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Gypsum as a source of sulfur for strawberry crops

Gesso agricola como fonte de enxofre para a cultura do morango

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Abstract

There are several studies on plant responses to Sulfur (S), but few are specific to the strawberry crop. The requirement for nutrients and the nutritional status of plants is a particular attribute of each species that should be taken into account when determining the plant's nutritional demand. The objective of this study was to evaluate the application of S and phosphate (P) rates in the development and productivity of strawberry crops. An experiment was conducted in a greenhouse in pots containing 2 kg soil (Oxisol) in Guarapuava city of Paraná State. The experiment consisted of a 6 × 2 factorial outlined in a randomized block design with three replications, with six doses of S: 0, 10, 20, 30, 40 and 50 mg kg^{-1} in the form of gypsum, and two doses of P: 300 and 600 mg kg^{-1} of P_2O_5. The Albion variety of strawberry plants was transplanted to pots and grown for 170 days. The fruits were harvested and weighed throughout the experiment; a similar procedure was followed for the shoots at the end of the experiment. The shoots and fruits were dried, weighed, ground, and analyzed for the content of S, Ca, and P. The production of strawberry fruits was influenced by S rates, with the highest productivity obtained by using S rates of 60 and 37 mg kg^{-1} with the application of 300 and 600 mg kg^{-1} of P, respectively.
Key words: Absorption, interaction, phosphorus, production

Resumo

De uma maneira geral, diversos são os estudos sobre a resposta das plantas ao enxofre (S), porém poucos são específicos para a cultura do morangueiro. A exigência por nutrientes e o estado nutricional é um atributo particular de cada espécie e deve ser levada em conta na determinação da demanda nutricional. O objetivo deste trabalho foi avaliar a influência da aplicação de doses S e fósforo (P) no desenvolvimento e produtividade do morangueiro. Foi conduzido um experimento em casa de vegetação, em vasos de 2 Kg de solo (Latossolo Bruno), em Guarapuava-PR. O experimento constituiu-se de um fatorial 6 x 2, delineado em blocos ao acaso, com três repetições, sendo seis doses de S: 0, 10, 20, 30, 40 e 50 mg kg^{-1}, na forma de gesso agrícola e duas doses de P: 300 e 600 mg kg^{-1} de P_2O_5. Nos vasos foram transplantadas mudas de morango variedade Albion, cultivadas por 170 dias. Os frutos foram colhidos e pesados ao longo do experimento e a parte aérea ao final do experimento. A parte aérea e os frutos foram secos, pesados, moídos e analisados em relação ao teor de S, Ca e P. A produção de frutos de morango foi influenciada pelas doses de S, sendo que a maior produtividade foi alcançada na dose de 60 mg kg^{-1} de S com aplicação de 300 mg kg^{-1} de P e na aplicação de 600 mg kg^{-1} de P combinada com a dose de 37 mg kg^{-1} de S.
Palavras-chave: Absorção, interação, fósforo, produção

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Introduction

There are several studies on the response of plant growth to sulfur (S). The intensive cultivation of soils with low organic matter and clay, the use of concentrated fertilizers, and the continuous export of S without replacement can lead to decreased availability of this element to plants, causing its deficiency and, consequently, a decrease in the crop yield. The correction of acidity at the crop surface without incorporation into the soil, promotes the movement of sulfate (SO_4^{-2}) to the deeper layers, and may be another aggravating factor in the decreased availability to plants if there is an impediment to root growth at depth.

Although the plants are able to absorb foliar S (VITTI; LIMA; CICARONE, 2006), the highest proportion of absorption occurs through the roots. Sulfur found in the plant cells is absorbed from the soil solution as SO_4^{-2} (ALVAREZ V. et al., 2007) and transported to the root system mainly by mass flow (SILVA; VENEGAS; RUIZ, 2002). According to the necessity of S, the cultivated plants may be classified into three groups: those that require large amounts of S for their development such as *Brassicaceae* and *Liliaceae*, those that require intermediate quantities such as legumes, cotton, and sunflowers, and those with low necessity for S such as *Gramineae* (JORDAN, ENSMINGER, 1958). There is no information in the literature on which these groups would comprise the *Rosaceae* or more specifically the strawberry plant.

