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EVOLUTION OF SOIL FERTILITY OVER TIME OF ADOPTION OF CROP-LIVETOCK INTEGRATION

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ABSTRACT
The soil fertility evolution was monitored in a Red Latosol, very clayey texture, under intensive management in a crop-livestock integration system, conducted for 15 years. The indicators of soil productivity potential and “bioavailability” of macro and micronutrients were monitored in different glebes, cultivated with grain crops, forage, and pasture, in rotation, succession and intercropping systems. In general, it was possible to maintain satisfactory conditions of chemical soil fertility over time, especially considering that it is a realistic management/production scheme, analogous to a small rural property. Nevertheless, there were possibilities for improvements in nutritional monitoring and management of correction and fertilization of the glebes. The results of the soil fertility indicators reveal some interesting results that serve as a basis for decision making in this area and, mainly, in future works to be developed with intensive production systems. The first aspect is related to the planning for carrying out soil sampling, considering the need to obtain more consistent and standardized results. Another aspect refers to establishing fertilization programs using the concept of fertilization of production systems according to the requirements of the crops and export of nutrients, taking into account the purpose of exploration, whether for the production of grains, silage, or forage.
Key words: Soil productivity; soil fertility; crop systems

INTRODUCTION

Crop-livestock integration has been identified as a land use strategy that makes it possible to combine gains in plant and animal productivity, with greater efficiency in the use of available resources, including nutrients, in addition to greater sustainability by improving the quality of the land ground. However, alternatives for intensifying agricultural production systems, such as crop rotation, succession, and intercropping, require more frequent monitoring (2 to 3 years) of the chemical, physical and biological attributes of soils, in order to maintain their productive potential and, consequently, its sustainability. This is due to the fact that the different types of crops and their production purposes (grains and forage) present different nutritional requirements and, consequently, nutrient exports and cycling, which can cause imbalance in the nutrient contents of the soils, thus limiting their productive potential. In this type of exploration, the balance of nutrients (applied quantity less exported in the harvested products) assumes fundamental importance, as an auxiliary tool, in the recommendation of liming and fertilization for production systems. This research aims to evaluate the evolution and variations in soil fertility indicators of an intensive production system, involving different crops in rotation, succession, and intercropping, in a pilot project for the integration of livestock farming, conducted from 2005 to 2018.

MATERIAL AND METHODS

The pilot project, in a crop-livestock integration system has been carried out in the experimental area of Embrapa Maize e Sorghum in Sete Lagoas, MG, since 2005. The project area comprises about 24 ha and was divided into four glebes of 5.5 ha each. The soil is classified as Yellow Red Latosol, very clayey texture, managed under no-tillage system since 2006.

Soil sampling and laboratory analysis

The sampling in each glebe was carried out at random points, in the traditional system, taking 25 simple samples from each glebe (5.5 ha) to compose a composite sample. The sampling depths were different for each year, and in 2005 sampling was carried out at depths of 0-20 cm and 20-40 cm. In 2006 and 2012 at depths of 0-10 cm, 10-20 cm, and 20-40 cm. In 2014, sampling was carried out at depths of 0-5 cm, 5-10 cm, 10-20 cm, 20-40 cm, and 40-60 cm. In 2017 and 2018, sampling was performed at depths of 0-10 cm, 10-20 cm, 20-40 cm, and 40-60 cm.

Due to these differences in the sampling depths, for the presentation of the results, we opted for uniformity for the depths of 0-20 cm (weighted average values of the sampled depths up to 20 cm) and 20-40 cm, for which it was possible obtain results for a greater number of years of sampling. The weighted averages for the 0 to 20 cm layer were calculated using the equation: $\{(P_{0\text{-}5} \times 5) + (P_{5\text{-}10} \times 5) + (P_{10\text{-}20} \times 10)\}/20$.

These differences in the sampling depths performed, without an adequate systematization of methods, such as standardization in the depths and sampling periods, make it difficult to use statistical tools to analyze this type of result. Thus, in studies of this nature, it is necessary to have an initial planning for carrying out soil sampling, defining the form of collection, randomized or systematized, the depth and timing of sampling (COELHO, 2005a). However, the need to compare non-standardized data also occurs in many agricultural properties that wish to obtain a history of the evolution of soil fertility in their glebes.

