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Phosphate fertilization influences macronutrient accumulation in watermelon cv Magnum

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ABSTRACT

Studies on nutrient uptake are important to understand nutritional needs of crops, which demand may also be influenced by fertilization management, particularly P fertilization. Thus, the aim of this study was to evaluate macronutrient accumulation and distribution in watermelon cv. Magnum, under two forms of phosphate fertilization. The experiment was carried out in a sandy-textured Argisol in Mossoró-RN. The experimental design was a randomized block design, arranged in split plot in time, with four replicates. We evaluated dose of 137 kg ha^{-1} of P_2O_5 under two forms of fertilization [pre-planting (F0) and pre-planting + topdressing (F1)]. Triple superphosphate (SFT) was used for pre-planting applications and topdressing applications were done through fertigation using monoammonium phosphate (MAP, 34 kg ha^{-1} of P_2O_5). Shoot samples (stem + leaf + fruit) of the experimental plots were collected at 27, 34, 40 and 55 days after emergence (DAE), and quantitative values of the accumulated nutrients were determined. In general, the highest accumulation of macronutrients occurred in the last third of the crop cycle. General accumulation of macronutrient was altered by fertilization form. An increase in P accumulation was observed using F1 fertilization, both in total and in fruits. Macronutrient accumulation rates increased during the evaluation period, except for Ca and Mg in F1 fertilization. F1 fertilization provided higher total accumulations of Ca and Mg, but the same did not occur for the accumulation in fruits.

Keywords: *Citrullus lanatus*, nutrient accumulation, phosphorus.

RESUMO

Formas de adubação fosfatada influenciam o acúmulo de macronutrientes pela melancieira ‘Magnum’

Estudos de marcha de absorção de nutrientes são importantes para a definição das necessidades nutricionais das culturas, cuja demanda pode também ser influenciada pelo manejo da adubação, particularmente no caso do P. Assim, objetivou-se com este trabalho avaliar a marcha de acúmulo de macronutrientes da melancieira cv. Magnum irrigada submetida a duas formas de adubação fosfatada. O experimento foi realizado em Argissolo de textura arenosa, em Mossoró-RN, no delineamento experimental de blocos casualizados com parcelas subdivididas no tempo, com quatro repetições. Foi avaliada a dose de 137 kg ha^{-1} de P_2O_5 sob duas formas de adubação [em pré-plantio (F0) e em pré-plantio + cobertura (F1)]. Superfosfato triplo (SFT) foi utilizado para as aplicações em pré-plantio e, as aplicações em cobertura foram feitas através de fertirrigação, utilizando fosfato monoamônico (MAP, 34 kg ha^{-1} de P_2O_5). Foram realizadas coletas aos 27, 34, 40 e 55 dias após a emergência (DAE) da parte aérea total (caule + folha + fruto) das parcelas experimentais, determinando-se os quantitativos dos nutrientes acumulados. De forma geral, os maiores acúmulos de macronutrientes ocorreram no último terço do ciclo da cultura. A ordem geral de acúmulo de macronutrientes foi alterada com a forma de adubação, havendo aumento do acúmulo de P com a adubação F1, tanto no total como nos frutos. A variação das taxas de acúmulo de macronutrientes é crescente no período de avaliação, exceto para Ca e Mg na adubação F1. A adubação F1 proporcionou maiores acúmulos totais de Ca e Mg, porém o mesmo não ocorre para o acúmulo nos frutos.

Palavras-chave: *Citrullus lanatus*, acúmulo de nutrientes, fósforo.

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Climatic conditions in Brazilian Northeast region are ideal to make watermelon a social and economic important crop. However, little information on nutritional needs of this crop may lead to an inefficient fertilization practice.

Phosphorus (P) stands out among the important elements for vegetative growth and fruit development. Despite the fact that watermelon extracts low quantities of this element, when compared to nitrogen (N) and potassium (K), great quantities are used in fertilizations due to its low natural availability and/or P-fixation capacity of soils, making it the main cause for low recovery efficiency of this element by most crops (Araújo & Machado, 2006).

Due to the mentioned above, in conventional fertilization, P is applied in pre-planting, aiming to minimize its reaction with soil components. Nevertheless, some studies suggested that under determined conditions, phosphorus topdressing (via fertigation) may provide an increase in the efficiency of its use by crops (Marouelli *et al*., 2015).

Marouelli *et al*. (2015) state that P applied at pre-planting associated to fertigation can be a good strategy to ensure initial availability for plant development, as well as to keep appropriate levels for absorption of the element by plants throughout cultivation cycle.

