%, respectively. The highest potassium demand by the fruit was during the period 44 to 59 DAS (R_2), with a rate of 1,528 mg day^{-1} of potassium. The high contribution by the fruit to the total potassium content in the plant is in accordance with other studies that report an association between a greater demand for potassium and higher yields and quality (Graveiro & Cecílio Filho, 2005b; Vidigal et al., 2009; Nogueira et al., 2014; Schiavon Júnior et al., 2017).

According to Teixeira et al. (2014), potassium is important in fruit formation due to its relation to the dry mass, since it is involved in processes of synthesis and the translocation of assimilates, maintenance of water potential in the tissues of the plant and stimulus to growth. In addition, although not part of organic compounds, it participates in photosynthesis, enzymatic activation and protein synthesis (Lucena et al., 2011). Santos et al. (2016) mention that potassium also has an effect on several parameters concerning the quality of the watermelon such as the color, size, acidity, resistance to transportation and cracking.

Calcium was the third most accumulated nutrient in the plant, with 17.52 g plant^{-1}, at 71 DAS. The highest demand by the plant occurred during the period from 45 to 59 DAS (R_2) (Figure 5). Differing from the results found for N, P and K, the highest accumulation of calcium was found in the leaves, accounting for 81.3% of the total amount in the plant, while the fruit and stems were 12.9% and 5.8%, respectively. Leaf accumulation was slow in the first 35 DAS, and the highest demand occurred from 35 to 44 DAS (R_1), with an average rate of 535.7 mg day^{-1}.

The contribution of leaves to calcium accumulation is a pattern observed in vegetables, due to the fact that they have higher transpiration rates than fruit (Grangeiro & Cecílio Filho, 2005b) and also because calcium is transported almost exclusively by xylem, presenting very low redistribution, favoring accumulation in the vegetative part as opposed to the fruit (Teixeira et al., 2014). In addition, another factor that may interfere with the accumulation of calcium in the fruit is potassium, since the higher flow of potassium to the fruit competes, thus decreasing the accumulation of calcium in the fruit (Grangeiro & Cecílio Filho, 2005b). Grangeiro & Cecílio Filho (2005b), for the Shadow hybrid, and Schiavon Júnior et al. (2017) for the Master hybrid, found that the aerial part contributed to 89% of the accumulation of this nutrient in the plant.

According to Schiavon Júnior et al. (2017), calcium is an important element for cucurbitaceae due to its role in flower formation, fruit quality and productivity. In addition, calcium is related to the incidence of apical rot, a common nutritional disorder in watermelon, and it has been verified that applications of this cation generate positive effects on the integrity and functionality of the cell wall, maintaining the consistency of the fruit and increasing the resistance to mechanical damage (Santos et al., 2016).

