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Soil acidity and soy phytometry under application of limestone and agricultural gypsum

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Abstract

The soybean is one of the main agricultural crops in Brazil, because the use of its grains is an important source of protein and vegetable oil. One of the main limiting factors for obtaining high yields in soybean in tropical soils is related to the need to correct soil acidity. The objective of this study was to evaluate the growth of (*Glycine max* (L.) Merrill) and the variation of soil pH values under the application of limestone and agricultural gypsum. The experimental design was completely randomized, distributed in a 4x4 factorial scheme. The treatments consisted of doses of 0, 1.5, 3.0 and 4.5 t ha^{-1} of only limestone, only gypsum and the combination of limestone and gypsum, repeated four times, totaling 64 experimental units. The soil pH was evaluated at 30, 45, 60, 75 days before sowing. The growth variables were: number of pods, shoot dry mass, root dry mass, root length and shoot/root ratio. The variables pH 75 days, root length and shoot/root ratio were significantly influenced by the treatments, alone or in interaction. For pH 30, pH 45 and pH 60 days, number of pods and shoot dry mass, there were isolated effects of treatments for gypsum and limestone. In root dry mass, the effect of the treatment was verified only with the use of limestone. As a conclusion, the application of limestone and gypsum reduces the soil acidity, obtaining higher pH values from the doses of 3000 kg ha^{-1}, with the combination of limestone and gypsum. The use of gypsum consortium with limestone promotes significant results in the growth of soybean plants.
Keywords: lime; gypsum; pH; *Glycine max* (L.) Merrill.

Acidez do solo e fitometria de soja sob aplicação de calcário e gesso agrícola

Resumo

A soja é uma das principais culturas agrícolas do Brasil, pois, a utilização de seus grãos é uma importante fonte de proteínas e óleo vegetal. Um dos principais fatores limitantes para obtenção de altos rendimentos na soja, em solos tropicais, está relacionado à necessidade de correção da acidez do solo. O objetivo do estudo foi avaliar o crescimento de (*Glycine max* (L.) Merrill) e a variação dos valores de pH do solo sob a aplicação de calcário e gesso agrícola. O delineamento experimental utilizado foi inteiramente casualizado, distribuídos em esquema fatorial 4x4, os tratamentos constaram de doses 0, 1,5, 3,0 e 4,5 t ha^{-1} sendo elas somente calcário, somente o gesso e a combinação de calcário e gesso, repetidos quatro vezes, totalizando 64 unidades experimentais. O pH do solo foi avaliado a 30, 45, 60 e 75 dias antes da semeadura. As variáveis de crescimento foram: número de vagens, massa seca da parte aérea, massa seca da raiz, comprimento da raiz e relação parte aérea/raiz. As variáveis pH 75 dias, comprimento da raiz e relação parte aérea/raiz, foram influenciadas significativamente pelos tratamentos, isoladamente ou em interação. Para o pH 30, 45 e 60 dias, número de vagens e massa seca da parte aérea ocorreram efeitos isolados dos tratamentos para gesso e calcário. Na massa seca da raiz o efeito do tratamento foi verificado apenas com a utilização do calcário. Como conclusão, a aplicação de calcário e gesso reduz a acidez do solo, obtendo maiores valores de pH a partir das doses de 3000 kg ha-1, com a combinação de calcário e gesso. A utilização do gesso consorciado com o calcário promove resultados significativos no crescimento das plantas de soja.

Palavras-chaves: calagem; gessagem; pH, *Glycine max* (L.) Merrill.

Introduction

Soybean (*Glycine max* (L.) Merrill) is one of the main agricultural plants cultivated in Brazil. This agricultural crop has an excellent protein, animal feed and oil for human consumption production capacity (OLIVEIRA NETO; GONÇALVES, 2019), with emphasis also on industrial products and as an alternative source of biofuel (MICHELON *et al.*, 2017). Brazil is the largest producer of oilseeds in the world, with 137.320 million tons in the 2020/21 crop. For the 2021/22 harvest, an increase of 4% is estimated in relation to the previous crop (CONAB, 2021).

Soybeans belong to the Fabaceae family, it is an annual cycle plant and, according to Neumaier *et al.* (2020), it adapts to regions with hot and humid climates. It is considered a short day plant, as it responds to the length of the day, and therefore, to the photoperiod. As for its growth habit, Bonato (2000) describes that it can present determined, semi-determined and indeterminate growth, depending on the variety used.

One of the main limiting factors for obtaining high yields in soybean is linked to the fertilization used in its cultivation (OLIVEIRA JUNIOR *et al.*, 2020). The management to obtain high yields in the soybean crop is translated into the interaction of climate, plant and soil, allied to the efficient and rational use of fertilizers (NEUMAIER *et al.*, 2020), since the correct fertilization will provide better conditions for maximizing yields.

Soil acidity limits agricultural production in many areas of the world, due to the toxicity caused by Al and Mn in combination with low basic cations such as Ca and Mg (LO MONACO *et al.*, 2016). Soils in the Amazon region have high acidity and high aluminum contents, low phosphorus, low cation exchange capacity (CEC) and macro and micronutrient deficiency, which can make crop production inefficient (VALE JÚNIOR *et al.,* 2011).

