Production and Quality of Radish Seeds with Sulfur in Top Dressing and Organic Compost at Planting Fertilization

ABSTRACT

Aims: This study evaluates the effects of top dressing sulfur (S) fertilization, with and without organic compost before planting, on radish seed production and quality.
Study design: Eight treatments were studied in a factorial scheme (4 x 2): four S doses in top dressing fertilization (0, 60, 120, 180 kg ha^{-1} of S), with or without organic compost (50 t ha^{-1}) in fertilization before seeding.
Place and Duration of Study: The experiment was carried out in the São Manuel Experimental Farm (22°46' South, 48°34' West, 740 m above sea level) from the School of Agriculture (FCA) of the Sao Paulo State University (UNESP) located in São Manuel, SP, Brazil. Radish sown happened in April, and harvest and seed analysis happened in October of 2017.
Methodology: Radish seeds were manually harvested (188 days after being sown), cleaned, and dried. Evaluations of seed production per plant, weight of 1000 seeds, and seed quality (germination, germination first count, germination speed index, and dry weight of normal seedlings) were performed.
Results: The application of organic compost increased radish seed production and the weight of 1000 seeds. Where no organic compost was applied, the higher the S dose, the greater the seed production per plant. With organic compost fertilization, the highest seed production and the weight of 1000 seeds were obtained with top dressing fertilization with 68 kg ha^{-1} of S. Germination and germination speed index were not affected by either factor, organic compost fertilization or S dose. Where no organic compost was applied, the higher the S dose, the lower the leachate level in the electrical conductivity test.
Conclusion: The radish base fertilization with organic compost plus top dressing S fertilization (68 kg ha^{-1}) is indicated for radish seed production.

Keywords: Ammonium sulfate; mineral nutrition; organic fertilization; Raphanus sativus; seed vigor; seed germination

1. INTRODUCTION

Radish (*Raphanus sativus* L.) is an important crop for many small farmers of green belts [1], and quality seeds is essential to get complete and uniform stands, because it is directed seeded. Farmers usually sow more seeds than necessary to avoid stand failures, but it demands posterior plant thinning. About 10 to 20 kg ha^{-1} of radish seeds are sown, which makes the seed costs very expensive. Vigorous seeds usually generate a better plant population and an improved initial development. In species with a short cycle, such as radish, a high seed vigor can affect plant performance through the crop cycle, presenting reduced field failures, increased uniformity and improved yield, which is advantageous to farmers. Thus, the research about radish seed production is essential, because it is the primary radish crop input.

Seed production and quality are highly affected by the availability of nutrients because plant requirements are higher after flowering. In addition, the amount of nutrients required for seed production is higher than that recommended for commercial vegetable production since the crop's cycle is prolonged and requires higher amounts of nutrients from soil solution [2]. Radish crop production is improved in fertile soils and responds well to organic fertilization [1,3], but, there are not many researches about the effects of fertilization on radish seed production. Reports of sulfur (S) great importance to plants of the Brassicaceae family are available [4,5], indicating that its application in top dressing fertilization increases seed production [6].

Sulfur is an essential nutrient in the composition of proteins, plant hormones, and amino acids. Besides the direct effect of S, it also interacts with nitrogen (N), and the lack of S decreases the synthesis of proteins and amino acids, consequently decreasing the efficiency of the use of N in plant metabolisms; however, the excess of S causes decreasing in yield [7].

In recent decades, reports of S deficiency in crops are becoming regular, and using concentrated fertilizers, without S, is the leading cause [8,9]. The soil organic matter is the primary S source to the plants [10,11], and the application of organic composts in large quantities can supply the necessity of S to plants. However, large organic composts quantities are not always available. In broccoli, Corrêa et al. [6] reported increased seed production and quality, both with organic compost fertilization before planting and with S fertilization in top dressing. The organic matter also favors the increase of seed production of other horticultural crop species [4,11,12,13]. However, there are no reports for radish seed production about the importance of S and organic fertilization in seed production.