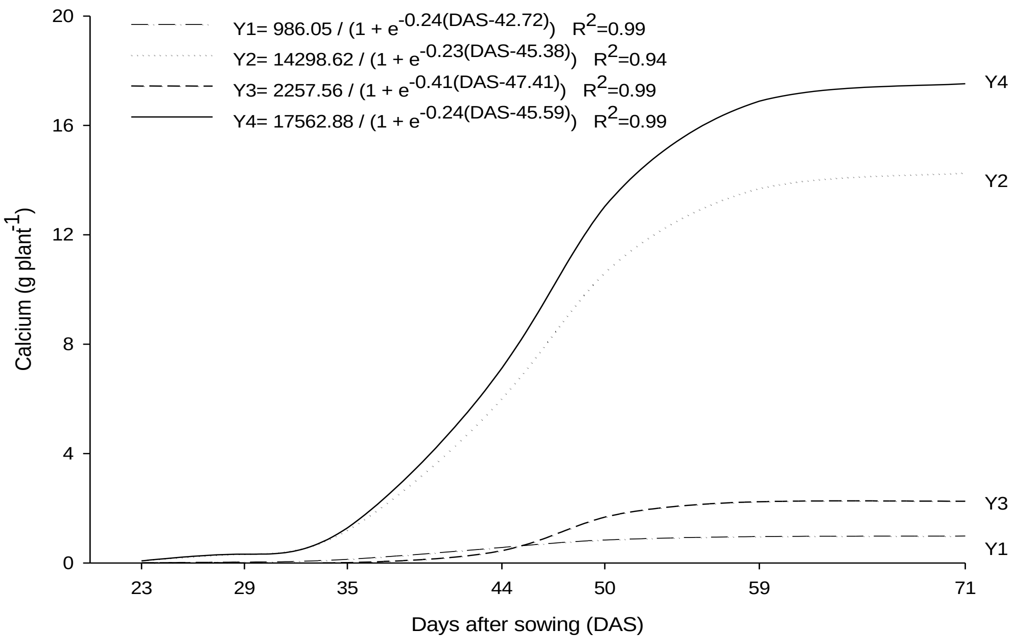

Figure *5* - Accumulation of calcium in stems (Y1), leaves (Y2), fruits (Y3) and plant without root (Y4), of watermelon 'Top Gun'.

The maximum accumulation of magnesium occurred at the end of the cycle, reaching 4.37 g plant^{-1}, at 71 DAS. The highest nutrient demands, in the whole plant, occurred during the period 45 to 59 DAS (R_2), presenting an average rate of 198 mg day^{-1}, corresponding to 87.9% of the total, coinciding with the largest increase of dry mass in the plant (Figure 6). Similar to that found in N, P and K, Mg was accumulated in larger amounts in the fruit. The contribution of the stems, leaves and fruit were 17.7%, 15.0% and 67.3%, respectively. According to Vidigal et al. (2009), who in the cultivar Crimson Sweet observed a contribution of 58% in the fruit to the total accumulated magnesium. However, Grangeiro & Cecílio Filho (2005a), in the Nova hybrid, and Schiavon Júnior et al. (2017), in the Master hybrid, found greater accumulation of Mg in the vegetative parts.

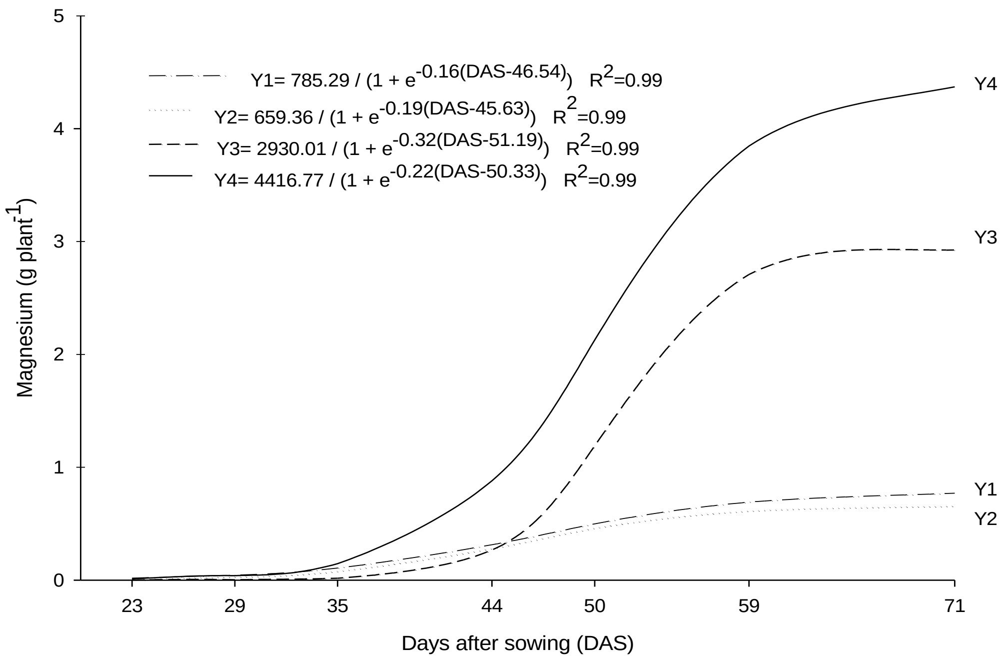

Figure 5 - Accumulation of magnesium in stems (Y1), leaves (Y2), fruits (Y3) and plant without root (Y4), of watermelon 'Top Gun'.