The foliar S in agriculture can vary from 1 to 5 g kg^{-1} (VITTI; LIMA; CICARONE, 2006). This wide variation in soil composition may depend on the availability of primary minerals, gypsum and iron sulfide, atmospheric deposition, plant and animal residues, and pesticides and fertilizers (ALVAREZ V. et al., 2007). Soils with a high availability of this nutrient allow the plant to absorb higher amounts for their needs, characterizing an excessive absorption (ALVAREZ, 2004). In such cases, part of non-metabolized S is stored as SO_4^{-2}, usually in the cell vacuole.

The availability of S in the soil is directly proportional to the presence of clay, oxides, and organic matter, and is also influenced by soil pH (CHAO; HARWARD; FANG, 1962). Both the total amount of S as the adsorption capacity of S-SO_4^{-2} are lower in soils with low clay content, and their retention is further reduced by the application of lime and phosphate (CAMARGO; RAIJ, 1989). The sulfate in the soil moves to the deeper layers, where it can be adsorbed due to higher clay content, lower organic matter content, and lower pH values (RHEINHEIMER et al., 2005). Plant nutrition studies demonstrated the positive effect of providing S and increasing the productivity of various crops (CRUSCIOL et al., 2006).

The nutritional status of strawberry is influenced by external factors, such as soil, temperature and humidity, fertilizer and cultural practices, but also by cultivar. The requirement for nutrients and nutritional status is a particular attribute of each cultivar that should be taken into account when determining the nutritional demand on strawberry (DAUGAARD, 2001).

According to a study made by Andriolo, Bonini and Boemo (2002), the results on the extraction of nutrients from strawberry plants found in the literature vary (BRANZANTI, 1985; CASTELLANE 1993; HENNION; VESCHAMBRE, 1997; ARCHBOLD; MACKOWN, 1995). In work performed by Souza (1976), the extraction of macronutrients from the strawberry occurred in the following order: K, N, Ca, Mg, S, and P, and that the level of extraction is variable based on the cultivar.

According to Castellane (1993), mineral nutrition and fertilization are important factors that could maximize the fruiting of strawberries because they are the less studied in Brazil, despite being included among the most important factors for increased production and better quality of fruits. There is still a great need for information about the nutrients required by the strawberry plant, and improvements for the use of fertilization technology, which would enable the establishment of satisfactory fruit production with a minimum increment of nutrients (TAGLIAVINI et al., 2005).

The objective of this study was to evaluate the application of S and phosphate (P) rates on the development and production of strawberries.

Materials and Methods

The experiment was conducted from June to December 2011 in a greenhouse at the Mid-West State University (UNICENTRO), in Guarapuava city of Paraná State, Brazil. The experiment was performed in plastic pots filled with 2 kg of soil (Oxisol type) sieved through a 4-mm mesh. The chemical characteristics of the soil were pH in $CaCl_2$, 5.1; organic matter, 39.9 g dm^{-3}; P (Mehlich-1), 0.7 mg dm^{-3}; H + Al, 41.4 mmol dm^{-3}; K, 2.1 mmol dm^{-3}, Ca, 27 mmol dm^{-3}; Mg, 26 mmol dm^{-3}; S-SO_4, 5.1 mg dm^{-3}; CTC, 96.5 mmol dm^{-3}; and base saturation, 57.2%.

To increase the soil base saturation to 80% liming was performed with the application of calcium carbonate. The soils were incubated for 7 days at 60% moisture retention capacity of water. The planting fertilization was conducted after correction of the soil, based on soil analysis.

