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Annual crop rotation of tropical pastures with no-till soil as affected by lime surface application

Carlos A.C. Crusciol[a,*], Rubia R. Marques[a], Antonio C.A. Carmeis Filho[a], Rogério P. Soratto[a], Claudio H.M. Costa[a], Jayme Ferrari Neto[a], Gustavo S.A. Castro[b], Cristiano M. Pariz[c], André M. de Castilhos[c]

[a] São Paulo State University (UNESP), College of Agricultural Sciences, Department of Crop Science, P.O. Box: 237, 18610-307 Botucatu, State of São Paulo, Brazil

[b] Brazilian Agricultural Research Corporation (EMBRAPA), 13070-115 Campinas, State of São Paulo, Brazil

[c] UNESP, School of Veterinary Medicine and Animal Science, Department of Animal Nutrition and Breeding, P.O. Box: 560, 18618-970 Botucatu, State of São Paulo, Brazil

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ABSTRACT

Soil acidity and low natural fertility are the main limiting factors for grain production in tropical regions such as the Brazilian Cerrado. The application of lime to the surface of no-till soil can improve plant nutrition, dry matter production, crop yields and revenue. The present study, conducted at the Lageado Experimental Farm in Botucatu, State of São Paulo, Brazil, is part of an ongoing research project initiated in 2002 to evaluate the long-term effects of the surface application of lime on the soil's chemical attributes, nutrition and kernel/grain yield of peanut (*Arachis hypogaea*), white oat (*Avena sativa* L.) and maize (*Zea mays* L.) intercropped with palisade grass (*Urochloa brizantha* cv. Marandu), as well as the forage dry matter yield of palisade grass in winter/spring, its crude protein concentration, estimated meat production, and revenue in a tropical region with a dry winter during four growing seasons. The experiment was designed in randomized blocks with four replications. The treatments consisted of four rates of lime application (0, 1000, 2000 and 4000 kg ha^{-1}), performed in November 2004. The surface application of limestone to the studied tropical no-till soil was efficient in reducing soil acidity from the surface down to a depth of 0.60 m and resulted in greater availability of P and K at the soil surface. Ca and Mg availability in the soil also increased with the lime application rate, up to a depth of 0.60 m. Nutrient absorption was enhanced with liming, especially regarding the nutrient uptake of K, Ca and Mg by plants. Significant increases in the yield components and kernel/grain yields of peanut, white oat and maize were obtained through the surface application of limestone. The lime rates estimated to achieve the maximum grain yield, especially in white oat and maize, were very close to the rates necessary to increase the base saturation of a soil sample collected at a depth of 0–0.20 m to 70%, indicating that the surface liming of 2000 kg ha^{-1} is effective for the studied tropical no-till soil. This lime rate also increases the forage dry matter yield, crude protein concentration and estimated meat production during winter/spring in the maize-palisade grass intercropping, provides the highest total and mean net profit during the four growing seasons, and can improve the long-term sustainability of tropical agriculture in the Brazilian Cerrado.

1. Introduction

No-tillage (NT) is one of the main strategies adopted to mitigate soil degradation. In this production model, the preservation of agricultural ecosystems is the main objective; additionally, this strategy has the potential to recover areas that are already considered unproductive. Because of its adaptability and enormous benefits for soil biodiversity, NT has been adopted in various regions of the world, especially in countries such as Argentina, Australia, Brazil, Canada and the United States (Derpsch et al., 2010). The large expansion of NT systems is primarily related to the productivity gains observed in legume and cereal crops.

Soil acidity reduces the availability of nutrients such as calcium (Ca^{2+}) and magnesium (Mg^{2+}) and increases the bioavailability of toxic elements such as aluminum (Al^{3+}) (von Uexküll and Mutert, 1995; Caires et al., 2005). Given these inappropriate conditions for

* Corresponding author.
E-mail address: crusciol@fca.unesp.br (C.A.C. Crusciol).

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crop development, liming is commonly employed to increase the productive potential of soil. However, the low solubility and mobility of limestone in soil cause its diminishing effect on soil acidity to occur slowly once it reaches certain depths in NT soil (Ernani et al., 2004).

In regions with a regular rainfall distribution, several reports have indicated an absence of any response of grain production to surface liming for years (Moreira et al., 2001; Caires et al., 2006a, 2008a,b,c, 2011, 2015; Joris et al., 2013). However, in the tropical regions where dry spells often occur during the rainy season and the dry winter, chemical disorders due to soil and subsoil acidity is an important factor limiting crop productivity (Marsh and Grove, 1992; Sumner, 1995; Castro and Crusciol, 2013a,b; Costa and Crusciol, 2016; Tiritan et al., 2016). This effect has been attributed to the toxic effects of Al on root growth at certain depths, inducing water stress and nutrient uptake by plants (Caires et al., 2008b). Thus, subsoil acidity alleviation can promote greater root development, increasing the plants' tolerance to water stress during dry spells.

The amount of soil organic matter has been considered an important factor to reduce free Al levels; however, tropical soils such as Oxisols and Ultisols exhibit a naturally low organic matter content. In NT systems, the addition of organic residues helps to regulate Al species in acid surface soils, but cash crops produce low amounts of straw (Alford et al., 2003; Allen et al., 2007; Zobeck and Schillinger, 2010). In addition, regions with dry winters (low and irregular rainfall), such as the Brazilian Cerrado or African Savanna, have large risks in growing a successful dry-season crop, resulting in a long fallow period without productivity (Borghi et al., 2013). In such warm conditions, straw decomposes rapidly (Nascente et al., 2013; Pariz et al., 2011a), and negatively affects success of NT system.