The application of agricultural correctives is necessary to correct soil acidity in order to obtain higher crop yields (SILVA *et al.*, 2019). Correction of soil acidity neutralizes Al toxicity and increases Ca contents (VASQUES *et al.*, 2020), positively influencing root growth. Liming is the most efficient practice to increase the pH, Ca content, and base saturation, neutralize exchangeable Al and Mn in the soil, making the nutrients more available, and increasing the efficiency of fertilizers (GALINDO *et al.*, 2017), as It reacts in the soil as follows: carbonates (from Ca^{2+} or Mg^{2+}) react with the hydrogen in the soil, releasing water and carbon dioxide; aluminum Al^{3+} is then removed from the soil solution in the form of hydroxide (RONQUIM, 2020).

Agricultural gypsum has been used to increase Ca supply and reduce Al toxicity in the subsoil, which has resulted in better deep root growth (JUNIOR *et al.*, 2020). As it is relatively soluble, the agricultural gypsum can promote the improvement of chemical characteristics of deeper soil layers (DALLA NORA *et al.* 2017).

Gypsum ($CaSO_4.2H_2O$) is a by-product of the production of fertilizers such as simple superphosphate (SFS), monoammonium phosphate (MAP) and diammonium phosphate (DAP), where the phosphate rock is attacked by sulfuric acid, obtaining phosphoric acid and calcium sulphate residue (RAMPIM; LANA, 2015).

The positive effects of agricultural gypsum observed in various soil and climate conditions are indicative that its use can also be good alternative for the improvement of the root environment in the subsoil (MARCHESAN *et al.*, 2017; DALLA NORA *et al.*, 2014). According to SDA/MAPA (2006), Normative Instruction No. 35, calcium sulfate is considered a soil conditioner. The objective of this study was to evaluate the growth of (*G. max* (L.) Merrill) and the variation of soil pH values under the application of limestone and agricultural gypsum.

Material and Methods

The experiment was carried out in a greenhouse located in the Soil Science Department, belonging to the Institute of Agricultural Sciences of the Federal Rural University of the Amazon - UFRA, located in the municipality of Belém, Pará. According to Köppen's classification, the climate of the Belém region is characterized as Equatorial Climate Af, with average annual temperatures of 25.9 to 32 °C and the period of greatest rainfall being between the months of December to May (KOTTEK *et al.,* 2006).

The soil used was collected from the university premises, in a secondary forest area with more than 20 years. It was, then, removed from the arable layer of 0-20 cm and classified as a typical Dystrophic Yellow Latosol (EMBRAPA, 2013). After collection, it was subjected to chemical analysis, evaluated following the methodology described by Embrapa (1997). From the analysis were determined pH H_2O: 3,97, N: 0,05%, P $^{(1)}$: 6,00 mg dm^{-3}, $K^{+ (1)}$: 0,06 cmolc dm^{-3}, $Ca^{2+ (2)}$: 0,30 cmolc dm^{-3}, $Mg^{2+ (2)}$: 0,20 cmolc dm^{-3}, $Na^{+ (1)}$: 0,06 cmolc dm^{-3} e $Al^{3+ (3)}$: 1,40 cmolc dm^{-3}, where $^{(1)}$ Mehlich extraction^{-1}; $^{(2)}$ extraction KCl 1,00 mol L^{-1}; $^{(3)}$ calcium acetate extraction 0,05 mol L^{-1}. SB: 0.62 cmolc dm^{-3}, effective CEC: 2.02 cmolc dm^{-3} and m%: 69.30 were calculated.

In the experiment, the treatments consisted of doses of dolomitic limestone (L) (0, 1.5, 3.0 and 4.5 t ha^{-1}) and agricultural gypsum (GS) (0, 1.5, 3.0 and 4.5 t ha^{-1}) and their combinations, according to studies by Zandoná *et al.* (2015). The experimental design used was completely randomized, in a 4x4 factorial arrangement, with four replications, totaling 64 experimental units. The treatments were organized as follows (Table 1).

Table 1. Treatments and their combinations.

Treatments	Treatment combinations
T1	No limestone or gypsum
T2	1.5 t of limestone without gypsum
T3	3.0 t of limestone without gypsum
T4	4.5 t of limestone without gypsum
T5	1.5 t of gypsum without lime
T6	1.5 t of limestone + 1.5 t of gypsum
T7	3.0 t of limestone + 1.5 t of gypsum
T8	4.5 t of limestone + 1.5 t of gypsum
T9	3.0 t of gypsum without limestone
T10	1.5 t of limestone + 3.0 t of gypsum
T11	3.0 t of limestone + 3.0 t of gypsum
T12	4.5 t of limestone + 3.0 t of gypsum
T13	4.5 t of gypsum without limestone
T14	1.5 t of limestone + 4.5 t of gypsum
T15	3.0 t of limestone + 4.5 t of gypsum
T16	4.5 t of limestone + 4.5 t of gypsum

The codes of the combinations in the interaction of gypsum with limestone were GS0; GS1.5; GS3; GS4.5, GS being the gypsum.

Initially, the soil was incubated for a period of 75 days, according to the treatments, with dolomitic limestone (PRNT 98%) and agricultural gypsum. In the experiment, doses (0, 1.5, 3.0 and 4.5 t ha^{-1}) of limestone and gypsum were used, distributed in treatments, respectively, in the following amounts: 0; 7.5; 15 and 22.5 g/plant, and incorporated into the soil, then distributed in the experimental units, consisting of plastic bags with a capacity of 10 dm^{-3}.

