

RESEARCH ARTICLE

Alternative for potassic fertilization of vegetables in organic management in low fertility natural soil of the humid tropics

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ABSTRACT

The organic food production and mainly the demand for these products have been growing much worldwide, and with this rising demand there is need for more adequate soil management. Organic fertilization is one of the points to improve and the alternative sources of nutrients should be better evaluated. Potassium is an essential nutrient required in large quantities by greenery and fruit, but according to the legislation of organic production, it can only be used as crushed rocks such as potassium sulfate. The objective of this work was to evaluate the efficiency of potassium sulfate (soluble source), wood ash and marble powder as alternative sources of potassium in organic system, using hybrid maize AG 1051 as the indicator crop. The experimental design applied was in randomized blocks in the 3x4x2 factorial scheme, consisting of three potassium sources applied in four doses (0, 60, 90 and 120 kg ha⁻¹ K₂O) in the presence and absence of Biofertilizer, with four repetitions. The data were submitted to analysis of variance (ANOVA) and the averages were compared by the Tukey test ($p < 0.05$). Both wood ash and marble powder tested can be used as complementary potassium fertilization in organic production systems. Marble powder proved to be the most efficient among the treatments and the Biofertilizer did not have a significant effect on the evaluated characteristics.

Keywords: Alternative sources; Biofertilizer, Potassium.

INTRODUCTION

Potassium (K) is one of the three main elements, namely, nitrogen (N), phosphorus (P) for the best development of plants. Soil fertility with K is vital for high crop yields (Zhao et al., 2014; Jiang et al., 2019). In the absence of K, plants may suffer growth reduction and often show no visible symptoms (Haberman et al., 2019).

Potassium is needed in large quantities for cultivation, but resource-poor farmers in developing countries generally do not fertilize their crops with K due to high fertilizer costs, an action that leads to K deficiencies. What makes this element limiting in K agricultural production systems, where the inadequate application of this fertilizer leads to

the depletion of available K reserves in the soil. To achieve and maintain self-sufficiency in food grain production, alternative sources of K are needed to replenish this nutrient in a sustainable manner (Shirale et al., 2019).

Wood ash is one of the main well-known alternative sources of K conventionally in field and horticultural crops. It is one of the ancient sources of K used to apply fertility to the soil (Basak, 2017).

The importance of wood ash in agriculture is mainly determined by the K content which varies from 5 to 7%. The K content in the wood ash depends on the age of the wood; the older the wood, the higher the K content (Beesley et al., 2019).

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The importance of using wood ash with K supplier has been demonstrated in studies. Ajala et al. (2019), report that wood ash increased the yield of maize and lima beans. Bonfim-Silva et al. (2019) showed that wood ash increased the pH of the soil to adequate values and made K available, resulting in better initial development of cowpea and Bhutia et al. (2019) find excellent yields for growing peas.

Another source of nutrient that has shown significant impact as an alternative source of K, is rock dust, also known as rockiness, a technique that positively alters soil fertility (Bianchini and Marques, 2019).

Several studies have investigated the ability of ground rocks to provide nutrients, in particular potassium for growing crops (Manning, 2018). Ramezani et al. (2013) reports the use of crushed volcanic rocks; positive responses are also found by Bakken et al. (2000). The ability to supply K from residual rock dust in the Seaham quarry in Australia has also been assessed for maize and basil crops (Basak et al., 2018). Leek plants and the K content of the plant material showed a positive response depending on the application rate of ground syenite (Manning et al., 2017) and Souza Maciel (2015) tested the marble powder in corn cultivation, obtaining excellent results.

The most used K source in conventional agriculture is KCL, however in organic agriculture this chemical fertilizer is not allowed, potassium sulfate can be used as long as it does not undergo chemical processes to increase solubility (Ciceri et al., 2019).

In tropical regions, where major agricultural innovations are needed to meet food security goals, the local cost of KCl is high and negligible leachate losses are frequently reported due to the soluble nature of this salt (Manning et al., 2017). The cost becomes important considering the large volumes of agricultural crops that are produced in tropical countries (Ciceri et al., 2019).

