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Accumulation of macronutrients in onion bulbs as a function of sulfur application

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Abstract

The amount of nutrients extracted by the bulbs represents an important component of nutrient removal from the soil, and its evaluation must be used to define the amount of nutrients to be replaced in the soil, through fertilization programs. The objective of the study was to verify the accumulation of nutrients in onion bulbs due to the application of sulfur at different phenological stages. The experiments were carried out in a conventional system, in a completely randomized design, in a 2 x 5 x 2 factorial scheme, with two cultivars (Dulciana and Vulkana), in five times of S application (control; transplanting; stage of 6 to 7 leaves; bulb differentiation stage, and full bulbing), and 2 years of cultivation, with four replications. After curing, four (4) bulbs of each treatment were chosen randomly, one per replication of each commercial plot formed by 20 bulbs from the field experiment, which were identified and taken to the laboratory for nutrient analysis. Subsequently, the amount accumulated in the bulb of each nutrient was determined. Fertilization with sulfur promotes greater accumulation of K and N. The order of extraction of nutrients in the presence of sulfur was K> N> P> S> Ca> Mg. The highest sulfur accumulations in the bulb occurred at the bulbing stage for both cultivars.

Keywords: Allium cepa L., fertilization, nutrient absorption

Introduction

The quantity and quality of compounds found in onions can be attributed to several nutrients. The mutual action of one nutrient on the performance of other results in interactions, which can have both positive and negative effects on growth, development, and yield, being variable according to climate, soil, and cultivars, thus, it becomes important to know how nutrients are absorbed by the plant (Noda, 2018).

Among the nutrients, nitrogen (N) and sulfur (S) stand out in onion growth, as they can influence important aspects of bulb development, such as size, maturation, and quality, which may impact the yield (Bystrická et al., 2014). In this sense, it is worth mentioning that N and S can interact with each other and with other nutrients, affecting several types of amino acids and the ferredoxin molecule, which is an important component in photosynthesis.

According to Kurtz et al. (2018), the nutrients N, P, K, and S accumulate preferentially in the bulb, while Ca and Mg in the shoot part, and there may be different translocations of nutrients during the development of the crop, mainly after onion bulbing process.

Among fertilizers, potassium is the most used and absorbed in greater quantities in onions (Kurtz et al., 2016). In addition to influencing yield, potassium is related to the final quality of the product, and consequently to the market value (Filgueira, 2008).

Sulfur absorption by plants takes place mainly in the form of sulfate (SO_4^{2-}) and contact with the root occurs by mass flow, so that the greater the concentration of the element in the solution and the volume of water absorbed, the greater the root-ion contact that will favor the absorption process itself (Rodrigues et al., 2020). Phosphates applied via fertilization preferentially occupy exchange positions in the soil that would be occupied

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by sulfates (Nicchio et al., 2021), thus high doses of phosphates can result in a higher concentration of sulfur in the soil solution.

However, there is little information about the influence of sulfur fertilization on the supply of these nutrients to the plant and the respective effect on onion quality. The sulfur found in the tissues depends on the plant's development stage. The highest demand for sulfur in onions occurs near the end of the cycle (Pôrto et al., 2006).

Therefore, the objective was to verify the influence of sulfur fertilization at different phenological stages on the accumulation of nutrients in onion bulbs.

Material And Methods

The bulbs used were obtained from experiments conducted in the municipality of Gurupi in the years 2015 and 2016, in the southern region of the state of Tocantins, in a location with geographic coordinates 11°43'45" in latitude and 49°04'07" in longitude, at 280 m of altitude. It is a region that traditionally does not produce onions. The climate classification of the region, according to Köppen (1948), is type B1wA"a", being of the hot humid type with moderate water deficit. The average annual temperature is 29.5°C, with an average annual rainfall of about 1800 mm.

The sowing in trays was carried out in May and the seedlings were transplanted 35 days later. The experimental design used was completely randomized, in a 2 x 5 x 2 factorial scheme, with two cultivars (Dulciana and Vulkana), five times of sulfur application (transplanting; stage of 6 to 7 leaves; stage of differentiation of bulb,s and full bulbing), and with four repetitions.

The sulfur dose used was defined according to data obtained by Milhomens (2015) under the same edaphoclimatic conditions. Elemental sulfur with 99% purity was used as a source of S.

