BIOSCIENCE JOURNAL

DOSES OF SULFUR AT TOPDRESSING AND ORGANIC COMPOST SUPPLY AT PLANTING IN THE PRODUCTION, QUALITY AND CONTENT OF MACRONUTRIENTS IN LETTUCE SEEDS

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How to cite: MARTINS, B.N.M., et al. Doses of sulfur at topdressing and organic compost supply at planting in the production, quality and content of macronutrients in lettuce seeds. *Bioscience Journal*. 2022, **38**, e38063. https://doi.org/10.14393/BJ-v38n0a2022-53783

Abstract

The purpose of this study was to evaluate doses of sulfur applied at topdressing, with and without organic compost supply at planting, in the production, physiological quality and content of macronutrients in lettuce seeds. Ten treatments were evaluated in a 5x2 factorial scheme (five sulfur doses at topdressing x with and without application of organic compost at planting). The experimental design was a randomized block design, with four replicates. The sulfur doses applied at topdressing fertilization were 50, 100, 150 and 200 kg ha^{-1} of S, in addition to the control treatment (dose zero). Regarding the treatments with organic compost, the dose of 70 t ha^{-1} of compost (wet basis) was supplied at planting. The following characteristics were evaluated: seed production (mass and number of seeds per plant), seed quality (mass of one thousand seeds, first count of the standard germination test, germination percentage, and germination speed index) and content of macronutrients and mineral accumulation. The organic compost supply at planting increased seed production by 43% compared to the treatment without the application of organic compost, while the doses of sulfur did not affect the production of lettuce seeds. The supply of organic compost increased the accumulation of a great part of the macronutrients, except for the accumulation of calcium. The lettuce seeds quality was not affected by both the main treatments, the sulfur doses at topdressing and the organic compost supply at planting. The descending order of nutrients accumulated in the lettuce seeds was nitrogen> potassium> phosphorus> magnesium> calcium> sulfur.

Keywords: Accumulation of nutrients. *Lactuca sativa* L. Organic matter. Seed vigor. Sulfated fertilization.

1. Introduction

Despite the economic importance of the lettuce seed production chain, there are still few studies that address the effects of nutrients on the production and quality of lettuce seeds (Albornoz et al. 2019). Probably, the amount of nutrients to be used for seed production may differ in relation to the production of lettuce for leaf consumption, mainly due to the fact that the crop presents a longer cycle, with the formation of new structures (flowers and fruits) and, consequently, higher nutrient extraction for seeds production (Quadros et al. 2010).

According to Carvalho and Nakagawa (2012), a well-nourished plant is able to produce more well-formed seeds. The authors state that the period of seeds formation is the most critical phase in terms of nutritional requirement of the plant, considering that there is a translocation of a considerable amount of nutrients for them at this stage of development.

In general, plants fertilized in proper and balanced ways can produce a greater number of viable seeds, a fact that can be explained due to the better development of the plants. The nutritional aspect of the plant might affect some of the seed characteristics, such as size, mass, and vigor; and in many cases, these effects are linked to the permeability and integrity of the membranes of the tissues, where the nutrients act as enzymatic activators or membrane constituent. Considering that size influences the quality of the seed, it can be concluded that mineral fertilization results in an indirect effect due to the increase caused in the size or mass of a seed (Carvalho and Nakagawa 2012).

Kano et al. (2012), studying the use of increasing doses of phosphorus on the production of lettuce seeds, observed a linear increase in the production and number of seeds per plant, but no interference of the doses in the seeds physiological quality.

In addition, balanced fertilization keeps the plant more resistant to pests and pathogens, which can affect the sanitary quality of the seeds. Thus, the fertilization management aims to supply the demand of all the nutrients required by the plant, in terms of quantity and appropriate time supply, and depends on a set of practices or actions. At the same time, there are well-established recommendations based on field research for some vegetables, and for other plant species the recommendations are still limited and, in the case of seed production, they are rare (Cardoso 2011).

