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ANTONIO CARLOS DE ALMEIDA CARMEIS FILHO

SOIL ACIDITY MANAGEMENT ON AN OXISOL QUALITY AND WHEAT-COMMON BEAN GROWTH UNDER A LONG TERM NO-TILLAGE SYSTEM

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Thesis presented to São Paulo State University, College of Agricultural Sciences, to obtain Doctor of Philosophy degree in Agronomy (Crop Science).

Advisor:
Profº Dr. Carlos Alexandre Costa Crusciol

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. / EMBRAPA Arroz e Feijão

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I dedicate this thesis to my spouse Tais and all my family.

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ABSTRACT

Soil chemical and physical disorders are among major limiting factors to improve productive potential of tropical agriculture. The low productive capacity has been associated especially to soil acidity and macronutrient deficient, thus the development of strategies that improve production capacity of tropical acid soils are required. Lime and phosphogypsum (PG) are materials commonly used to improve soil chemical condition, but there is few information about the long-term effects of these products, applied superficially, especially on Oxisol physical properties and organic matter pools. Therefore, this research aimed to evaluate the effect of surface application of lime and PG on the soil chemical and physical attributes, root growth, plant nutrition, yield components, technological characteristics and yield of wheat and common bean, and soil organic matter (SOM) pools considered critical to make agricultural tropical systems sustainable and productive. A randomized complete block design was used and treatments were replicated four times. Four treatments were carried out: control (without lime and gypsum application); PG (2.1 Mg ha^{-1}); lime (2.0 Mg ha^{-1}); and a combination of lime and PG (2.0 and 2.1 Mg ha^{-1}, respectively). Since the experiment was established in 2002, the amendments rates have been applied three times (2002, 2004, and 2010). Superficial liming alleviated Oxisol acidity in the surface and subsurface layers after twelve years under soil acidity management, with positive results of PG associated to lime on soil pH, Ca^{2+} and Mg^{2+} levels, and base saturation in the topsoil layers (0-0.10 m). The surface application of lime is effective to improve root growth in subsurface layers, crop nutrition and wheat and common bean grain yield. The high correlation between soil chemical attributes and organic carbon pools shows that the soil organic matter (SOM) input was favored mainly by high levels of Ca and Mg and low levels of exchangeable Al in the soil. The combination lime and PG improved the SOM quality, increasing the formation and stabilization of humic substances in the soil. The use of both soil amendments combined also provided significant improvements on soil physical properties, manly in the formation and stabilization of large aggregates (>1.0 mm). This condition provided better physical protection of SOM, inducing higher organic carbon accumulation in these structures. Consequently, it was observed a better soil structure, resulting in greater macroporosity as well as lower soil bulk density and penetration resistance. Lime rate estimated to increase

the base saturation in the topsoil (0-0.20 m) to 70% was considered appropriate for surface liming recommendation in a tropical Oxisol under no-tillage system, but the combination with phosphogypsum provides major benefits on soil chemical and physical attributes and SOM quality.

Keywords: lime, phosphogypsum, plant nutrition, root growth, grain yield, grain quality, soil aggregates, organic carbon, humic substances.

RESUMO

Os distúrbios químicos e físicos do solo estão entre os principais fatores que restringem o potencial produtivo da agricultura tropical. A baixa capacidade produtiva tem sido associada principalmente à acidez do solo e deficiência de macronutrientes, portanto, é fundamental o desenvolvimento de estratégias que ampliem a capacidade de produção de solos ácidos tropicais. O calcário e o gesso agrícola (PG) são materiais comumente empregados na agricultura para melhorar as propriedades químicas do solo, mas existem poucas informações sobre os efeitos da aplicação superficial desses produtos nas propriedades físicas dos Latossolos e nas diversas frações da matéria orgânica do solo (SOM). Diante destes aspectos, este trabalho objetivou avaliar o efeito da aplicação superficial de calcário e PG sobre os atributos químicos e físicos do solo, crescimento radicular, nutrição de plantas, componentes de produção, características tecnológicas e produtividade de trigo e feijão e sobre as diversas frações de SOM, as quais são consideradas críticas para tornar os sistemas agrícolas tropicais sustentáveis e produtivos. O delineamento experimental foi em blocos casualizados com quatro repetições. Foram estabelecidos quatro tratamentos: controle (sem aplicação de calcário e gesso); PG (2,1 Mg ha^{-1}); calcário (2,0 Mg ha^{-1}); e uma combinação de calcário e PG (2,0 e 2,1 Mg ha^{-1}, respectivamente). Desde a instalação do experimento em 2002, as doses de calcário e PG foram aplicadas três vezes (2002, 2004 e 2010). A calagem superficial reduziu a acidez do solo nas camadas superficiais e subsuperficiais, com resultados positivos de adição de PG e calcário no pH do solo, teores de Ca^{2+} e Mg^{2+} e saturação de bases nas camadas superficiais do solo (0-0,10 m). A aplicação superficial de calcário é eficaz para aumentar o crescimento radicular do trigo e feijão nas camadas subsuperficias, além disso, favoreceu os aspectos nutricionais e rendimento de grãos de ambas as culturas. A alta correlação entre os principais atributos químicos do solo e as diversas frações da SOM demonstra que a adição de Ca e Mg e a redução na toxicidade do Al no solo são fundamentais para favorecer o acúmulo de SOM. A combinação de calcário e PG melhorou a qualidade da SOM, aumentando a formação e estabilização de substâncias húmicas no solo. Além disso, a associação de ambos os produtos também proporcionou melhorias significativas nas propriedades físicas do solo, induzindo maior formação e estabilização de macroagregados (> 1,0 mm). Esta condição proporcionou melhor proteção física da SOM, induzindo maior

acúmulo de carbono orgânico nessas estruturas. Consequente, foi observado uma significativa melhoria na estrutura do solo, resultando em maior macroporosidade, bem como menor densidade do solo e resistência à penetração. A dose de calcário calculada para aumentar a saturação de base no solo (0-0,20 m) a 70% foi considerada adequada para a recomendação de calagem superficial em um Latossolo tropical conduzido sob sistema plantio direto, porém a combinação com PG proporciona maiores benefícios nos atributos químicos e físicos do solo e qualidade da SOM.