The chemical and physical analyzes were carried out in the chemical and physical analysis laboratories of Embrapa Maize and Sorghum, being determined: the pH in water, the potential acidity (H + Al) extracted with calcium acetate solution pH 7.0; exchangeable acidity (Al), Ca and Mg extracted in 1N KCl solution; K, P, Zn, Cu, Mn and Fe extracted by the Mehlich1 extractor, B extracted in hot water, organic carbon in a carbon analyzer at 800 ºC, and the organic matter contents being obtained by multiplying the organic carbon contents by the 1.72. Based on these results, the CEC-pH7 (T), effective CEC (t), saturation by Al of the effective CEC (m), sum of bases (SB) and base saturation (V) were calculated. The granulometric analysis (sand, silt, and clay) was performed using the pipette method.

The results were analyzed statistically through the classic descriptive analysis in SAS software version 8.2 and the figures (graphs) elaborated in Origin75 software. The results of these analyzes were organized into three groups: (a) indicators of the productive potential of the soil, which includes data on organic matter (OM), cation exchange capacity (CEC-pH7), pH-water, saturation by aluminum of the effective CEC (m) and base saturation of the CEC-pH7 (V) and clay content; (b) indicators of the "bioavailability" of macronutrients (Ca, Mg, K and P) and (c) indicators of the "bioavailability" of micronutrients (Zn, Cu, Mn, Fe and B).

Soil amendment and fertilization history

The application of correctives and fertilizers according to the results of the soil analysis for each glebe. The limestone doses were calculated by the base saturation method, aiming to increase to a value of 60%, with dolomitic limestone. Gypsum in the doses of 1.0 Mg ha^{-1} and 2.0 Mg ha^{-1} was applied to the soil surface in 2005 and 2014, respectively. In 2018, as a source of magnesium, 1.0 Mg ha^{-1} of serpentinite rock powder (MgO - 38%) was applied to each glebe.

At sowing time, fertilizers formulated N, P, K and Zn were used for corn, sorghum and brachiaria pastures (300 to 400 kg ha^{-1} of formula 08-30-15 of N, P_2O_5 and K_20, respectively). For soybeans, formulated fertilizers containing P, K and Zn were used (300 kg ha^{-1} of the formula 00-30-15 of N, P_2O_5 and K_2O, respectively). In the top dress fertilizations for corn and sorghum, doses ranging from 90 to 130 kg ha^{-1} of N in the form of urea were applied in the stage of 5 to 6 leaves. When maize and sorghum crops were used for the production of forage, potassium was also applied top dressing, together with N (200 kg ha^{-1} of the formula 20-00-20 of N, P_2O_5 and K_2O, respectively). In pasture glebes, 200 kg ha^{-1} of N were applied in the top dressing, divided into three applications.

RESULTS AND DISCUSSIONS

In the implementation of the crop-livestock integration project in 2005, the initial results of the chemical soil analyze showed a marked variation in the soil fertility indicators among the glebes (Table 1), thus suggesting a different management for the correction of acidity and fertilization.

Table 1. Chemical and physical attributes of soil samples collected in 2005, before the implementation of the component areas of the pilot project.

Glebes	Glebe 01		Glebe 02		Glebe 03		Glebe 04	
Depth - cm	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
Indicators of the productive potential of the soil								
O.M.[1] (%)	3.98	3.31	3.55	2.98	3.25	2.84	4.28	3.50
pH (water)	5.40	5.40	5.20	5.40	5.60	5.30	5.10	5.00
CEC[2] (cmol$_c$ dm^{-3})	11.57	11.19	11.07	9.90	9.88	8.92	10.76	10.43
Al Sat.[3] (%)	3.0	6.0	12.0	7.0	2.0	8.0	20.0	32.0
Base Sat.[4] (%)	48.0	44.0	38.0	43.0	51.0	38.0	29.0	20.0
Clay (%)	62	69	69	71	62	71	69	62
Indicators of the "bioavailability" of macronutrients								
Ca (cmol$_c$ dm^{-3})	4.49	1.06	3.50	3.64	4.29	2.85	2.69	1.87
Mg (cmol$_c$ dm^{-3})	0.72	0.61	0.48	0.44	0.61	0.37	0.29	0.18
K (mg dm^{-3})	140	89	92	52	64	48	45	23
P (mg dm^{-3})	20	14	39	11	9	5	11	6
Indicators of the "bioavailability" of micronutrients								
Zn (mg dm^{-3})	4.5	2.5	7.0	14.5	2.5	4.0	12.5	1.5
Cu (mg dm^{-3})	1.2	1.1	1.4	1.5	1.2	1.4	0.8	4.1
Mn (mg dm^{-3})	134	121	85	81	61	50	19	31
Fe (mg dm^{-3})	43	45	52	71	43	47	47	51

[1]O.M.-organic matter, [2]CEC-pH7-cation exchange capacity, [3]Al Sat.-aluminum saturation, [4]Base Sat.-base saturation.