According to Marschner (2011), of the total accumulated magnesium in the plant, between 6 and 25% is related to the chlorophyll molecule and, therefore, the macronutrient is expected to accumulate in greater proportion in the leaves (Schiavon Júnior et al., 2017). However, the results suggest that there are differences between the cultivars in terms of absorption and redistribution of magnesium, a hypothesis that has already been verified in standards of grafted watermelon (Santos et al., 2016).

Sulfur was the macronutrient that presented the lowest accumulated amount in the plant, reaching 1.40 g plant^{-1} at 71 DAS (Figure 7). The period of greatest accumulation was from 45 to 59 DAS (R_2), when the plant accumulated close to 89% of the total, at an average rate of 58.2 mg day^{-1}. The stems were responsible for 5.1%, the leaves 21.3% and the fruit 73.6%. In the stems and leaves, the accumulation of sulfur was continuous throughout the cycle, having the greatest demand during the period from 35 to 44 DAS (R_1). The maximum accumulation of S by the fruit was 1.06 g plant^{-1}, and was characterized by being slow in the first 44 DAS and then increasing in demand until the end of the cycle. The results found agree with those obtained by Grangeiro & Cecílio Filho (2005a), for the Nova hybrid, and Santos et al. (2016), for crop BGCIA 941, which reported accumulated sulfur values of 1.75 and 1.70 g plant^{-1}, respectively.

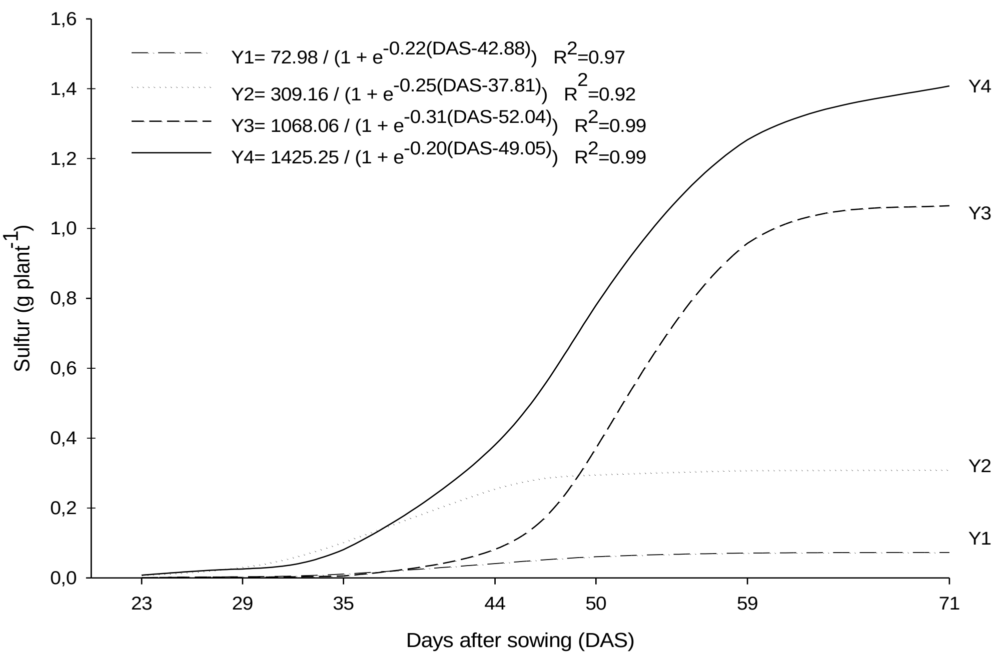

Figure 6. Accumulation of sulfur in stems (Y1), leaves (Y2), fruits (Y3) and plant without root (Y4), of watermelon 'Top Gun'.