The experiment consisted of a 6 × 2 factorial, delineated in randomized blocks with three replicates, totaling 36 experimental plots. The factors and rates studied were S rates of 0, 10, 20, 30, 40 and 50 mg kg^{-1} of S in the form of gypsum and P_2O_5 rates of 300 and 600 mg kg^{-1} of P, in the form of Triple superphosphate. After 7 days of incubation, each pot received a seedling of strawberry, cultivar Albion.

During the experiment, phytosanitary tracts were used for the control of pests and diseases through acaricide and fungicide spraying when necessary. Fertilization was performed with KCl and urea at a dose of 75 and 210 mg kg^{-1} of N and K respectively, divided into six applications throughout the experiment. When the strawberry plant started flowering, a biweekly foliar fertilization was performed with boron at a concentration of 1 g L^{-1}.

The strawberries were harvested weekly during the experiment, when the fruits presented a reddish color. The fruits were weighed and the total amount produced was calculated by using the sum of all harvests made during the production cycle (170 days). The fruits were washed, dried in an oven at 65 °C, weighed, and ground into a powder. At the end of the harvest, the shoots of the plants were cut close to the soil, washed, dried at 65 °C, weighed, and ground.

The samples of shoots and fruits were analyzed for total S concentration by dry combustion at LECO S-144DR equipment. The P and calcium (Ca) contents were analyzed according methods described by Silva (2009).

The data were examined for analysis of variance considering a factorial 2 × 6, and two rates of six doses of P and S. When a significant effect by F-test at 5% probability was detected, regression equations were adjusted according to the degree of significance. A comparison of the effect of P, when significant by F- test at 5% probability, was carried out by the Tukey test at 5% probability. Statistical analyses were performed using the program Assistat 7.6 beta version (ASSISTAT, 2012).

Results and Discussion

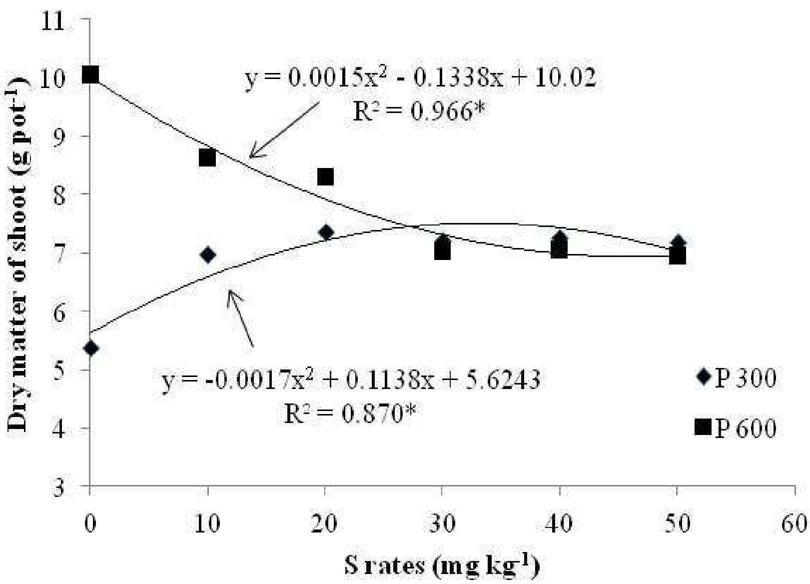
The dry matter production of shoots (DMPS) of the strawberry crop in function of rates of S and P in soil presented different behavior (Figure 1). In the treatments applied, a dose of 300 mg kg^{-1} of P (P300) together with the doses of S was observed to increase the production of DMPS, and a dose of 600 mg kg^{-1} of P (P600) reduced the production of DMPS. The average values of all treatments with S combined with the application of P300 caused DMPS production of 6.89 g pot^{-1}, and with the application of P600, the mean value was around

8.00 g $vaso^{-1}$ of DMPS, these being statistically different values.