Thus, the objective of this research was to evaluate the effect of S top dressing application, with and without organic fertilization before planting, on the production and quality of radish seeds.

2. MATERIAL AND METHODS

2.1 Experimental area and treatments

The experiment was carried out in the São Manuel Experimental Farm (22°46' South, 48°34' West, 740 m above sea level), from the School of Agriculture (FCA) of the Sao Paulo State University (UNESP) located in São Manuel, SP, Brazil. The soil of the experimental area is a Dystrophic Red Latosol, with a sandy texture. The results of soil chemical analysis before the experiment installation were: pH (H_2O) = 5.5; organic matter = 12 g dm^{-3}; P (resin) = 94 mg dm^{-3}; H+Al = 18 $mmol_c dm^{-3}$; K = 1.9 $mmol_c$ dm^{-3}; Ca = 29 $mmol_c$ dm^{-3}; Mg = 5 $mmol_c dm^{-3}$; S = 5 $mmol_c dm^{-3}$; and base saturation (V) = 66%.

Eight treatments (4x2 factorial scheme) were studied, with four S doses in top dressing fertilization (0, 60, 120, 180 kg ha^{-1} of S), with and without fertilization with organic compost before planting. Ammonium sulfate (20% N and 23% S) was used as the S source. The N level was uniformized with urea (45% N). To the plots with organic compost, 50 t ha^{-1} was applied before sowing [14]. The organic compost was manually incorporated into the soil of the experimental plots. The organic compost analysis presented the following percentages: N = 0.7; P_2O_5 = 1.0; K_2O = 0.7; Ca = 6.8; Mg = 0.4; S = 0.4; organic matter = 24; total carbon = 13, and water = 22. Before radish sowing, 1100 kg ha^{-1} of 04-14-08 (N, P_2O_5, K_2O) were applied [14]. The top dressing fertilization with S and N was divided into six applications, and the first fertilization occurred at the beginning of the seed stalk elongation (114 days after sowing), and the others every seven days.

2.2Experimental design

The experiment was designed in randomized blocks and set in subdivided plots - the plot factor was the presence or absence of organic compost, and the subplot factor was the S doses in top dressing fertilization. The radish cultivar Vip Crimson Special Selection was sown in Autumn (April 12th, 2017). Each plot consisted of three lines (1 m long) spaced by 0.7 m. The spacing between plants after thinning was 0.05 m. Irrigation was applied using a sprinkler system until root formation (40 days after sowing) and drip irrigation after this plant phase until the radish seed harvesting.

2.3Evaluations

Radish seeds were manually harvested 188 days after sowing. Impurities and damaged seeds (density difference) were extracted following the methodology of Cardoso et al. [5]. After cleaning, radish seeds were stored in a dry chamber (40% RH, 20 °C) in order to stabilize water content (about 8%). The beneficiated seeds were weighed (precision of 0.0001 g) to determine the production (g) of seeds per plant. The 1000 seed weight was also estimated (precision of 0.0001 g).

The radish germination test was carried out according to the Seed Analysis Rules [15]. The seeds were placed in a gerbox with two germination paper sheets moistened with water (2.5 times the dry weight of the germination paper). The gerboxes were placed in the BOD (biochemical oxygen demand) chamber at a temperature of 30 °C for 8 hours and 20 °C for 16 hours. Six replicates of 50 seeds each were performed. The first count of normal seedlings was performed four days after the start of the germination test, and the final evaluation six days later (10 days after sowing).

The germination speed index (GSI) was also calculated during the germination test using the daily germination results until 10 days after sowing, divided by the number of days elapsed between the sowing and the germination [16]. The dry weight of normal seedlings from the germination test was also evaluated. Ten seedlings were collected at the last germination evaluation and were placed in a forced air circulation oven at 40 °C. The seedlings were evaluated until weight stabilization and were expressed in milligrams per seedling.

