



EFFECT OF AGROSILICON PLUS AND DOLOMITIC LIMESTONE ON THE ACIDITY CORRECTION OF SOIL CULTIVATED WITH BUTTER CABBAGE (*Brassica oleracea*)

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ABSTRACT

The objective of this study was to evaluate the agricultural potential of the product based on steel slag, marketed as Agrosilício Plus®, as to the efficiency in the correction of soil acidity, in comparison to dolomitic limestone, on the morphophysiological aspects of butter cabbage with the application of the two agricultural inputs. To this end, an experiment was conducted in Ibiapaba, Ceará, in randomized blocks with three treatments: 2,500 kg ha⁻¹ of limestone, 2,625 kg ha⁻¹ of Agrosilicon Plus® and control (0 kg ha⁻¹) with three repetitions, and the plants used were butter cabbage for evaluation. The soil was evaluated before and after 90 days of the experiment, and the morphological aspects of the cabbage plants were also evaluated. It was observed that the two amendments have similar effects in the soil correction, being significant in the Ca and Mg contents in the soil, besides the changes in pH, CEC, V%, and reduction of H+Al, with significant effect in the length and width of the leaf lamina of the cabbage. Agrosilicon Plus® was more efficient in raising the soil pH to 6.0, the ideal for cabbage cultivation. The leaves were positively influenced by both Agrosilicon Plus® and dolomitic limestone.

PALAVRAS-CHAVE: Acidity corrective; Ibiapaba; Olericulture; Siderurgic residue.

EFEITO DO AGROSILÍCIO PLUS E DO CALCÁRIO DOLOMÍTICO NA CORREÇÃO DA ACIDEZ DE SOLO CULTIVADO COM COUVE-MANTEIGA (*Brassica oleracea*)

RESUMO

O objetivo deste estudo foi avaliar o potencial agrícola do produto à base de escórias de siderurgia, comercializado como Agrosilício Plus[®], quanto à eficiência na correção da acidez do solo, em comparação ao calcário dolomítico, sobre os aspectos morfofisiológicos da couve-manteiga com a aplicação dos dois insumos agrícolas. Para tanto, conduziu-se um experimento na Ibiapaba, Ceará, em blocos casualizados com três tratamentos: 2.500 kg ha⁻¹ de calcário, 2.625 kg ha⁻¹ de Agrosilício Plus[®] e o controle (0 kg ha⁻¹) com três repetições e a planta utilizada foi a couve-manteiga para avaliação. O solo foi avaliado antes e após 90 dias do experimento, avaliou-se também os aspectos morfológicos das plantas de couve. Notou-se que os dois corretivos têm efeitos semelhantes na correção do solo, sendo significativo nos teores de Ca e Mg no solo, além das mudanças de pH, CTC, V% e redução de H+Al, com efeito significativo no comprimento e largura do limbo foliar da couve. O Agrosilício Plus[®] foi mais eficiente em elevar o pH do solo para 6,0, o ideal para o cultivo da couve. As folhas foram influenciadas de forma positiva tanto pelo Agrosilício Plus[®] e pelo calcário dolomítico.

KEYWORDS: Corretivo de acidez; Ibiapaba; Olericultura; Resíduos siderúrgico.

INTRODUCTION

In recent years, the consumption of butter cabbage (*Brassica oleracea*) has been gradually increasing, probably due to new ways of using it in cooking and recent scientific discoveries about its nutritional and medicinal properties. Compared to other leafy vegetables, kale stands out for its higher content of protein, carbohydrates, fiber, calcium, iron, iodine, vitamin A, niacin, and vitamin C (TRANI *et al.*, 2015).

This plant can be propagated by seed or by seedlings, depending on the variety. One of the methods preferred by farmers is vegetative propagation, with the formation of seedlings from shoots that appear in the axils of the leaves, in most cultivars. As for the management of fertilization and liming of this crop, it is extremely important to have the soil analysis at hand and, according to its results, to adequately apply each of the inputs. If there is a need for soil correction, it is recommended to incorporate lime before planting (30 to 90 days), increasing the base saturation to 80%, the magnesium content to a minimum of 0.9 cmolc dm⁻³, and adjusting the pH in the range 5.5 to 6.0 (OLIVEIRA *et al.*, 2020).