Decreased production of DMPS after treatment with P600 may be related to the increase in the soil pH due to liming and the addition of Ca through the gypsum, which may have promoted the precipitation of phosphate added by triple superphosphate (NOVAIS; SMYTH; NUNES, 2007). Thus, the solubility of P in soil was compromised and its absorption by the strawberry crop was decreased. In the literature, studies have reported the positive effect of S in DMPS. For example, the work by Moreira, Carvalho and Evangelista (1997) evaluated gypsum in increasing concentrations as a source of S for the Alfalfa plant and found that S increased the production of DMPS. The increased production of DMPS for turnips and corn after application of S in the form of superphosphate was also observed by Rheinheimer et al. (2005).

In relation to treatments with P300, the highest production of DMPS with 7.53 g pot^{-1} occurred with the application of 33.47 mg kg^{-1} of S, and there was a decrease in the production of DMPS up to 44.6 mg kg^{-1} of S rate with P600 treatments. Cunha et al. (2001) achieved the maximum dry matter yield of herbage at the rate of 33.4 kg ha^{-1}, and Crusciol et al. (2006), when evaluating the bean crop, observed an increase in dry matter production of shoots to an estimated maximum rate of 51 kg ha^{-1}.

Figure 1. Dry matter production of shoots of strawberry plants according to the sulfur and phosphorus rates. * Statistically significant at 5%.



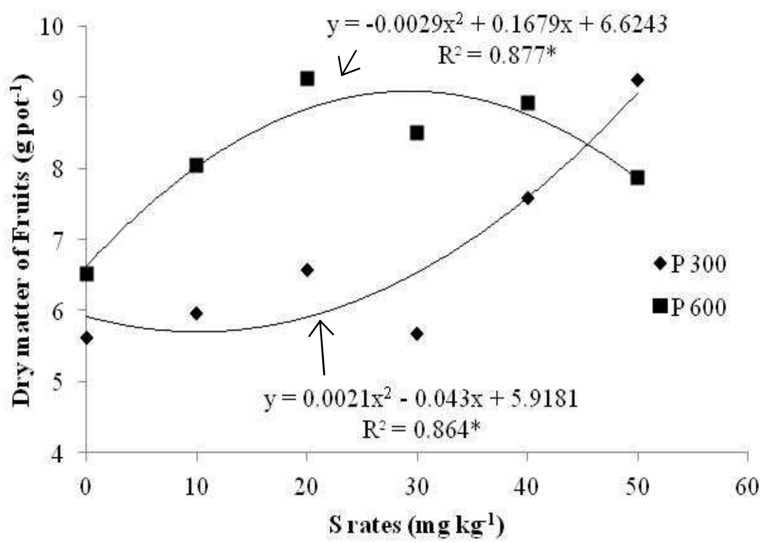
Source: Elaboration of the authors.

The effects that result from the combined application of P and S to the soil can be observed in fruit production (Figure 2). The dry matter production of fruit (DMF) in treatments with P300 increased with the application of S to the soil until the last rate evaluated and P600 treatments with the application of 29 mg kg^{-1} of S provided the highest production of DMF. Comparison of the treatment of P and S rates revealed statistical difference for DMF, where the P300 value was 6.78 g pot^{-1} and the P600 value was 8.19 g pot^{-1}.

The same result was observed for fresh fruits (FF) as shown in Figure 3. The production of FF increased depending on the dose of S applied for treatments with P300 and in P600 treatments. The highest production of FF was 105.3 g pot^{-1} obtained with the application of 37 mg kg^{-1} of S. On average, the treatments with P300 produced a DMF of 77 g pot^{-1}, whereas with P600, the production was 96.4 g pot^{-1}, an increase of 25.19% compared to treatments with P300.

