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Macro-and micronutrient content in native varieties of *Phaseolus lunatus* L. fertilized with rock dust

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Abstract

The objective of this study was to evaluate the macro- and micronutrient content in the leaves of *Phaseolus lunatus* L. fertilized with MB-4®. The research was carried out in two consecutive experiments, with a 2x5 randomized factorial block design and four replicates, in which two native varieties of *Phaseolus lunatus* L. were evaluated (Lima bean 'Cara Larga' and Lima bean 'Branca') based on responses to five varying doses of MB-4® (0, 100, 200, 400, and 800 g hole^{-1}). Leaf analyses were performed to quantify nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, copper, iron, manganese, and zinc. Leaf analysis indicated that N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn levels increased significantly in the second year of cultivation, and that only B content decreased. The contents of N, P, Ca, B, Fe, Mn, and Zn were within the recommended range, whereas only K and Mg were outside the recommended range for the species. The values found between 200 and 400 g hole^{-1}, corresponding to 4 and 8 t ha^{-1} of MB-4®, respectively, were the ones that contributed the most to the nutrient content increase in Lima bean varieties.

Keywords: Lima bean 'Cara larga'; Lima bean 'Branca'; Fertility; Mineral nutrition of plants.

Introduction

The broad bean (*Phaseolus lunatus L.*), commonly known as "lima bean," is one of the four cultivated species of the genus *Phaseolus*.It is the second most important legume of the genusand is widely distributed and cultivated in the tropical region (Martínez-Nieto et al., 2020). Its cultivation takes place through creole seeds, which are extremely important for the culture. However, it may make it difficult to follow the recommended process of fertilization (Assunção Filho et al., 2022).
The cultivation of broad beans in northeast Brazil, the main producing region, is carried out by intercropping with corn (*Zeamays spp*.), pumpkin (*Cucurbita moschata Duch.*), common bean (*Phaseolus vulgaris L.*), macassar bean [*Vigna unguiculata L. (Walp)*], yam (*Dioscorea cayennensis Lam.*), and cassava (*Manihot esculenta Crantz*) (De Jesus et al., 2018).
To ensure the success of these intercropping systems, proper management must be used, especially regarding balanced fertilization. However, there are few studies concerning fertilization, and there is littleinformation about nutrition and adequate fertilization in Brazil.
In search of solutions to reduce external dependence on fertilizers in Brazil, research on alternative nutrient sources has been conducted. Such sources include materials such as the practice of rocking, a fertilization technique based on the addition of powder of certain types of rock or minerals regulated by Law 12,890 on December 10, 2013, Normative Instruction No. 5 on March 10, 2016, and the Federal Official Gazette, Federative Republic of Brazil.
The use of rock dust has numerous advantages over soluble fertilizers, such as labor savings due to its low solubility; thus, there is no need to fertilize frequently becauseof its slow and gradual residual effect. Additionally, it does not acidify the soil and can correct its acidity. Lastly, it does not salinize the soil and can improve soil chemical characteristics. However, owing to the low solubility of basalt powder, studies with successive evaluations of the chemical attributes of the soil are recommended to evaluate the nutrient availability in the long term (Alovisi et al., 2021; Duarte et al., 2021; Alovisi et al., 2020; Almeida Júnior et al., 2020; Writzl et al., 2019).
Some research works were carried out with rock dust in some crops such as bean (Duarte et al., 2021; Bertoldo et al., 2015), corn (Writzl et al., 2019; Almeida Júnior et al., 2020), and soy (Alovisi et al., 2020; Alovisi et al., 2021). However, information regarding its effects on plant nutrition is poorly understood. Therefore, the present study aimed to evaluate the macro-and micronutrient content in the leaves of two strainsof *Phaseolus lunatus L.*, fertilized with rock powder (MB-4®).

Results

Analysis of variance was performed separately between the first and second experiments, referred to as the first and second cultures, respectively. It was not verified whether there was an interaction and significant difference between the broad beans for the foliar contents and doses of N, P, S, B, Cu, Fe, Mn, and Zn in the first culture, and K, S, and Zn in the second culture. However, there was an increase in leaf content for N, P, Mn, and Fe when compared to the crops in the second culture (Table1).

N and K content in broad bean leaves

Dosage had no significant effect on N content in the first culture. However, a significant interaction was verified by the 5% probability F test in the second culture (Figure 1A). In the regression analysis, a quadratic polynomial fit was observed for the 'Branca' and 'Cara larga' lima bean varieties.