Studying nutrient uptake of watermelon plant, Gonçalves *et al*. (2016) pointed out that recommendation for fertilization depends on each nutrient need for the crop, but also fertilization management and weather conditions in the cultivation region.

Studies on nutrient uptake under some management conditions provide information on nutritional needs, allowing adjustment of fertilizer rates and their higher efficiency.

Thus, the aim of this study was to evaluate nutrient accumulation and macronutrient partitioning by watermelon cv. Magnum irrigated under phosphate fertilization.

MATERIAL AND METHODS

The experiment was carried out at the Experimental Farm of UFERSA, municipality of Mossoró-RN, located in Alagoinha (5°3'30"S; 37°24"W, 72 m altitude), from November, 2014 to January, 2015. The climate of the region is hot and dry, BSwh type, according to Köppen.

Soil fertility evaluation was done following the methodology recommended by Embrapa (2009), showing the initial characteristics: pH (H_2O)= 5.7; organic matter (in g kg^{-1}) = 18.43; P Mehlich (in mg dm^{-3}) = 4; K^+, Na^+, $Ca^{2+,}$ Mg^{2+}, Al^{3+}, $H+Al^{3+}$ (in $mmol_c$ dm^{-3}) and V (%) = 2.30; 4.40; 14.7; 5.0; 0.0; 24.8; and 52, respectively. The authors also determined clay fraction by pipette method (80 g kg^{-1}) sand fractions (905 g kg^{-1}) and silt (1.5 g kg^{-1}) by sieving and by mass difference, respectively.

After soil preparation, which consisted of plowing and harrowing, the authors built ridges (30 cm height x 60 cm width). Soil was previously plowed and harrowed, building seedbeds (20 cm height x 60 cm width).

Watermelon cv. Magnum was planted direct in the field, spaced 0.60 m between plants and 2.0 m between lines, on November 11, 2014. The authors adopted dripping fertilization system; Emitters were spaced 30 cm, using an emitter flow rate of 1.13 L h^{-1} (under 64 kPa pressure), and emission uniformity coefficient of 91%. Irrigation was performed through monitoring soil moisture measuring the surface tension, keeping soil water matric potential greater than -20 kPa.

Pre-planting phosphate fertilization was manual in 10-cm depth pits, each 30 cm and next to each emitter (10 cm). Topdressing applications were via fertigation using a shunt tank, connected to irrigation nets. Sources of P, used during pre-planting and topdressing (fertigation), were triple superphosphate (41% P2O5) and monoammonium phosphate (61% P2O5), respectively.

Sources of N (urea and ammonium sulfate), K (potassium chloride and potassium sulphate), Ca (calcium nitrate) and Mg (magnesium sulfate) were applied as topdressing via fertigation, from the first week after planting, totalizing 141, 148, 33, 7 and 28 kg ha^{-1} of N, K_2O, CaO, MgO and S, respectively.

The experimental design was of randomized blocks, factorial scheme, subdivided into four evaluation periods, with four replications. Experimental plots consisted of 24 m² (12.0 x 2.0 m), being the useful plot of 9.60 m² (4.8 x 2.0 m), with eight plants.

Two fertilization systems were evaluated [pre-planting (F0) and pre-planting + topdressing (F1)]. All plots received a total dose of 137 kg ha^{-1} of P_2O_5, considering that in F1 fertilization, part was applied as topdressing via fertigation, using monoammonium phosphate (MAP). For pre-planting applications, the authors used triple superphosphate (SFT).

Data were collected at 27, 34, 40 and 55 days after emergence (DAE) from total shoot area (stem + leaf + fruit) of experimental plots. Plants were removed from field and put into plastic bags, taken immediately to Laboratório de Irrigação e Salinidade from Departamento de Ciências Ambientais of UFERSA, in order to be separated into stem, leaves and fruits. Then, these parts were weighed and taken into forced air circulation at 65°C, being weighed again after drying.

Then, samples were ground (Willey type mill), for chemical analysis, according to Malavolta *et al*. (1997), in order to determine total N, using semi-micro Kjeldahl method, K, using flame emission photometry, Ca and Mg, using atomic absorption spectrophotometry, S, using turbidimetry and P through reduction of phosphor-molybdic complex.

Nutrient accumulations were obtained using the product between dry biomass and its concentration in the material.

Nutrient accumulation data (g $plant^{-1}$) were submitted to F test, at 5% significance, using computer statistical software SISVAR 5.3 (Ferreira, 2010), then submitted to regresssion analysis, using software Table Curve 2D (Scientific, 1991).