In terms of micronutrient accumulation, manganese was the most accumulated in Top Gun, reaching 404.1 mg plant^{-1} at 71 DAS (Figure 8). Of the total manganese accumulated, 7.1% was found in the stems, 77.6% in the leaves and 15.3% in the fruit, respectively. This result resembles that obtained by Schiavon Júnior et al. (2017), for the Master hybrid, which reported manganese accumulation in the fruit of 32%, while the participation of the vegetative part was 67.4%. According to Almeida et al. (2014), this pattern of accumulation was also observed in other cucurbits such as melons (Maggio et al., 2017). This high demand by the leaves is due to manganese's functions in photosynthesis and nitrogen metabolism. The highest demand for manganese from the whole plant occurred 45 to 59 DAS (R_2), a period which represented 53.7% of the total accumulated manganese, with an average rate of 14.5 mg day^{-1}. The accumulation was slow in stems and leaves in the first 35 DAS, followed by increment and higher demand between 45 and 59 DAS with average rates of 1.0 and 10.2 mg day^{-1} of manganese, respectively. The maximum accumulation of manganese in the fruit was at the end of the cycle (61.7 mg plant^{-1}).

Iron was the second most accumulated micronutrient, with a maximum of 231 mg plant^{-1} at 71 DAS (Figure 9). The accumulation was slow in the first 35 DAS with a subsequent increase. The highest demand by the entire plant occurred between 45 and 59 DAS (R_2), a period which represented 64% of the total iron accumulated, with an average rate of 9.9 mg day^{-1}. Similar to that found for manganese, the contribution of stems, leaves and fruit was 7.3%; 62.8% and 29.9%, respectively. These results are higher than those found by Vidigal et al. (2009), Schiavon Júnior et al. (2017) and Santos et al. (2016), who reported accumulations of 200, 107.6 and 57 mg plant^{-1}, respectively. According to Prado (2008), iron is a constituent of cytochromes and proteins that are involved in photosynthesis and respiration, which explains the high levels of iron found in the leaves. In addition, iron accumulates in old leaves in poorly soluble chemical forms, such as phytoferritin complex, limiting the ability of being redistributed to the fruit of the plant (Malavolta et al., 1997), which would explain the low accumulation of iron in the fruit of the watermelon plant.