The cultivation of butter cabbage is very present in Brazilian family farming mainly due to its ease of propagation (TRANI *et al.*, 2015), however, it is important the correct management of inputs such as fertilizers and correctives by producers to obtain better yields, since one of the characteristics of the olericulture is the intensive use of soil, demanding high amount of nutrients per unit area, which present considerable production costs (SILVA *et al.*, 2014).

Soil acidity, for example, is one of the main chemical attributes that is related to the development of cultivated plants, affecting the availability of almost all nutrients for crops. Based on the concepts of acidity and the need for agricultural cultivation in acid soils, it is necessary to apply efficient correctives to change the pH of the medium, which, by raising the pH level, neutralize the effect of toxic elements to

plants, especially aluminum (EBELING *et al.*, 2008; SORATTO *et al.*, 2010; McGRATH; SPARGO; PENN, 2014).

Certainly, limestone is one of the low-cost and efficient inputs in agriculture. However, as this material is poorly soluble and its reaction products have limited mobility, its initial action is usually restricted to the surface layers, especially in soils cultivated under a no-till farming system, due to the absence of soil disturbance (SORATTO; CRUSCIOL, 2008).

On the other hand, the use of steel mill slag in agriculture represents an important way to take advantage of this waste, which can be used as a soil acidity corrective and a source of calcium, magnesium, and silicon for plants, given that, the use of soil acidity corrective products that are within our reach still needs information, both in the production of seedlings and in agricultural production itself and at all technological levels (BRASIL; NASCIMENTO, 2019).

One of the steel mill slags is the product commercially called Agrosilício Plus[®], which is a mineral fertilizer that contains the micronutrient silicon (Si) and the macronutrients calcium (Ca) and magnesium (Mg). Thus, it can contribute in the correction of soil acidity and increase the availability of phosphorus (SOUZA, CHAVES; 2015) by containing silicon, can also provide a more uniform distribution of manganese in the leaf reducing its toxicity, acts in the structure of the plant improving its photosynthetic capacity (LIANG *et al.*, 2015) and in the height and diameter of the thatch (SOUZA *et al.*, 2015), reducing excessive transpiration of plants (ÁVILA *et al.*, 2010), increasing photosynthetic efficiency and resistance to lodging (DEREN, 2001). Therefore, the use of materials containing silicon (Si) in their constitution for the correction of acidity is valid, provided they contain a "neutralizing constituent" such as oxides, hydroxides, carbonates and silicates of calcium and magnesium (CASTRO *et al.*, 2015).

In this context, the objective was to evaluate the agricultural potential of the product based on steel slag, marketed as Agrosilicon Plus[®], regarding the efficiency in correcting soil acidity, comparison to dolomitic limestone, on the morphophysiological aspects of butter cabbage with the application of both agricultural inputs.

MATERIAL AND METHODS

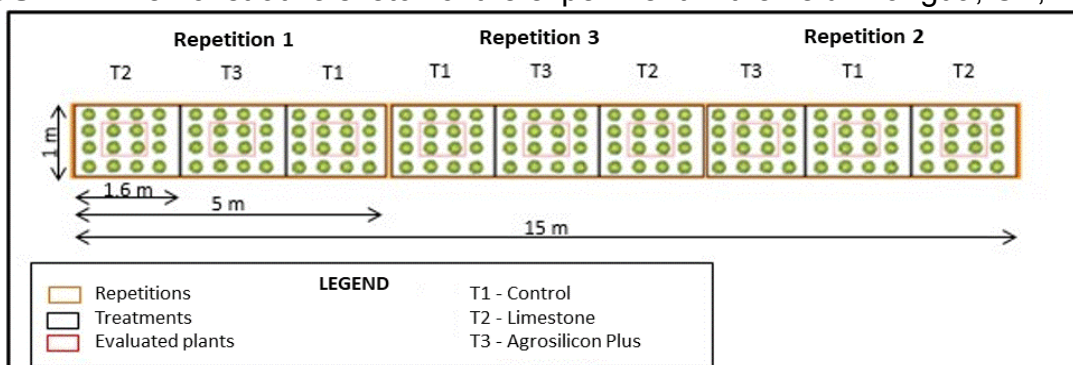
The experiment was conducted in the county of Tianguá – CE, in Pitanga farm in the period December 2021 to June 2022, located at coordinates 3°45'59.05" South latitude and 40°58'34.95" West longitude and altitude of 808 m. According to the climatic classification of Köppen (1931), the climate of the Ibiapaba region is characterized by Aw, a tropical climate with a dry winter. It has a rainy season in the summer from November to April and a clear dry season in the winter from May to October.