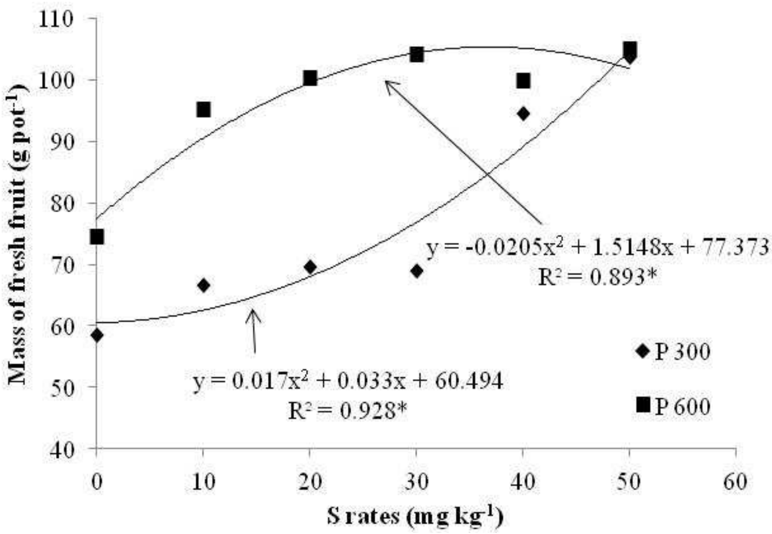
Significant increases in grains production resulting from the application of gypsum as a source of nutrients were observed in wheat, which showed responses to applied Ca (ADCOCK; GARTRELL; BRENNAN, 2001; BREENAN; BOLLAND; WALTON, 2007) and the supply of S (GANESHAMURTHY; TAKKAR, 1997; SHARMA et al., 2007). The results for the wheat are related to the benefits provided to the root environment due to the decrease in Al toxicity or by improving plant nutrition by supplying Ca and S.

Figure 2. Dry matter production of strawberry fruits according to the sulfur and phosphorus rates.



*Statistically significant at 5%.
Source: Elaboration of the authors.

Figure 3. Mass production of strawberry fresh fruit according to the sulfur and phosphorus rates.



*Statistically significant at 5%.
Source: Elaboration of the authors.

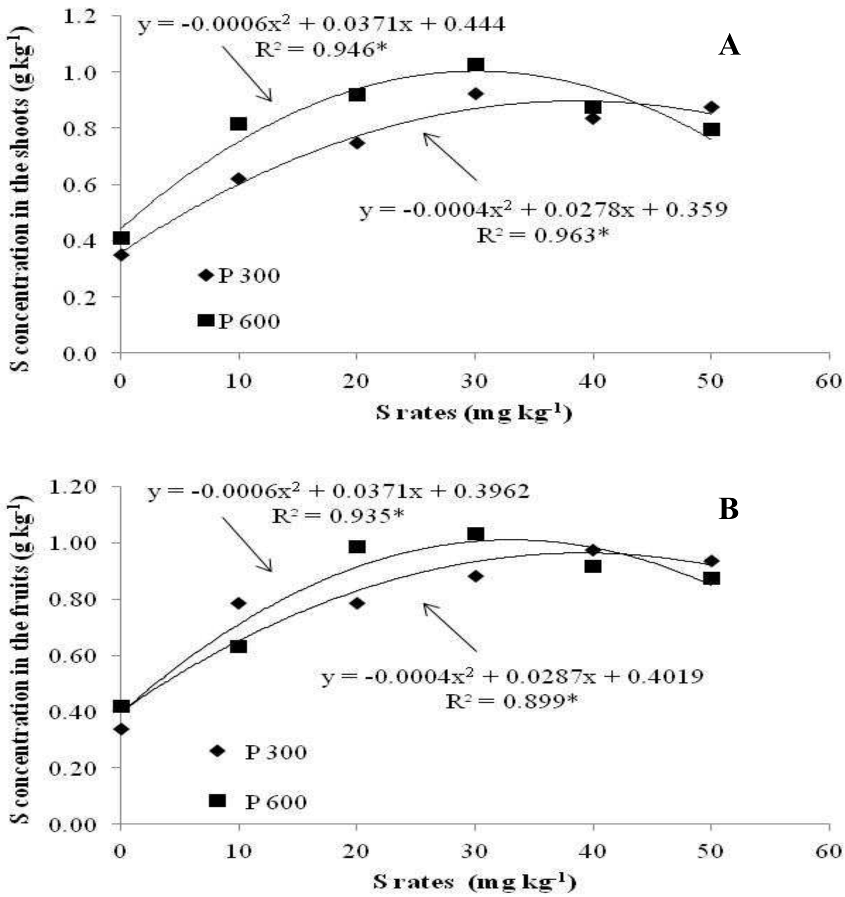
The concentrations of S in dry matter plant ranges from 1 to 5 g kg^{-1} for a good plant development (VITTI; LIMA; CICARONE, 2006). According to Ahamad at al. (2005), the content may vary from 1 to 15 g kg^{-1}, and according to Stevenson (1986), 90% of S in the plant are in the form of amino acids. The concentrations of S in the DMPS and DMPS ranged from 0.34 to 1.03 g kg^{-1}. As observed in Figure 4A, the concentration of S in the DMPS increased quadratically according to doses of S, with the highest concentrations found in the P600 treatments.