Therefore, it is of extreme importance the adequate supply of nutrients in the production and quality of seeds, especially of sulfur, a nutrient which in appropriate amounts participates as a component of acetyl-CoA, a compound that represents the active center of Krebs cycle, thus influencing the metabolism of lipids and carbohydrates (Corrêa et al. 2017; Bardiviesso et al. 2020).

It is important to emphasize that organic matter is the main source of sulfur in the soil, since during the decomposition process several elements are released. It is estimated that more than 95% of the sulfur is fixed on the organic compounds of the organic matter of the soil. Although less immediate and striking than those obtained with mineral fertilizers, increases in yield provided by organic fertilizers present a longer duration, possibly due to the progressive release of nutrients (Bardiviesso et al. 2020; Nasser et al. 2020).

Bardiviesso et al. (2020), evaluating the production and quality of zucchini seeds as affected by the use of organic compost at planting in association with different sulfur doses, obtained a quadratic model with maximum production estimated at 32 g per plant for the dose of 59 kg ha^{-1} of sulfur.

Hence, the purpose of this study was to evaluate the influence of sulfur doses at topdressing associated with organic compost supply at planting on the production and physiological quality of lettuce seeds.

2. Material and Methods

The experiment was carried out at the Experimental Farm São Manuel, located in the municipality of São Manuel - SP, belonging to the School of Agronomic Sciences (FCA) of the São Paulo State University (UNESP), Campus of Botucatu - SP. The geographical coordinates of the area are 22°46' S, 48°34' W, and 740 m asl.

The plants were conducted in an arc-protected greenhouse (20 m long, 7 m wide, and 2.5 m height), covered with a low-density polyethylene film of 150 µm, with the sides closed with an anti-aphid insect screen.

The soil of the area is classified as a typical Red Dystrophic Latosol (Ferralsols, Oxisols). The results obtained in the chemical analysis of the surface layer (0-20 cm depth) before the installation of the experiment were: pH ($CaCl_2$) = 3.9; M.O. = 3 g dm^{-3}; Press = 70 mg dm^{-3}; S = 11 mg dm^{-3}; H + Al = 30mmol dm^{-3}; K = 0.2 mmol dm^{-3}; Ca = 6mmol dm^{-3}; Mg = 2 mmol dm^{-3}; SB = 8 mmol, dm^{-3}; CEC = 38 mmol dm^{-3} and V = 22%. The soil correction was conducted based on the soil chemical characteristics, applying dolomitic limestone of high reactivity (TNP = 96%) 30 days before the seedlings transplanting in order to elevate the base saturation to 80% and the pH range close to 6.0.

The fertilization at planting was carried out 7 days before the transplanting of the seedlings using 0.53 g plant^{-1} of N (urea), 2.92 g plant^{-1} of P_2O_5 (triple superphosphate, TSP), and 1.5 g plant^{-1} of K_2O (potassium chloride, KCl). The organic fertilization was performed according to the treatments.

Ten treatments arranged in a 5x2 factorial scheme were evaluated (five doses of sulfur at topdressing x two application forms of the organic compost at planting). A randomized block design with four replicates containing five plants per plot, from which three plants were considered useful, was adopted.

The incorporation of the organic compost was performed taking into consideration the treatments with and without organic compost supply. The organic compost used was from the trademark Provaso®, and the amount used at planting was based on the average dose recommended by Trani et al. (1997) for lettuce, which is 70 t ha^{-1} of compost (wet basis). The chemical analysis of the organic compost indicated, in percentage (%), values of N = 0.6; P_2O_5 = 1.0; K_2O = 1.76; OM = 19.2; C-total=10.8; Ca = 2.3; Mg = 0.21; S = 0.26; RH-65 °C = 27.6.