The objective of this study was to evaluate the effect of three alternative sources of potassium (potassium sulfate, wood ash and marble powder), so that they can be used in the production of organic vegetables in tropical regions and that it is able to reduce production costs.

MATERIAL AND METHODS

The experiment was installed and conducted in the area of the company Alimentum Ltda., located on the road of Juçatuba, village Andiroba in the rural area of São Luís-MA, between November 2014 and March 2015, whose geographical coordinates of the experimental area are 2° 37' 39,69" South Latitude and 44° 11' 15.7" longitude. The climate of the region in the classification of Köppen is of the type Aw ' equatorial hot and humid, with two well-defined seasons, a rainy season stretching from January to June and a dry season with a marked water deficit from July to December. Rainfall precipitations range from 1700 to 2300 mm annually and the average temperature are around 26.7 °C. The precipitation was more intense during January, but it was necessary to use additional irrigation by sprinkling twice a day in the following months while conducting the experiment due to water deficit.

The soil used for installation of the experiment was classified as upper yellow red dystrophic Arênico (Embrapa, 2013). Before the installation of the experiment, soil samples were collected at the depth of 0.20 cm for chemical characterization (Table 1, and Table 2).

The experimental delineation applied was in randomized blocks with subdivided parcels and four repetitions, in 3x4x2 factorial scheme, consisting of three sources of potassium: potassium sulfate, wood ash, and marble powder. These treatments were applied in such a way that when obtained four doses 0, 60, 90, 120, kg ha⁻¹ of K₂O the fertilizers were evaluated in the presence and in the absence of a biofertilizer (Fig 1).

Table 1: Chemical characteristics (total levels) of the soil of the area of implantation of the experiment in the company Alimentum LTDA, populated Andiroba, municipality São Luis-Ma.

Prof. (cm)	pH (CaCl ₂)	M.O (g/dm ³)	P Melich (mg/dm ³)	H+Al	K	Ca	Mg	SB	T	V (%)
0-20	4.9	25	495	26	2.2	20	5	27.2	53.2	51

Table 2: Chemical characterization of alternative potassium sources used in the maize experiment in the company Alimentum LTDA, populated Andiroba, São Luis-Ma municipality

Potassium sources	N	P	K	Ca	Mg	Mn	Cu	Fe	Zn
	(g kg ⁻¹)			(mg kg ⁻¹)					
Wood Ash	22.82	-	22.11	4.55	-	25	7.90	20.10	20.19
Marble powder	0.74	0.47	10.03	3.75	0.98	9	8.45	64.70	77
Biofertilizer	16.5	-	17.3	4.72	-	37	5.50	35	37



Plate 1. A: área demarcada, com os tratamentos aplicados; B: biofertilizante pronto para a aplicação; C: experimento em campo, 33 dias após o plantio; D: Experimento em campo, 50 dias após plantio.

The biofertilizer used presented the following attributes: N_{total} 12.7 g kg⁻¹; P 18 g kg⁻¹ and K 1.5 g kg⁻¹, pH 6.6 (table 3). It was produced in anaerobic form from bovine manure 250 L, Organic compound 5 kg, Wood Ash 5 kg, bovine milk 10 L, sugar cane broth 6L, GAFSA phosphate 5 kg, Boric acid 2 kg and Zinc sulfate 2 kg. The volume was completed up to 500 L with water. The doses of biofertilizer, as well as that of other materials, were defined on the basis of their chemical analysis (Fig 1).

Each experimental parcel presented an area of 2.5 x 2.70 m (6.75 m²) consisting of four planting lines spaced at 0.90 m between lines and 0.25 m between plants, with a population density of 44.400 plants ha⁻¹.