For the treatments with P300, the highest concentration of S (0.84 g kg^{-1}) in DMPS was found with the application of 34.75 mg kg^{-1} of S, and for treatment with P600, the highest concentration (1.01 g kg^{-1}) was obtained with application of 30.9 mg kg^{-1} of S. The average concentration of 0.72 g kg^{-1} for P300 treatment and 0.80 g kg^{-1} for P600 treatment were statistically different.

For DMF the higher concentration of S (0.91 g kg^{-1}) was obtained with the application of 35.9 mg kg^{-1} of S, after treatment with P300; in case of treatment with P600, the highest concentration (0.97 g kg^{-1}) was obtained with application of 30.9 mg kg^{-1} of S. The interaction is strongly positive between P and S with respect to the growth and production of crops (ALVAREZ V. et al., 2007); however, in case of the application of S in soil with P deficiency, the response of cultures can be negative, and excess of S can compromise some metabolic pathways in the absence of P. Accordingly, as noted earlier in the production of DMF, the combination of the S and P fertilization were favorable in production, and the results certified by the concentrations found in shoots and fruits (Figures 4A and 4B).

Another important factor is related to adsorption of sulfate, which can be reduced by the application of soluble phosphates (RICHART et al., 2006; RHEINHEIMER et al., 2005). The phosphate anion is more strongly adsorbed than sulfate because it is more reactive with the functional groups (RAIJ, 2011; RHEINHEIMER et al., 2005) and can be used as an extractor to release the adsorbed sulfate; it is currently employed in the extraction of sulfate available in the soil. This behavior explains that the results of DMPS, DMF, and FF obtained with P600 treatments are higher than those obtained with P300 treatments.

Figure 4. Concentration of S in the shoots (A) and fruits (B) according to sulfur and phosphorus rates. *Statistically significant at 5%.