The significance of models was verified based on F-test probability and the model coefficients using t test, with * and ** showing significance at 5% and 1%, respectively. The models were selected considering their significance and coefficients and among those, the ones with the highest R^2 value offered a simpler and more coherent explanation.

Rates of daily macronutrient accumulation were obtained through derivation of the models used.

RESULTS AND DISCUSSION

Total accumulation

A significant effect of macronutrient accumulation in relation to time was observed; considering that, for Ca and Mg, shape X DAE interaction was also significant.

Overall, higher nutrient accumulations occurred in the last third of the cycle (Figure 1).

About 50% of total N, P, K and

S were accumulated at 41, 42, 44 and 42 DAE, respectively (Figure 1), which may be related to the fast plant development in experimental conditions, coinciding with the period in which fruits had already reached approximately 50% of their final dry biomass (45 DAE) (data not shown).

Climatic conditions which were favorable to shorten cycle allowed fast nutrient accumulation to meet fruit development demand, which began from the first collect (27 DAE), representing an important drain.

Studies on cv. Quetzale, in Mossoró, Lucena *et al*. (2011) verified higher increase of macronutrient accumulation after plant fructification. High nutrient requirement for the crop after fructification is corroborated in other studies, according to Gonçalves *et al*. (2016).

Maximum N accumulation was 12.64 g plant^{-1} or 105 kg ha^{-1} (8.333 plants ha^{-1}), with increasing accumulation rates and ranging from 0.16 to 0.64 g day^{-1} (Figure 1A).

Vidigal *et al*. (2009) verified a similar total N accumulation (105.8 kg ha^{-1}) for cv. Crimson Sweet (5,000 plants ha^{-1}); however, with a superior accumulation per plant (21.16 g plant^{-1}). Grangeiro & Cecílio Filho (2004a) verified a total of N equivalent to 70.79 g plant^{-1} or 138.8 kg ha^{-1} (1,960 plants ha^{-1}) for watermelon Tide hybrid.

Despite the greater variability of accumulation per plant in literature, these represent better nutritional demand in relation to their production, as verified by Paula *et al*. (2011), relating extraction of N, P and K by the crop with respective total productivity and productivity per plant, according to data found in literature.

In relation to P, significant effect isolated both for DAE (Figure 1B) and for fertilization system was verified, considering that average accumulation of P in F1 fertilization (0.96 g plant^{-1}) was superior than in F0 fertilization (0.67 g plant^{-1}), approximately 43% or 0.29 g.

F1 fertilization may have provided an increase in P availability in soil due to the effect of phosphate applied to fertigation. Simulating P uptake by roots in relation to the effect of fertilization, Wang & Chu (2015) concluded that P in liquid form reduced fixation and increased P availability in soil.

Studying tomato crop, Marouelli *et al*. (2015) verified that P fertigation was more efficient than P availability at pre-planting. According to Fernandes & Soratto (2012) and Marouelli *et al.* (2015), it is important to highlight that an increase in P uptake is not necessarily related to an increase in crop production.

P accumulation rates are increasing, ranging from 0.03 to 0.05 g day^{-1} from 27 to 42 DAE and reaching maximum value at 55 DAE, 0.08 g day^{-1} (Figure 1B).

Considering the model presented in Figure 1B and average difference of P accumulation (0.29 g) comparing fertilization systems, the authors estimated maximum accumulation of 1.56 and 1.85 g plant^{-1} for F0 and F1 fertilizations, respectively, which correspond to estimates of 13 and 15.4 kg ha^{-1} of P.

Grangeiro & Cecílio Filho (2004a) reported similar P extraction for Tide hybrid (13.5 kg ha^{-1}) despite using a much lower planting density (1960 plants ha^{-1}).

In relation to P, cultivation conditions, including soil and fertilization management, may show greater effect on this element uptake by plants than planting density. Due to its relative immobility in soil, competition for P between plants is minimal (Novais & Mello *et al*., 2007).

Vidigal *et al*. (2009) obtained total extraction equivalent to 18.1 kg ha^{-1} of P (5,000 plants ha^{-1}) for cv. Crimson Sweet, using a dose of about 300 kg ha^{-1} of P_2O_5 in sandy soil with high P content, though.

Silva *et al*. (2012) reported total accumulations of only 8.12 and 8.80 kg ha^{-1} for cultivars Olímpia (5,144 plants ha^{-1}) and Leopard (7,716 plants ha^{-1}), adopting a dose of 220 kg ha^{-1} of P_2O_5 in an Eutrophic Cambisol.