First, soil samples were collected for chemical and physical analysis in the 0 - 20 cm layer 60 days before the experiment and, later, for liming and fertilization calculations.

The seedlings were prepared in the Semear nursery located in the city of Tianguá-CE, for the time of transplanting to the experimental site, the seedlings were in phenological stage II, i.e., with at least five definitive leaves. The variety of butter cabbage used was the hybrid Hi-crop of the brand and manufacturer Takii, the choice of variety was based on information from the use of this variety by local producers, which has wide adaptability and high yield in different climatic conditions and acceptability in the local market.

The experiment was conducted in randomized blocks corresponding to three treatments: Control treatment (T1), treatment with dolomitic limestone (T2) at a proportion of 2,500 kg ha⁻¹, and treatment with Agrosilicon Plus® (T3) at a proportion of 2,625 kg ha⁻¹. Each treatment was performed in three repetitions and with 18 butter cabbage plants per plot with a spacing of 0.4 m between plants and 0.3 m row. For morphological evaluation of the plants four central plants were considered disregarding the border as shown in figure 1.

FIGURE 1. Demonstrative sketch of the experiment in the field. Tianguá, CE, 2022.



Source: Authors (2022).

The doses of lime and agrosilicon Plus as soil corrective treatments were determined based on the soil analysis performed before the implementation of the experiment, according to the formula below, considering the PRNT of each input, being 92.38 and 88 for lime and agrosilicon Plus, respectively.

$$NC = \left(\frac{V2 - V1}{PRNT} \right) T, \dots\dots\dots(01)$$

In which:

- NC – Need for correction (t ha⁻¹);
- V2 – Desired base saturation (70% as required by the crop);
- V1 – Initial base saturation (%);
- T – Cation exchange capacity (cmol_c dm⁻³)
- PRNT – Relative neutralizing power total inputs (%)

The treatments (doses) used were applied uniformly and incorporated into the soil (layer elevated 20 cm from the surface) fifteen days before transplanting. The 15 m long field divided into three equal parts of five meters, which were called repetitions, subdivided into three equal parts of 1.66 m to receive each treatment used.

The Agrosilicon Plus used in this research was registered under the No. MG-1001910002-4 in the Ministry of Agriculture, Livestock and Supply (MAPA) with the following characteristics: silicon (10.5%), calcium (25%), magnesium (6%), and PRNT indicated on the package (88%). The dolomitic limestone used was also registered under the number CE-08141-10000-7 in MAPA with the composition of calcium (32%), magnesium (15%), and PRNT (92.38%).

The soil was evaluated before the experiment, the chemical characteristics such as pH in water, O.M (g kg⁻¹), P (mg dm⁻³), Ca (cmol_c dm⁻³), Mg (cmol_c dm⁻³), K (cmol_c dm⁻³), Na (cmol_c dm⁻³), Al (cmol_c dm⁻³), H+Al (cmol_c dm⁻³), SB (cmol_c dm⁻³), CTC (cmol_c dm⁻³), V%, m (%) and physical as grain size: sand, silt and clay (%). At

the end of the experiment, after three months, a new soil collection was made to evaluate changes in pH, Ca, Mg and P availability. In the kale plant, plant height (AP), leaf limb width (LLF), leaf limb length (CLF), and root biomass (BR) were evaluated.

The data were tabulated and subjected to the Shapiro-Wilk test to verify normality, the analysis of variance, the F test, and the comparison of means by the Tukey test at 5% probability using statistical software SISVAR 5.6 (FERREIRA, 2019).