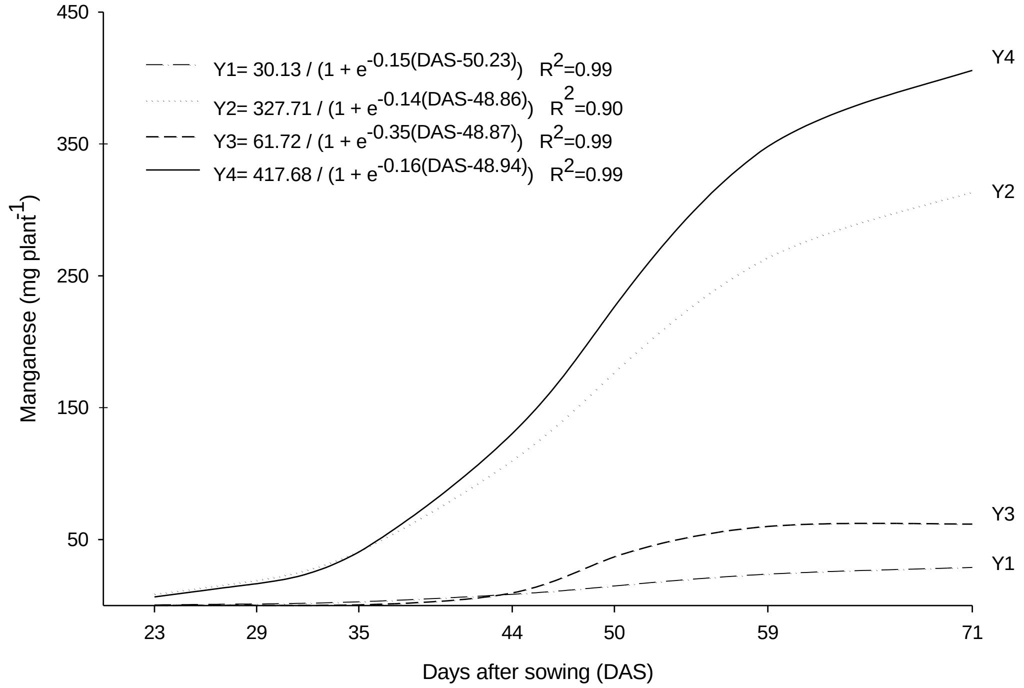

Figure 7 - Accumulation of manganese in stems (Y1), leaves (Y2), fruits (Y3) and plant without root (Y4), of watermelon 'Top Gun'.

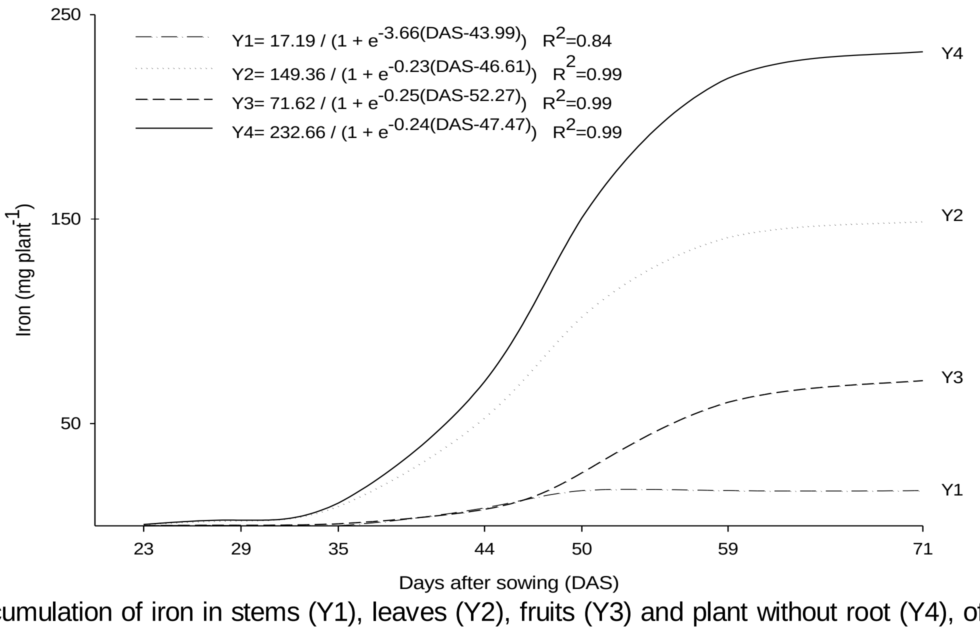

Figure 8. Accumulation of iron in stems (Y1), leaves (Y2), fruits (Y3) and plant without root (Y4), of watermelon 'Top Gun'.

Boron was the third most accumulated micronutrient in the Top Gun watermelon. The accumulation increased until the end of the productive cycle, reaching 87.7 mg plant^{-1} (Figure 10). The maximum accumulation rate was observed in the plant during the period from 44 to 59 DAS, with a value of 5.1 mg day^{-1}. Of the total boron accumulated in the plant, 16.2% was accumulated in the stems, 25.7% in the leaves and 58.1% in the fruit. This result is similar to that found by Schiavon Júnior et al. (2017), who found in the Master hybrid, that 50.6% of the total accumulation was in the fruit. The high baron contribution of the fruit to the total amount in the plant was also found in a study on 'Fantasy' melon (Melo et al., 2013).