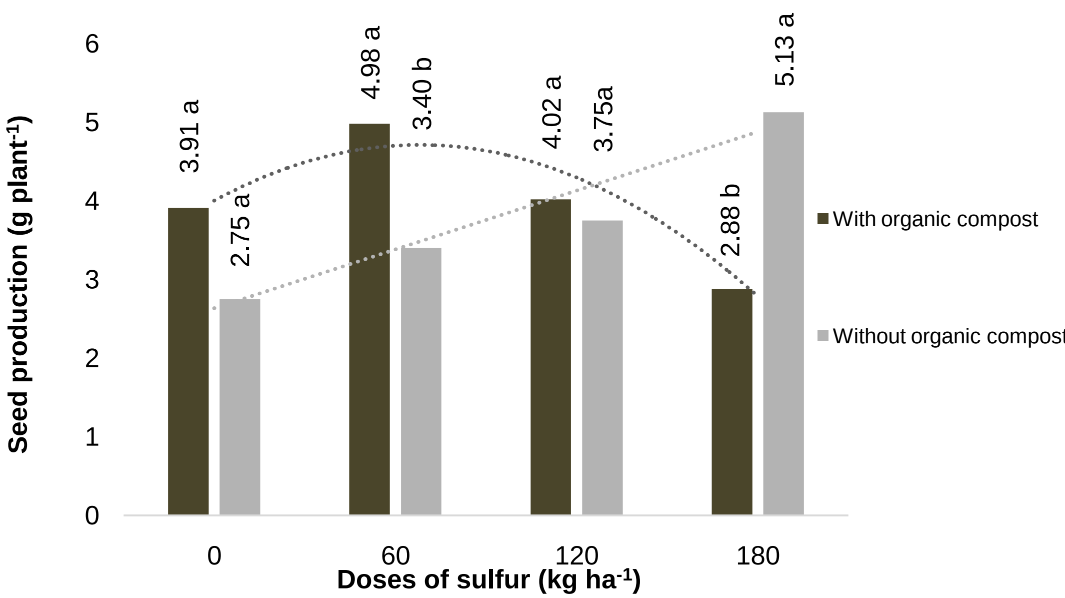
The seed electrical conductivity test was carried out with six replicates of 50 radish seeds each, weighed and conditioned in 200 mL plastic cups with 25 mL of distilled water. The cups were kept in a BOD chamber at 25 °C. The evaluation was performed after four hours of soaking with a conductivity meter. The results were expressed in $\mu S\ cm^{-1}\ g^{-1}$, according to the methodology described by Marcos Filho and Kikuti [17].

2.4Statistical analysis

The results of the variables evaluated were submitted to the analysis of variance (p value < 0.05) and polynomial regressions at 5% probability (p value < 0.05, R^2> 0.70) to study the effect of S doses in top dressing radish fertilization. To compare the application or not of organic compost before radish sowing, Tukey's test of averages was used (p value < 0.05), using Sisvar software [18].

3. RESULTS

A significant interaction was identified between sulfur doses in top dressing fertilization and organic compost before radish sowing for seed production. In the absence of organic compost before radish sowing, the effect of the sulfur doses was linear (Figure 1), with an estimated increase of 46.4% in the highest sulfur dose (180 kg ha^{-1}) compared to the control without sulfur in top dressing fertilization (0 kg ha^{-1}). On the other hand, when organic compost was applied before radish sowing the data adjusted to a quadratic regression model for sulfur doses. The estimated maximum radish seed production was 4.71 g per plant for 68 kg ha^{-1} of S. There was a pronounced decrease in radish seed production from this sulfur dose (68 kg ha^{-1}) on. In the highest sulfur dose (180 kg ha^{-1}), the yield obtained (2.88 g plant^{-1}) was lower than in the treatment without sulfur application (0 kg ha^{-1}) in top dressing (3.91 g plant^{-1}).



$y = 0.01263x + 2.6167$
$R^2 = 0.93$

$yOC = -0.00015x2 + 0.0209x + 4.0055$
$R^2 = 0.92$

Figure 1. Production of radish seeds as a function of the sulfur doses in top dressing with organic compost (yoc) and without organic compost (y) and averages with and without organic compost for each dose of sulfur.