The 192 soybean seeds (*G. max* (L.) Merrill), variety M8210 IPRO from the brand Cultivar Sementes were used, with 3 seeds sown per bag. The bags were already filled with sieved, air-dried and treated with lime and gypsum soil. Germination occurred three days after sowing and, 10 days after germination, thinning was carried out, leaving two plants per bag. Soil moisture was maintained, the soil was irrigated as needed.

The experimental units were fertilized normally, according to the soil analysis. Urea was used as the nitrogen source, simple superphosphate as the phosphoric source and potassium chloride as the potassium source and they were applied to the soil 15 days after soybean sowing. Fertilization was carried out according to the soil analysis with 20 kg of N kg ha^{-1}, 100 kg of P_2O_5 ha^{-1} and 100 kg of K_2O kg ha^{-1}, respectively in the quantities: 0.22 g/bag of urea, 2.5 g/bag of simple superphosphate and 0.75 g/bag of KCl, calculated according to Cravo *et al.* (2007). For the supply of micronutrients, FTE BR12 was used in the amount of 0.15 g/bag, considering 30 kg ha^{-1}, calculated according to Cravo *et al.* (2007).

The experiment was carried out for a period of 138 days, in which the soil pH was evaluated at 30, 45, 60, 75 days before sowing. The pH analysis was carried out using a glass electrode, suspended in the soil-liquid ratio of 1:2.5, according to the methodology of Embrapa (1997).

Plants were collected 63 days after sowing, at stage R5 of the scale by Fehr *et al.* (1971). The growth variables were: number of pods (NP), shoot dry mass (SDM), root dry mass (RDM), root length (RL) and shoot/root ratio (S/RR). NP was counted manually before plant cutting. The samples were stored in paper bags and dried in a forced air circulation study at a temperature of 65 °C for a period of 72 hours, resulting in their dry mass. The root, before being dried in the oven, was washed and the excess soil removed and after that its length was measured with the aid of a measuring tape.

The results were submitted to the F test and regression study, compared by Tukey test at 5% probability and the equations adjusted to adequately express the behavior of the results as a function of the applied treatments.

Results and Discussion

The pH 75 days, root length and shoot/root ratio variables were significantly influenced by the treatments, alone or in interaction. For pH 30, pH 45 and pH 60 days, number of pods and shoot dry mass there were isolated effects of treatments for gypsum and limestone. In root dry mass, the treatment effect was only verified with the use of limestone (Table 2).

Table 2. Summary of the analysis of variance for the variables pH 30 days, pH 45 days, pH 60 days, pH 75 days, number of pods (NP), root length (RL) , shoot dry mass (SDM), root dry mass (RDM) and shoot/root ratio (S/RR) of soybean (*G. max* L.) under the effect of limestone and agricultural gypsum doses.

Source of variation	DF	pH1	pH2	pH3	pH4	NP	RL	SDM	RDM	S/RR
Gypsum (GS)	3	**	**	**	**	**	**	**	ns	**
Limestone (L)	3	**	**	**	**	**	**	**	**	**
GS x L	9	ns	ns	ns	**	ns	**	ns	ns	**
Error	48	-	-	-	-	-	-	-	-	-
VC %	-	4.81	4.53	4.38	3.41	15.26	18.67	15.94	44.67	39.51

(**) significant at the 5% probability level, (ns) not significant at the 5% probability level.

For days 30, 45 and 60 days, with the application of limestone doses, the equations were adjusted to the linear regression model, increasing until the last dose applied (4.5 t) (Image 1; 2; 3 A). For the gypsum doses (Image 1; 2; 3 B) the equations were fitted to the quadratic polynomial regression model and presented the highest pH values (5.19, 5.29 and 5.33) for the maximum doses 3459, 3376 and 3378 kg ha^{-1}, respectively.

In the periods of evaluation of pH (30, 45 and 60 days) there was a decrease in acidity in both treatments containing gypsum and limestone. However, in treatments with doses of gypsum there was a decrease in pH from the dose of 3376 kg ha^{-1} of gypsum on (Figure 1; 2; 3 B). In studies carried out by Caires *et al.* (2001) in a Red Distrofic Latosol, when using a maximum dose of 6 t ha^{-1} of limestone, at a depth of 5 cm there was an increase in pH of 1.5, and at 10 cm it was 0.6, being reduced as the depth increased. When applied to gypsum doses, exchangeable Ca contents were high, causing a significant reduction in Al contents. The increase in soil surface pH can accelerate the speed with which HCO^{3-} , accompanied by Ca and Mg, move to deeper layers, reacting with acidity (COSTA, 2000).

Figure 1. Behavior of soil pH at 30 days after application of treatments.