On the occasion of the installation of the experiment, all parcels received a dose of P₂O₅ corresponding to 100 kg ha⁻¹ using calcium phosphate as a source. The nitrogen fertilization was made in the form of organic

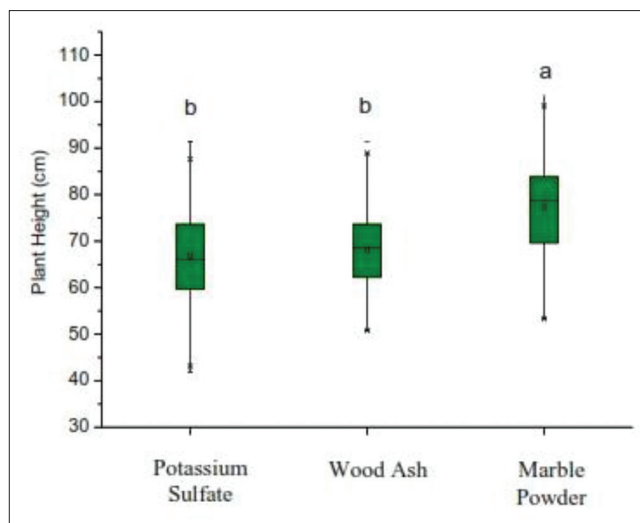


Fig 1. Average of the height of maize plants cultivated in field conditions in organic management with different organic sources of potassium.

Table 3 : Average levels of nitrogen (N), phosphorus (P) and potassium (K) in the leaf of maize plants grown under field conditions and organic cultivation with different sources and doses of potassium, in the presence and absence of biofertilizer

Sources	N (g kg ⁻¹)	P (mg dm ⁻³)	K (mg dm ⁻³)
Wood Ash	26,20 ^A	30,71 ^A	41,21 ^B
Marble powder	28,52 ^A	24,10 ^B	47,19 ^A
Marble Powder	26,85 ^A	21,69 ^B	46,14 ^A

compound at the occasion of planting to supply all the N need of the green maize culture.

For the installation of the experiment, the preparation of the area was carried out seven days in advance of the planting of maize, with mowing and the application of the treatments and irrigation. Subsequently was carried out the manual sowing of the corn hybrid AG 1051. At 22 days after sowing (DAS) when 100% of seedling emerged, the first application of the Biofertilizer was performed, applying the dose of 5%, being 16 L of Biofertilizer/304 L of H₂O, equivalent to 10 L of the solution for parcel and 1L M⁻¹ line of planting or 0.25 L of plant⁻¹ Biofertilizer solution. The applications were made weekly, with a total of four applications.

The sampling of leaf for macro and micronutrient determination with the purpose of evaluate the nutritional state of the plant was performed by collecting the leaf below and opposite to the cob at the time of the appearance of the stigmata in the feminine inflorescence (45 days after sowing), according to the methodology described by (Malavolta et al.,1997). The leaves of one third of the canopy were used, discarding the midrib, and five leaves were collected in each experimental parcel.

The plant material was washed in running water and subsequently with a solution of 0.1% distilled water plus

neutral detergent, and finally rinsed with distilled water. Then the fresh matter was placed in paper bags for drying in circulating greenhouse air force at 65° C for 72 hours, and subsequently grinded in a Wiley mill.

The laboratory analyses for the determination of N levels of maize leaf were subjected to sulfuric digestion, using the method established by Kjeldahl and described by (Tedesco et al., 1995). For the determination of phosphorus (P) and potassium (K) levels, samples underwent a nitro-perchloric digestion, a method also described by (Tedesco et al., 1995) as well.

At 45 days after sowing (DAS), the following variables were measured: plant height (AP), measured from the ground level to the apex of the male inflorescence, and stem diameter in the first internode (DC). It was also quantified (70 DAS) the diameter of the cob without straw (DESP), cob length without straw (CESP), weight of cobs with straw (PCWP) and weight of cobs without straw (PESP) (Fig 1).

The data were submitted to analysis of variance (ANOVA) and the averages were compared by the Tukey test ($p < 0.05$), for the isolated factors as well as for the interaction between them.

RESULTS AND DISCUSSION

The different sources of potassium, doses and interactions varied significantly among the evaluated variables, but the larger variations occurred between the organic sources of potassium and there was no significant effect between the different doses of K and the biofertilizer when evaluated in isolation. However, differences were found for some interactions resulting from the combinations of the factors.