Palavras-chave: calcário, gesso agrícola, nutrição de plantas, crescimento radicular, produtividade de grãos, qualidade de grãos, agregados de solo, carbono orgânico, substancias húmicas

TABLE LIST

Chapter 2 – Root development and annual crop production as affected by lime and phosphogypsum application in a tropical Oxisol under no-tillage system

FIGURE LIST

Chapter 2 – Root development and annual crop production as affected by lime and phosphogypsum application in a tropical Oxisol under no-tillage system

SUMMARY

Introduction

Soil acidity is one of the major limiting factors for crop production in several locations around the world, occurring mainly in tropical areas dominated by Ultisols and Oxisols. Among the main consequences of acid soils are the high toxicity of elements such as Al^{3+} and Mn^{2+} and the low availability of macronutrients, which affect severally root growth, water and nutrient uptake by plants, and consequently the crop yield and farm profitability.

In order to neutralize soil acidity and improve soil fertility, liming is the most common practice used by farmers due to low economic cost, in addition, is considered an important source of Ca and Mg for soils with low natural levels of exchangeable bases. Because of the chemical properties, lime has low solubility in water, reducing the mobility of the product down the soil profile. In conventional management systems, lime is usually incorporated into the soil during tillage processes, however, plowing and disking severally impact the physical, chemical, and biological attributes of soil, inducing transformations which contribute for land degradation.

The losses on productive capacity and soil health due to intensive tillage have affected drastically their capacity to sustain food production. As a result, in the last decades a massive conversion of conventional tillage to conservative ecosystems has occured, it minimizes the environmental impacts and increases soil capacity to produce food, fiber, and fuel, making the agricultural production more ecologically sustainable.

No-tillage (NT) system is the main conservative agricultural ecosystem spread and adopted in Brazil, however, the impact of soil acidity has restricted the benefits of the system in improving crop production. Due to environmental sustainability concepts, practices such as plowing and disking, commonly used for acidity amendments incorporation, are not recommended, thus lime is only applied superficially, which theoretically may limit limestone reaction below the point of placement.

Following up on this research, several long-term studies were conducted in subtropical areas, attesting the viability of lime applied superficially in NT system due to the greater accumulation of soil organic matter (SOM), which induces several physical and chemical mechanisms involved on lime action in subsurface layers. On

the other hand, limited information is available for tropical conditions, where rainfall distribution, soil physical attributes and SOM content are distinct compared to subtropical soils. Dry winter, high decomposition rates of SOM, frequent dry spells, and dense soil profile are important characteristics of tropical areas, which can affect the lime reaction applied superficially.

High acidity and low fertility of subsoils have been limiting crop production in several countries located in the tropics due to the chemical effect on root development of crops, limiting the growth and water and nutrient uptake by plants. Following up this information, further studies are required to evaluate the long-term effect of surface liming on tropical soil profile.

In order to improve root growth to subsurface layers severally affected by chemical disorders, the phosphogypsum (PG) can be an important strategy for improving lime reactions. The higher solubility, the capacity to neutralize Al^{3+} toxicity and increase the levels of basic cations (BC) at subsoil layers makes this by-product a possible complement to liming. In addition, the effect on improving root development may affects some soil attributes that can enhance lime reaction applied superficially.

The Brazilian Cerrado region has great potential to increase wheat and common bean production in Brazil, but Al toxicity and soil acidity has been considered one of the most important yield-limiting for both crops. Given these facts, liming has been recommended to improve crop production, but there is restrict information about the long-term effects of surface application of lime and PG combined on wheat and common bean growth, especially in tropical Oxisols managed under NT system.

We hypothesized that surface liming with PG addition play a crucial role in improving subsoil chemical attributes, SOM pools and soil physical attributes, being an important strategy to increase the crop production in regions with dry winter and frequent dry spells during rainy season. However, for tropical condition, there is restricted scientific information involving the long-term effects of surface application of lime and PG combined on SOM pools and soil physical attributes, considered critical factors to make agricultural tropical systems sustainable.

Therefore, this research aimed to evaluate the effect of surface application of lime and PG on the soil chemical and physical attributes, root growth, plant

nutrition, yield components, technological characteristics and yield of wheat and common bean, and soil organic matter pools considered critical to make agricultural tropical systems sustainable and productive.

3.6. Conclusions

Surface liming is considered an important tool to increase SOM input in tropical acid soils conducted under long-term NT systems. The maintenance of high concentrations of basic cations (such as Ca and Mg) and low levels of exchangeable Al in soil solution demonstrated high correlation to quantity and quality of SOM. Although PG had no effect on plant growth, the combination of PG with lime increased the formation and stabilization of humic substances, mainly as fulvic and humic acids, which can be attributed to soil fertility improvement and the higher input of organic residues. Therefore, surface application of lime and gypsum, associated with conservative practices, are considered key factors to improve soil health and consequently the sustainability of agricultural systems in tropical regions.

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