Phosphorus demand is also dependent on expectation for productivity (Paula *et al*., 2011). Estimates of nutrient accumulation, as well as average fresh weight per plant (6.98 kg with 4.47% fresh mass) obtained in this experiment can be a reference for this kind of study.

K is the most accumulated nutrient in plant, estimating a total of 18.03 g plant^{-1} at 55 DAE, being equivalent to 150 kg ha^{-1} of K or 181 kg ha^{-1} of K_2O. Grangeiro & Cecílio Filho (2004a) noticed similar maximum accumulation for Tide hybrid (155.5 kg ha^{-1} of K). Other studies show lower accumulations, approximately 121 kg ha^{-1} for both cv. Crimson Sweet (Vidigal *et al*., 2009) and for cv. Olímpia (Silva *et al*., 2012).

The authors verified little range in total concentration of K from 27 to 55 DAE (between 42.51 and 38.17 g kg^{-1}) (data not shown), pointing out a close relationship between biomass production and uptake of this nutrient.

This fact can be related to K role in transporting photosynthesis from source to drain (Marschner, 2012), being particularly important after fructification, when an intense translocation to fruits is noticed (Grangeiro & Cecílio Filho, 2004b).

The rate of S accumulation is increasing, reaching 0.05 g day^{-1} at 55 DAE, when a maximum accumulation, 0.90 g plant^{-1} (7.50 kg ha^{-1}), could also be verified.

Vidigal *et al*. (2009) verified maximum accumulation and uptake rate for S of 1.26 g plant^{-1} (6.30 kg ha^{-1}) and 0.06 g day^{-1}, respectively, for cv. Crimson Sweet in sandy soil in the Northern region of Minas Gerais State.

Grangeiro & Cecílio Filho (2004a) showed superior S accumulations both in area (9.1 kg ha^{-1}) and per plant (4.64 g plant^{-1}), studying Tide hybrid in spacing 3.0 x 1.7 m in a yellow red Argisol.

For Ca and Mg, the authors verified that about 50% of these totals are accumulated at 40 and 42 DAE in F0 fertilization (Figure 2A), whereas for F1 fertilization, this accumulation occurs at 35 and 37 DAE. This behavior is due to the higher initial uptake rates of plants under F1 fertilization, although being decreasing (Figure 2B).

In F1 fertilization, maximum accumulations both for Ca (8.71 g plant^{-1}), and for Mg (2.64 g plant^{-1}) are higher than in F0 fertilization, 6.27 g plant^{-1} of Ca and 1.82 g plant^{-1} of Mg (Figure 2).

Taking into consideration that transport of Ca and Mg to the roots is mainly via mass flow (Vitti *et al*., 2006; Marschner, 2012), plant transpiration, as well as nutrient concentration in soil solution shows direct relation to its uptake.

Chien *et al*. (2011) mention that some researchers have been stating about the acidifying effect of MAP ammonium nitrification and its uptake by the roots, which may increase the dissolution of precipitated Ca-P compounds. Thus, MAP in F1 fertilization may have favored dissolution of Ca and Mg, both soil and SFT (12% CaO).

A more uniform P availability in soil in F1 fertilization may also have led to a better distribution of absorbent roots, making better water catchment and nutrient uptake. Changes in distribution and/or root activity may occur depending on phosphate fertilization system (Pan *et al*., 2011) or the combination of nutrients, such as N and P, in fertilizers (Marschner, 2012).

Studying seedlings grafted on different coffee genotypes, Tomaz *et al*. (2003) attributed the increase of Ca content, in some treatments, to an increase of root system.

The general order of macronutrient accumulation in the plant in F0 fertilization (K>N>Ca>Mg>P>S) is similar to the one verified by Vidigal *et al*. (2009) working with cv. Crimson Sweet in sandy soil and Grangeiro & Cecílio Filho (2004a) studying Tide hybrid in medium-texture soil.

In F1 fertilization, the concentration order was: K>N>Ca>P>Mg>S, showing an increase in P proportion in total composition of the nutrients. Silva *et al*. (2012) also verified a greater P proportion in relation to Mg working with cv. Olímpia, in which the phosphate foundation fertilization was complemented with applications via fertigation.

Fruit accumulation

For fruit accumulation, the authors did not verify any significant interaction (shape X DAE). Maximum N accumulation estimated in fruits was 7.48 g plant^{-1} (Figure 3A), which corresponds to, approximately, 59.1% of the total plant accumulation.