With respect to the height of plants (AP), there were difference between the sources of potassium. The treatment that received the powder of marble differed from the others (Fig 1). Potassium sulfate and wood ash did not differ from each other and the wood ash was superior to potassium sulfate. In relation to the doses of K, no significant distinction was observed for this variable. The presence or absence of the biofertilizer did not significantly influence the height of the plants, evincing that the increase in the level of potassium in the soil has no effect on the height of maize plants. The ratio of the variety employed associated to, particularly water and temperature, explain the differences of height and the chemical composition of the organic maize plant. The average height found in this study was 80 cm, the close results in the case of corn plant height were also found (72.10 cm) by Yadav (2019). The lower plant height observed can be attributed to the low solubilization of the rock and, consequently, low release of

nutrients to the corn plant. On the other hand, the growth of plants in the absence of K can be justified by the use of this element in the nutrient reserves of the rhizome (Boldrin et al., 2019).

There were significant distinctions in the interaction between the different organic sources of potassium and the doses (Fig 2). In general, the height of the plants increased proportionately to the dose and varied with the alternative source. The treatment with the marble powder presented the highest averages, but there were no differences between doses for this treatment. The major differences occurred between the witness and the dose of 90 and 120 kg ha⁻¹ of K₂O for treatments with potassium sulfate and wood ash (Fig 2). The heights of the corn plants were influenced by the interaction between the sources and the rate of K used, alternative sources of K produced plants of height similar to plants grown with the conventional nutrient source (Boldrin et al., 2019).

Regarding the weight of the cob with straw (PECP), in general there was a significant effect on the different sources of potassium (Fig 3). The best performance was obtained for the treatment with marble powder followed by wood ash and potassium sulfate (Fig 3). However, there was no statistical difference between marble powder and wood ash, and the latter did not differ from potassium sulfate. Literature data indicate an increase in corn cob weight as a result of potassium fertilization (Yu et al., 2009; Alias et al. 2011; Liu et al., 2011; Maleki et al., 2014; Zhang et al., 2014; Szczepanek et al., 2016). In addition, some researchers claim that fertilization of corn with potassium can contribute to higher weights, since potassium affects osmotic regulation, sweating rate and water uptake by the roots (Aslam et al. 2014; Zhang et al., 2014; Szczepanek et al., 2016).

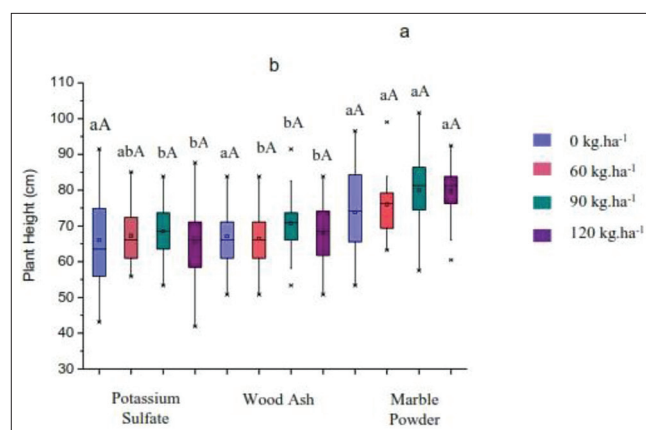


Fig 2. Average of the height of the maize plants grown in field conditions in organic management with different organic sources of potassium and different doses. Averages with lowercase equal letters between doses and averages with letters equal uppercase between sources do not differ by the Tukey test at a level of 5% of probability.