According to soil analysis results (**Table 1**), 150 kg ha^{-1} of phosphorus applied in the form of MAP was applied; 120 kg ha^{-1} of nitrogen was applied in the form of urea, and 180 kg ha^{-1} of potassium was applied in the form of potassium chloride, according to the needs of the crop and soil analysis. All phosphorus was applied during the preparation of the beds before transplanting the seedlings. Nitrogen and potassium fertilization was divided into three parts (40% at transplant, and the remaining top-dressed at 30 and 60 days after transplanting the seedlings). Sulfur was applied manually between the planting lines of the bed.

Harvesting was performed approximately 90 days after transplanting. Curing was done in a shed for a period of 15 days. After curing, 4 bulbs from each treatment were randomly chosen, one per repetition of each commercial plot, formed by 20 bulbs from the field experiment, which were identified and taken to the laboratory. Subsequently, the amount accumulated in the bulb of each nutrient was determined, as per Sarruge & Haag (1974).

The steps for the digestion of the samples by this method are briefly described below. After washing the samples with distilled water, which were placed in a paper bag and placed in a calibrated oven between 65° C to 70° with air circulation, until constant mass (approximately 72 hours) and subsequently ground in a mill.

After grounding the samples, the following steps were performed: a) 0.5 g of ground sample was placed in a digestion tube; b) 6.0 ml of concentrated HNO3 (nitric acid) was added to the tube; c) left to rest until the following day, in a chapel, covered with a sheet of clean paper; d) each tube was manually shaken, taking care so the mixture does not adhere to the walls of the tube; e) the tube was heated to 80-90 °C for 1/2 hour; f) the temperature was increased to 120 °C. At this point the solution resulted in strong N oxide vapors (brown color); g) the tube was kept at this temperature until 0.5 ml of acid remained, taking care to remove the tubes that tend to dry out. h) After cooling the tubes, 50 ml of distilled water heated to 60°C was added; i) the tubes were shaken in a tube shaker and reserved in 100 ml glass bottles overnight to decant suspended particles; j) A blank test for each gallery of 50 samples was carried out.

- Potassium: through the Flame Photometer (pipette 1 ml of extract and add 9 ml of water, prepare in Becker);

- Calcium and Magnesium: through atomic absorption (pipette 0.5 ml of extract, 22 ml of distilled water, and 2.5 ml of lanthanum oxide).

- Phosphorus: pipette 1 ml of nitro-perchloric

Table 1- Chemical attributes and granulometry of the soil used in the experiments

Year	pH	Pmeh	S-SO_4^{2-}	K	K	Ca	Mg	Al	H+Al	O.M.	O.C.	Clay	Silt	Total Sand
$CaCl_2$			-mg dm^{-3}		cmolc dm^{-3}					dag Kg^{-1}		%		
2015	5.3	26.3	-	32	0.08	1.7	0.9	0.0	2.2	1.9	1.1	24.8	1.2	74.0
2016	5.1	20.2	4	63	0.16	1.9	1.2	0.0	1.18	2.1	1.2	27.2	5.0	67.8

O.M. – organic matter; O.C. – organic carbon Soucer: SELLAR extract, add 4 ml of deionized water and 2 ml of R.M.

- Sulfur: through the Reactive Turbiometric method - pipette 10 ml of the nitro-perchloric extract, 1 ml of 6.0 N HCl, and 50 mg of Barium chloride.

With the averages obtained from each plot for each characteristic in each year, a descriptive analysis of the data was carried out. The statistical analyzes were performed with the Sisvar software (Ferreira, 2019), and the graphs with the Sigma Plot software (2008) version 10.0.

Results And Discussion

Potassium (K) and nitrogen (N) were the macronutrients most accumulated by Dulciana in the first year of cultivation at different stages of sulfur application (**Figure 1**), as observed for short-day cultivars 'Optima' (0, 27 g plant^{-1}) and 'Superex' (0.29 g plant^{-1}) studied, respectively, by Aguiar Neto et al. (2014).

For the Dulciana cultivar, in the first year of cultivation, sulfur was the fourth nutrient with the highest accumulation in the bulb at the transplanting, with 4.2 mg kg^{-1} of sulfur. The application at transplanting gives the plant a longer period for sulfur to be reduced in the soil by microorganisms, then absorbed by the plant, after which it can be translocated to the development of the bulb.