Ammonium sulfate (21% N and 23% S) was used as the source of sulfur, applying the doses of 0 (control, without S), 50, 100, 150 and 200 kg ha^{-1} of S, at topdressing fertilization after the lettuce vegetative phase. The fertilizer urea (45% N) was used in order to correct and standardize the N topdressing fertilization in 174 kg ha^{-1} of N since the ammonium sulfate used already had N in its composition. Urea was the only fertilizer used during the lettuce vegetative phase, with three applications at 10, 20 and 30 days after transplantation (DAT) of the seedlings. Each application of urea provided 0.33 g plant^{-1} of N, according to the recommendation of Trani et al. (1997). The sulfur doses studied were applied only after the vegetative phase, and were divided into seven applications (39, 46, 53, 60, 67, 74 and 81 DAT).

The lettuce cultivar *Vera* was used for the experiment, and the seeds were sown in polypropylene trays with 200 cells containing a commercial substrate for vegetables. The transplant was carried in plastic pots with a volume of 12 liters placed in the spacing of 1.0 m between rows and 0.50 m between plants (center to center of pots). The lettuce plants were tutored using two-meter-long bamboo poles during the reproductive phase in order to avoid tipping. All phytosanitary control was carried out according to the needs of the crop, and the irrigation was performed through the use of drip irrigators.

The seeds were harvested manually when the plants reached the stage of "white hair" (physiological maturation), and the first harvest was realized on August 08, 2017. Once harvested the seeds were taken to a dry chamber at 40% of relative air humidity and at a temperature of 20 ºC, in order to be preserved until the end of the harvest period. After stabilization of the water content, the seeds were cleaned, processed, and the damaged seeds removed with the use of a seed separator by density ('De Leo Type 1' model). Subsequently, the evaluation of production (mass and number of seeds per plant), mass of one thousand seeds, and physiological quality (germination and vigor) were conducted.

Based on the Seed Analysis Rules (Brasil, 2009), the germination test was carried out using a seed germination chamber at 20ºC, with four replicates of 50 seeds per treatment arranged in Gerbox boxes with blotting paper, which were moistened with distilled water to a corresponding value of 2.5 times the mass of the dry paper. The boxes were then packed in individual plastic bags to avoid dehydration. The first count of the germinated seeds was carried out on the fourth day after test installation, and the second count was realized on the seventh day. The seeds were considered germinated when they perceived the radicle prism. The first seed count was considered as a vigor test. The germination speed index (GSI), which is indicative of the seed vigor, was obtained through daily evaluations from the first until the 7th day after sowing (DAS).

The seed quality was also evaluated by the percentage of seedlings that emerged in the polypropylene trays with 200 cells containing the commercial substrate Carolina® for vegetables. Fifty seeds were sown for each plot, which was kept in a greenhouse during the evaluations. The seedlings were considered emerged when the cotyledon leaves were fully open. The evaluation of seedlings emergency was carried out until the 7th day after sowing, and the emergence speed index (ESI) was obtained through the sum of the number of seedlings that emerged daily (not cumulative), and this value divided by the number of days elapsed between sowing and emergence.

The determination of macronutrients (N, P, K, Ca, Mg, S) contents of the seeds were carried out with representative seed samples collected from three plants per plot. The seeds were identified and taken to drying in a forced air circulation oven at 65 ºC until reaching a constant weight (Malavolta et al. 1997).

Thereafter, the dry matter weight of each sample was obtained by means of a precision analytical scale (precision of 0.001g). Subsequently, each sample was milled in a Willey type mill.

The samples were sent to the Department of Soils and Environmental Resources of FCA/UNESP to be chemically analyzed, according to the methodology of Malavolta et al. (1997). The samples were submitted to sulfuric acid digestion in order to obtain the extract for N content determination, and for the other macronutrients (P, K, Ca, Mg and S) content the nitric-perchloric acid digestion was performed. The content of N, P, K, Ca, Mg and S, in g kg^{-1} of dry matter, of the samples were obtained from the chemical analyzes. The amount of nutrients accumulated in the seeds was obtained by multiplying the content of each nutrient by the weight of the seeds dry matter produced per plant.