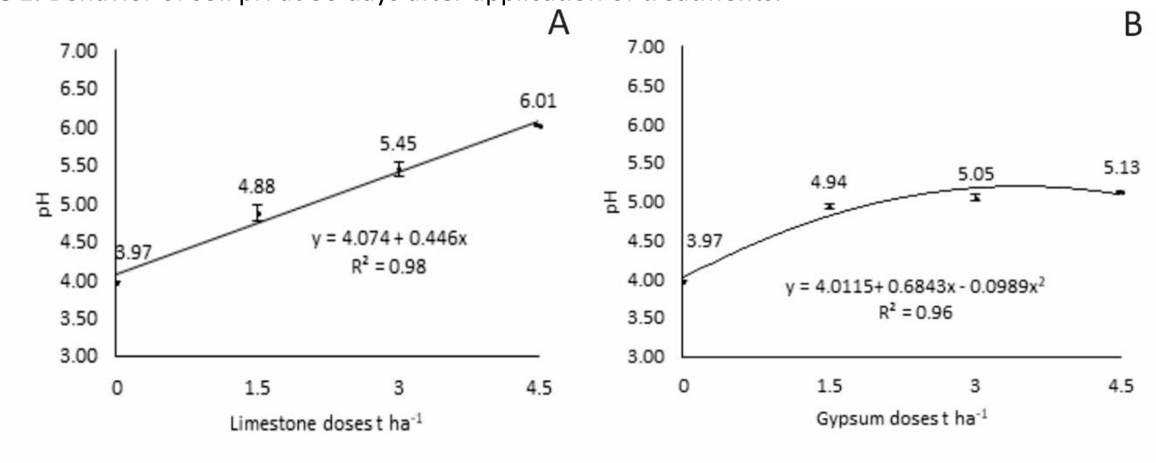


Figure 2. Behavior of soil pH at 45 days after application of treatments.

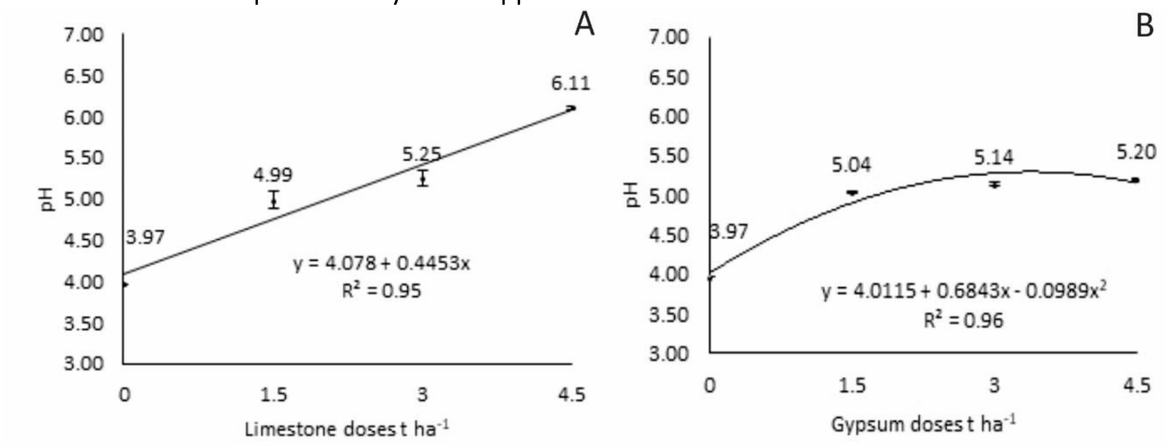
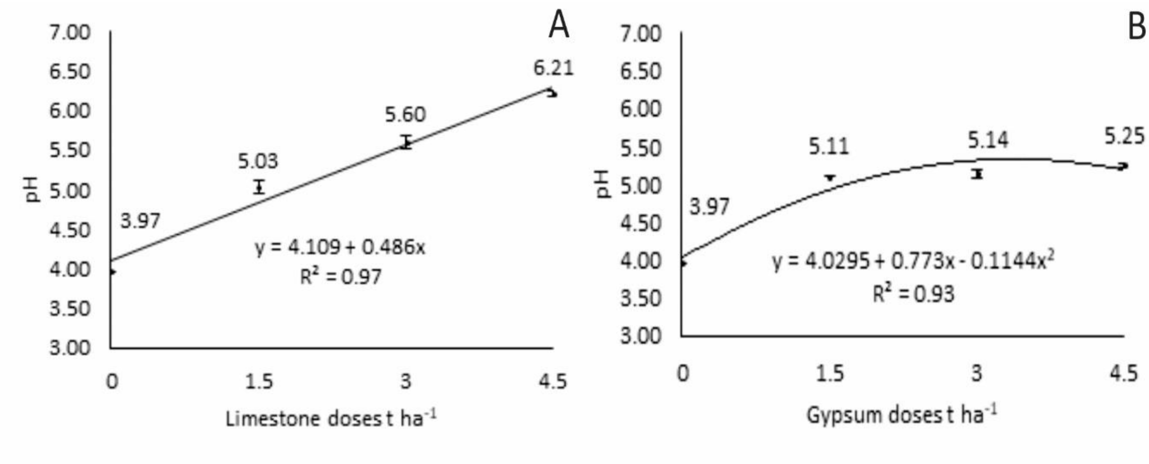