In NT systems, tropical forages such as palisade grass {*Urochloa brizantha* cv. Marandu (Hochst. ex A. Rich.) R.D. Webster [syn. *Brachiaria brizantha* cv. Marandu (Hochst. ex A. Rich.) Stapf]} can be available for use in the winter to spring (grazed by animals or cut and removed as fodder) and can be intercropped with grain crops in the summer (Kluthcouski and Aidar, 2003) using an integrated crop-livestock system. Therefore, intercropping maize, sorghum [*Sorghum bicolor* (L.) Moench], and soybean [*Glycine max* (L.) Merr.] with tropical perennial grasses is an excellent alternative for producing grain and forage for livestock during the dry season and for increasing the supply of straw for the continuity of NT management (Pariz et al., 2011a,b; Borghi et al., 2013; Crusciol et al., 2011, 2012, 2013, 2014, 2015; Mateus et al., 2016). Consequently, food production is increased without the requirement of cultivating additional areas, and the system is considered sustainable (Sani et al., 2011; Surve and Arvadia, 2011). Most of the agricultural research in tropical and subtropical regions has focused on developing methods to identify liming requirements for soil correction and on determining the rates and application methods that result in higher crop response (Martins et al., 2014a,b). Intercropping grain with forage crops is a new practice, and it requires more information before widespread adoption of the technology (Mateus et al., 2016). Knowledge of species competition for water, light, and nutrients is important for successful grain production and adequate forage availability (Pariz et al., 2011b). For example, understanding the changes in soil chemical attributes and their effects on grain and pasture yield is necessary for establishing and adjusting lime requirements in a crop rotation scheme under NT management (Tiritan et al., 2016).

This study aimed to evaluate the changes in the soil chemical properties, plant nutrition and kernel/grain yield of peanuts, white oat and maize intercropped with palisade grass, as well as forage dry matter yield of palisade grass in winter/spring, its crude protein concentration, estimated meat production, and revenue resulting from superficial liming under no-tillage during four growing seasons in a region with dry winters, such as that of the Brazilian Cerrado.

2. Materials and methods

2.1. Site description and climatic data

The experiment was conducted from October 2004 to October 2008 at the Lageado Experimental Farm of the College of Agricultural Sciences, FCA/UNESP, in Botucatu, São Paulo State, Brazil. The geographical coordinates of the study site are 48°23′W, 22°51′S and the elevation is 765 m. During the experimental period, rainfall was measured daily using a 50 cm tall plastic rain gauge (pluviometer) placed on the ground at a height of 1.20 m in the experimental area (Fig. 1).

The soil is classified as a Typic Hapludox (USDA, 2014), with sand, silt, and clay contents of 54, 11, and 35%, respectively, at a depth of 0–0.20 m. The area had been managed since 2002 under a no-till system: in the growing season of 2002/2003, upland rice (*Oryza sativa*) in the summer and black oat (*Avena strigosa* Schreb.) in the fall; in the growing season of 2003/2004, common bean (*Phaseolus vulgaris* L.) in the summer and black oat in the fall.

Prior to the beginning of the experiment (October 2002) and before the last limestone application (August 2004), eight subsamples were randomly obtained from useable areas of each plot at depths of 0–0.05, 0.05–0.10, 0.10–0.20, 0.20–0.40, and 0.40–0.60 m and were combined into one composite sample to determine the soil chemical attributes (Table 1). The soil pH was determined in a 0.01 mol L^{-1} $CaCl_2$ suspension (1:2.5 soil/solution). Soil organic matter was determined via the colorimetric method proposed by Haynes (1984) using a sodium dichromate solution. The total acidity at pH 7.0 (H + Al) was evaluated with 0.5 mol L^{-1} calcium acetate at pH 7.0 and determined through titration with a 0.025 mol L^{-1} NaOH solution. Exchangeable Al was extracted with neutral 1 mol L^{-1} KCl at a 1:10 soil/solution ratio and determined by titration with a 0.025 mol L^{-1} NaOH solution. Available P and exchangeable Ca, Mg, and K were extracted using an ion exchange resin. Exchangeable Ca^{2+}, Mg^{2+} and K^{+} were determined using a Shimadzu AA-6300 atomic absorption/Flame-Emission spectrophotometer. Phosphorus was determined calorimetrically (Murphy and Riley, 1962) using a FEMTO 600S spectrophotometer. The cation exchange capacity (CEC) was calculated from the sum of the concentrations of the H, Al, K, Ca, and Mg cations. Given the low natural level due to the climate conditions and mineralogical composition of the soil (Leal et al., 2009), exchangeable Na was not measured. Base saturation (BS) values were calculated by dividing the sum for K, Mg, and Ca (the bases) by the CEC and multiplying the result by 100% (van Raij et al., 2001).

2.2. Experimental design

In this study, we adopted a completely randomized block experimental design with four treatments, replicated six times. The plot size was 5.4 m × 10.0 m. The plots were subjected to four rates of dolomitic limestone application: (i) Control (no lime); (ii) 1.0 Mg ha^{-1} (half the recommended dose); (iii) 2.0 Mg ha^{-1} (calculated to raise base saturation to 70%); and (iv) 4.0 Mg ha^{-1} (twice the recommended dose).

2.3. Establishment of treatments

At the beginning of the experiment (October 15, 2002), limestone rates were applied superficially. The reapplication on November 2004 was based on a soil analysis that was performed in August 2004, where the base saturation in the treatment in