The results were submitted to analysis of variance (ANOVA). The regression analysis was performed for the sulfur doses, and the F test was used for the comparison of the treatments with and without organic compost, both in case of significant effects, using the statistical program Sisvar 5.3.

3. Results and Discussion

Production and physiological quality seeds

The variables mass of seeds (g $plant^{-1}$) and the number of seeds per plant (nº $plant^{-1}$) were affected only by the organic compost supply at planting, showing a significant difference by F test (Table 1). The supply of 70 t ha^{-1} of organic compost at planting increased seed production (mass) by 43% in relation to the treatments without the use of the same compost (Table 2).

Quadros et al. (2012) evaluated the influence of organic compost on the production of lettuce seeds and obtained higher values of seed mass (17.14 g $plant^{-1}$) when using 33.43 t ha^{-1} of the organic compost, that is, less than half the dose used. It is worth noting that the dose recommended by Trani et al. (1997) ranges from 60 to 80 t ha^{-1} of manure for lettuce production.

Table 1. F values for doses of sulfur at topdressing, organic compost supply at planting, and interaction between the main treatments, general average, and coefficient of variation (CV) of the analysis of variance for the characteristics of mass production and number of seeds per plant.

Variation Factor	Seed mass production per plant	Number of seeds per plant
Doses of sulfur (S)	1.75^{ns}	2.06^{ns}
Organic compost (CO)	30.9**	50.67**
Doses of S x CO	0.89^{ns}	1.55^{ns}
CV (%)	20.04	20.18
Overall average	20.62	19246

CV = coefficient of variation. ns = not significant at 5% of probability, * significant at 5% of probability, ** significant at 1% of probability.

Table 2. Mass and number of seeds per plant in treatments with and without application of 70 t ha^{-1} of organic compost at planting.

Treatments	Seed mass per plant (g)	Number of seeds per plant
With organic compost (70 t ha^{-1})	24.25 a	23618 a
Without organic compost	16.98 b	14874 b
CV (%)	20.04	20.18

CV = coefficient of variation. Means followed by the same letter do not differ from each other by F test at 5% of probability.

The number of seeds increased from 14874 to 23618 seeds per plant, a tendency that was also observed for the mass of seeds. In relation to the values obtained, these were higher than those verified by Quadros et al. (2012) and Kano et al. (2012), who obtained 15917 and 17458 seeds per plant, respectively. Also, Magro et al. (2010) studying broccoli obtained an increase in the number of seeds per plant with the application of organic compost.

According to Carvalho and Nakagawa (2012), the period of greatest nutritional demand for most species is during the beginning of the reproductive phase, with intensification during the seed formation; in which a considerable quantity of nutrients is translocated to the seeds. Kano et al. (2011a) and Quadros et al. (2010, 2011) point out that the period of greatest nutritional requirement of macronutrients by lettuce plants for seed production is during the beginning of bolting and flowering, when the values of accumulation of N, P, K, Ca, Mg and S, are 2.3 times greater than the values observed by the lettuce intended only for leaf consumption.

In this way, it can be concluded that the organic compost supply was determinant for the greater seed production, being considered an advantageous fertilization technique. Besides the nutrient supply, it presents other benefits that can contribute for the lettuce production, such as structuring the soil, by means of filled polymers that bind the isolated clay particles forming aggregates, increasing the soil porosity and cation exchange capacity (CEC), which is an important component in the regulation of retention and release of chemical elements (Ca, Mg, K and others in smaller quantities) in available forms to plants, as well as other soil conditioning properties (Raij 2017). It is possible that these factors had a positive influence on the increase of the lettuce seed production through the physical and chemical improvement of the soil.