Application with 6 to 7 leaves resulted in the lowest accumulation rates of all nutrients, however, sulfur continued to be the fourth most accumulated nutrient at this stage, resulting in 2.4 mg kg^{-1} of sulfur in the bulb. This result may be explained by the fact that the leaves are already developed, starting the differentiation stage, therefore, the available photosynthesis products, mainly the sulfur that was applied at that time, are still not available.

The application of sulfur at the differentiation stage resulted in increased accumulation of sulfur in the bulb, as well as potassium compared to the 6 to 7 leaf stage. S was the fourth most accumulated element in onion. Therefore, it has a direct relationship with the accumulation of matter in the bulbs. Moreover, S plays an effective role in plant growth due to the biosynthesis of hormones that induce, in turn, plant growth, i.e. cell division, the meristematic activity of plant tissue, and cell expansion (Laxmi et al., 2019).

The maximum accumulation of sulfur by the plant occurs during the period of full development, during bulbing (Pôrto et al., 2007; Souza et al., 2017). In this phase, there is a greater translocation of photoassimilates for the formation of the bulb and, consequently, a greater demand for nutrients, probably due to the increase in metabolic activity associated with hormonal activity and cell division and growth for the formation of new tissues (Noda, 2018).

This result corroborates with Pôrto et al. (2006), who reported that the highest demand for sulfur in onions occurs near the end of the cycle.

In third place in terms of accumulation was phosphorus (P) at transplanting, 6 to 7 leaves stage, and bulbing. Subsequently, Ca and Mg were accumulated in smaller amounts (Figure 1).

In the second year of cultivation of 'Dulciana', potassium (K) and nitrogen (N) continued to be the most accumulated macronutrients at different stages of sulfur application (**Figure 2**).

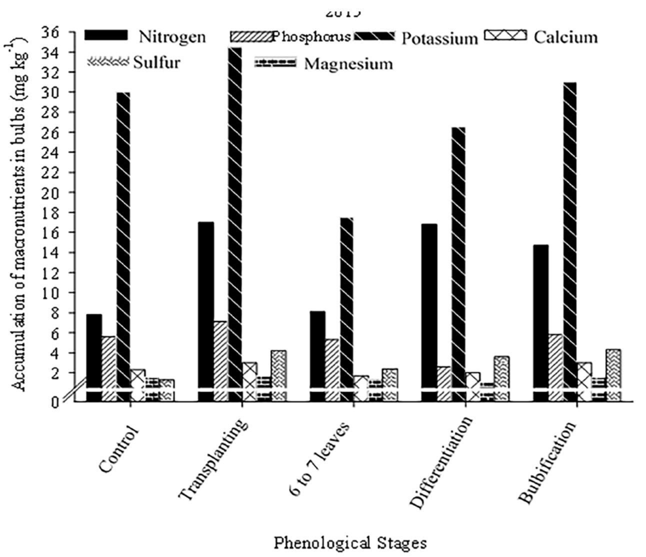

Figure 1- Accumulation of macronutrients in bulbs (mg kg^{-1}) of the onion 'Dulciana' as a function of sulfur application at different phenological stages. Gurupi-TO, 2017.

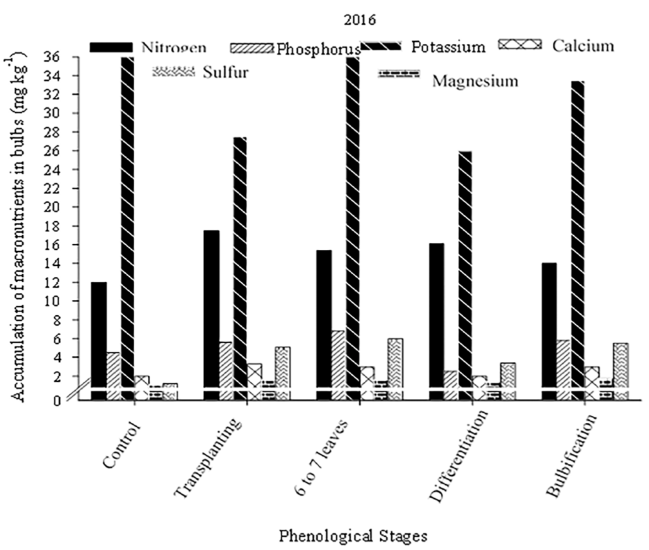

Figure 2- Accumulation of macronutrients in bulbs (mg kg^{-1}) of the onion 'Dulciana' as a function of sulfur application at different phenological stages. Gurupi-TO, 2017.