Means, with and without organic compost, followed by the same letter, for each dose of sulfur, do not differ from each other by the Tukey's test at 5% probability.

The application of organic compost resulted in greater seed production compared to the absence of organic compost when no sulfur were applied and for the lowest dose (60 kg ha^{-1} of S) in top dressing (Table 1). However, in the greatest dose (180 kg ha^{-1} of S) the application of organic compost reduced seed production (about 43.8%) compared to the absence of organic compost.

Table 1. Seed production per plant and eletrictal conductivity of radish seeds in the presence and absence of fertilization with organic compost before planting for each sulfur dose.

Organic Compost	Sulfur dose (kg ha^{-1})			
	0	60	120	180
	Seed production per plant (g)			
Presence	3.91^{a}	4.98^{a}	4.02^{a}	2.88^{b}

Absence	2.75[b]	3.40[b]	3.75[a]	5.13[a]
	Eletrictal conductivity of seeds (µS cm^{-1} g^{-1})			
Presence	131.7[a]	134.8[a]	136.6[a]	137.4[a]
Absence	168.0[b]	149.2[a]	132.9[a]	122.9[a]

Means followed by the same letter in each column do not differ from each other by the Tukey's test at 5% probability.

The sulfur doses did not affect the 1000 seed weight (average of 7.30 g); however, the application of organic compost before the radish sowing resulted in higher 1000 seed weight (7.51 g) compared to the non-application of organic compost (7.10 g) (Table 2). Additionally, there was no significant difference in total germination, germination first count, GSI and dry weight of normal seedlings (Table 2), with mean results of 87.7%, 42%, 26.6 and 0.0058 mg $plant^{-1}$, respectively.

Table 2. Averages of the weight of one thousand seeds (WTS), germination, germination first count (GFC), germination speed index (GSI) and dry weight of normal seedlings (DWNS) in the presence and absence of fertilization with organic compost before planting.

Organic Compost	WTS (g)	Germination (%)	GFC (%)	GSI	DWNS (mg $plant^{-1}$)
Presence	7.51[a]	89.5[a]	44.0[a]	27.8[a]	0.0062[a]
Absence	7.10[b]	85.9[a]	40.0[b]	25.4[a]	0.0054[a]

Means followed by the same letter, in the columns, do not differ from each other by the Tukey's test at 5% probability.

The only seed quality characteristic that was affected by the factors was electrical conductivity. When organic compost was applied, sulfur doses did not influence the electrical conductivity of the seeds, with a mean of 135.14 µS cm^{-1} g^{-1}. However, in the absence of organic compost, a linear reduction in the electrical conductivity of the radish seeds was observed (Figure 2). When no sulfur was applied (0 kg ha^{-1}) in top dressing fertilization the application of organic compost before radish sowing resulted in lower electrical conductivity of seeds compared to the absence of organic compost (Table 1), showing better seed quality. On the other hand, when sulfur was applied in top dressing, regardless of dose, there was not difference between presence or absence of organic compost fertilization before radish sowing.