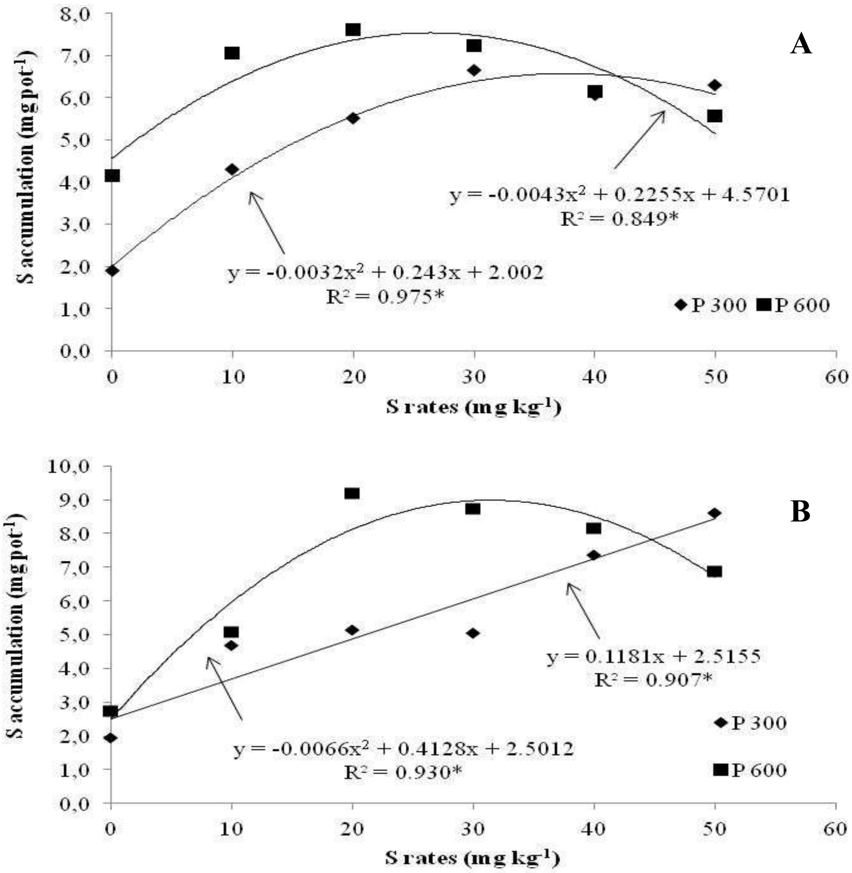


Source: Elaboration of the authors.

To highlight the importance of S jointly with the doses of P, S accumulation in the shoots of strawberries was calculated. Sulfur accumulation in shoots was demonstrated to quadratically increase in both treatments with P, a behavior similar to that obtained with S treatment. Results showed the higher accumulation (6.61 mg pot^{-1}) in P300 was achieved with application of 37.9 mg kg^{-1} of S and for P600 (7.52 mg pot^{-1}) by applying 26.2 mg kg^{-1} of S (Figure 5) and the highest accumulation values were generally found after treatment with P600. The treatment with P300 presented an S accumulation average of 5.11 mg pot^{-1} and that with P600 showed an average of 6.28 mg pot^{-1}. These values were significantly different.

S accumulation in the fruit was not different from the results of S accumulation in the shoots. In P300 treatment, the accumulation of S in fruits increased linearly with S rates, and treatment with P600 revealed higher accumulation (10.2 mg pot^{-1}) than with the application of 37.5 mg kg^{-1} S. The accumulation values for treatments with P were significantly different, showing a difference of 24.3%.

Figure 5. Accumulation of S in shoots (A) and fruit (B) according to sulfur and phosphorus rates. *Statistically significant at 5%.



Source: Elaboration of the authors.