Other studies present proportions of N exports relatively close, 54% for cv. Olímpia (Silva *et al*., 2012) and 63% for cv. Crimson Sweet (Vidigal *et al*., 2009).

Grangeiro & Cecílio Filho (2004a) pointed out the participation of N in fruits corresponding to 77% of the total accumulated by Tide hybrid; nevertheless, a reduction of N in

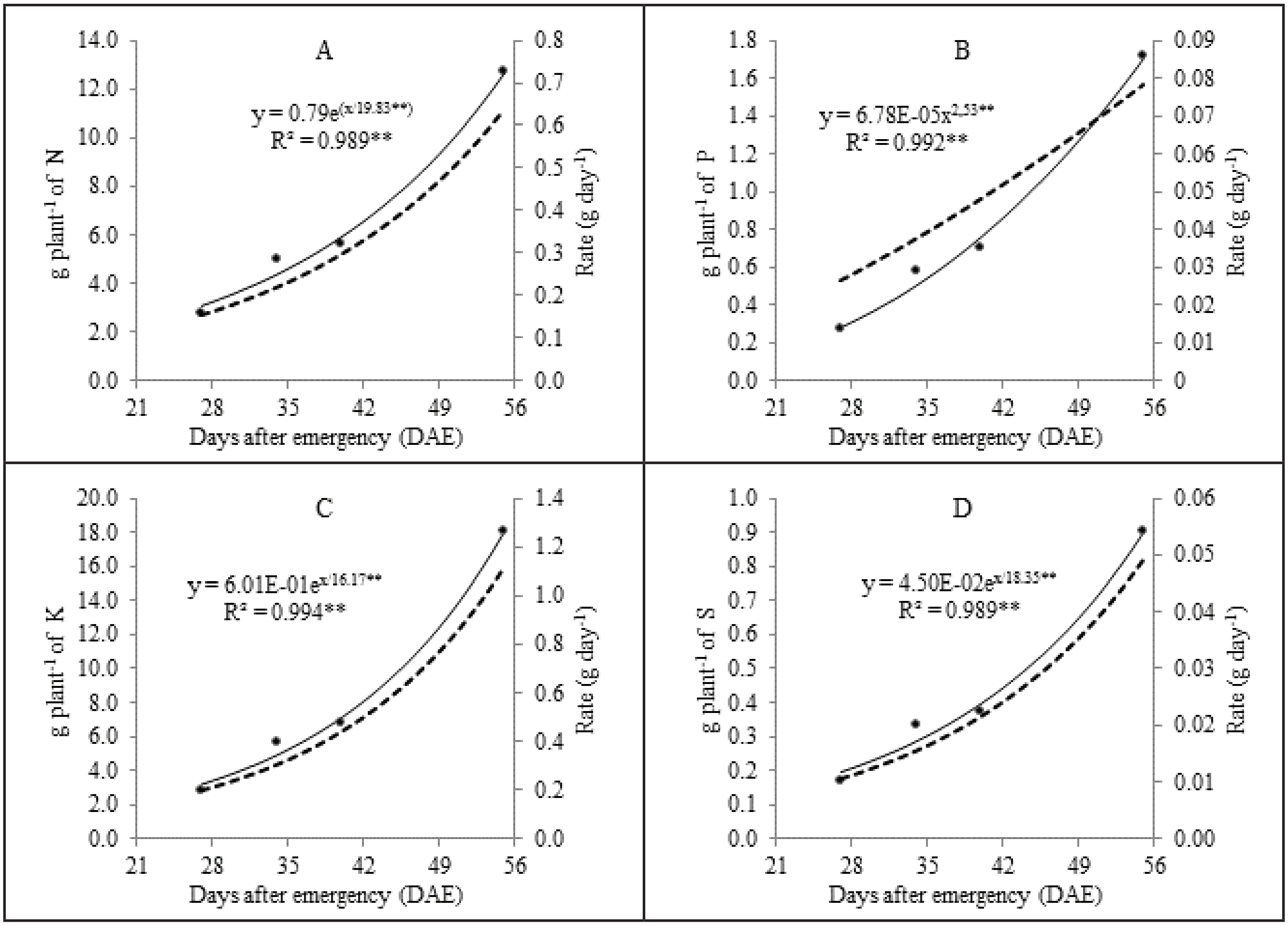

Figure 1. Total accumulations of N (A), P (B), K (C) and S (D) on watermelon crop cv. Magnum in relation to days after emergence (DAE) and their daily accumulation rates. Mossoró, UFERSA, 2015.