For example, if we consider the need for limestone to raise the base saturation (V) to a theoretical value of 60%, the calculated quantities, would indicate doses of 1.38; 2.43; 0.89 and 3.33 Mg ha^{-1} of a limestone with 100% effective calcium carbonate equivalent, respectively, for glebes 01, 02, 03 and 04, to be incorporated into the soil in the 20 cm layer. However, due to the high buffer capacity of the soil, associated with the reaction speed of the granulometry fractions of the limestones, the expected value of 60% of base saturation is hardly reached, thus requiring adjustments in the doses and in the application of the limestone, mainly in soils with higher levels of CEC-pH7 and organic matter. The average pH-water values of 5.0 to 5.5, aluminum saturation of 5 to 20% and base saturation of 25 to 35%, verified in the analyzed period, support these considerations.

Within this focus, it is important to mention that in experiments conducted by Coelho (1994) in a Red Latosol, very clay texture, the limestone dose calculated by the base saturation method (2.5 Mg ha^{-1}), was not enough to raise base saturation to the target value of 60%. In order to reach this value, it was necessary to apply 6.0 Mg ha^{-1}, as revealed by the results of soil analysis of samples collected 11 months after the application of lime and successive crops of corn and beans.

According to CFSEMG (1999), the maximum values of saturation by aluminum in the superficial layer (20 cm) tolerated by the crops are 15% for corn and sorghum and 20% for soybeans. For brachiaria these values are 20% to 30%. However, in an intensive system of grain and forage production like the one used in this work, the objective must be to completely neutralize Al in the surface layer, which can be obtained by applying lime in an appropriate dose and incorporated into the soil at depth maximum possible. This management becomes more important when the objective is to implement the no-till system, where the subsequent application of lime will be carried out on the soil surface and, therefore, without possibilities of incorporation.

In the present work, although gypsum applications were carried out in 2005 (1.0 Mg ha^{-1}) and 2014 (2.0 Mg ha^{-1}), the presence of exchangeable Al^{3+} was also found in the 20 to 40 cm layer, whose values represented 6 to 21% of saturation by aluminum of the effective CEC. The existing recommendations for applying gypsum on Brazilian soils for the cultivation of grain crops are based on the following critical limits in the subsurface layer (20 - 40 cm): ≥ 20% for Al saturation (m), and or ≥ 0.5 $cmol_c$ dm^{-3} for exchangeable Al^{3+} and/or ≤ 0.5 $cmol_c$ dm^{-3} for exchangeable Ca^{2+} (SOUZA and LOBATO, 2004; PAULETTI and MOTTA, 2017). Considering these criteria, only for glebe 04, it would be recommended to apply gypsum. Considering that the main recommendations for gypsum doses for Brazilian soils are based on clay content, the following equation has been suggested: Gypsum dose (Mg ha^{-1}) = 0.05 × clay content (%) (SOUZA and LOBATO, 2004). Therefore, based on this equation, the recommended gypsum dose for glebe 04 is 3.10 Mg ha^{-1}.

According to Pias et al. (2020), cereals (corn, wheat, white oats, barley, and rice) had a high probability (77-97%) that their grain yields would be increased by the application of gypsum on soils with Al saturation greater than 5% in the 20 to 40 cm layer. The average increase in grain production was 14 and 7% in crops that developed in the presence and absence of water deficit, respectively. A positive response of soybeans to gypsum was observed in soils deficient in water and with an Al saturation greater than 10%. Under these conditions, the probability of a positive response from soybeans was 88% and the average increase in grain production was 12%.

Regarding the levels of P and K revealed by soil analysis of samples collected during the period of conduction of the crop-livestock integration system, there were variations over the years and among glebes (Figure 1), also indicating that different management could be used in fertilization of crops, in order to balance the reserves of these nutrients among the glebes.