The application of sulfur at transplanting accumulated 5.1 mg kg^{-1} of sulfur in the bulb (Figure 2).

The application of sulfur at the stage of 6 to 7 leaves accumulated 6.0 mg kg^{-1} of sulfur in the bulb, equivalent to a 17.7% increase with the application at that time (Figure 1). The stage of 6 to 7 leaves is the phase of greatest demand for nutrient absorption, as the translocation of photoassimilates and other compounds to the bulb initiates, observing a rapid accumulation of dry matter in this part of the plant, which is regulated by the interaction between photoperiod and temperature (Silva, 2015).

At the differentiation stage, a 43.3% decrease in sulfur accumulation in the bulb (3.4 mg kg^{-1}) was observed. Under these edaphoclimatic conditions, no significant effect was detected when sulfur was applied at this phenological stage for this cultivar, as the plant is going through bulb formation.

During bulbing, increases in the accumulation of sulfur in the bulb of 5.5 mg kg^{-1} were observed, equivalent to 61.7% more than what was found at the differentiation stage (Figure 2).

Magnesium was the macronutrient accumulated in smaller amounts by 'Dulciana' in all treatments (Figures 1 and 2). This result corroborates with Moraes et al. (2016), but with 'Aquarius'. The period of intensification of Mg accumulation for the whole plant occurred from 92 days after sowing until harvest.

According to Porto et al. (2007) also reported that Mg was one of the macronutrients absorbed in smaller amounts, reaching an estimated value of 0.03 in g $plant^{-1}$ for 'Optima' and 'Superex' hybrids.

For both Vulkana and Dulciana cultivars, K and N were the nutrients most accumulated in the bulbs in the first year of cultivation (**Figure 3**).

When sulfur was applied at transplanting, an accumulation of 3.7 mg kg^{-1} of sulfur in the bulb was observed (Figure 3). The sulfur found in the tissues is variable depending on the plant development stage, as this nutrient is not very mobile in the plant.

As for the application at the 6 to 7 leaves stage, a decrease of 48.3% of sulfur accumulation in the bulb was observed. A similar result was observed for 'Dulciana' in the same year and stage.

An accumulation of 2.1 and 3.8 mg kg^{-1} of sulfur in the bulb was observed in the stages of differentiation and bulbing, respectively, representing an increase of 10.5% and 100% compared to the 6 to 7 leaves stage. There was also an increase in nitrogen and potassium contents during these stages in relation to the stage with 6 to 7 leaves. The increase in N accumulation by the bulb at the differentiation and bulbing stage may have occurred due to the redistribution of N from the leaves to the bulb since the interactions between nutrients are considered relevant for plant nutrition (Kurtz et al., 2016; Fayad, 2018; Kurtz et al., 2020). Between N and S there may be a synergistic interaction, which acts directly on the quality of the harvested products (Malavolta & Moraes, 2007). In this context, it is observed that cysteine synthesis connects the three main pathways of primary metabolism: carbon fixation, and nitrate and sulfate absorption Long et al. (2015). Vidigal et al. (2010) reported a similar behavior for 'Alfa Tropical', which showed increased accumulation of N by the bulb at the end of the productive cycle, reaching 0.09 g $plant^{-1}$.

Potassium present in plants plays an important role in opening stomata and regulating the osmotic potential of plant cells (Laxmi, 2019). The latter probably explains the high demand for K during bulbing (19.5 g kg^{-1}), when it promotes a reduction in the osmotic potential, favoring the entry of water and photoassimilates and contributing to the development of the bulbs (Aguiar Neto et al., 2014).

As in the first year of cultivation, in the second, K and N were the nutrients most accumulated in the bulbs (**Figure 4**).

At transplanting, the application of sulfur led to the accumulation of 4.7 mg kg^{-1} of sulfur in the bulbs, with an increase of 34% for the stage of 6 to 7 leaves with a value of 6.3 mg kg^{-1} of sulfur in the bulb (Figure 4). This increase in the accumulation of sulfur in the bulb is probably due to the greater demand for nutrient absorption by the plant so that it can be translocated to the formation of bulbs during differentiation. It should be noted that the average temperature in this period was higher than in the previous year, which may have interfered with the action of sulfur-reducing microorganisms in the soil.