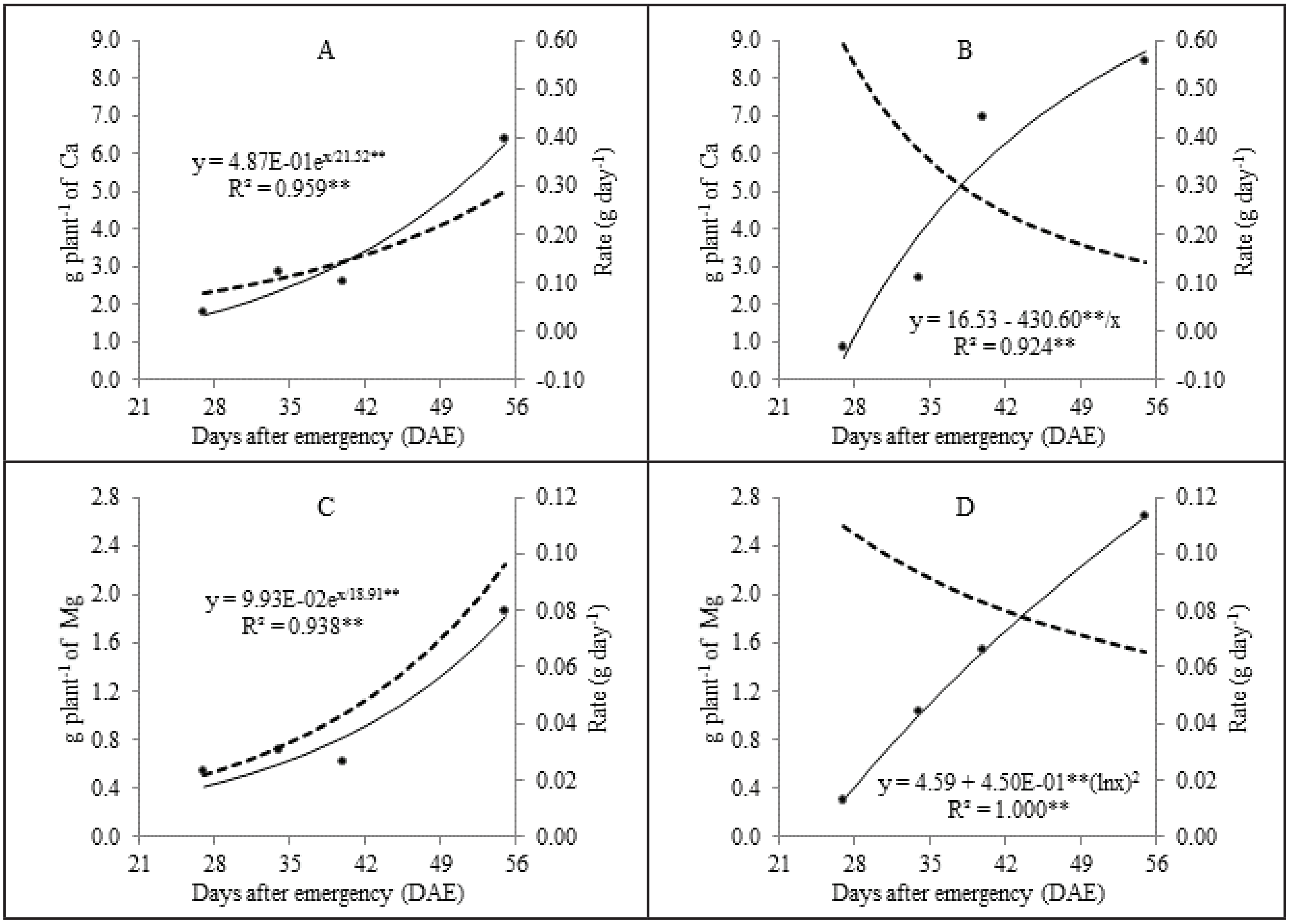

Figure 2. Total accumulations of Ca and Mg of watermelon cv. Magnum: Ca in F0 (A) and F1 (B) fertilizations and Mg in F0 (C) and F1 (D) fertilizations in relation to days after emergence (DAE) and respective daily accumulation rates. Mossoró, UFERSA, 2015.

vegetative part was explained due to a strong translocation of this nutrient to fruits.

At 55 DAE, plants accumulated an average of 1.42 g of P in their fruits (Figure 3B), significant differences between fertilization systems were noticed, though. Average accumulation in F1 fertilization during the cycle (0.66 g plant^{-1}) was significant superior (p = 0.01) comparing to F0 fertilization (0.43 g plant^{-1}), approximately 0.23 g.