It was verified that dosagehada significant effect only inthe lima bean varieties for the P content in the first crop. A significant interaction was verified by the 5% probability F testin the second crop (Figure 1B). When performing the regression analysis for the second crop, a quadratic polynomial and a linear fit were observed for the 'Branca' and 'Cara larga' lima beans, respectively. A significant interaction was verified by the 5% probability F test for K content in the first culture (Figure 1C). When the regression analysis was carried out, it was observed that the 'Branca' and 'Cara Larga' lima bean varieties did not fit any model; thus, the average was used. In the second crop, the dosage effect onK content in the leaves (Figure 1D) was verified using quadratic polynomial adjustment by regression analysis.

Ca and Mg content in broad bean leaves

When performing regression analysis for the first crop, a quadratic polynomial fit was observed for the 'Branca' and 'Cara Larga' lima bean varieties. In the second crop, a regression analysis of Ca indicated a quadratic adjustment of the 'Branca' variety; there was no adjustment for the 'Cara Larga' lima bean variety. A significant interaction was verified by the F test at 5% probability for the Mg content of the first and second cultures (Figure 2C and 2D). When the regression analysis of Mg for the first and second crop was observed, a second degree polynomial fit was observed for the 'Branca' variety, while no adjustment was seenfor the 'Cara larga' lima bean variety.

B and Cu content in broad bean leaves

It was verified that dosage had no significant effecton Cu and Fe content in the first culture. In the second culture, a significant interaction was verified by the 5% probability F test (Figures 3C and 3D). A second-degree polynomial fit was found for the 'Branca' variety, and a linear fit was observed for the 'Cara larga' variety when performing the regression analysis for Cu. The regression analysis of Fe did not indicate adjustment for the 'Branca' variety. However,a second-degree polynomial adjustment was foundfor the 'Cara larga' variety.

In the second crop, an increase in MB-4® dosage promoted an increase in the absorption and accumulation of B in the leaves of the 'Branca' lima bean variety (Figure 3B). Additionally, the highest dose applied was not sufficient to cause a decrease in the absorption or accumulation of B in the 'Branca' variety.

Mn and Zncontent in broad bean leaves

It was verified that dosage had no significant effect on Mn and Zn content in the leaves of the first crop. In the second crop, a significant effect was verified by the 5% probability F test (Figure 4A and 4B). Regression analysis for Mn and Zn showed a linear adjustment for hole^{-1}.

Discussion

The dosage concentrations used in this study were 0, 2, 4, 8, and 16 t ha^{-1}. It was observed that there was an increase in Nlevels when the effect of these doses on the N content in leaves was verified, mainly after ten months of MB-4®application in the soil. The 'Branca' lima bean cultivar had the highest N content. The 'Branca' lima bean variety had the highest N content at 505g of MB-4® hole^{-1}. Moreover, in the 'Cara larga' lima bean variety, the maximum levels were obtained with a dose of 155g hole^{-1} (Figure 1). A previous study by Silva (2007) showed that application of 0, 10, 20, 50, and 100 t ha^{-1} of basalt powder on beans resulted in an increase in N content after one year of the experiment.

The two largest doses, 400 and 800g hole^{-1}, did not contribute to the increase in N content in the leaves, mainly in the 'Cara larga' variety (Figure 1A). Notably, even with reduced dosage, the N values that were observed were in the appropriate range (between 30–50 g kg^{-1}) for *Phaseolus vulgaris*. This is in accordance with a previous study by Ambrosanoet al. (1996) because there are no recommendations for lima bean culture in Brazil.

In the second crop, the increase in the dose of MB-4® promoted a progressive reduction in the absorption and accumulation of P by the 'Cara larga' lima bean variety (Figure 1B), following a linear relationship. The reductions were given constant rates from dose up to the highest dose applied. This shows that the application of MB-4® to the soil caused a decrease in the nutrient absorption or accumulation by the plants. In the 'Branca' lima bean, this decrease was perceived by the plant only when the MB-4® dose was 450g hole^{-1}.

The overall mean revealed that P levels increased from the first to the second year of cultivation, ranging from 3.0 to 4.0g kg^{-1}. This is supported by a previous study, where the P levels ranged from 2.0 to 3.0 g kg^{-1} for *P. vulgaris* (Malavolta et al., 1997).

Phosphorus is recognized as one of the most important elements in plant metabolism and is essential for the establishment and development of plants (Gonçalveset al., 2000). This nutrient is crucial for plant metabolism andplays an important role in cell energy transfer, respiration, and photosynthesis. It is also a structural part of nucleic acids of genes and chromosomes, as well as of many coenzymes, phosphoproteins, and phospholipids (Marschner, 2012)

The overall K mean showed an increase in the content of this element from the first to the second crop (Figures 1C and 1D). However, the values remained well below the appropriate range (20-25 g kg^{-1}) for *P. vulgaris* (Malavolta et al., 1997).