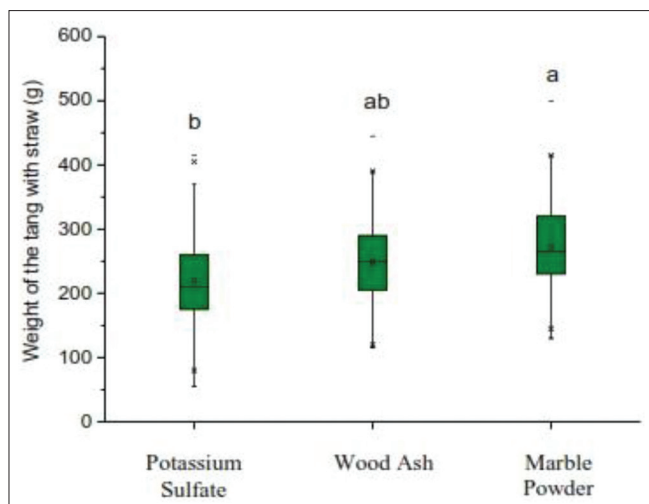


Fig 3. Average of the weight of the corn on the cob, grown in organic management with different organic sources of potassium.

The weight of the ear of corn without straw (PESP), at 70 (D.A.S.), was similar to the weight of the ear with straw (Fig 4). There was a significant effect only between the different potassium sources. As with the other evaluated parameters, the treatment with marble powder stood out in relation to other sources of potassium.

In relation to the basal diameter of the stem (DC) of the maize plants, there was no significant difference between the different sources of potassium, doses and the interactions among sources x doses x biofertilizer. However, it was observed that the treatments that provided greater height of the plants obtained a higher basal diameter, therefore, the largest diameters were observed for treatments consisting of marble powder, followed by wood ash and potassium sulfate. There was no difference in basal diameter of the stem comparing the doses of potassium, but the largest diameters were observed on the witness (3.02 cm) and the dose of 120 t. ha⁻¹ (1.93 cm) presented the smallest diameter. These results can be explained by the fact that, in the plant, K exists in ionic form and plays important roles in the adjustment of osmotic pressure and in the translocation of carbohydrates (Hawkesford et al., 2012). Thus, the addition of K can trigger a greater consumption of water to avoid excessive osmotic pressure, consequently causing a greater increase in the diameter of the stem than in the length of the stem (Zörb et al., 2014; Nieves-Cordones et al., 2019).

There were also no significant variations in relation to the presence or absence of the biofertilizer. Corn plants that have a larger basal stem diameter, consequently, obtain greater resistance and balanced growth of the aerial part. In addition, the stem diameter is an important characteristic, because the higher its value, the greater the vigor, robustness and resistance of the plant (Guimarães et al.,

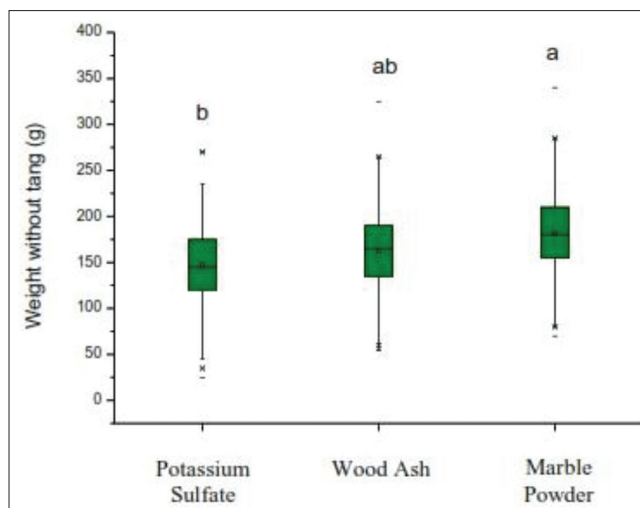


Fig 4. Average of the weight of the corn-free cob, grown in organic management with different organic sources of potassium.

2009). Potassium is a macronutrient that has crucial effects on corn, inducing changes in internode characteristics (Xu et al., 2018).