In this experiment, it was observed that there was an increase in CEC, sum of bases and base saturation in the soil were the organic compost was applied. Cardoso et al. (2011), studying the use of organic compost for the production of lettuce seeds, also reported linear increases in the contents of organic matter, calcium, and magnesium, the sum of bases, CEC and base saturation of the soil at the end of the lettuce production cycle. According to Monsalve et al. (2017), together with the increase of exchangeable base contents and CEC, the continuous release of N by the mineralization of the organic material better adjusts to the lettuce needs.

Regarding the sulfur doses, there was no effect of this treatment on the production of lettuce seeds by both the F test (Table 1) and the regression analysis, showing that even in the absence of organic compost supply at planting, the application of S at topdressing does not affect this parameter. Probably, the content of this nutrient in the soil before the experiment implantation (11 mg dm^{-3}) was sufficient to meet the needs of the plants until the end of their reproductive cycle. It is worth noting that sulfur is the macronutrient less required by the lettuce crop for seed production (Quadros et al. 2010; Kano et al. 2011). On the other hand, it was observed that even in the highest sulfur doses there was no excess, that is, it did not affect seed production.

Regarding quality characteristics, both the sulfur doses at topdressing and the organic compost supply at planting did not affect the quality of the lettuce seeds, and neither the interaction between the main factors was significant (Table 3).

An average value of 1.10 g was obtained for the mass of a thousand seeds (Table 3), a value similar to that described by Kano et al. (2012) and Quadros et al. (2012), who mention average values ranging from 0.90 g to 1.15 g. In addition, high values for first count of germination (88%), percentage of germination (93%), germination speed index (112.9), emergence speed index (34.04) and emergency test (94%) were observed (Table 3), showing that the seeds obtained in the experiment presented high-quality characteristics.

Table 3. F values for the factors sulfur dose at topdressing, organic compost supply at planting, interaction between the main factors, general average and coefficient of variation (CV) of the analysis of variance for the characteristics of mass of a thousand seeds, first count of germination (FCG), germination speed index (GSI), emergence speed index (ESI) and emergency test.

Variation Factor	Mass of a thousand seeds (g)	Test of germination (%)				Emergency Test (%)
		FCG	Germination	GSI	ESI	(%)
Doses of sulfur (S)	1.60^{ns}	2.56^{ns}	2.34^{ns}	2.46^{ns}	0.22^{ns}	0.17^{ns}
Organic compost (CO)	2.14^{ns}	0.05^{ns}	0.01^{ns}	1.07^{ns}	2.03^{ns}	3.01^{ns}
Doses of S x CO	1.37^{ns}	1.21^{ns}	1.36^{ns}	1.06^{ns}	0.60^{ns}	0.61^{ns}
CV (%)	11.77	12.81	7.62	13.77	9.64	6.16
Overall average	1.10	88.0	93.0	112.9	34.04	94.0

CV = coefficient of variation; ns = not significant at 5% of probability; * significant at 5% of probability, ** significant at 1% of probability.

According to Cardoso (2011), 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

(1980), who emphasizes that under conditions of stress, such as deficiency or excess of nutrients, seed production is initially affected and only then the physiological quality can be affected. This is a defense mechanism of the plant, probably aiming the species perpetuation, because it is better to have fewer seeds that germinate with vigor than many with low germination and/or vigor. The few seeds produced under marginal conditions are usually as viable and vigorous as those produced under favorable conditions.

Similar cases with no differences in physiological characteristics were also observed in the production of lettuce seeds with phosphorus (Kano et al. 2011), and organic compost (Cardoso et al. 2011; Quadros et al. 2012) doses, and in the production of broccoli seeds with doses of sulfur and organic compost application (Magro et al., 2010; Corrêa et al. 2017). However, Kano et al. (2011a) and Magro et al. (2012) reported that after one year of storage, differences in seed vigor can be observed.

