Limed in sandy soils for soybean cultivation: A mini-review

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Abstract

Liming is the method in which limestone is applied to regulate the pH of the soil reducing its acidity and making the minerals labile. This study aimed to evaluate the management of liming using dolomitic limestone in sandy textured soils, on the development of soybean cultivation through a bibliographical survey. Sandy soil also, known as “light soil” is largely composed of sand and a smaller proportion of clay around 70% and 15% respectively, its grain size is higher, and the presence of nutrients is very scarce. Correcting soil acidity through liming is the first step towards obtaining a considerably productive crop, especially in recently cleared areas. Since in acidic soils, the limitation to plant development arises mainly from the indirect effects of pH. Therefore, it is necessary to analyze the soil continuously as well as the weather conditions in order to obtain the desired result. Several results have been observed in which the use of liming in acidic soils, mainly in the Brazilian Cerrado, reduces the toxic action of aluminum on the plant and promotes greater absorption of nutrients and micronutrients for the plants, in addition to maintaining the soil microbiota.

Keywords: liming, sandy soils, soybean cultivation, available macro and micronutrients, greater grain production.

Calagem em solos arenosos para cultivo de soja: Uma mini-revisão

Resumo

A calagem é o método em que se aplica calcário para regular o pH do solo diminuindo sua acidez e tornando os minetais lábeis. Este estudo, teve por objetivo avaliar o manejo da calagem por meio de calcário dolomítico, em solos de textura arenosa, sobre o desenvolvimento da cultura da soja através do levantamento bibliográfico. O solo arenoso, também conhecido como “solo leve” é composto em grande parte por areia e uma menor proporção de argila, cerca de 70% e 15% respectivamente, sua granulação é mais alta e a presença de nutrientes é bem escassa. A correção da acidez do solo, através da calagem, é o primeiro passo para se obter um cultivo consideravelmente produtivo, principalmente se tratando de áreas recém desbravadas. Já que, em solos ácidos, a limitação ao desenvolvimento das plantas decorre, principalmente, dos efeitos indiretos do pH. Portanto, é preciso analisar o solo de forma contínua, como as condições climáticas, a fim de obter o resultado desejado. Observa-se diversos resultados em que a utilização de calagem em solos ácidos principalmente do Cerrado brasileiro, diminui a ação tóxica do Alumínio sobre o vegetal e promove maior absorção de marco e micronutrientes para os vegetais além de manter a microbiota do solo.

Palavras-chave: calagem, solos arenosos, cultivo de soja, macro e micronutrientes disponíveis, maior produção de grãos.

1. Introduction

Cultivation of soybeans (*Glycine max* L.) is potentially important for the Brazilian economy, and because of this, the production of this crop is combined with new production technologies, including fertilization and soil correction through liming, which makes it possible to implement soybeans in new areas, including areas known to have low fertility rates (Pavinato et al., 2020; Miotto et al., 2020).

Soybean crops have high demands on the absorption of essential macronutrients. The nutrients to be efficiently used by the plant must be present in the soil in balanced relationships and in quantities satisfactory for the development of the crop. The imbalance or insufficiency of these macronutrients results in the deficiency of absorption of some and excessive absorption of others (Lange et al., 2021). Therefore, for balance to be achieved and preserved, practices such as fertilization and liming must be used correctly. In several Brazilian regions, such practices have been satisfactory, when established based on soil analysis and all activities that complement them, followed strictly and efficiently. A soil management system therefore has the purpose of preparing the area for planting crops with efficiency capable of absorbing good results both for the soil and for production through the conditions of a healthy soil and satisfactory growth and development of plants (Freitas et al., 2016).

According to Freitas (2019), in Brazil, liming plays a determining role, as the soils are acidic and contain a significant amount of aluminum (Al). Such acidity is mainly represented by the presence of two components (H^+ and Al^{+3} ions). While these components originate from the intense washing and leaching of nutrients from the soil. Furthermore, the removal of cationic nutrients by the crop without proper replacement and the use of acidic fertilizers. Thus, the use of liming is seen as a promising practice in improving soil fertility, where the application of liming materials improves the acidity condition of the soil, provides essential elements such as Calcium (Ca) and Magnesium (Mg) and reduces emission of N_2O in acidic soils (Rodrighero et al., 2015; Wang et al., 2021).