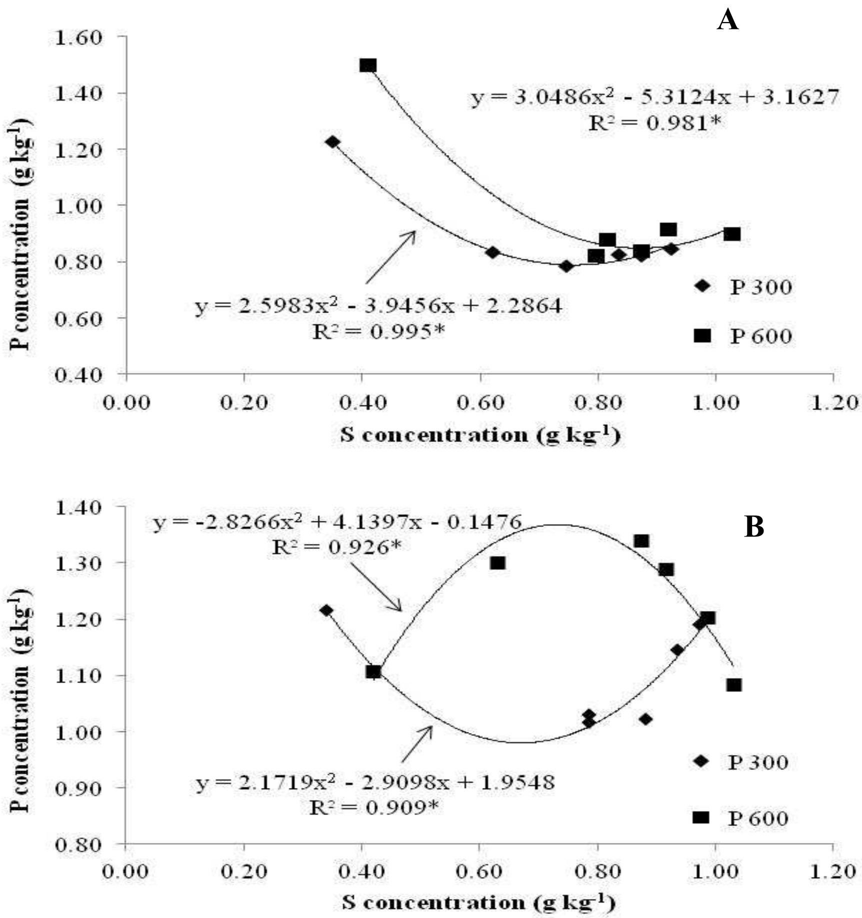
The relationship between the concentrations of S and P in shoots showed a quadratic relationship between the variables (Figure 6A). It is observed that for both P rates, in the control treatment, the highest concentrations of this element in the plant are accompanied by lower levels of S. With the increase in S concentration in the shoot, P concentration decreased providing a P:S ratio of about 1:1 at the highest S rates. In the fruits, the treatment with P300 resulted in a quadratic decrease when the correlated S and P concentrations were applied, while treatment with P600 showed a quadratic increase of this ratio (Figure 6B).

There is little information about the interaction between the P and S concentrations in the shoots; however, studies showed that the combined application of P and S in the soil can induce the development and growth of crops (ALVAREZ V. et al., 2007). Furthermore, a negative response of production to the supply of S to the soil can be obtained in soil with P deficiency, in the absence of S and P addition to the soil the responses are low or negative (ALVAREZ V. et al., 2007).

Kumar and Sing (1980) demonstrated that the interaction S, P and molybdenum in soybean plant showed synergistic effects between S and P, with increased absorption of P and S in different parts of the plant. Cravo et al. (1985) also studied the interaction S and P in the soybean and observed that the P rates can be a limiting factor in the production when S rates are high. Some studies, cited by Alvarez V. et al. (2007), shows that S and P addition to the soil for growing peanuts, induced the growth of branches and flowers in function of these nutrients in the soil.

Gypsum is not only a source of S and its composition includes a significant concentration of Ca. In order to determine the influence of the results previously presented for S, Ca concentrations were calculated in the shoots and fruits of strawberry. The concentrations found no statistical differences between the S rates and/or with the P application, as shown in Table 1. The values obtained are close to each other.

Figure 6. Correlation between the sulfur and phosphorus concentrations in the shoots (A) and fruit (B), according to sulfur and phosphorus rates applied to the soil. * Statistically significant at 5%.



Source: Elaboration of the authors.

Table 1. Concentrations of Ca in shoots and fruits of strawberry according to sulfur and phosphorus rates.

S rates	Shoot		Fruits	
	P rates (mg kg^{-1})			
mg kg^{-1}	300	600	300	600
	--------------- g kg^{-1} --------------			
0	13.1	13.2	4.8	3.0
10	13.0	13.2	3.2	3.3
20	13.0	13.3	3.1	2.8
30	13.1	14.4	3.2	2.6
40	13.1	13.3	3.1	2.9
50	13.1	13.0	3.2	2.9

Source: Elaboration of the authors.

Conclusions

The production of strawberry fruits was influenced by the S rates. The highest production was obtained at a rate of 60 mg kg^{-1} of S with application of 300 mg kg^{-1} of P and application of 600 mg kg^{-1} of P combined with the rate of 37 mg kg^{-1} of S.

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