According to Cardoso et al. (2011), besides the plausible answer of the plants to adverse conditions aiming the species perpetuation with vigorous seed production, another point that may be providing no difference in quality is the classification of the seeds. Most of the time, the seeds harvested in the experiments are processed, with the removal of the impurities and damaged ones, before the evaluation of the quality. Thus, there is a standardization of seed batches of different treatments regarding physiological quality. It should be noted that this processing is always carried out in order to commercialize the seeds.

Content of macronutrients and mineral accumulation

There were no effects of the sulfur doses at topdressing, and neither of the interaction between the main factors (sulfur doses x organic compost supply) by F test for the content and accumulation of macronutrients in the seeds of the lettuce cultivar Vera. Only the organic compost treatment showed significant effects by F test (Table 4).

Table 4. F values for the factors sulfur doses at topdressing, fertilization with organic compost at planting, and interaction between the factors, general average, and coefficient of variation (CV) of the analysis of variance for the content and accumulation of macronutrients in lettuce seeds.

	Content of macronutrients					
Variation Factor	N	P	K	Ca	Mg	S
		---------------------- g kg^{-1} of dry matter ----------------				
Doses of sulphur (S)	2.50^{ns}	0.79^{ns}	1.63^{ns}	1.08^{ns}	0.26^{ns}	1.25^{ns}
Organic compost (OC)	2.05^{ns}	0.34^{ns}	1.09^{ns}	4.96*	2.43^{ns}	4.88*
Doses of S x OC	0.47^{ns}	1.19^{ns}	1.54^{ns}	1.08^{ns}	0.85^{ns}	1.25^{ns}
CV (%)	3.60	5.03	7.56	15.36	4.82	5.70
Overall average	45.96	7.41	8.13	2.13	4.12	1.16
	Accumulation of macronutrients					
Variation Factor	N	P	K	Ca	Mg	S
		--------------------------- g $plant^{-1}$ ---------------------------				
Doses of sulphur (S)	2.40^{ns}	3.82^{ns}	1.35^{ns}	1.35^{ns}	2.33^{ns}	2.93^{ns}
Organic compost (OC)	18.33**	22.15**	15.76**	2.36^{ns}	15.13**	15.12**
Doses of S x OC	1.03^{ns}	0.91^{ns}	0.73^{ns}	1.50^{ns}	1.06^{ns}	2.93^{ns}
CV (%)	20.92	18.87	23.98	32.91	21.40	22.45
Overall average	0.91	0.15	0.16	0.04	0.08	0.02

CV = coefficient of variation. ns = not significant at 5% of probability, * significant at 5% of probability, ** significant at 1% of probability.

Higher contents of calcium and sulfur were obtained in the absence of organic compost supply, whereas for the other macronutrients (N, P, K, and Mg) no differences were obtained in the contents with or without fertilization with organic compost (Table 5). In the case of calcium and sulfur, perhaps, this difference is due to the dilution effect and the low mobility that both nutrients present in the plant, since the production of seeds with organic compost (24.25 g per plant) was 50% higher than the treatments without organic compost (16.98 g per plant). Calcium presents low mobility in the plant (Malavolta, 2006) and was not redistributed to the seeds during the development of these structures that are the main drain of a plant. According to these authors, this happens due to the fact that the transport of this nutrient occurs preferentially in the xylem, with little translocation for the development of fruits and seeds, facilitating the contribution of calcium in the vegetative part to the detriment of the areas of fruiting of the plant. Kano et al. (2011) reported that the calcium content in the vegetative parts of lettuce plants was six times higher than those of the seeds.

Table 5. Macronutrient content in lettuce seeds in the treatments with and without organic compost supply at planting.