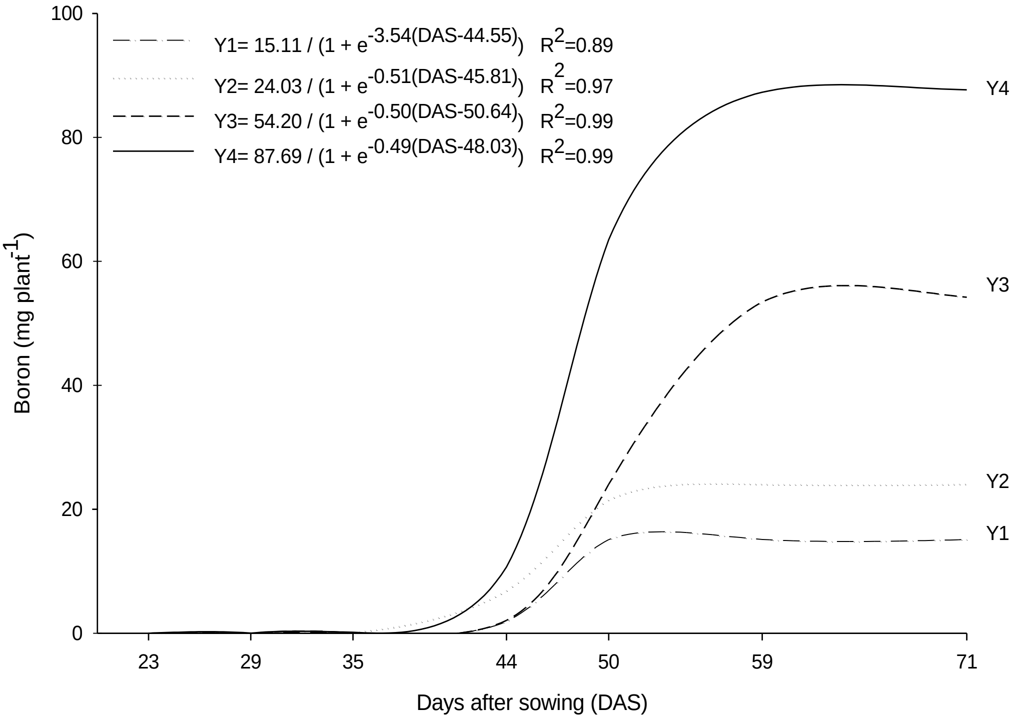

Figure 9 - Accumulation of boron in stems (Y1), leaves (Y2), fruits (Y3) and plant without root (Y4), of watermelon 'Top Gun'.

The accumulation of zinc was constant throughout the cycle, reaching 41.27 g plant^{-1} at 71 DAS. Similar to that found in the other micronutrients, the highest demand by the whole plant was observed during the period from 45 to 59 DAS (R_2), with a mean rate of 1.3 mg day^{-1} (Figure 11). The fruit accounted for the largest accumulation, with 62.6%, followed by the leaves (27.8%) and the stems (9.6%). The demand by leaves and stems was slow in the first 35 DAS having the greatest demand during R_1, with average accumulation rates of 0.92 mg day^{-1} in the stems and 0.17 mg day^{-1} in the leaves. It is noteworthy that in the leaves, the maximum accumulation was achieved at 45 DAS, while in the stems and fruit the accumulation was continuous until the end of the cycle. These results contrast with those found by Almeida et al. (2014) with the cultivar Crimson Sweet, and by Schiavon Júnior et al. (2017) with the Master hybrid, which reported a greater contribution of zinc by the vegetative part of the plant. However, in melons, the highest accumulation of zinc was in the fruit, according to studies by Melo et al. (2013) and Maggio et al. (2017).

According to Epstein & Bloom (2006), zinc is an element involved in the activation of numerous enzymes and is a precursor to the formation of auxins, RNA and ribosomes. Therefore, the increase in zinc requirements during the reproductive phase of Top Gun watermelon would be associated with the synthesis of auxins, enzymes and proteins required for the formation of flowers and fruits.