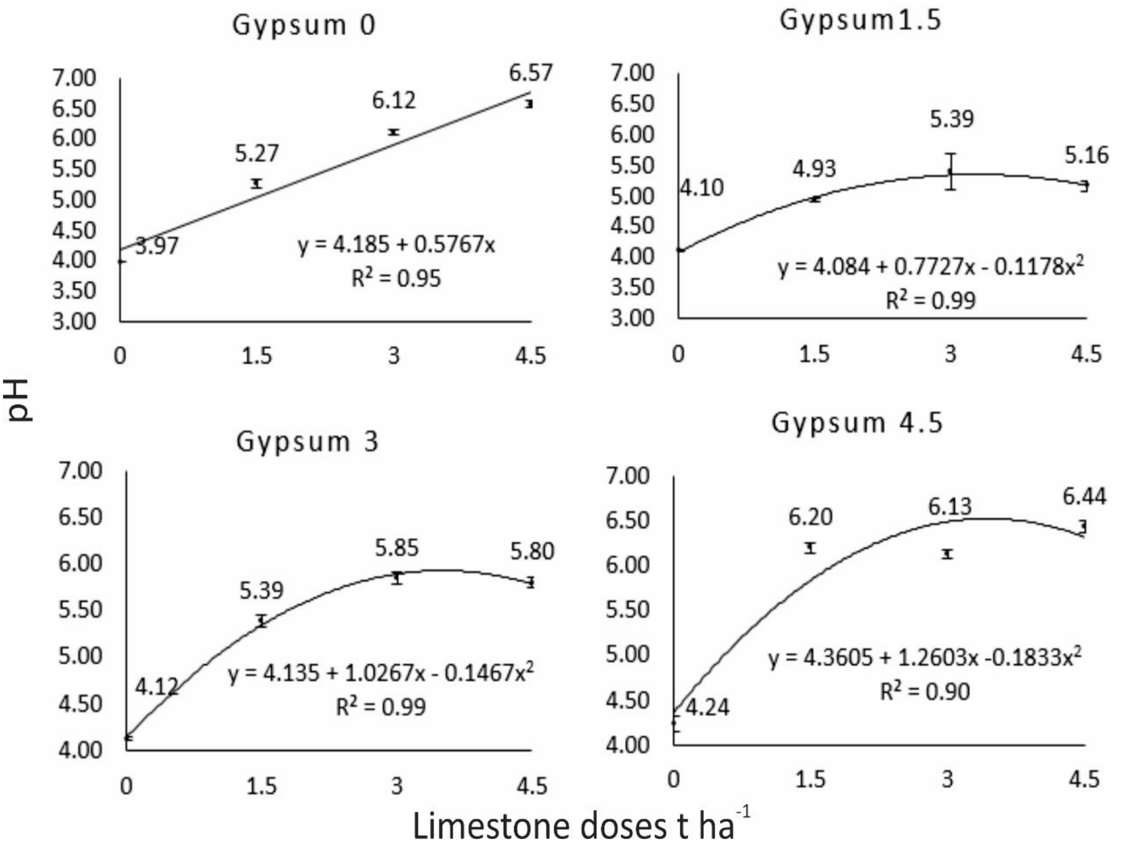
Figure 3. Behavior of soil pH at 60 days after application of treatments.



When gypsum was applied, the levels of exchangeable Ca were elevated, causing a significant reduction in Al levels. According to Ghisleni *et al.* (2020), gypsum decreases the activity of toxic aluminum in the subsurface, besides providing calcium and sulfur in the form of sulfate. The application of gypsum caused an increase in pH (Figure 1; 2; 3 B). Although gypsum does not correct soil acidity, increases in soil pH with gypsum may occur due to the ligand exchange reaction on the surface of soil particles, reacting hydrated aluminum and iron oxides, with $SO4^{2-}$ displacing OH^- and thus enabling the partial neutralization of acidity (COSTA; CRUSCIOL, 2016; CRUSCIOL *et al.,* 2016; REEVE; SUMNER, 1972). The values observed are within the ideal average pH around 6.5, where there is a greater absorption of nutrients by the plants, as suggested by Malavolta *et al.* (1976).

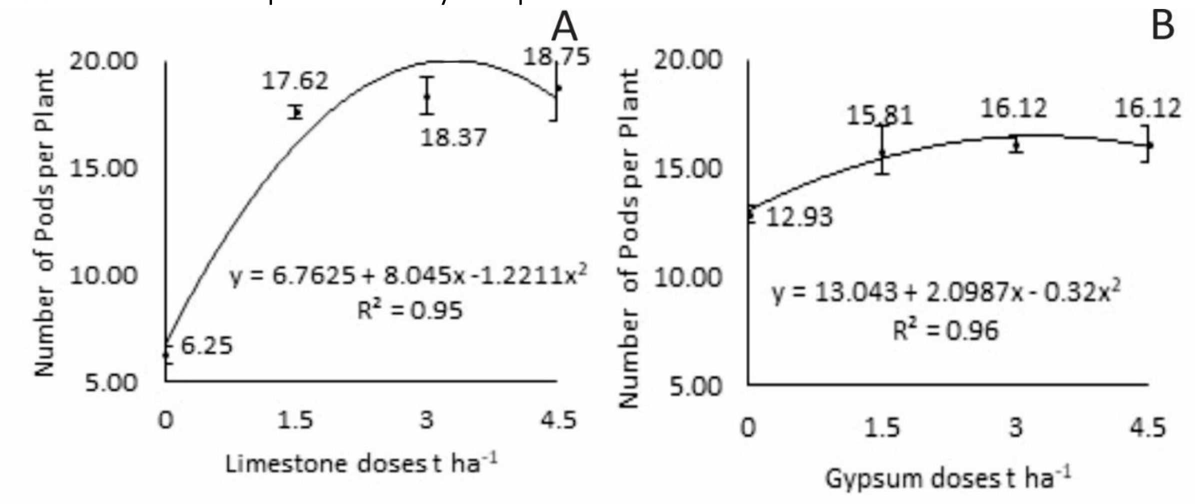
For the pH at 75 days (Image 4), interaction effects were observed between the treatment doses of limestone and gypsum, with the equations fitting to the quadratic polynomial regression model, except for the treatments with 0 t ha^{-1} gypsum dose, which showed a linear regression model. When using the 0 t ha^{-1} gypsum dose, the highest pH value (6.57) was observed in the treatment with 4.5 t of limestone without gypsum (T4). For the gypsum doses 1.5, 3 and 4.5 t ha^{-1}, the highest pH values 5.75; 5.93 and 6.52, were observed with the maximum dose of 3279, 3499 and 3437 kg ha^{-1} of limestone, respectively.