In acidic soils, the limitation to plant development arises mainly from the indirect effects of pH, such as the increase in the availability of Al and Manganese (Mn), to toxic levels, or the induction of Ca, Mg, Phosphorus deficiency (P) or Molybdenum (Mo), which prevail over the effects of H^+ (Marschner, 1995; Gurmessa, 2020). As a result of this process, the efficiency of fertilizers in acidic soils is lower and, therefore, the first alternative to adequately correct soil fertility should be liming. Macro and micronutrients may be available in the soil; however, acidity makes absorption by the plant difficult, causing low productivity, and with liming, the pH rises to acceptable levels, favoring absorption by the installed crop (Yakuwa et al., 2020).

The fact is that the nutrients present in the soil become available for absorption by plants in a pH range between 5.5 and 6.5. This is why correcting soil acidity is crucial for the good development of crops (Freitas, 2019). Cavalcanti (1998) adds that a limed soil, in addition to promoting and making nutrients available at a balanced pH, improves the chemical, physical and microbiological characteristics of the soil, increasing the efficiency of fertilizers and favoring the supply of Ca and Mg to vegetables.

Over the years, liming works in direct planting mitigating the harmful consequences that soil acidity produces in deeper layers. This factor is extremely important, since acidity in the subsurface layers can impede the development of plant roots when Al levels or Ca deficiency become toxic (Wang et al., 2021).

It is also worth mentioning that the application of Ca doses above the recommended level, that is, superliming, causes the dispersion of clay in the soil, especially in sandy soils. This process triggers the clogging of pores below the 0-20 cm layer, which causes erosion of the most superficial layer of the soil (Yang et al., 2023). Furthermore, this excessive dosage of limestone will cause excessive mineralization of soil organic matter (OM), reducing its content levels, which compromises the sustainability of all agricultural production.

Therefore, there is a need for competent and specialized professionals for the correct dosage of lime to be used in the soil, generating greater crop productivity, especially soybeans in soils in Brazil (Metzger et al., 2021). This review study aimed to present the results of studies on the use of liming in sandy soils producing soybeans, especially in Brazil.

2. Materials and Methods

2.1 Type of search and search engines

In this work, a bibliographical review was carried out on the subject of liming in sandy soils for soybean cultivation, with consultation in the academic journals SciELO Brasil, Science Research, Google Scholar, Elsevier and Portal CAPES, bringing together and comparing the different results found by various authors. The objective of a bibliographical research is to put the researcher in contact with what has been produced on a given subject. The research consisted of using key words such as: Liming; Sandy soils; Soybean cultivation; Lime reduction consumption; porosity-to-lime index, and Lime-soil. The selection of articles was based on the search for topicality and compliance of the limits of the subjects with the objectives of this work in a broad annual manner.

3. Literature review

3.1 Soil acidity

The concept of soil refers to all unconsolidated material originating on the Earth's surface through the action of pedogenesis and weathering, capable of ensuring the life of animals and plants. Soils manifest different chemical and physical characteristics and properties, depending on the local and environmental conditions in which they are found. Furthermore, the soil is not just a storehouse of nutrients, but rather a complex ecosystem, rich in microorganisms that promote health. of this environment, favoring maximum productivity (Silva et al., 2021).

> The soil is the result of nature's patient work. Mineral and organic particles are deposited in layers due to the action of rain, wind, temperature changes and organisms and microorganisms, which slowly wear down the rocks. To better understand a soil, it is necessary to carry out a detailed analysis of it, which consists of an effective and low-cost method to evaluate the soil's ability to provide nutrients to plants, as well as its physical properties, enabling the adequate supply of fertilizers, avoiding waste and possible damage to the environment. Through this analysis, it is also possible to determine the acidity of a soil and with this data in hand, appropriately recommend liming (Camargos, 2021).

The absence of satisfactory amounts of the elements Potassium (K), Ca and Mg in the soil results in a biochemical condition called acidity. Therefore, in the composition of the soil, the existence of Hydrogen ions (H^+) is analyzed, characterizing acidity based on its content (Pahalvi et al., 2021).