For P, the available levels (Mehlich1), presented themselves during the conduction period of the crop-livestock integration system, with small increases (Figure 1), but with values always above the critical level of 8 to 10 mg of P dm^{-3}, previously established for the soil of the area managed under conventional tillage (COELHO and FRANÇA, 1994) and 6.0 mg dm^{-3} for this same type of soil managed under no-tillage already established (SOUSA et al., 2019). This probably occurred due to the application to the crops of doses of P greater than the amount exported in the crops, thus creating a reserve of P in the soil that could be better used, adjusting the doses of P to be applied according to the expectation of crop yields and the respective exports of P by harvests.

For K, there was an inverse situation in relation to P (Figure 1), that is, the levels available in the soil, in the period from 2005 to 2014, decreased to values well below the critical level of 100 mg dm^{-3} of K in the soil (COELHO, 2005b), reflecting a greater export of the nutrient in the harvests in relation to the applied doses. However, after that period, the K content in the soil increased considerably to values above the critical level, reflecting a better adjustment in the applied doses, as occurred in 2014, with the application of 200 kg ha^{-1} KCl (120 kg ha^{-1} of K_2O).

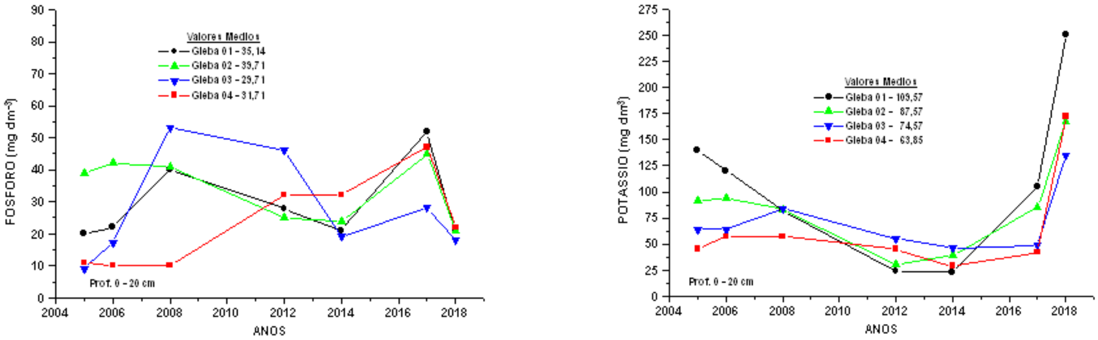

Figure 1. Phosphorus and potassium contents in the soil at a depth of 0-20 cm in the different glebes, over the period of conduction of the crop-livestock integration system.

With regard to micronutrients, it was found that in the period of conduction of the crop-livestock integration system, the levels in the soil have always remained close to or above the established critical levels of: 1.5 mg dm^{-3} of Zn; 1.2 mg dm^{-3} of Cu; 8 mg dm^{-3} of Mn; 30 mg dm^{-3} of Fe (Mehlich1) and 0.6 mg dm^{-3} of B (hot water) (CFSEMG, 1999), thus not constituting limitations for the development and productivity of crops.

CONCLUSIONS

In general, the crop-livestock integration system conducted in the pilot project, made it possible to maintain satisfactory conditions of chemical soil fertility over time, especially considering that it is a realistic management/production scheme, analogous to a small rural property, associated with the dynamics of alternating crops, and animal purposes in the glebes. Nevertheless, there were possibilities for improvements in nutritional monitoring and management of correction and fertilization of the glebes.

The results of the soil fertility indicators in the glebes, evaluated in the period from 2005 to 2018, reveal some interesting results that serve as a basis for decision making in this area and, mainly, in future works to be developed with intensive production systems. involving intercropping, rotation, and succession of crops for different purposes, such as grain production, forage, and pasture.

The first aspect is related to the planning for carrying out soil sampling, considering the need to obtain more consistent and standardized results. In this respect, the system of systematic sampling, in grids and georeferenced, with repetitions, would make it possible to obtain more consistent results and statistical analysis using appropriate models.

Another aspect refers to establishing fertilization programs using the concept of fertilization of production systems according to the requirements of crops and export of nutrients, taking into account the purpose of exploration, whether for the production of grains, silage, or forage.

This information is essential for establishing a balance of nutrients that, associated with the results of soil analysis, allows the elaboration of a more adequate program for soil correction and fertilization of the system, thus avoiding excessive or insufficient applications of correctives and fertilizers and providing greater sustainability of the production system. Management based on the balance of nutrients would certainly allow for a better adjustment in the supply of phosphorus and potassium, increasing the efficiency of utilization of the P reserves already existing in the soil and avoiding deficit levels of K will limit the productive potential of the glebes.

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