The verified K deficiency can probably be explained by the high Mg content in rock dust. However, according to Marschner (2012), K deficiency causes an increase in N, P, Ca, and Mg levels, and accumulation of B.For Ca content,a significant interaction was verified by the 5% probability F test in the first and second cultures (Figure 2A and 2B).

In this study, the effect of fertilization onleaf Ca content was observed. This effect was observed in the increased Ca

Table 1. Lima bean leafanalysisof N, S, P, B, Cu, Fe, Mn, and Zn content in thefirstcropand K, S, and Zn content in the secondcrop. Therewas no significant interaction according to the F test (p<0.05).

	N	P	S	B	Cu	Fe	Mn	Zn	K	S	Zn
	--Firstcrop-----------------------------------								--------Secondcrop------		
Varieties	----------g kg^{-1}----------			-------------------------mg kg^{-1}----------------------					----g kg^{-1}----		mg kg^{-1}
'Cara larga'	34.76a	2.63a	2.47a	34.73a	3.09a	89.84a	40.10a	29.32a	6.42a	2.33a	26.61a
'Branca'	36.57a	2.24a	2.46a	49.38a	3.61a	8567a	45.50a	24.34a	7.23a	2.58a	25.52a
Mean	35.66	2.43	2.46	42.05	3.35	87.75	42.80	26.83	6.83	2.45	26.06
CV%	9.41	16.27	10.68	10.04	16.25	7.14	12.29	10.04	8.79	7.37	5.96

Means followed by the same letter do not differ according to the Tukey´s test (p<0.05).

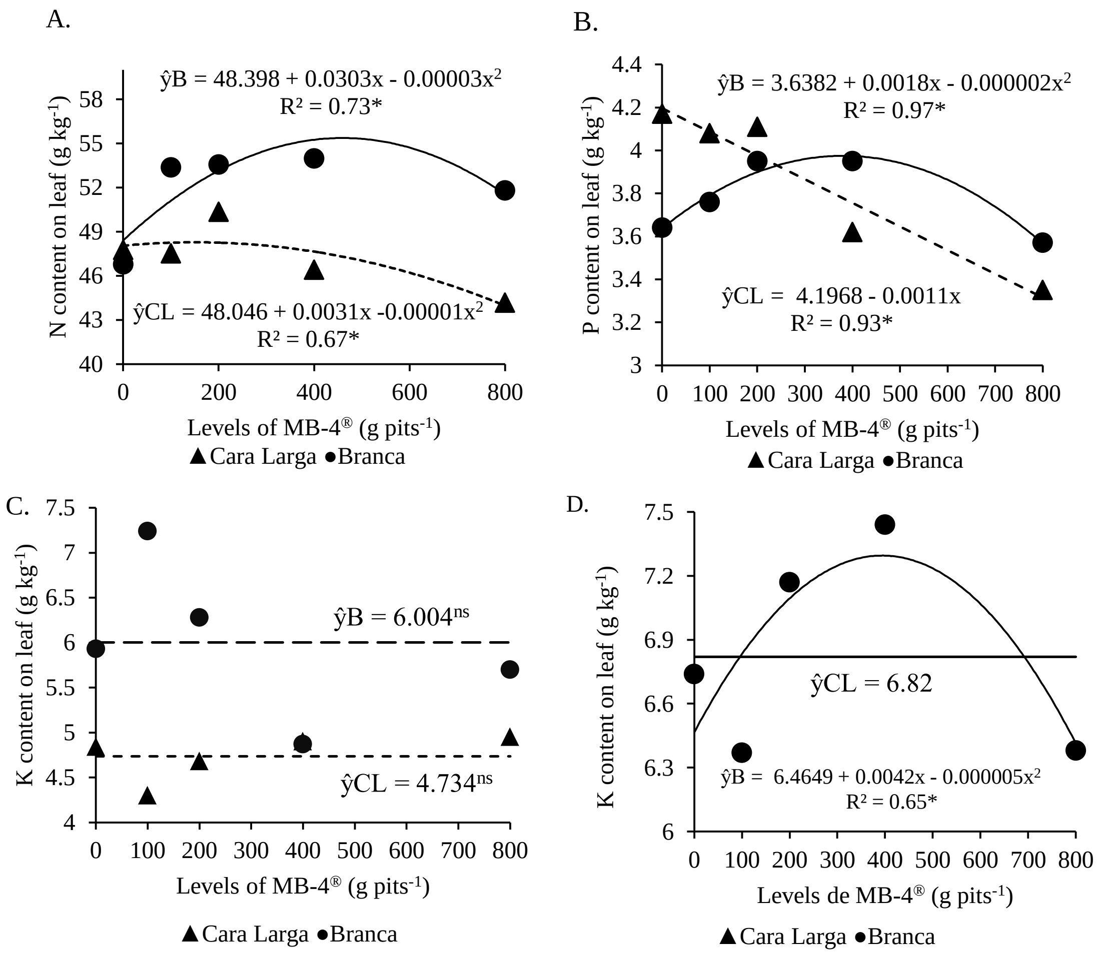

Figure 1. Nitrogen valuesin leaves, mean = 49.56 and CV (%) = 6.16 (A); phosphorus values in leaves, mean = 3.85 g and CV (%) = 7.02 (B); potassium values in leaves in the second planting, mean = 5.37 g and CV (%) = 16.89 in the first planting (C) and mean = 6.79 g and CV (%) = 8.79 in the second planting (D) as a function of MB-4® dosage.