> In the process of decomposition of OM, both organic and inorganic acids are formed. The simplest, found in greatest abundance, is carbonic acid, which results from the combination of Carbonic oxide (CO) with water. As it is a weak acid, it cannot be held responsible for the low pH values of the soil. Inorganic acids such as sulfuric acid and nitric acid and some strong organic acids are potent suppliers of H^+ ions in the soil. Soil acidity arises with the contact of soil acids and aqueous solution, where it reacts with water, causing dissociation (Oliveira; Costa, 2005).

On the other hand, extremely acidic soils constitute a major obstacle to agricultural production, since this acidity causes severe damage to plant development, due to elements that are toxic to crops, such as Mn and Al, concomitantly reducing the availability of nutrients (Michael, 2021).

> Soils can be acidic due to the base poverty of the source material, or to formation processes that favor the removal or washing of basic elements such as K, Ca, Mg, Sodium (Na) among others. Furthermore, soils can have their acidity increased by crops and fertilization. In both cases, acidification begins, or increases, due to the removal of bases from the surface of soil colloids. The origin of soil acidity is mainly caused by the washing of Ca and Mg from the soil by rain or irrigation, removal of nutrients by crops and the use of most chemical fertilizers (Oliveira; Costa, 2005).

Soil acidity and toxicity are interconnected, where acidity is not only caused by H+, but by other amounts of acidic minerals (Al^{3+}, Fe^{2+} and Mn^{4+}) where the concentration increases as pH decreases (Michael, 2021). Measuring soil pH determines the amount of H^+ ions, the so-called hydrogenion potential. The higher the pH value, the lower its acidity, and *vice versa*. Therefore, if the pH found is less than 7.0, the soil is considered acidic. Michael (2021) presents in Table 1 and Figure 1 the optimal pH for soils and nutrient availability in soils with different pH without liming.

Table 1. pH values and nutrient availability in the soil.

Nutrients	N	P	K and S	Ca and Mg	Fe	Mn	B and Cu	Zn	Mo
pH range	6-8	6.5-7.5	> 6	7-8.5	< 6	5-6.5	5-7	4-5	7

Source: Michael, 2021.

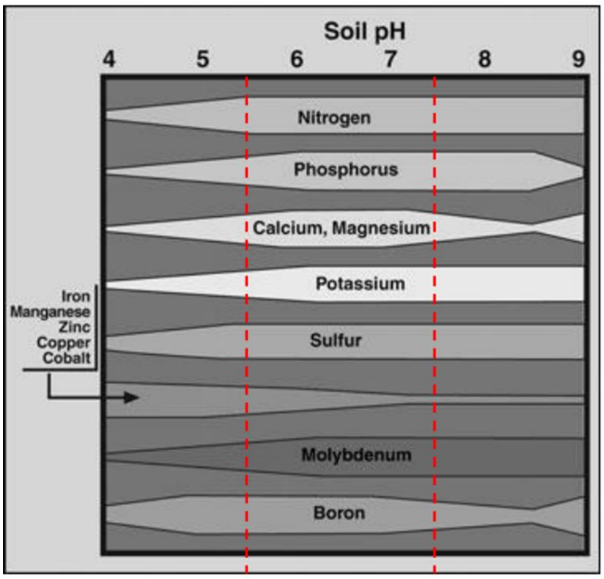

Figure 1. pH-dependent availability of essential soil nutrients (adapted from National Soil Survey Manual, USDA, NRCS (National Research Council, 1982). The relative availability is indicated by the width of the band. pH less than 5.5 and 7.5 units is over acidic and alkaline, respectively. Source: Michael, 2021.

Soils in tropical and subtropical regions are generally chemically poor, being naturally acidic and presenting high levels of exchangeable Al^{3+}. It is estimated that 75% of areas with potential for agricultural activity in Brazil have serious problems with soil acidity, which have a pH between 3.8 and 5.5. However, to correct this it is necessary to apply acidity correctors, including agricultural limestone (Macalli, 2022).