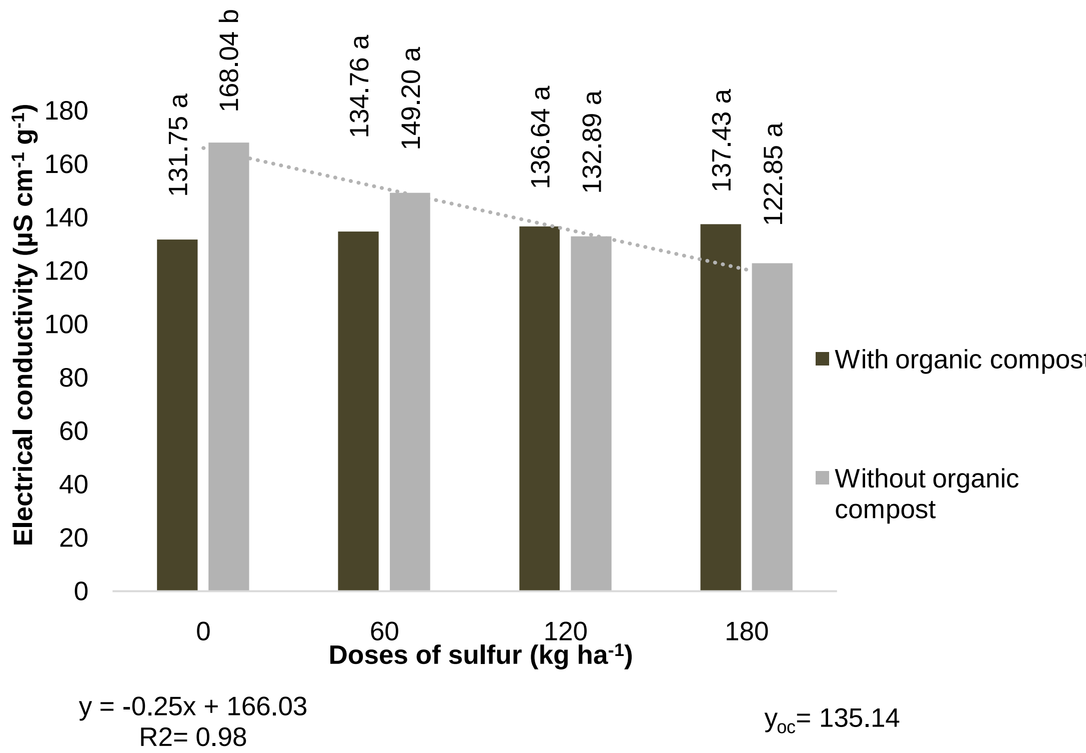


Figure 2. Electrical conductivity of radish seeds as a function of the sulfur doses in top dressing with organic compost (yoc) and without organic compost (y) and averages with and without organic compost for each dose of sulfur.

Means, with and without organic compost, followed by the same letter, for each dose of sulfur, do not differ from each other by the Tukey's test at 5% probability.

3. DISCUSSION

The results reported in the present study show the sulfur fertilization importance to produce radish seeds, especially when no organic compost is applied before planting. However, excess of sulfur was harmful when the application of organic compost was combined with sulfur doses higher than 68 kg ha^{-1} of S. The organic compost add sulfur to the soil via its mineralization; 50 t ha^{-1} of the studied organic compost (22% of water, 0.4% of S) can add to the soil system about 156 kg ha^{-1} of S, that is, a value close to the highest dose of sulfur studied.

The sulfur availability to the plants is closely related to the soil organic matter content [10,19,20]. However, not all the sulfur present in the organic compost was readly made accessible to the plants, since this availability is regulated by adequate levels of water and temperature, and microorganisms that perform the organic matter decomposition [21,22]. Besides this, it is more difficult and expensive to make or buy 50 t ha^{-1} of organic compost than to buy ammonium sulfate to provide 180 kg ha^{-1} of S. On the other hand, the results show that just organic compost can provide the sulfur necessary to radish seed production what is important for production in an organic seed production system.

Bardiviesso et al. [11] also reported a quadratic effect on the production of zucchini seeds with the application of sulfur in top dressing fertilization associated to organic compost before planting. The maximum zucchini seed production was estimated for the dose of 59 kg ha^{-1} of S; after this dose pronounced reduction in seed production was observed, similar to the results obtained in the present research. The authors also emphasizes that the use of the organic compost reduces the nutrient leaching in the soil, in this way, there was a greater retention of the leacheable nutrients such as sulfur.

Additionaly, Corrêa et al. [6] observed greater seed production in broccoli as the sulfur dose in top dressing increases. Sahoo et al. [23] and Tao et al. [24] reported higher seed production with sulfur fertilization in sunflower and wheat, respectively. In canola, Malhi and Gill [25] reported that regular supply of sulfur is required throughout the plant cycle to achieve high seed yields. On the other hand, Martins et al. [26] did not reported difference in the production of lettuce seeds for organic compost and sulfur application in top dressing and Figas [27] did not observe difference in the production of *Brassica napus* seeds comparing the effect of sulfur application via soil and by foliar application.