Figure 4. Behavior of soil pH at 75 days after application of treatments.



For the variable number of pods, the equations were fitted to the quadratic polynomial regression model, and for the largest number of pods (20 in limestone doses and 16 in gypsum doses) (Figure 5 A and 5B), it was required doses of 3313 kg ha^{-1} of limestone and 3150 kg ha^{-1} of gypsum, respectively.

Figure 5. Number of Pods per Plant in soybean plants.

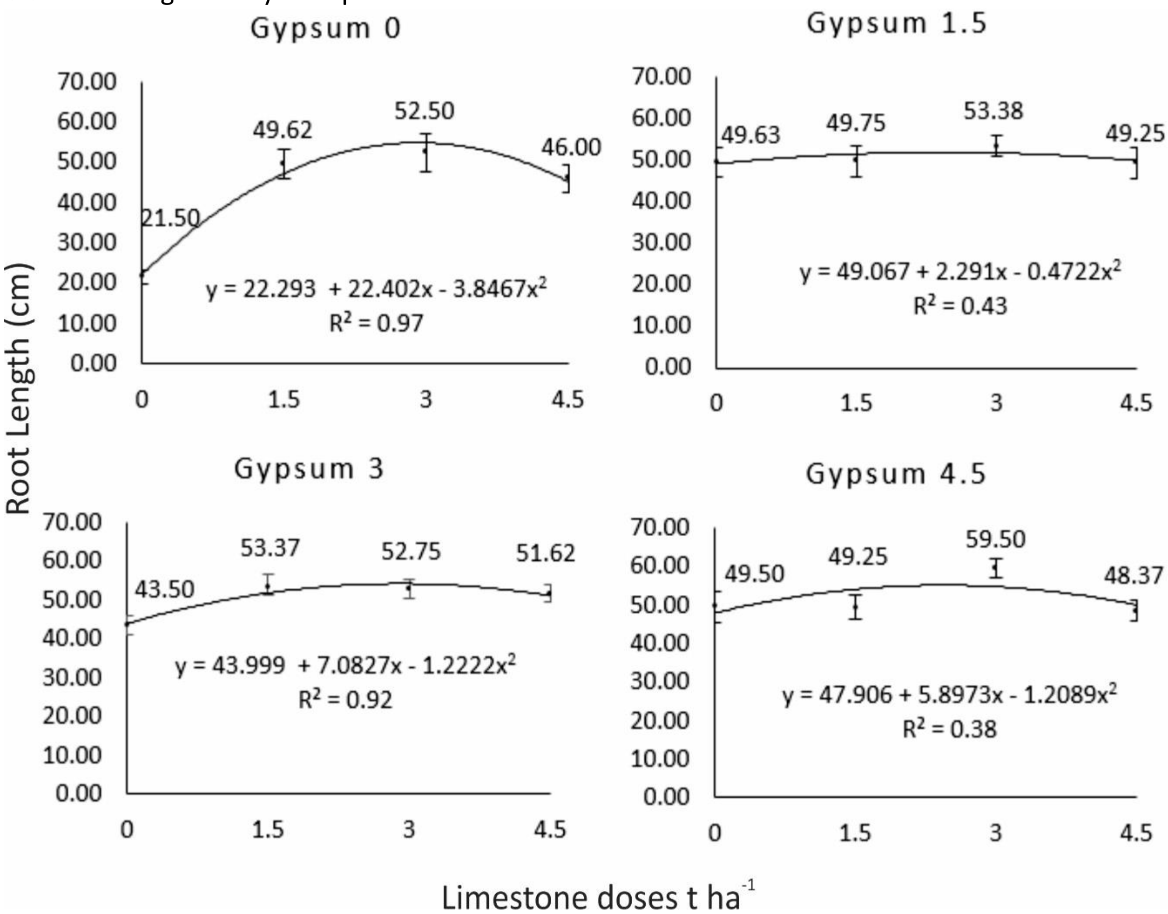


The application of limestone and gypsum made it possible to increase productivity, as it is directly related to the number of pods per plant. Possibly, the increase in soil fertility provided more favorable chemical conditions for root growth, absorption of water and nutrients, as stated by Zandoná *et al.* (2015). Sávio *et al.* (2011) studying the productivity of soybeans in a Yellow Red Latosol, found a 20% increase in the number of pods compared to the control, with the use of limestone and gypsum, possibly provided by the additions of N and Ca in leaf tissues, assuming that soybean plants have explored the soil more effectively, enabling the increase in crop yield.