However, it is necessary to apply fertilizers, whether soluble or organic, when the availability of nutrients is low, applying them in the sowing line or broadcasting in the location where the fertilizer is retained on the soil surface, as it happens, for example, in the case of direct planting situations.

In other situations, the application of fertilizers can be done by broadcasting in the sowing line, or with incorporation into the conventional cultivation system. The greater efficiency of fertilizers with the aim of providing a productive and quality crop, can be determined by the choice of method used as the technique used, in fertilization can interfere with the reactions that occur between fertilizers and the soil. This can influence the availability of nutrients for the developing crop. Studies on different forms of fertilizer application are very common, mainly to reduce losses and increase efficiency (Iqbal et al., 2020; Macalli, 2022).

Most agricultural crops grow in environments close to neutral (pH = 7) or only slightly acidic, therefore they do not do well in very acidic soils. According to Ernani et al. (2001) acidic soils can present another serious problem in established crops, the element Aluminum (Al) is absorbed by the plant and this element is toxic.

Soil acidity is one of the factors that limit soybean production, as acidic soil presents restrictions to the development of most cultivated plants, such as a drastic reduction in their growth, and consequently a drop in agricultural production. Furthermore, high acidity compromises the availability of nutrients. With the exception of cationic micronutrients (Iron (Fe), Copper (Cu), Manganese (Mn) and Zinc (Zn), all other important nutrients for the plant have reduced availability in soils with a pH below 7 (Bakari et al., 2020; Macalli, 2022).

In this sense, soil correction plays a fundamental role in the cultivation of crops in regions with high acidity. Liming brings benefits to this process that allows maintaining soil health and making nutrients available for crops, especially soybeans (Caire; Fonseca, 2000). In order to identify the real needs of the soil, the physicochemical analysis of the soil is essential so that it is possible to determine the application of the most appropriate corrective agent. In general, correction work precedes the planting season by approximately 60 to 90 days, constituting the first land preparation measure (Li et al., 2019).

2.2 Sandy soils

According to Wang et al. (2005) and Centeno et al. (2017) texture is one of the main indicators of quality and productivity in arable soils. This influences the dynamics of adhesion and cohesion between the content of soil particles and the management of this soil. These influence soil resistance to traction and water dynamics in this environment. Santos et al. (2003) discussed this parameter with the principle that a productive soil must have a clayey texture and a pleasant pH to provide nutrients for vegetables and a low effect of Al.

On the other hand, sandy soils had little relevance for agriculture. This thought is due to management limitations, fertility deficiency, high susceptibility to erosion, effluent contamination and water deficiency when rainfed (Ramalho Filho; Beek, 1995). According to Brady & Weil (2013) there are three main groups of classes regarding the textural classification of a soil; sandy, loamy and clayey soils; each group coexists with specific textural classes, with 13 textural classes. These classes provide valuable information about particle size distribution and indicate the behavior of soil physical properties. Soils with a sandy texture are more deficient in P and OM. This deficiency is due to the fact that around 70% of its composition is made up of sand, making it highly permeable, with low water retention capacity, low levels of OM and ion afsorption.

Due to these deficiencies, sandy soils must be managed with appropriate use and management, investing in OM replacement and conservation practices, thus reducing erosion and increasing their agricultural suitability (Brady; Weil, 2013). According to Santos et al. (2003) current soil management systems have made soils productive regardless of their texture. Still in this study, Santos and collaborators observed that soybean productivity showed superior results in medium and sandy textured soils with liming when compared to clayey soils.

Liming plays a fundamental role in sandy soils where there is an increase in productivity, this is due to the neutralization of toxic Al, by raising the pH and thus releasing the Ca and Mg needed by the plants. Brady & Weil (2013) discuss the incorporation of limestone in sandy soils at doses higher than recommended since, for cotton cultivation, the recommended doses present low productivity. Donagemma et al. (2016) explains that this high dosage technique is explained by the low reactivity of limestone in sandy soils, due to the low Al content and the low buffering power of the soil and also by the losses of cations in depth caused by leaching.