For the diameter of the cob without straw (DESP), at 70 (DAS), no significant effects were observed among the independent treatments of sources and doses of potassium used in the presence or absence of the biofertilizer. The diameter of the tenon ranged from 3.57 to 4.41 cm and generally, the highest values were obtained with marble powder treatments, in the presence and absence of the biofertilizer. The average diameter of cobs depends, in addition, to the genetic characteristics of the cultivator and of the cultivation system. As the leaf is the main photosynthetic device, the smaller leaf area found in this study is associated with less production of photoassimilates, resulting in less translocation of the photoassimilates to the ear. On the other hand, the greater production of area resulted in more production of photoassimilates and translocation to the ear, increasing its diameter (Khan et al., 2019). According to Chiamolera et al. 2013, the length and diameter of the ear are characteristics that determine the productivity potential of the corn crop.

As for the length of the cob without straw, there was a significant difference among the sources. The treatment consisting of marble powder resulted in larger cobs, followed by the wood ash and potassium sulfate. A length greater than 15 cm is within the recommended technical standards for the marketing of green maize. However, consumers prefer higher-length cobs for consumption “in natura”. Thus, tangs with length around 18.57 cm, obtained in the treatments consisting of marble powder, with a dose of 60 kg ha⁻¹ and in the presence of the biofertilizer, fit the taste of consumers.

Regarding the levels of potassium and phosphorus in the leaves of maize plants, a significant difference was observed among the alternative sources of potassium (Table 3). In general, the treatment containing wood ash showed higher potassium levels compared to other sources, but did not differ statistically from marble powder (Table 3). The phosphorus levels found were higher for potassium sulfate treatments, whereas for potassium, there was no difference between wood ash and marble powder.

For nitrogen levels, there were no significant differences among the distinct sources, except when in interaction with sources x doses x biofertilizer, probably because there is a suitable supply from that nutrient to the plants for the evaluated treatments.

Although there is a significant difference in the interaction of the factors for nitrogen, the values found were quite varied. In maize plants, potassium is part of biochemical processes that involve the assimilation of nitrogen in the plant, thus the exchangeable potassium contents can facilitate the absorption of nitrogen by the roots, since the greater accumulation of K however, the higher accumulation of K occurs at the roots than facilitates N uptake (Fernandes et al., 2013).

CONCLUSION

The use of marble powder as an alternative source proved to be efficient in making K available to plants, and it can be used by farmers looking to reduce their production costs and who intend to produce sustainably. The presence or absence of biofertilizer did not respond significantly to the variables evaluated, since the use of biofertilizer is associated with the induction of resistance in the control of the disease. No differences were observed between the doses of K. Just like marble powder, wood ash and potassium sulfate also demonstrated that they can be used as a source of K, but it is necessary to test these alternative sources, under different conditions. of soil, cultivation and climate.

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CONTRIBUTIONS OF AUTHORS

Aline Moreno, Valter Barbosa, Mary Jane Nunes and Ronald Alvarez performed the installation of the experiment, such as analysis in the laboratory and writing of the Manuscript. Glauco Souza performed the statistical analysis. Ana Maria

Silva and Altamiro Ferraz were responsible for supervising the project and revising the manuscript. All authors read and approved the final manuscript.