Therefore, it is observed that the use of sulfur may be beneficial for the production of seeds in different species, but not all. However, one should be careful about the excess of sulfur that can be harmful. So, the use of only ammonium sulphate as a source of nitrogen in top dressing for the radish seed production, when using organic compost in the planting, can be harmful to the seed production. Yamada et al. [28] reported that when sulfur is in excess, there is a reduction in crop production, probably due to toxicity, however, so far there are no studies about this probable toxicity in radish production.

Application of organic compost increased radish 1000 seed weight, and this was also observed in other crops, such as zucchini [11], lettuce [12], and broccoli [4,6]. According to Carvalho and Nakagawa [28], most of the plant species present higher nutritional needs during the reproductive stage and seed formation, and adequate fertilization during this stage favors the formation of more and larger seeds. Due to this, the application of organic compost has a positive influence on seed formation, since it has a slow nutrient release characteristic, being able to supply them to the plants for a longer period [6,22].

For most seed quality characteristics evaluated there was not difference for both factors studied, that is, organic compost application before sowing ans sulfur doses in top dressing, except for the electrical conductivity of seeds. The average germination (87.7%) was higher than the minimum required for the sale of radish seeds, which is 75%, according to Brasil[15]. In the treatments without organic compost before sowing, the application of S in top dressing reduced the electrical conductivity of seeds, showing the importance of this nutrient for seed quality, since in field conditions, the loss of large quantities of exudates in the germination process may favor the attack by microorganisms that cause dumping off disease and reduce the plant stand[39]. These results indicate that the higher the sulfur dose, the lower the radish seeds release leachates, and this response is a reaction to improved cell membrane integrity to a higher sulfur dose and indicate higher seed quality.

Other studies reported other results regarding the importance of S to plant development. Corrêa et al. [6] found that S did not affect broccoli seed quality, only seed production. Martins et al. [26] also did not observe differences in lettuce seed quality by testing organic compost and S in top dressing fertilization. However, Bardiviesso et al. [11] observed that S in top dressing fertilization improved zucchini seed germination and vigor, both in the presence or absence of organic compost before planting. Therefore, the effect of fertilization with organic compost and S on seed quality may vary according to the species and even with the cultivar studied. However, on average, organic or inorganic fertilization usually influences seed production and, in most research, does not affect seed quality [2].

According to Cardoso [2], adequate fertilizers' doses commonly provide an increase in seed production, possibly due to the better development of the plants provided by fertilization. However, their influence on seed quality does not always show improvement. This result is in agreement with Delouche[31] comments that plants have developed extraordinary adaptability in adjusting seed production to the available resources. A common plant response to low soil fertility is first reducing the number of seeds produced, and only in severe conditions it is observed reducing the seed's quality. The few seeds produced under marginal conditions are usually as viable and vigorous as those produced under good conditions. From the evolutionary standpoint, the seed production adjustment to the available resources has a high survival value. The few high-quality seeds would have better chances to germinate and develop under adverse conditions.

In many Brazilian soils, such as Oxisols and Ultisols, there is low availability of S, and in sandy soils, with low organic matter content, higher doses of S are necessary [32], as observed in the present research. Besides this, in recent decades, reports of S deficiency in crops are becoming regular, and using concentrated fertilizers, without S, is the leading cause [8,9]. So, in theabsenceoforganic compost, itisbetterto use ammonium sulfate than urea for top dressingfertilization in radishseedproduction.

4. CONCLUSIONS

In the absence of fertilization with organic compost, the higher the S dose in top dressing fertilization, the greater the seed production per plant.

In the presence of organic compost fertilization, the dose of 68 kg ha^{-1} of S in top dressing fertilization provided higher seed production per plant and a greater 1000 seed weight. Higher S doses in top dressing fertilization are harmful to seed production in the presence of organic compost fertilization.

The radish fertilization with organic compost before sowing and the S in top dressing did not affect most of seed physiological quality parameters (germination, first count, GSI, and the dry weight of normal radish seedlings in the germination test).

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