In a study carried out on sandy soil where doses of cattle manure were applied, Galvão et al. (2008) found gains in the accumulation of Carbon (C), N, P, K and Ca at a depth of 0-60 cm, demonstrating that the management of this type of soil makes its production possible. Rheinheimer et al. (2000) corroborates what was discussed where the superficial application of lime in the direct planting system consolidated in sandy soil decreased the action of exchangeable Al and increased the pH and Ca and Mg levels up to a depth of 5 cm, thus ensuring availability of these nutrients. essential for cultivated vegetables.

3.3 Liming management

The liming stage, in order to prepare the soil for agricultural production, has two main objectives: to provide Magnesium (Mg) and Calcium (Ca), important mineral salts for the development of vegetables, and to reduce soil acidity. These factors influence the increase in soil pH. It is essential to correct the acidity of the planting soil with a pH range between 5.5 and 6.5. In this pH range, essential minerals for plants are available (labile) and can be absorbed by seedlings (Souza Filho et al., 2000; Souza et al., 2010).

The pH affects microbial activity, the number of electrical charges, the stability of aggregates, the presence or absence of elements toxic to plants, as well as precipitation, dissolution, redox reactions, exchange of cations and anions (Ernani, 2008). In the same sense:

> Acidic soils with a pH below 5.0, imply lower microbial activity, affecting the mineralization of organic matter (OM) and the availability of nutrients. Furthermore, they impact the availability of Phosphorus (P) to plants, not only due to reduced root development, which makes it difficult to reach this macronutrient, but also by

increasing P retention in soil colloid loads. Liming, therefore, is essential for increasing agricultural productivity, in addition to providing better initial establishment of the crop, where this critical period between plant and soil acidity is also associated with an increase in the incidence of fungal diseases due to low pH (Sousa et al., 2009).

The process of neutralizing soil acidity through liming begins with the solubilization of $CaMg(CO_3)$ carbonates, enabling the release of hydroxyls (OH^-) into the soil, forming bicarbonate (HCO_3) and neutralizing H+ in solution, and then Al^{3+} can precipitate. The correction of acidic soil, through the use of limestone, (Kaminski et al., 2005) can be demonstrated by the following reactions:

$$Ca\,(Mg)CO_3 + H_2O \rightarrow Ca^{2+}(Mg^{2+}) + HCO^{-3} + OH^-$$

$$OH^- + H^+ \text{ (soil solution)} \rightarrow H_2O$$

$$HCO^{-3} + H^+ \text{ (soil solution)} \rightarrow H_2CO_3 \rightarrow H_2O + CO_2$$

$$Al^{3+} + 3OH^- \rightarrow Al(OH)_3$$

As previously mentioned, the application of limestone, in addition to precipitating Al^{3+} and neutralizing soil pH, can enable the emergence of other positive effects, such as an increase in Sulfur (S) and P in soybean leaf tissue as well as , the increase in Mg and Ca levels and promote greater N fixation through microorganisms existing in the nodules of the plant's root system (Bolo et al., 2021).

The application of lime varies depending on the type of soil and management. It is essential to have a good distribution of limestone in the area for successful liming. However, it is often observed in practice that limestone is applied using inappropriate or poorly adjusted equipment, which causes excessive wind to drag resulting in poor distribution (Gitti; Roscoe, 2017; Li et al., 2018).

As noted, it is essential to evaluate the best way to apply lime and fertilizer when first cultivating soybeans. Therefore, at the end of this work it will be feasible to make productivity estimates regarding the main fertilization and liming practices used in cultivation thus, contributing to studies that aim to improve the technical recommendations offered to producers in the region (Fageria, 2001; Foloni et al., 2023).

3.4 Soybean cultivation

Soybean is one of the oldest agricultural crops in the world, having been cultivated for more than five thousand years. Of Asian origin, with greater relevance in Chinese agriculture, where it was known as a sacred grain. Over time, the United States began to explore forage soybeans, making them more widely recognized in the West at the beginning of the 20th century. However, the crop only gained greater importance from the 1940s onwards, when the area dedicated to grain production began to grow in the United States and the rest of the world (Zhu et al., 2023).

The soybean grains are used by the agroindustry (production of vegetable oil and animal feed), chemical and food industries and pharmaceuticals. Recently, its use as an alternative source of biofuel has also been growing (Costa Neto; Rossi, 2000; Singh et al., 2008; Nguyen et al., 2018).