Treatments	N	P	K	Ca	Mg	S
		---------------- g kg^{-1} of dry matter ---------				
With organic compost (70 t ha^{1})	45.55^{a}	7.37^{a}	8.13^{a}	2.00^{b}	4.06^{a}	1.13^{b}
Without organic compost	46.40^{a}	7.45^{a}	8.13^{a}	2.26^{a}	4.18^{a}	1.18^{a}
CV (%)	3.60	5.03	7.56	15.36	4.82	5.70

CV = coefficient of variation. Means followed by the same letter in the columns do not differ from each other by F test at 5% of probability.

The following order of nutrients contents was observed in the seeds: nitrogen> potassium> phosphorus> magnesium> calcium> sulfur. These results resemble those obtained by Kano et al. (2010). The authors pointed out that the N content found in lettuce seeds was three times higher than that observed in the vegetative part of the plant. They related the importance of this element in the composition of the seed, usually rich in proteins. For K and P, second and third nutrients with higher contents in seeds, Kano et al. (2010) observed that the redistribution of these nutrients from the vegetative part of the plant to the seeds of lettuce occurred in a similar way to that observed for N, since the obtained content was much higher in the seeds.

Quadros et al. (2011) reported the following order of nutrient contents in seeds of lettuce: nitrogen (45.0 g kg^{-1}) > phosphorus (6.2 g kg^{-1}) > potassium (6.1 g kg^{-1}) > calcium (3.5 g kg^{-1}) > magnesium (3.3 g kg^{-1}) > sulfur (2.1 g kg^{-1}).

The application of organic compost at planting (70 t ha^{-1}) increased the amount of N, P, K, Mg, and S accumulated in the seeds; however, it did not affect the amount of Ca (Table 6). The higher accumulation of these nutrients occurred due to higher seed production in the treatments with the supply of organic compost compared to the treatments with the absence of the compost. In the case of Ca, the lack of difference may be related to the lower content of this nutrient observed in the seeds obtained from the plants cultivated with the application of organic compost at planting, probably due to the dilution effect of the nutrient. As the accumulation of nutrients results from the multiplication of their contents by the dry matter weight of the seeds, the treatment with organic compost, which had a higher seed production and a lower Ca content, presented similar accumulation of Ca than those from treatments without organic compost supply at planting.

Table 6. Cumulative amount of macronutrients in lettuce seeds in treatments with and without organic compost supply at planting.

Treatments	N	P	K	Ca	Mg	S
		-------------------- g plant^{-1}------------------				
With organic compost (70 t ha^{-1})	1.06^{a}	0.17^{a}	0.19^{a}	0.05^{a}	0.10^{a}	0.03^{a}
Without organic compost	0.77^{b}	0.12^{b}	0.13^{b}	0.04^{a}	0.07^{b}	0.02^{b}
CV (%)	20.92	18.87	23.98	32.91	21.40	22.45

CV = coefficient of variation. Means followed by the same letter in the columns do not differ from each other by F test at 5% of probability.

The average descending order of nutrients accumulated in the seeds was: nitrogen > potassium > phosphorus > magnesium > calcium > sulfur. Kano et al. (2010) also observed the same order in the seeds of the lettuce cultivar Veronica. However, Kano et al. (2011) reported the following descending order: potassium > nitrogen > calcium > magnesium > phosphorus > sulfur. On the other hand, Quadros et al. (2010), studying doses of organic compost in the production of lettuce seeds, obtained the following order: nitrogen > phosphorus > potassium > calcium > magnesium > sulfur.

Nitrogen was the most accumulated nutrient in the lettuce seeds (mean of 0.91 g plant^{-1}). According to Malavolta (2006), nitrogen is the most abundant nutrient in plants, presenting high mobility in the vegetative organs, that is, if the nitrogen absorption and/or transport process is interrupted, the plant has the capacity to mobilize the nutrient present from older parts to younger parts, such as new leaves or any other growing organs that shows high N demand. In a review with several crops, Cardoso (2011) related that N content and accumulation in seeds was higher than the other nutrients.