Table 2. Chemical analysis of soil and MB-4® dosage.

	pH H_2O (1:2,5)	P**	K^+	Na^+	H^++Al^{+3}	Al^{+3}	Ca^{+2}	Mg^{+2}	SB	CTC	V	m	M.O.
		Mg dm^{-3}		------------------------Cmol dm^{-3}----------------							---%---		g kg^{-1}
Soil	5.6	34.69	30.00	0.22	3.38	0.00	1.35	1.00	2.64	6.03	44	0.00	30.90
MB-4	8.4	18.63	40.00	0.48	0.83	0.00	8.30	2.65	11.53	12.36	93	0.00	49.41

pH determined in water; P and K with the Mehlich^{-1} extractor; and Al^{+3}, Ca^{+2}, Mg^{+2} with the 1 mol L^{-1} KCl extractor.

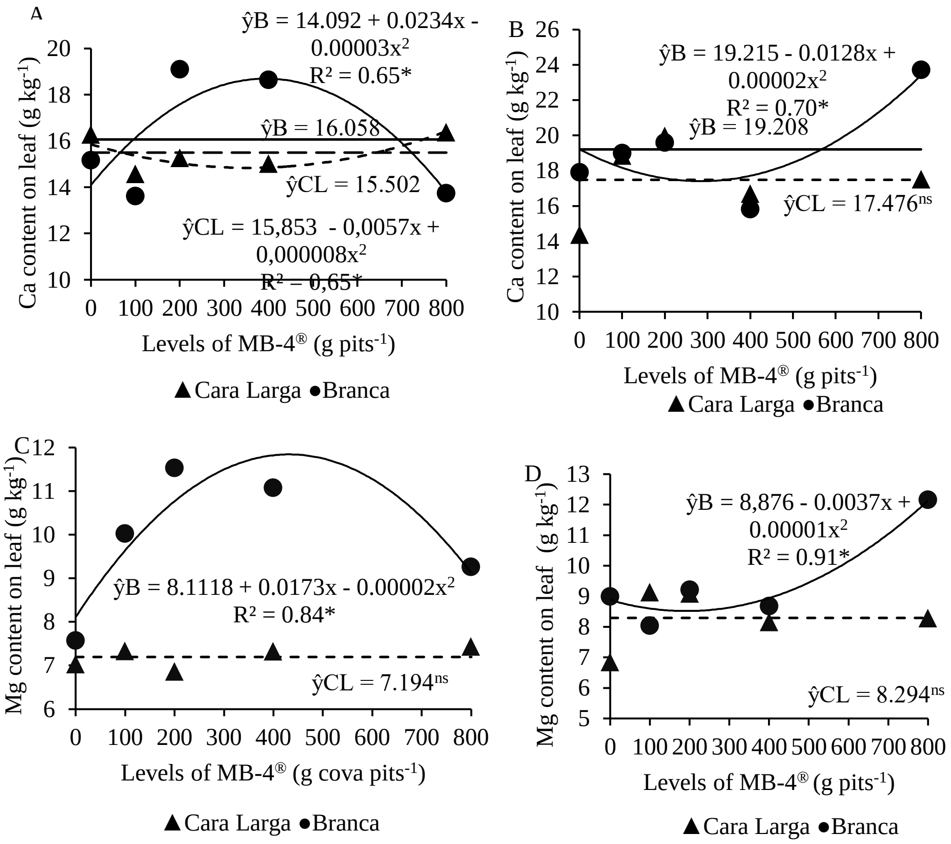

Figure 2. The mean values ofcalcium in leaves, mean = 15.18 and CV (%) = 7.09 in the first crop (A) and mean = 18.34 g and CV (%) = 8.49 in the second crop (B), the mean values ofmagnesium in leaves,mean = 8.54 g and CV (%) = 10.31 (%) = 10.31 in the first crop (C) and mean = 8.85 g and CV (%) = 11.53 in the second crop (D) as a function of MB-4® dosage.