Among the micronutrients studied, copper was in the least demand, which is in accordance with the results obtained by Vidigal et al. (2009), Almeida et al. (2014) and Schiavon Júnior et al. (2017). The maximum accumulation was 14.4 mg plant^{-1}, at 71 DAS (Figure 12). The period of greatest demand by the plant occurred from 45 to 59 DAS (R_2), with an average rate of 0.55 mg day^{-1} of copper, reaching 84.4% of the total copper accumulated by the plant. At the end of the crop cycle, the contributions by the stems, leaves and fruit were 7.0%; 23.9% and 69.1%, respectively. According to Markossian & Kurganov (2003), copper is involved in seed formation and pollen production, so the demand for copper by the fruit throughout their formation increases; behavior that has already been verified by Almeida et al. (2014) in watermelon 'Crimson Sweet'.

In summary, the rate of accumulation of nutrients by watermelon was low until flowering, which coincided with the period of lower accumulation of dry mass. The largest increases occurred between 35 and 59 DAS (phases R1 and R2), characterizing the highest demand for all nutrients. In general, nutrient accumulation followed the pattern of dry mass accumulation, with a higher accumulation after fruiting, a behavior observed also in the Shadow cultivar and the Nova hybrid (Grangeiro & Cecílio Filho, 2005a, b).

The decreasing order for extracted macronutrients was: K> N> Ca> Mg> P> S, similar to that found by Vidigal et al. (2009) and Aguiar Neto et al. (2016). In terms of micronutrient uptake, they were accumulated in smaller amounts, but continuously until the end of the cycle, with the following decreasing order: Mn> Fe> B> Zn> Cu.

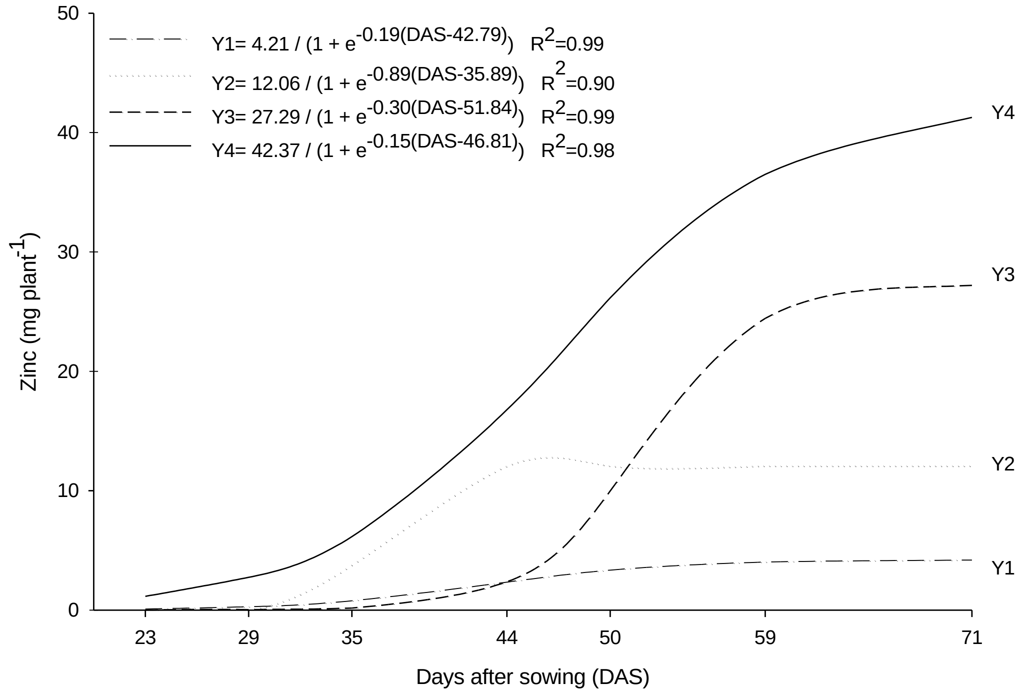

Figure 10. Accumulation of zinc in stems (Y1), leaves (Y2), fruits (Y3) and plant without root (Y4), of watermelon 'Top Gun'.