RESULTS AND DISCUSSION

According to Table 1, the results obtained by comparing them to the control treatment, it was observed that some soil chemical attributes changed, such as pH, P, Ca, Mg, Al, H+Al, SB, CTC, V%, and m. This fact shows that the two inputs act on the soil in different ways, but both have positive effects in the process of correcting agricultural soils, that is it was noted that the inputs have similar effects in correcting soil acidity, thus providing an increase in Ca and Mg in the soil consequently, there were changes in pH, CTC, V% and reduction of H+Al. Our results, are similar to those found by Sousa *et al.* (2015) these authors reported that there was a linear increase in the calcium, magnesium and pH indices of the soil according to the doses of silicate of the commercial product Agrosilicon Plus® applied to the soil after cultivation of okra (*Abelmoschus esculentus*).

TABLE 1. Results of soil analysis performed before and after 90 days of experiment installation.

SV	Tratamentos			
	Before ¹	Agrosilicon ²	Limestone ²	Control ²
pH (H ₂ O)	4.9	6.0	5.4	4.6
O.M (g kg ⁻¹)	12.9	10.1	13.5	11.6
P (mg dm ⁻³)	155.2	123.9	122.1	134.5
K (cmol _c dm ⁻³)	0.10	0.11	0.09	0.09
Ca (cmol _c dm ⁻³)	1.86	2.75	1.78	1.42
Mg (cmol _c dm ⁻³)	0.60	0.82	0.78	0.39
Al (cmol _c dm ⁻³)	0.21	0.0	0.0	0.34
H+Al (cmol _c dm ⁻³)	4.35	1.67	2.40	3.70
SB (cmol _c dm ⁻³)	2.56	3.68	2.63	1.90
CEC (cmol _c dm ⁻³)	6.91	5.35	5.03	5.6
V (%)	37.0	68.8	52.3	34
m (%)	7.59	0.0	0.0	15.17
Sand (%)	68	68	68	68
Silt (%)	11	11	11	11
Clay (%)	21	21	21	21
Soil texture	Sandy-sandy clay			

SV – Source of variation; ¹ – before the implementation of the experiment; ² – soil analysis results after 90 days. **Source:** Authors (2022).

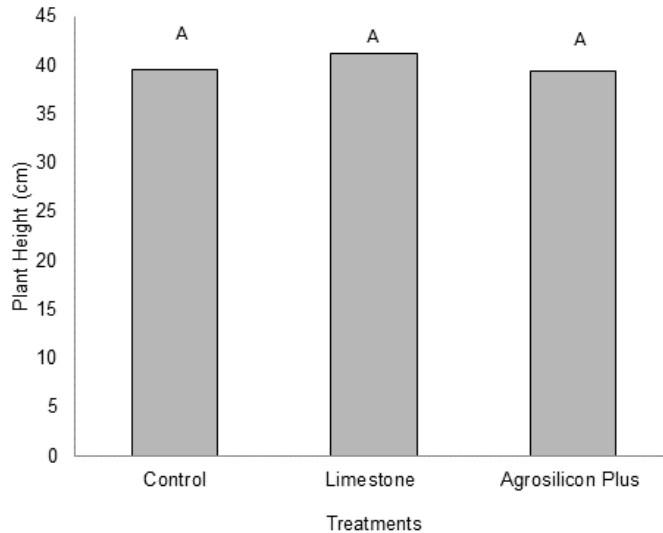
Despite the similarity between dolomitic limestone and Agrosilicon Plus[®], Agrosilicon Plus[®] showed an improvement in soil pH (6.0), while dolomitic limestone the final pH was 5.4, it can be said that a slower change occurred compared to the control treatment and Agrosilicon Plus (Table 1). Therefore, Agrosilicon Plus[®] and Agricultural Limestone were efficient in raising the pH of the soil making it suitable for the cultivation of butter cabbage since its ideal pH range required between 5.5 to 6.0 (OLIVEIRA *et al.*, 2020).

On the other hand, when it comes to soil pH, the results are in contrast to those obtained by Rezende *et al.* (2007) and Prado *et al.* (2002) because the authors observed that slag is less effective than lime in raising soil pH. In a study conducted by Ali and Shahram (2007) in Iran on the use of slag to correct acidic soil, the authors observed that slag has the potential to be used to correct soil pH, which is similar to the results obtained in this research. In Brazil, Prado *et al.* (2002) evaluated the effects of steel mill slag and magnesian and dolomitic limestone on the dry matter production of lettuce (*Lactuca sativa* L.) and concluded that all the corrective materials were efficient in correcting soil acidity, especially when magnesian limestone was used. Thus, siderurgia slag possibly has positive responses in cultivation of oleric crops.