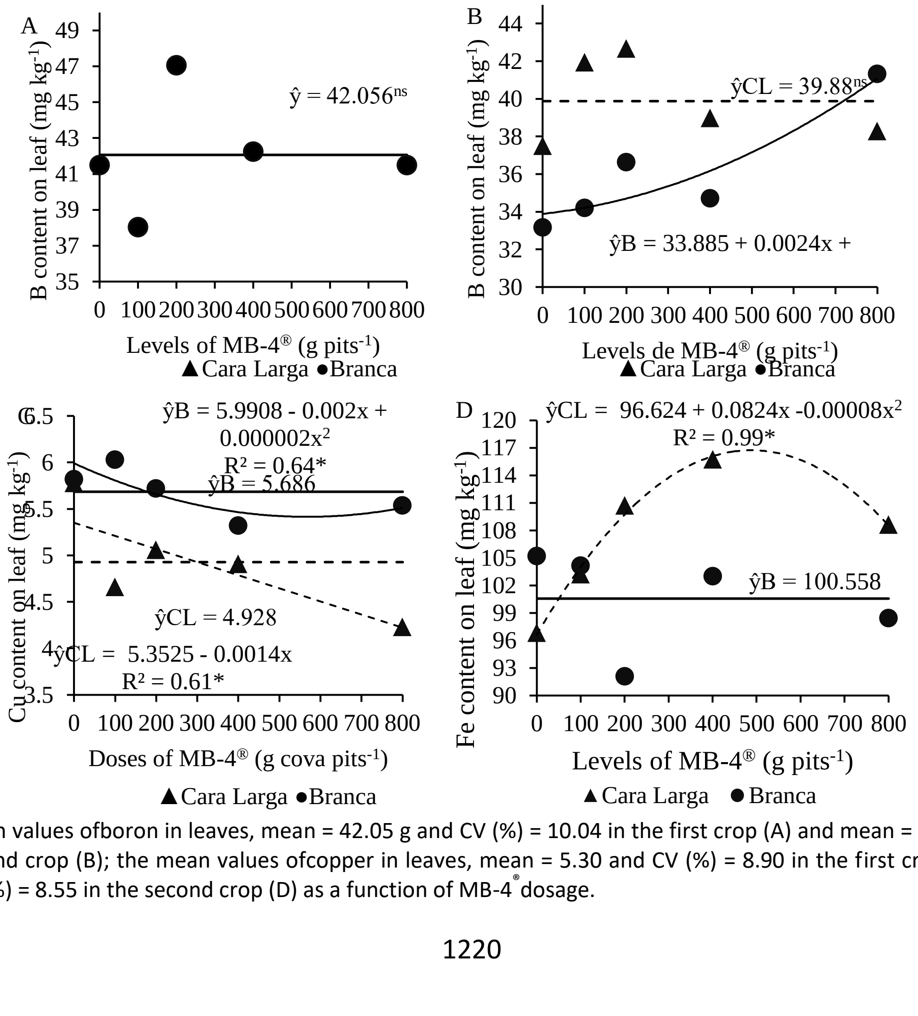

Figure 3. The mean values ofboron in leaves, mean = 42.05 g and CV (%) = 10.04 in the first crop (A) and mean = 37.94 g and CV (%) = 6.42 in the second crop (B); the mean values ofcopper in leaves, mean = 5.30 and CV (%) = 8.90 in the first crop (C) and mean = 103.78 g and CV (%) = 8.55 in the second crop (D) as a function of MB-4® dosage.

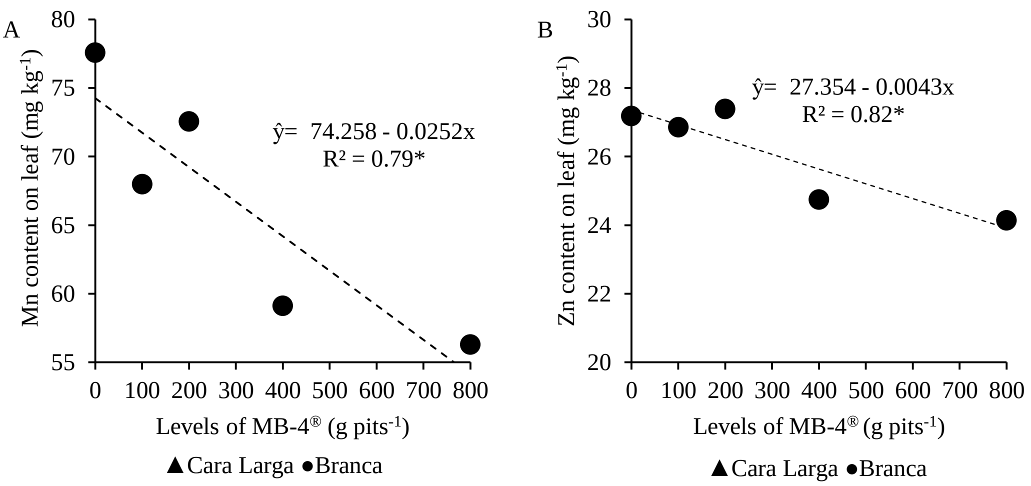

Figure 4. The mean values of manganese in leaves, mean = 66.71 g and CV (%) = 12.80 in the second crop (A), the mean values of zinc in leaves, mean = 26.06 g and CV (%) = 5.96 in the second crop (B) as a function of MB-4® dosage.