REFERÊNCIAS

- Ajala, R. O., M. A. Awodun, A. J. Adeyemo and B. F. Dada. 2019. Assessment of wood ash application on yield advantage indices of maize and lima beans in an intercrop. *J. Exp Agric. Int.* 34: 1-11.
- Alias, M. A., H. A. Bukhsh, R. Ahmad, A. U. Malik, S. Hussain and M. Ishaque. 2011. Profitability of three maize hybrids as influenced by varying plant density and potassium application. *J. Anim. Plant Sci.* 21(1): 42-47.
- Aslam, M., M. S. I. Zamir, I. Afzal and M. Amin. 2014. Role of potassium in physiological functions of spring maize (*Zea mays* L.) grown under drought stress. *J. Anim. Plant Sci.* 24(5): 1452-1465.
- Bakken, A. K., H. Gautneb, T. Sveistrup and K. Myhr. 2000. Crushed rocks and mine tailings applied as K fertilizers on grassland. *Nut. Cycl. Agroecosyst.* 56(1): 53-57.
- Basak, B. B., B. Sarkar, P. Sanderson and R. Naidu. 2018. Waste mineral powder supplies plant available potassium: Evaluation of chemical and biological interventions. *J. Geochem. Explor.* 186: 114-120.
- Basak, B. B. and E. B. Sarkar. 2017. Scope of natural sources of potassium in sustainable agriculture. In: *Adaptive Soil Management: From Theory to Practices*. Singapore: Springer, pp. 247-259.
- Beesley, L., R. Hough, C. M. Deacon and G. J. Norton. 2019. The impacts of applying metal (loid) enriched wood ash to soils on the growth and elemental accumulation of rice. *Expo. Health.* 11(4): 311-324.
- Bhutia, P., P. M. Anal, P. Sarma, A. K. Singh, S. R. Singh and A. S. Mailappa. 2019. Influence of organic manures, biofertilizers and wood ash on growth and yield of edible podded pea (*Pisum sativum* var. *macrocarpon*) var. Arka Apoorva. *Int. J. Curr. Microbiol. App. Sci.* 8(8): 210-219.
- Bianchini, H. C. and D.J. Marques. 2019. Sources of potassic fertilization in soybean production under different irrigation blades. *J. Exp. Agric. Int.* 1: 1-8.
- Boldrin, K. V. F., P. D. de Oliveira Paiva, P. F. Boldrin, A. E. F. Neto and B. R. Almeida. 2019. Alternative sources of potassium in the growth of calla lily. *Sci. Hortic.* 255: 96-102.
- Bonfim-Silva, E. M., A. S. Costa, J. V. José, A. P. F. Ferraz, A. P. A. Damasceno and T. J. A. da Silva. 2019. Correction of acidity of a brazilian cerrado oxisol with limestone and wood ash on the initial growth of cowpea. *Agric. Sci.* 10(7): 841-851.
- Chiamolera, F. M., C. R. Dias-Arieira, T. P. L. da Cunha, F. Biela, S. de Melo Santana and T. R. B. da Silva. 2013. Agronomic performance of maize with different fertilizers in winter crop succession. *Afr. J. Agric. Res.* 8(18): 1852-1858.
- Ciceri, D., T. C. Close, A. V. Barker and A. Allannore. 2019. Fertilizing properties of potassium feldspar altered hydrothermally. *Commun. Soil Sci. Plant Anal.* 50(4): 482-491.
- de Souza Maciel, R. J., A. S. D. Junior and H. Braun. 2015. Viabilidade de fontes alternativas de potássio para cultivo orgânico de milho verde. *Cader. Agroec.* 9: 1-7.
- Embrapa. 2013. Sistema Brasileiro de Classificação de Solos. Centro Nacional de Pesquisa de Solos, Rio de Janeiro.
- Fernandes, L. A., R. V. Valadares, S. V. Valadares, S. J. Ramos, C. A. da Costa, R. A. Sampaio and E. R. Martins. 2013.