The potential acidity (H+Al) was markedly reduced by the application of Agrosilicon Plus[®] when the correctives promoted positive linear increments and, consequently, the CEC and the base saturation also increased. It was noted that Agrosilicon Plus[®] provided important modifications in chemical attributes when compared to dolomitic limestone.

As for plant growth (Figure 2), there was no statistical difference by Tukey test ($p > 0.05$) among the treatments, however, the treatment with lime the plants presented higher averages (41.16 cm), followed by the control treatment (39.50 cm) and finally, the treatment with Agrosilicon Plus[®] (39.41 cm). According to Novo *et al.* (2010), cultivars with plants 40-80 cm tall are classified as medium to tall, and those with at least 90 cm are called tall. In Brazil, these plants are medium to tall; in the present study, they are considered medium height. In the study of Moura *et al.* (2018), the productivity of organic transition cabbage (*Brassica oleracea*) in the treatment with lime presented 40.6 cm in height, corroborating the data demonstrated in the present work. In summary, for any of the inputs the height of cabbage plants will not have significant interference.

FIGURE 2. Average height of butter cabbage plants under different soil correctives. Tianguá, CE, 2022. The same letters in the columns do not differ from each other by Tukey test at 5% probability.

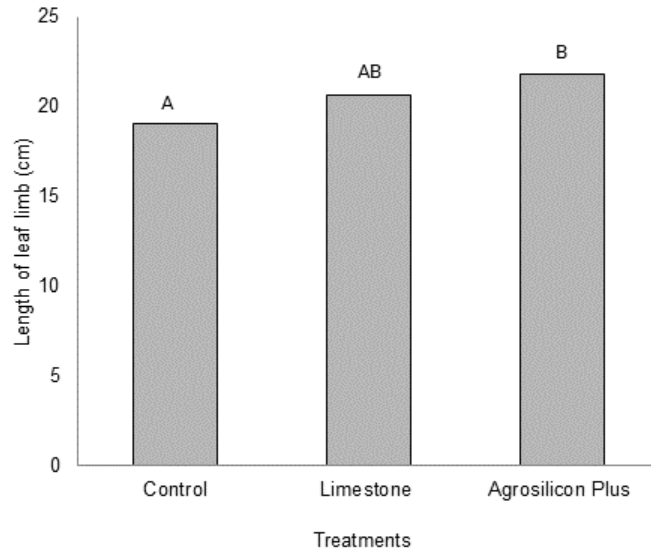


Source: Authors (2022).

An alternative for obtaining the leaf area is its estimation utilizing geometric measurements such as the length and width of the lamina (ODABAS *et al.*, 2013). The advantage of this method is that the measurement of the width and length can be done with high precision in cabbage leaves, being a low-cost, fast, and non-destructive method. Leaf limb length and width have been used for leaf area estimation in several vegetables such as tomato and cucumber, broccoli, strawberry, zucchini, radish, and pepper (AHMADIAN, 2012).

It is worth mentioning that in the cultivation of butter cabbage the leaf and its area are important because it is the commercialized part of this plant that, is a plant with healthier and larger leaves will have greater commercial visibility. According to Figure 3, the leaf lamina length (CLF) was significant ($p \leq 0.05$) and the best result was obtained with the treatment using Agrosilicon Plus® (21.81 cm) compared to the control treatment (19.04 cm). According to Filgueira (2013), these leaves are considered long and meet the marketing standard in Brazil, which vary from 20 to 30 cm.