At the differentiation stage, it was observed a decrease of 65.1% in sulfur accumulation in the bulb (2.2 mg kg^{-1}) compared to the previous stage. At this stage, the bulb is already in formation, and the S is important for the complete development of the bulbs.

When applied at bulbing, 'Vulkana' had a sulfur accumulation in the bulb of 5.5 mg kg^{-1} in relation to the differentiation stage. The quantification of nutrient distribution varies between cultivars and is distributed differently in the plant, as observed by Santos et al. (2007) for 'Alfa São Francisco' and 'Franciscana IPA 10'. For these cultivars, the order of extraction and accumulation of nutrients were: N > K > Ca > S > P > Mg. In this work,

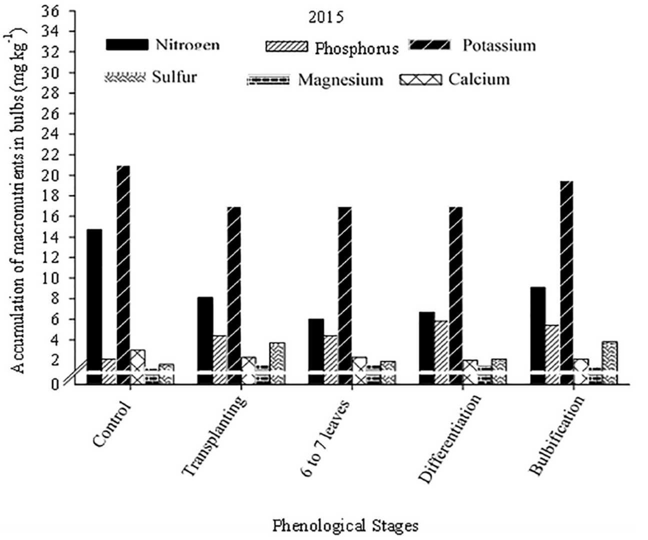

Figure 3- Accumulation of macronutrients in bulbs (g kg^{-1}) of the onion 'Vulkana' as a function of sulfur application at different phenological stages. Gurupi-TO, 2017.

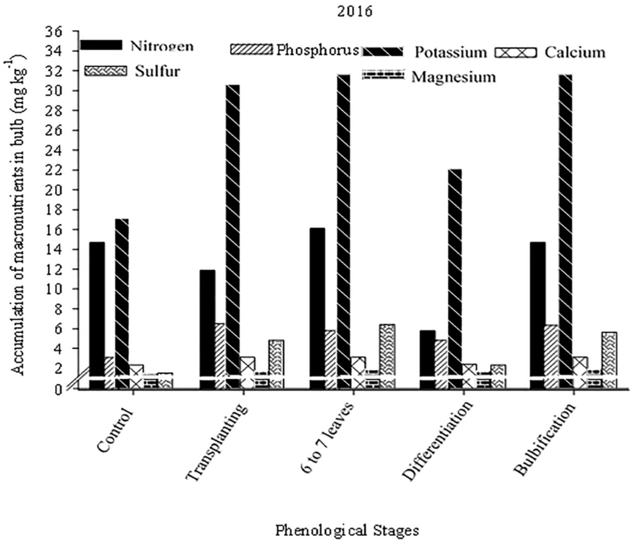

Figure 4- Accumulation of macronutrients in bulbs (g kg^{-1}) of the onion 'Vulkana' as a function of sulfur application at different phenological stages. Gurupi-TO, 2017.

'Alfa São Francisco' accumulated more nutrients than the cultivar 'Franciscana IPA 10'.

In the present study, S was the fourth most accumulated macronutrient in the two cultivars studied (Figures 1, 2, 3, and 4). The accumulation in the bulbs had the following order of extraction: K> N> P> S> Ca> Mg. These results were also observed by Vidigal et al. (2010), who also found that S was the fourth nutrient in the order of absorption by 'Superex' and 'Alfa Tropical' onions. However, according to these authors, P was the fifth and Ca the third most absorbed nutrient in the onion bulb, different from what was found in this study, probably due to the use of sulfur, which may have interfered with the absorption of Ca.

Conclusions

Sulfur is an important nutrient for bulb development and nutrient accumulation in the plant.

Fertilization with sulfur promotes greater accumulation of K and N.

The order of nutrient extraction in the presence of sulfur was K> N> P> S> Ca> Mg.

The greatest accumulations of sulfur in the bulb occur when sulfur is applied at the bulbing stage in both cultivars.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.