389.17 g hole^{-1}when evaluating the weight of seedlings without the 'Branca' variety seeds. In this study, the 'Branca' lima bean variety reached its peak Ca absorption and accumulation at anMB-4®dose of 390 g hole^{-1}in the first culture. In the second culture, it was observed that Ca uptake continued and increased linearly with increasing doses of MB-4®. There was also an increase in Ca in the second cropfor the 'Cara Larga' variety, even if the equation was not adjusted. This result shows that in the 'Branca' variety, Ca absorption occurred more rapidly and at a greater intensity. Dantas et al. (1979) suggest that 17.9 g kg^{-1} of Ca content in leaves is suitable for *P. vulgaris*. Foliar analysis of Mg content revealed a behavior very similar to that of Ca, especially in the first crop. The overall mean Mg content increased from the first crop to the second crop. However, the values were much higher than those recommended for the first cropfor Mg.

According to Dantas et al. (1979), Mg content of 1.4 g kg^{-1}in leaves is within the range suitable for *P. vulgaris*. However, VanRaij*et al*. (1996) cites that an Mg content of 2.5–5.0 g kg^{-1}in the leaves as a critical range for assessing nutritional status. According to Marschner (2012), N and Mg are synergistic. Thus, it was observed that increased Mg uptake may have influenced the appropriate N values due to this favorable availabilityaccording to the analysis of the rock dust verifying Mg^{2+}. Although the 'Branca' variety was responsible for higher absorption and accumulation of Mg in the first and second cultures, it was the second cultivation that showed higher absorption and accumulation of Mg, including the 'Cara larga' variety. This shows that the release of nutrients from rock dust to the soil solution is slow (Brandão, 2012). The 'Branca' variety responded more rapidly toMgabsorption and accumulation in relation to MB-4 ® dosage. The effect of dosage was verified using the F test at 5% probability for B content in the first culture (Figure 3A). When performing the regression analysis, we observed no adjustment; thus, the mean was used. In the second crop, a significant interaction was observed between dosage and the lima bean varieties with respect toB content (**Figure 3B**). A second-degree polynomial fit was observed for the 'Branca' varietywhen performing the regression analysis. No adjustment was found for the 'Cara larga' variety.

The means showed that there was a decrease in B micronutrient content in the second culture compared to in the first culture. Even with this reduction, the values wereabove those indicated by Van Raij et al. (1996), where a B content of 15-26 mg kg^{-1}was the critical range for *P.vulgaris*. There was a linear decrease in the Cu value of the 'Cara larga' variety in the second crop (Figure 3C). Despite this reduction, the means showed that there was a considerable increase when the two crop cultures were compared. This increase is within the Cu content range indicated by Van Raij et al. (1996), with 4–20 mg kg^{-1}in *P. vulgaris*. There was also a reduction for the 'Branca' variety, reaching the minimum point at the dose of 500 g hole^{-1}. However, the Cucontent remained within the range indicated for the cultivation of *P. vulgaris*. The Fe values in the first crop were already within the range indicated by Van Raij et al. (1996), with 40–140 mg kg^{-1} for *P. vulgaris*. However, Fe levels increased in the foliar tissues of the bean varieties cultivated in the second crop. This increase was more accentuated in the 'Cara larga' variety at 515g hole^{-1}. In the second crop, MB-4® dose increase promoted a progressive reduction in Mn and Zn absorption and accumulation in the leaves of the lima bean varieties, according to a linear relationship. The reductions occurred at constant rates from the dose up to the highest dose applied. This result demonstrates that anapplication of MB-4® in the soil was sufficient to cause a decrease in Mn and Zn absorption or accumulation inthe lima bean varieties investigated in this study. According to Marschner (2012), high B content reduces the Mn content in leaves. Thus, the reduction in Mn content may be a function of another micronutrient. In the case of Zn, VanStevenincket*et al*. (1987) considered that their reduction in translocation in plants subjected to excessive doses of Zn is a possible mechanism forincreasingtolerance to toxicity. According to the aforementioned authors, Zn accumulates in a greater proportion ofvacuoles in the cells of the root cortex. The doses of Zn used in this studydecreased the translocation of the root element to the leaves of lima bean plants. Even with the linear reduction in Mn and Zn leaf content in the native varieties of lima bean (Figures 4A and4B), the values found in the studywere within the range indicated by Van Raij et al. (1996), where Zn ranged from 18–50 mg kg^{-1}and Mg ranged from 15–100 mg kg^{-1} for *P. vulgaris*.