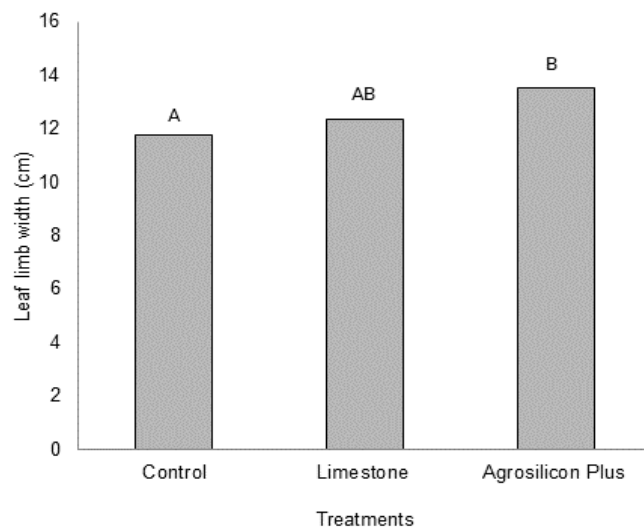
FIGURE 3. Median leaf limb length of butter cabbage under different soil amendments. Tianguá, CE, 2022. The same letters in the columns do not differ from each other by Tukey test at 5% probability.



Source: Authors (2022).

Figure 4 shows the average results obtained for the leaf lamina width (LLF). There is a statistical difference between the treatments, with the Agrosilicon Plus[®] treatment showing the greatest difference (13.54 cm) compared to the control (11.74) however, it differs statistically from the treatment with lime (12.35 cm). Therefore, in general, it was observed that from the results of LLF and CLF both limestone and agrosilicon positively influence a good leaf area.

FIGURE 4. Average leaf limb width of butter cabbage under different soil amendments. Tianguá, CE, 2022. The same letters in the columns do not differ from each other by Tukey test at 5% probability.

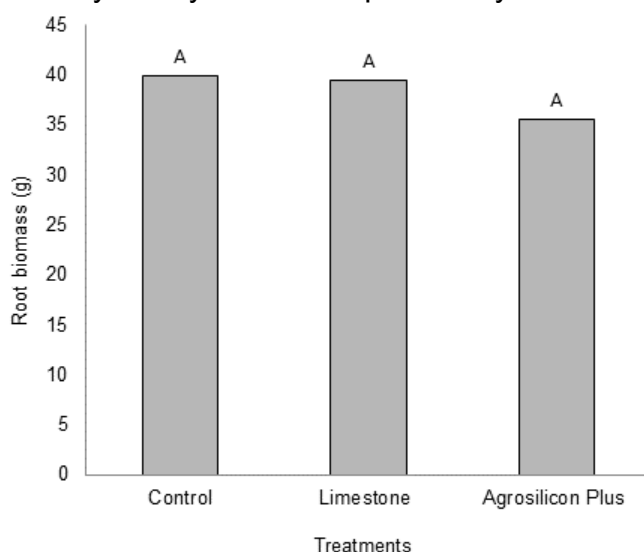


Source: Authors (2022).

The root biomass of butter cabbage (figure 5), it was noted that there was no statistical difference ($p > 0.05$) among treatments however, slightly greater biomass was for the control treatment (39.91 g) this is due to the growth of plants by the search for nutrients in the soil, followed by the treatment with lime (39.41 g) and finally for the treatments with Agrosilicon plus[®] (35.50 g). Certainly, a soil can be chemically good, but if its compaction occurs, the plants do not benefit adequately from the nutrients since the development of new roots is harmed and it is in them that the highest rate of absorption occurs.

Furthermore, with the compaction of the soil layer explored by the roots, there is a reduction of the pore space and consequently, the amount of oxygen available in the rhizosphere, limiting the metabolic processes of the plant (QUEIROZ-VOLTAN; NOGUEIRA; MIRANDA, 2000). Finally, the development of the root system is also due to good agricultural practices because one of the ways to always have a good performance of the root system is to rotate crops so that the soil is not exhausted.

FIGURE 5. Mean values of root biomass of butter cabbage under different soil amendments. Tianguá, CE, 2022. The same letters in the columns do not differ from each other by Tukey test at 5% probability.



Source: Authors (2022).

Therefore, the use of soil acidity correctives is of utmost importance to increase agricultural production, considering that most Brazilian soils are acidic and the benefits that acidity correction can provide. Through this work, it was possible to observe that there are inputs with the same agricultural potential compared to lime for correcting soil acidity; however, further studies with other agrosystems are necessary.

In figure 6, it was observed that there is a positive linear relationship between the pairs K and pH; Ca and pH; Mg and pH; SB and pH; V and pH; CLF and pH; LLF and pH; D and pH, indicating a strong correlation, that is, the direct effect of the correctives on soil acidity that by raising the pH values positive influences the soil fertility variables, consequently on the growth variables of butter cabbage.