- Potassium sources on yield, mineral nutrition and chemical composition of caigua plants. *Hortic. Bras.* 31(4): 607-612.
- Guimarães, A. S., B. N. E. Macedo and S. G. Costa. 2009. Growing sources and doses of organic and mineral fertilizers in the initial growth of *Jatropha*. *Mens. Agitat.* 4: 17-22.
- Haberman, A., A. Dag, N. Shtern, I. Zipori, R. Erel, A. Ben-Gal and U. Yermiyahu. 2019. Long-term impact of potassium fertilization on soil and productivity in intensive olive cultivation. *Agronomy.* 9(9): 525.
- Hawkesford, M., W. Horst, T. Kichey, H. Lambers, J. Schjoerring, I. S. Møller and P. White. 2012. Functions of macronutrients. In: Marschner's Mineral Nutrition of Higher Plants. Academic Press, New York, pp. 135-189.
- Jiang, N., B. Hu, X. Wang, Y. Meng, B. Chen and Z. Zhou. 2019. Effects of crop residue incorporation and inorganic potassium fertilization on soil potassium supply power. *Arch. Agron. Soil Sci.* 65(9): 1223-1236.
- Khan, Z. H., S. K. Khalil, M. A. Ikramullah, A. Iqbal, B. Islam, K. Ali and F. Shah. 2019. Physical characteristics of cobs and kernels in sweet corn under varying planting environments. *Fresenius Environment. Bull.* 28: 6568.
- Liu, K., B. L. Ma, L. Luan and C. Li. 2011. Nitrogen, phosphorus, and potassium nutrient effects on grain filling and yield of high-yielding summer corn. *J. Plant. Nutr.* 34(10): 1516-1531.
- Malavolta, E., G. C. Vitti and S. A. D. Oliveira. 1997. Avaliação do Estado Nutricional das Plantas: Princípios e Aplicações. Universidade Cornell, São Paulo.
- Maleki, A., S. Fazel, R. Naseri, K. Rezaei and M. Heydari. 2014. The effect of potassium and zinc sulfate application on grain yield of maize under drought stress conditions. *Adv. Environ. Biol.* 8: 890-894.
- Manning, D. A. and S. H. Theodoro. 2018. Enabling food security through use of local rocks and minerals. *Extrac. Ind. Soc.*
- Manning, D. A., J. Baptista, M.S. Limon and K. Brandt. 2017. Testing the ability of plants to access potassium from framework silicate minerals. *Sci. Total Environ.* 574: 476-481.
- Nieves-Cordones, M., R. Ródenas, A. Lara, V. Martínez and F. Rubio. 2019. The combination of K⁺ deficiency with other environmental stresses: What is the outcome? *Physiol. Plant.* 165(2): 264-276.
- Ramezani, A., A. S. Dahlin, C. D. Campbell, S. Hillier, B. Mannerstedt-Fogelfors and I. Öborn. 2013. Addition of a volcanic rockdust to soils has no observable effects on plant yield and nutrient status or on soil microbial activity. *Plant. Soil.* 367(1-2): 419-436.
- Shirale, A. O., B. P. Meena, P. P. Gurav, S. Srivastava, A. K. Biswas, J. K. Thakur and A. S. Rao. 2019. Prospects and challenges in utilization of indigenous rocks and minerals as source of potassium in farming. *J. of Plant. Nutr.* 42(19): 2682-2701.
- Szczepanek, M. and E. Wilczewski. 2016. Maize response to soil-applied humic substances and foliar fertilization with potassium. *J. Anim. Plant Sci.* 26(5): 1298-1303.
- Tedesco, M. J., C. Gianello, C. A. Bissani, H. Bohnen, S. J. Volkweiss and S. Volkweiss. 1995. Análises de solo, plantas e outros materiais. UFRGS, Departamento de Solos, Porto Alegre.
- Xu, Z., T. Lai, S. Li, D. Si, C. Zhang, Z. Cui and X. Chen. 2018. Promoting potassium allocation to stalk enhances stalk bending resistance of maize (*Zea mays* L.). *Field. Crops. Res.* 215: 200-206.
- Yadav, M., R. Umrao and S. Rota. 2019. Efeitos de orgânicos, inorgânicos e bio-fertilizantes no crescimento do milho em sistema agroflorestais baseado em subabul (*Leucaena leucocephala*). *J. Plant. Dev. Sci.* 11: 189-199.
- Yu, W. T., Z. S. Jiang, H. Zhou and Q. Ma. 2009. Effects of nutrient cycling on grain yields and potassium balance. *Nutr. Cycl. Agroec.* 84(3): 203-213.
- Zhang, L., M. Gao, S. Li, A. K. Alva and M. Ashraf. 2014. Potassium fertilization mitigates the adverse effects of drought on selected *Zea mays* cultivars. *Turk. J. Bot.* 38(4): 713-723.
- Zhao, S., P. He, S. Qiu, S. L. Jia, M. Liu, J. Jin and A. M. Johnston. 2014. Long-term effects of potassium fertilization and straw return on soil potassium levels and crop yields in north-central China. *Field. Crops. Res.* 169: 116-122.
- Zörb, C., M. Senbayram and E. Peiter. 2014. Potassium in agriculture status and perspectives. *J. Plant. Phys.* 171(9): 656-669.