During the senescence phase, a great part of the nutrients present in the leaves is translocated to the reproductive structures or other growing organs of the plants. When the foliar proteins are degraded, the nitrogen released as NH_4^+ is assimilated and converted mainly into glutamine and asparagine amides, which are translocated to growing and developing organs, such as the seeds (Malavolta 2006).

Potassium was the second nutrient most accumulated in the seeds (0.16 g plant^{-1}). Usually, N and K are the most accumulated nutrients in plants (Malavolta 2006). Potassium presents great mobility in the plant, which facilitates its translocation to the seeds. The fertilization with organic compost favors the increasing of K content in the soil and its uptake in the plants (Magro et al. 2010).

Similar to N and K, phosphorus is also translocated for plant growth through leaf senescence (Raij 2017). Phosphorus is stored in the salts of phytic acid, constituting the phytin accumulated in the seeds. During the germination process, the phytase enzyme is activated, releasing this nutrient to be used in the development of the embryo and the seedling, being the P incorporated into the membrane lipids and nucleic acids. Therefore, phytin is the main storage form of P in the seed and has an important function during germination (Carvalho and Nakagawa 2012).

Calcium was relatively little accumulated in the seeds, with an average of 0.04 g plant^{-1}, possibly because it is an element with low mobility in the plant and, therefore, its accumulation in the seed must have occurred only by absorption and transport during the maturation of the seeds, without redistribution from the leaves in senescence. Kano et al. (2011) observed that most of the Ca was in the leaves and just a small proportion in the lettuce seeds.

The Mg accumulated in the seeds (average of 0.08 g plant^{-1}) was almost twice the amount of Ca. According to Raij (2017), under conditions of well-drained soils, the natural frequency of occurrence of exchangeable cations is in the following order: $Na^+ > K^+ > Mg^{2+} > Ca^{2+}$. Similar to P, Mg also enters the composition of phytin (Ca and Mg salt) that accumulates in the seeds (Carvalho and Nakagawa 2012).

Sulfur was the nutrient less accumulated by the seeds, with an average value of 0.03 g plant^{-1}. This was also observed by Kano et al. (2010, 2011) and Quadros et al. (2010, 2011), confirming that this nutrient is little accumulated in lettuce seeds, unlike the seeds of brassicas, broccoli, and cauliflower, where it is the second most accumulated mineral (Magro et al. 2009; Cardoso et al. 2016).

4. Conclusions

The supply of 70 t ha^{-1} of the organic compost at planting increased the production of seeds by 43% in relation to the non-use of the same compost, however the doses of S studied had no effect on the production of lettuce seeds. There was no effect of both the organic compost supply at planting and the sulfur doses at topdressing on the physiological quality of the seeds of lettuce.

The sulfur doses applied at topdressing did not show effect either on the content and accumulation of macronutrients in the seeds of lettuce. The supply of 70 t ha^{-1} of organic compost increased the accumulation of a great part of the macronutrients, except for the accumulation of calcium.

The average descending order of nutrient content and accumulation in lettuce seeds was: nitrogen > potassium > phosphorus > magnesium > calcium > sulfur.

Authors' Contributions: MARTINS, B.N.M.: acquisition of data, analysis and interpretation of data, drafting the article; JORGE, L.G.: acquisition of data, analysis and interpretation of data; COLOMBARI, L.F.: acquisition of data, analysis and interpretation of data; BARDIVIESSO, E.M.: acquisition of data, analysis and interpretation of data; NASSER, M.D.: acquisition of data, analysis and interpretation of data; SOUSA, M.C.: acquisition of data, analysis and interpretation of data; CARDOSO, A.I.I.: acquisition of data, analysis and interpretation of data, drafting the article.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethics Approval: Not applicable.

Acknowledgments: The authors thank the CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil) for granting a scholarship for the conduction of this study.

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Received: 14 April 2020 | **Accepted:** 17 January 2022 | **Published:** 12 August 2022