FIGURE 6. Person correlation matrix for soil variables and butter cabbage plant growth.

	pH	O.M	P	K	Ca	Mg	Al	H+Al	SB	CEC	V	m	AP	CLF	LLF	DC	BR
pH	1																
O.M	-0.365	1															
P	-0.839	-0.201	1														
K	0.822	-0.830	-0.379	1													
Ca	0.942	-0.655	-0.608	0.965	1												
Mg	0.937	-0.016	-0.976	0.571	0.766	1											
Al	-0.904	-0.068	0.991	-0.500	-0.709	-0.996	1										
H+Al	-0.997	0.291	0.879	-0.775	-0.913	-0.961	0.935	1									
SB	0.983	-0.531	-0.724	0.913	0.988	0.856	-0.810	-0.965	1								
CEC	-0.510	-0.615	0.896	0.071	-0.193	-0.778	0.828	0.576	-0.342	1							
V	0.999	-0.413	-0.809	0.851	0.959	0.917	-0.881	-0.991	0.991	-0.464	1						
m	-0.904	-0.068	0.991	-0.500	-0.709	-0.996	1.000	0.935	-0.810	0.828	-0.881	1					
AP	0.037	0.917	-0.575	-0.539	-0.300	0.384	-0.460	-0.115	-0.149	-0.878	-0.016	-0.460	1				
CLF	0.999	-0.403	-0.816	0.845	0.955	0.922	-0.886	-0.993	0.990	-0.474	1.000	-0.886	-0.004	1			
LLF	0.963	-0.602	-0.661	0.945	0.998	0.808	-0.756	-0.939	0.996	-0.260	0.976	-0.756	-0.234	0.973	1		
DC	0.948	-0.643	-0.621	0.961	1.000	0.776	-0.721	-0.920	0.990	-0.209	0.963	-0.721	-0.284	0.960	0.999	1	
BR	-0.886	0.755	0.490	-0.992	-0.990	-0.668	0.603	0.847	-0.956	0.052	-0.909	0.603	0.432	-0.904	-0.978	-0.988	1

Source: Authors (2022).

As for potential acidity (H+Al), there is a negative linear relationship for the soil bases (K, Ca and Mg), indicating a strong to moderate correlation between the variables that is, there is a negative relationship with the presence of aluminum in the soil (Al), showing that its neutralization is extremely necessary by means of correctives, since the soil bases are important components of soil fertility and essential to the plants. Logically, also because there is a positive relationship between cabbage growth variables (CLF, LLF and CD) and soil bases, with positive Pearson correlation coefficients, considered moderate to very strong, indicating a direct relationship between the effects of correctives on plant growth. On the other hand, there is a direct moderate to very strong negative relationship between the growth variables (CLF, LLF and DC) and the presence of Al, well as the potential acidity (H+AL). Therefore, the correction of acidity and neutralization of aluminum in the soil is fundamental in areas cultivated with kale.

CONCLUSION

Agrosilicon Plus[®] and dolomitic limestone showed similar effects in correcting the acidity of the weak-clayey-sandy soil. The uses of these inputs provided significant increases in Ca and Mg in the soil, consequently influencing changes in pH, CEC, V% and reduction of H+Al.

Agrosilicon Plus[®] behaved as more sensitive in elevating the pH, Ca, and Mg values, making the pH the ideal condition for butter cabbage cultivation.

The morphophysiological characteristics of butter cabbage related to the leaves are significantly influenced positively by both Agrosilicon Plus[®] and dolomitic limestone.

Finally, after field evaluation for this type of soil, we arrived at the following doses to be recommended: Agrosilicon Plus[®] will be 2.60 t ha⁻¹, and dolomitic limestone will be 2.46 t ha⁻¹ however, when we compare market values the limestone has lower cost-benefit, whose 40 kg bag is sold for average value R\$ 25.00, on the other hand, the 50 kg bag of Agrosilicon Plus[®] costs an average of R\$ 85.00, thus, it is up to the producer to choose these inputs aiming at cost-benefit and efficiency in soil correction to obtain high productivity.

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