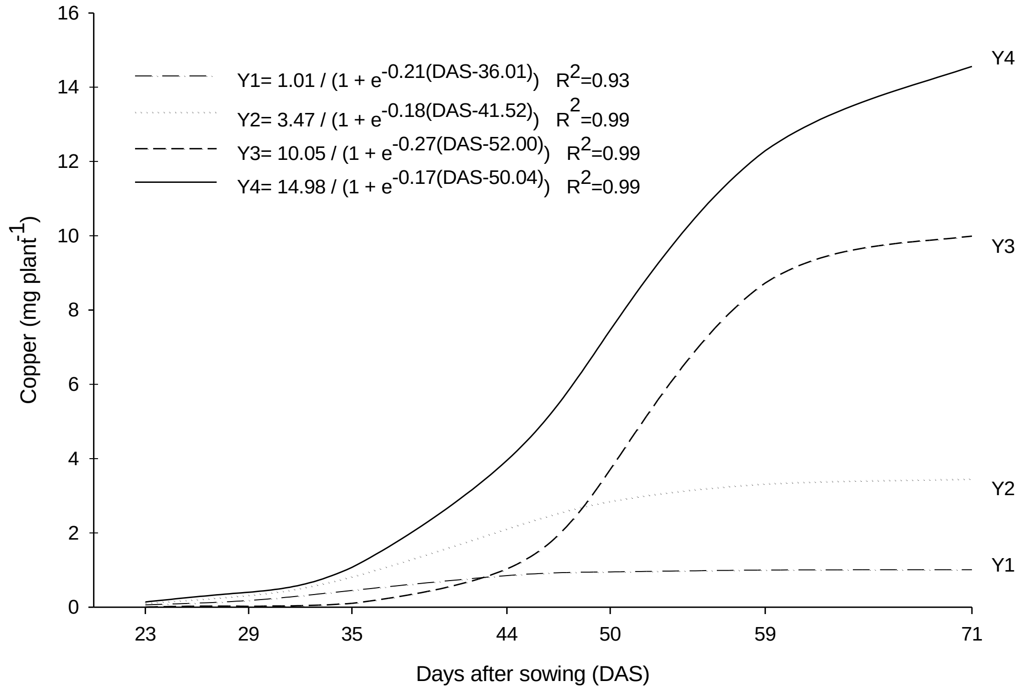

Figure 11. Accumulation of copper in stems (Y1), leaves (Y2), fruits (Y3) and plant without root (Y4), of watermelon 'Top Gun'

Exportation of nutrients

The fruit corresponded to 69% of the total dry mass of the plant. On the other hand, of the total nutrients accumulated, the contribution of the fruit was 68.4% of N, 78.5% of P, 73.0% of K, 12.8% of Ca, 67.0% of Mg and 73.6% of S. In relation to micronutrients, the contribution was 15.3% of Mn, 29.9% of Fe, 58.0% of B, 62.6% of Zn and 69.1% of Cu.

The amount of macronutrients exported by the fruit, in kg ha^{-1}, considering a population of 2,222 plants ha^{-1} of Top Gun cultivar and expected yield of 31 t ha^{-1}, were 36.4; 4,3; 62.7; 5.0; 6.5; and 2.3 for N, P, K, Ca, Mg and S, respectively. For Mn, Fe, B, Zn and Cu, the values exported in g ha^{-1} were 137.0; 157.7; 120.4; 60.4 and 22.1, respectively.

Conclusions

The growth of Top Gun watermelon is slow up to 35 days after sowing.

There is an accelerated increase in dry mass, identifying the period of greatest growth from 45 to 59 days after sowing.

At the end of the cycle, the plant accumulates 1,528 g of dry mass, of which 11.6% is made up of stems, 19.5% of leaves and 68.9% of fruit.

The highest nutrient demand occurs between 45 and 59 days after sowing, with the following order of magnitude: K> N> Ca> Mg> P> S> Mn> Fe> B> Zn> Cu.

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