Based on the adjusted model for P in relation to DAE (Figure 3B) and on differences between fertilization systems, the authors estimated proportions of P exports in fruits of 84.1% and 83.1%, respectively for F0 and F1 fertilizations. This result shows that an increase in P uptake practically does not change the nutrient partitioning pattern in plant.

This high proportion of P export corresponds to the one verified by Grangeiro & Cecílio Filho (2004a), working with Tide hybrid (82%). However, this behavior must also be related to balance of source-drain ratio in the plant.

Silva *et al*. (2012) and Vidigal *et al*. (2009) verified P export of 57% and 55% for cultivars Olímpia and Crimson Sweet, respectively. Some studies point out that movement and partitioning of P in the plant may not be a direct effect of its demand by the drains, but mainly a carbohydrate demand by the drains (Araújo & Machado, 2006).

In relation to K, the authors verified that, at the end of the experiment (55 DAE), about 13.95 g (Figure 3C) or 77.4% of the maximum accumulated amount of K is allocated in fruits. Grangeiro & Cecílio Filho (2004a) presented similar K export proportion for Tide hybrid (76%).

Other studies show exports equivalent to 73% for Shadow hybrid (Grangeiro & Cecilio Filho, 2005) and to 72% and 63.6% of the amount of K for cv. Leopard and cv. Olímpia, respectively (Silva *et al*., 2012).

Vidigal *et al*. (2009) stated that K in fruits corresponded to only 56% of the total in cv. Crimson Sweet. Some of these differences should be related to fruit partitioning, which in this study corresponded to approximately 70% of total biomass at the end of the cycle.

At the end of the experiment, Ca accumulated in fruits was of approximately 24.0% and 17.3% of the maximum accumulations in F0 and F1 fertilizations, respectively. This fact is due to the higher Ca accumulation in vegetative part, in F1 fertilization, noticed and that no differences for accumulation in fruits, 1.51 g plant^{-1}, at 55 DAE were verified (Figure 3D).

According to Vitti *et al*. (2006), an increase in Ca concentration in the external solution may lead to an increase of accumulation in leaves, but not necessarily in fruits in relation to the mechanisms developed by plants to reduce the transport of this nutrient.

Reduction of Ca concentration in tissues is necessary for rapid cell expansion and membrane permeability (Marschner, 2012). Moreover, Ca is uptaken via transpiration, which leads an accumulation of this nutrient, mainly in the vegetative part (Marschner, 2012; Vidigal *et al*., 2009).

Final Mg accumulation in fruits is 0.93 g (Figure 3E), corresponding to 51.35% and 35.40% of the respective nutrient total maximum in F0 and F1 fertilizations (Figures 2C and 2D), showing the relative mobility in the phloem when compared to Ca.