Fois *et al.* (2018), when studying the effect of gypsum on soybean productivity in an Argissolo and Latosolo, observed that the number of pods was not influenced by the application of gypsum doses in the two locations studied. The authors attribute this fact to the sulfur content from the mineralization of organic matter in the soil, which may have been sufficient to meet the needs of the crop, as well as the absence of water deficit.

For root length (Figure 6), the effects of the interaction between treatments promoted a fit to the quadratic polynomial regression model. In gypsum doses 0, 1.5, 3 and 4.5 t ha^{-1}, the highest values of root length were 54.90, 51.84, 54.26 and 55.09 cm, for these results the doses of 2911, 2425, 2897 and 2439 kg ha^{-1} of limestone were required, respectively.

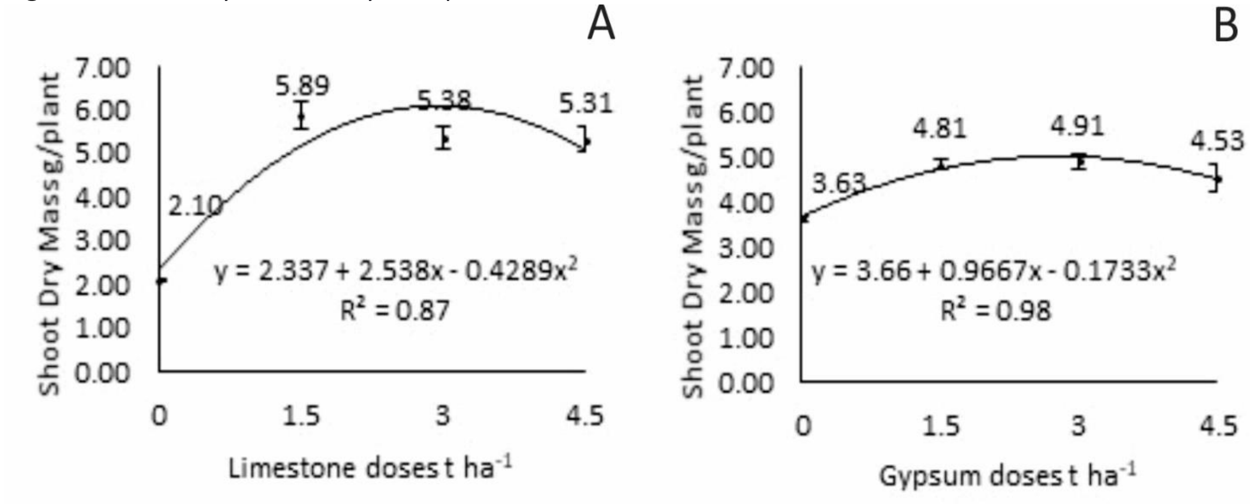
Figure 6. Root Length in soybean plants.



Studies conducted in Latosols, in no-till systems, by Caires *et al.* (2005; 2008a), Dalla Nora; Amado (2013), Pauletti *et al.* (2014) and Zandoná *et al.* (2015), observed chemical improvement in the rooting zone, after application of gypsum alone or in combination with limestone (SORATTO; CRUSCIOL, 2008; CRUSCIOL *et al.*, 2016), with increased Ca^{2+} and Mg^{2+} contents and decreased Al^{3+} activity. Marchesan *et al.* (2017), when studying application of agricultural gypsum in a Planosol grown with soybean, reported that root length was not affected by gypsum application.

For the variable shoot dry mass, the equations were fitted to the quadratic polynomial regression model. The doses considered maximum for the production of shoot dry mass were 2958 kg ha^{-1} of limestone (Image 7A) and 2789 kg ha^{-1} of gypsum (Figure 7B), producing 6.09 g/plant in the doses of limestone and 5.00 g/plant in gypsum doses.

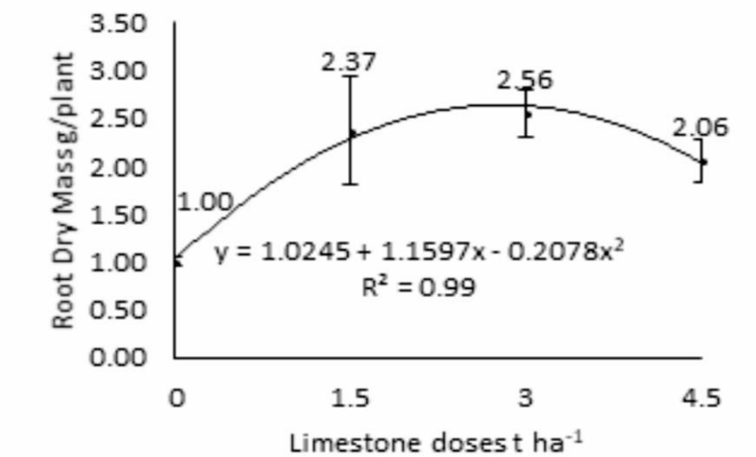
Figure 7. Shoot Dry Mass in soybean plants.



Soybean dry mass production increased by 65% with liming, compared with gypsum, which increased by 27% (Figure 7). Souza *et al.* (2020), when studying the effect of liming on soybean plant growth, observed a 14% increase in dry mass production compared to the control treatment, without liming. In addition to neutralizing acidity, liming provides Ca and Mg and promotes increased availability of P and K in the soil (ERNANI, 2016). These factors, added to the neutralization of toxic elements, can explain the increment of dry mass production of the aerial part of soybean with the use of liming (BRIGNOLI *et al.*, 2020).