Material and methods

Research area

The experiments were conducted at coordinates of 6º 46 S and 35º 38 W, with an elevation of 617 m. The climate of the region is rainy, tropical, hot, and humid, according to the classification of Köppen (year).

The soil in the experimental area was classified as yellow dystrophic ultisol (Embrapa, 2006). The experimental area was plowed and arrowed prior to experiment 1, corresponding to the first crop. At that time, soilwas collected fromthe 0–20cm layer for chemical analysis, as well as the chemical analysis of a sample of MB-4® rock dust used for fertilization (Table 2) following Embrapa's methodology (2009).

Experimental design

The experiment was set up in a randomized block design (DBC), with four replicates, in a 2 × 5 factorial scheme corresponding to two lima bean varieties ('Cara Larga' and 'Branca') and five dose concentrations of rock dust: 0, 100, 200, 400, and 800 g hole^{-1}, corresponding to 2, 4, 8, and 16 t ha^{-1}, respectively, intercropped with maize. Each experimental plot consisted of three lines with seven holes each, spaced 1.0 m between rows and 0.50 m between holes. To eliminate edge effects, the plants in the five holes in the central line were analyzed for plotting.

Plant materials, Conduction of study and experimental design

The maize (*Zea mays*) native 'Palha Roxa' and lima bean (*P. lunatus*) native 'Branca' and 'Cara larga' varietieswere manually sowed in a hole. Four corn seeds and three Lima bean seeds of each variety were placed in each well. The doses of rock dust were applied and homogenized with the soil in the hole when sowing corn and Lima beans, only for the first crop (experiment 1). Thinning was performed on the fifteenth day post-germination, leaving two plants of each species per hole. Experiment 2, corresponding to these corn crops in the same area, was carried out forty days after the harvestto verify the residual effect of rock dust on subsequent cultivations. The average cycle time for both types of Lima beans was 165 days.

Traits measured

The methodology described for beans were used for nutritional analysis of the lima bean varieties. In this study, the first fully developed leaf was collected from the tip (Malavolta et al., 1997). One leaf per plant was taken from the centerline, totaling 10 leaves per plot.

The leaves were cleaned with cotton, moistened in distilled water, packed in kraft paper bags, dried in a forced-air oven at 72°C for 48 h, milled in a Wiley mill with a 30-mesh screen, and stored in hermetically sealed vials.

The nutrients analyzed were nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, copper, iron, manganese, and zinc. To determine the N content, the plant material was subjected to Sdigestion, using the method described byNessler (Jackson, 1965). The other nutrients (P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn) were quantified viaICP-OES, after digestion with concentrated HNO_3 and H_2O_2 in an open digestion system. ICP conditions: plasma gas 8.0 L min^{-1}, 0.70 L min^{-1} auxiliary gas and 0.55 L min^{-1} carrier gas (Peters, 2005).

Statistical analysis

The data were submitted to analysis of variance (F Test).In significant cases (p<0.05), a regression study was performed usingthe statistical software Assistat (v7.7) (Silva and Azevedo, 2009).

Conclusions

The leaf analysis indicated that the applied doses increased N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn content significantly in the second crop, and that only B content decreased. The N, P, Ca, B, Fe, Mn, and Zn contents were within the recommended range, while only K and Mg valueswere outside the recommended range. The values found between 200 and 400 g hole^{-1}, corresponding to 4 and 8t ha^{-1} of MB-4®, respectively, contributed the most to the increase in nutrient content in the lima bean varieties. Management with MB-4® is recommended for the species studied; however, it should not be used as the only source of fertilization.

Acknowledgments

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References

Ambrosano JE et al. (1996) Feijão. In: Van RAIJ, B. et al. (Ed.). Fertilization and liming recommendations for the State of São Paulo. 2.ed. Campinas: Instituto Agronômico, 1996. p. 194-195.

Almeida Júnior JJ, Smiljanic KBA, Matos FSA, Perozini AC, Sousa AC, Ribeiro Junior LF, Silva RF, Araújo SL, Dutra JM, Liberato PV (2020) Análise das variáveis tecnológicas do milho em função das doses crescentes de condicionadorpó de rocha. Braz J Develop. 6(11): 88440-88446.

Alovisi AMT, Taques MM, Alovisi AA, Tokura LK, Silva JAM, Cassol CJ (2020) Rocking as a sustainable alternative for soil fertilization. Ver Gestão Sust Amb. 9: 918-932.