The cultivation of soybeans of Chinese origin took over the Cerrado from the 1980s onwards, due to the improvement of legumes to adapt to this natural domain. Among other areas of research, they also presented significant advances that made technologies available to the agribusiness sector (Liao et al., 2002). Technologies dedicated to correct soil management, such as balanced fertilization with available micro and macronutrients, expansion of acidity correction techniques with limestone, and development of the seed inoculation process with microorganisms for biological N fixation, have allowed the legume to express its potential in the varied climatic conditions in Brazilian territory (von Bloh et al., 2023; Telles et al., 2023).

The implementation of soybean breeding programs in Brazil made it possible to advance the crop to low latitude regions, through the development of more adapted cultivars through the incorporation of genes that delay flowering even under inductive photoperiod conditions, giving the characteristic of long juvenile period (Kiihl; Garcia, 1989; Yamanaka et al., 2011).

In recent decades, technological improvement work has been developing new cultivars with high adaptability and stability, which demonstrate desirable agronomic characteristics, in addition to high grain productivity for other producing regions in the national territory (Farias e Silva et al., 2023). Soy is cultivated throughout Brazil, being the crop that has developed the most in recent decades. This process is mainly due to the improvement that led to the “tropicalization” of the legume, which began to be cultivated in low latitude regions, close to the equator (Reis et al., 2024).

The expansion of soybeans in recent years in Brazil has reached high proportions and can be identified as a new cycle of agricultural production. This, with high significance regarding the impacts generated on the Brazilian economy through the sugarcane and coffee cycle in the 16th and 19th centuries. According to data from the *Companhia Nacional de Abastecimento* (CONAB) Brazil (Brasil, 2023), occupies the first position in the world ranking as the largest producer of soybeans, with a projection of 151.4 million tons of grains, and in addition to being the largest exporter since 2003, to date, using only half of the arable area for this crop (Dou et al., 2023).

The main challenge we face in soybean cultivation is involving its cultivation with more sustainable practices that will give greater longevity to the technologies currently in use. In this sense producers are increasingly attentive to the integration and diversification of management strategies, aware of soil improvement; disease and pest control; use of environmental resources; elimination of weeds, among other interesting processes for the better use of the soybean plant (MacLaren et al., 2020). In this way, soy will continue to be the main crop used to boost the Brazilian economy, since Brazil has reached the first position as a world producer of this commodity, bringing profitability to many families who live off the profits from agriculture. Soy is currently used in the food, pharmaceutical, cosmetics and livestock industries, as an important source of nutrients in the composition of animal feed (Chua; Liu, 2019; Etemadian et al., 2021).

4. Conclusions

The use of liming is necessary to control the pH of the soil in addition, to avoiding the action of toxic elements such as aluminum and maintaining a healthy soil with a microbial load capable of acting in synergy with agricultural vegetables. A good study and monitoring of the area favors the implementation of the liming method that will contribute to increasing agricultural productivity, promoting greater absorption of macro and micronutrients already available in the soil, this scenario being the essential purpose of this review study.

Brazil is relatively new to soybean cultivation, and its history and development of this crop in brazilian soils merit recognition of the importance of expanding agricultural technology for the use of different types of soils, through appropriate correction with liming and thus, the study in question, based on sandy soils could be carried out properly.

Liming in Brazil plays a determining role in the satisfactory development of crops since the soils are naturally acidic and contain a large amount of Al. This acidity originates from the intense washing and leaching of nutrients, whether naturally or due to due to human actions, and the soils due to the lack of replacement of removed nutrients and the use of acidic fertilizers, the course of the agricultural process is harmed with poor or non-existent plant development and consequently low productivity. In relation to liming processes and their applications on rural properties, we can assume that the suggestions based here are applicable and will possibly present positive results, if well developed.

5. Authors’ Contributions

Mateus Borges Rodrigues: idea and concepts about liming and soybean cultivation, study writing, translation and submission. *Carla Regina Pinotti*: advisor, corrections and publication.

6. Conflicts of Interest

No conflicts of interest.

7. Ethics Approval

Not applicable.

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