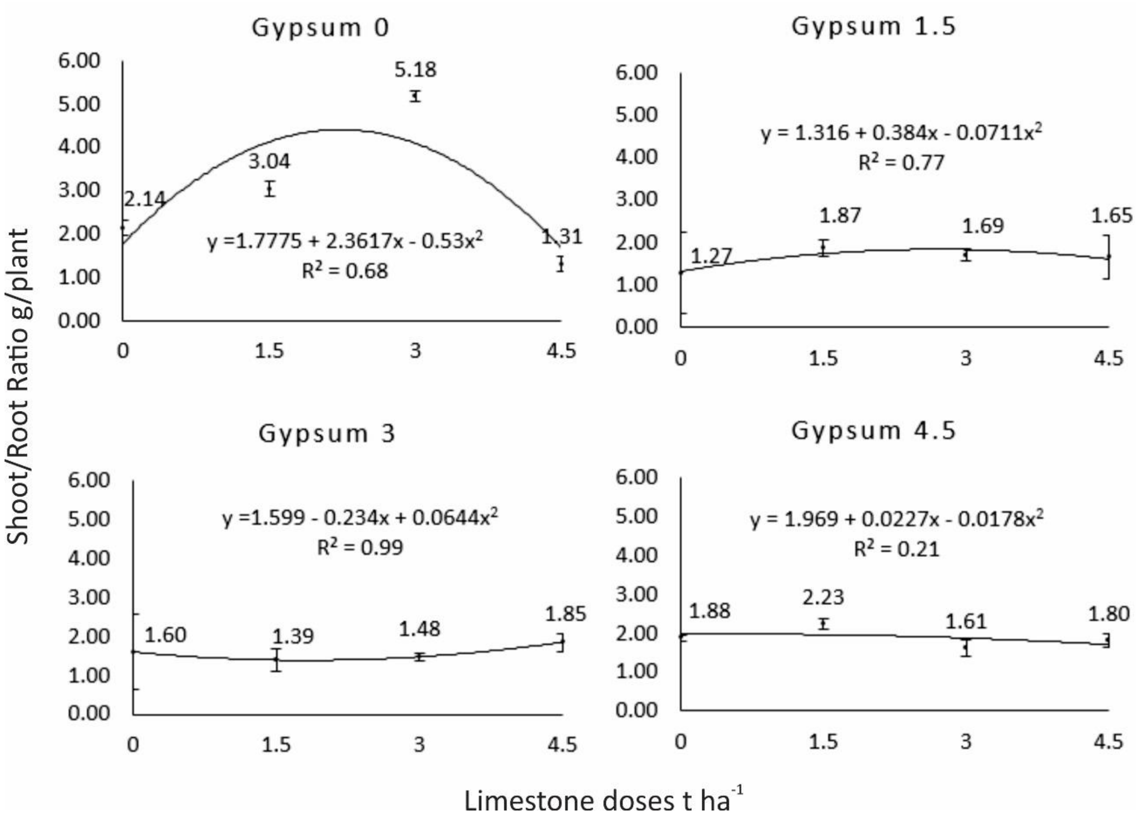
For the root dry mass variable (Image 8), the equation was fitted to the quadratic polynomial regression model, where a dose of 2790 kg ha^{-1} of limestone was necessary to reach the maximum root dry mass value of 2.64 g/plant. According to Cardoso *et al.* (2014), the ability of gypsum to provide better root development can make soybean plants have a better capacity to absorb water from subsurface layers, giving them better conditions to withstand periods of stress due to lack of water, thus explaining the best yields obtained for treatments that contain gypsum. However Caires *et al.* (2008b) states that low soybean response to gypsum application may be related to the fact that the growth of the soybean root system is not influenced by the reduction of Al saturation in the subsurface of the soil when it has a good water supply.

Figure 8. Root Dry Mass in soybean plants.



In shoot/root ratio (Figure 9) there was interaction between treatments, with the equations adjusting to the quadratic polynomial regression model, the highest relationship was observed in the treatments with the gypsum dose 0 t ha^{-1}, being 4.40 g/plant with the maximum dose of 2228 kg ha^{-1}. For the gypsum doses 1.5, 3 and 4.5 t ha^{-1} there was a lower ratio, being 1.83, 1.38 and 1.97 g/plant, these results were obtained with doses of 2700, 1816 and 637 kg ha^{-1} of limestone, respectively. The shoot/root ratio was higher in treatments with 0 t gypsum ha^{-1} where the shoot was smaller compared to the other treatments. However, in the treatments with the presence of gypsum and limestone, this difference was smaller, demonstrating greater equality between the shoot and root. According to Zandoná *et al.* (2015), in a study conducted with soybeans and application of gypsum to the soil, there was an improvement in soil fertility in the subsurface, which allowed better root growth and greater tolerance to water deficit. In another study with soybean, Zapparoli *et al.* (2013) observed that when liming was used in good rainfall conditions, root dry mass had a lower growth decreasing with increasing doses.

Figure 9. Shoot/Root Ratio in soybean plants.



Conclusions

The application of limestone and gypsum reduces soil acidity, obtaining higher pH values from the doses of 3000 kg ha^{-1}, with the combination of limestone and gypsum. The use of gypsum in combination with limestone promotes significant results in the growth of soybean plants.

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