Alovisi AMT, Rodrigues RB, Alovisi AA, Tebar MM, Villalba LA, Muglia GRP, Soares MSP, Tokura L.K, Cassol CL, Silva RS, Tokura WI, Gning A, Kai PM (2021) Uso do pó de rochabasálticacomofertilizantealternativonacultura da soja. Research, Society and Dev. 10(6): 1-12.

Assunção Filho JR, Costa MF, Pinheiro JB, Carvalho LCB, Ferreira-Gomes RL, Lopes ACA (2022) Selection of superior genotypes of lima bean landraces by multivariate approach. Rev Caatinga Mossoró. 35(1): 87-95.

Bertoldo JG, Pelisser A, Silva RP, Favreto R, Oliviera LAD (2015) Alternativasnafertilização de feijãovisando a reduzir a aplicação de N-ureia. Pesq Agropec Tropical. 45(3): 348-355.

Brandão JAV (2012) Rock dust as a source of nutrients in the context of agroecology**.** PhD dissertation, Universidade Federal de São Carlos, Araras-SP.

Dantas JP, BergaminFilho H, Malavolta E (1979) Studies on mineral nutrition of macassar beans (*Vigna sinensis* (L) Endl.). I: Mineral deficiencies. Paper presented Annals of Escola Superior de Agricultura Luiz de Queiroz, Piracicaba-SP, Brazil. 36: 231-246.

De Jesus LGA, Tavares LR, Gomes MFC, Valente SES, Gomes RLF, Lopes ACA, Costa MF (2018) Eficiência de testes colorimétrico spara determinação da viabilidade do pólenemacessos de feijão-fava (*Phaseolus lunatus* L.). Ver.

Brasileira de Agropec Sustentável. 8(1): 59-64.
Duarte JRM, Basílio SA, Vaz MBV, Pires JPD, Berti MPS (2021) Productivity and quality of bean seeds in response to mineral fertilizer, biofertilizer and rock powder. Ver Cultura Agronômica. 30(1):78-92.
Embrapa. National Soil Research Center (2006) Brazilian Soil Classification System. 2 ed. Rio de Janeiro: Embrapa Solos.
Embrapa. National Soil Research Center. 2009. Manual of chemical analysis of soils, plants and fertilizers. 2ª ed. Rio de Janeiro: Embrapa Solos.
Gonçalves JDM, Stape JL, Benedetti V, Fessel VAG, Gava JL (2000) Reflections of the minimum and intensive cultivation of the soil in its fertility and in the nutrition of the trees. Nutrition Forest Fertilization. Piracicaba: IPEF, p. 1-57.
Jackson ML (1965) Soil chemical analysis. New Jersey: Prentice Hall, 498p.
Malavolta E (1997) Evaluation of the nutritional status of plants: principles and applications/EurípedesMalavolta, Godofredo Cesar Vitti, Sebastião Alberto de Oliveira. —2. ed., ver. e atual. Piracicaba: Potafos.Marschner, H.2012.Marschner's Mineral Nutrition of Higher Plants. 3rd Edition. Academic Press. 672p.
Martínez-Nieto MS *et al.* (2020) Resilience capacity assessment of the traditional lima bean (*Phaseolus lunatus* L.) landraces facing climate change. Agronomy. 10: 758-773.
Peters JB (2005) Wisconsin Procedures for Soil Testing, Plant Analysis andFeed & Forage Analysis**:** Plant Analysis. Department of Soil Science, College of Agriculture and Life Sciences, University of Wisconsin-Extension, Madison, WI.<http://uwlab.soils.wisc.edu/files/procedures/plant_icp.pdf>Accessed: 20 fev. 2020.
Silva A (2007) Effect of application of basalt powder on soil chemical properties, nutrition and productivity of common bean and nutrient uptake by *Eucalyptus benthamii*. PhD diss, Universidade Federal de Santa Catarina, Lages-SC, Brazil.
Silva FAS, Azevedo CAV (2002) Version of the computer program Assistat for the operating system Windows. Rev Bras Prod Agroind. 4(1):71-78.
Van Raij B. et al. (1996) Fertilization and liming recommendations for the State of São Paulo. Campinas: IAC.
Van Steveninck RFM, Van Steveninck ME, Fernando DR, Godbold DL, Horst WJ, Marschner H (1987) Identification of zinc-containing globules in roots of a zinc-tolerant ecotype of Deschampsia caespitosa. J Plant Nutrition. 10 (9-16): 1239-1246.
Writzl TC, Canepelle E, Stein JES, Kerkhoff JT, Steffler AD, Silva DW, Redin M (2019) Produção de milhopipoca com uso do pó de rocha de basaltoassociado à cama de frangoemlatossolo. Ver. Brasileira de Agropecuária Sustentável (RBAS). 9(2):101-109.