Thus, as for Ca, an increase of Mg uptake in plant does not mean higher

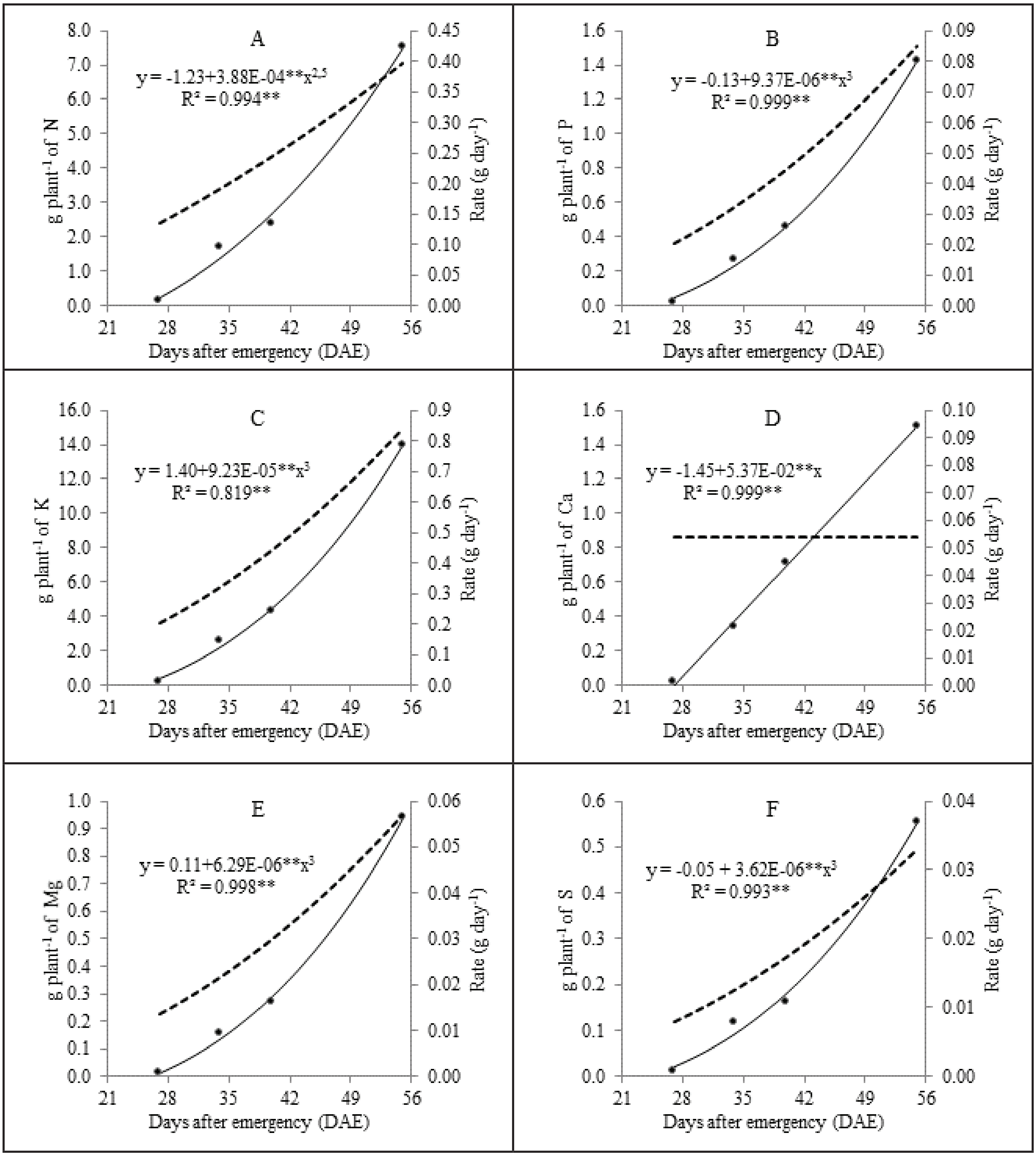

Figure 3. Accumulations of N (A), P (B), K (C), Ca (D), Mg (E) and S (F) in fruits of watermelon crop cv. Magnum in relation to days after emergence (DAE) and respective daily accumulation rates. Mossoró, UFERSA, 2015.

exports of the nutrient in fruit. Marschner (2012) explains that continuous uptake and import via leaves after anthesis is one of the main causes of insufficiency of remobilization both of Ca and Mg.

Silva *et al*. (2012) verified export proportion of 20% Ca and 53% Mg for cv. Olímpia and of 19% Ca and 42% Mg for cv. Leopard, in an experiment carried out in Baraúna, RN.

S is the nutrient with the lowest accumulation in fruits (0.55 g plant^{-1}); it corresponds to the highest part of what is accumulated in plant (61.38%), though. Vidigal *et al*. (2009) and Grangeiro & Cecílio Filho (2004a) also verified low S accumulation when comparing to other macronutrients in watermelon, exporting 52% and 65% of total accumulated for cv. Crimson Sweet and Tide hybrid, respectively.

Using the maximum values of the adjusted models, it is possible to establish the following order of nutrient accumulation in fruits in F0 fertilization: K>N>Ca>P>Mg>S and in F1 fertilization: K>N>P>Ca>Mg>S (Figure 3). Difference between fertilizations is due to higher P uptake in F1 fertilization, being also an indicative of P translocation capacity to fruits.

Considering planting density used (8,333 plants ha^{-1}), the authors are able to estimate that at the end of this experiment (55 DAE), the amounts exported of N, K, Ca, Mg and S to fruits were 62.30, 116.28, 12.54, 7.79 and 4.60 kg ha^{-1}, respectively. For P in fruits, the authors estimated 10.93 and 12.81 kg ha^{-1} in F0 and F1 fertilizations, respectively.

Overall, the highest macronutrient accumulations occurred in the last third of the crop cycle.

The general order of macronutrient accumulation was altered according to fertilization system used, considering an increase of P accumulation in F1 fertilization, both for the total and in fruits.

Range of macronutrient accumulation rates was increasing during evaluation, except for Ca and Mg in F1 fertilization.

F1 fertilization provided higher total accumulations of Ca and Mg; the same did not occur for accumulation in fruits, though.

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