REVISTA DE CIÊNCIASAGRÁRIAS
Amazonian Journal
of Agricultural and Environmental Sciences
www.ajaes.ufra.edu.br

http://dx.doi.org/10.4322/rca.2013.012

ORIGINAL ARTICLE

Increasing doses of agricultural gypsum, aggregate stability and organic carbon in Cerrado Latosol under Coffee crop

Doses crescentes de gesso agrícola, estabilidade de agregados e carbono orgânico em Latossolo do Cerrado sob Cafeicultura

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KEYWORDS
Aggregation
Brachiaria sp.
Gypsum
Soil organic matter

PALAVRAS-CHAVE
Agregação
Braquiaria sp.
Fosfogesso
Matéria orgânica do solo

ABSTRACT: The management of perennial crops could encourage the improvement of the soil, making it more productive, provided that appropriate agronomic practices are adopted. In order to evaluate the structure of a Cerrado Latosol subjected to soil management that adopts the use of high doses of gypsum and brachiaria on the coffee plants interrow, we studied the stability of aggregates and total soil organic carbon after two years of deployment of coffee. Soil samples were collected at 5 and 15 cm of depth in the crop coffee row located in the Alto São Francisco region, Minas Gerais states. The treatments were: G-0, no gypsum on the row, G-7, 7.0 Mg ha^{-1} of gypsum distributed in the coffee row, G-28, 28 Mg ha^{-1} of gypsum distributed in the coffee row, G-56, 56 Mg ha^{-1} of gypsum distributed in the row, CV-0, conventional management without gypsum CV-0 conventional tillage without gypsum in the row and grasses between row Brachiaria sp. between rows of coffee plants. Chemical analyzes were performed to determine the cations K^+, Ca^{+2}, Mg^{+2}, P, and Al^{+3}, total organic carbon and physical analysis of soil aggregate stability. It was determined the mean weight diameter and geometric mean diameter of aggregates retained on sieves with diameters ranging from 4 to 0.105 mm. All treatments were found more than 90% of aggregates with a diameter >2 mm suggesting that the management adopted a positive influence soil aggregate stability. The total organic carbon were positive and significantly correlated with aggregation. The dose of gypsum 7 t ha^{-1} positively altered the aggregation of soil specially in the superficial layer (15 cm).

RESUMO: *O manejo de culturas perenes pode favorecer a melhoria da qualidade do solo, tornando-o mais produtivo, desde que sejam adotadas práticas agronômicas adequadas. Com o objetivo de avaliar a agregação de um Latossolo da região do Cerrado Mineiro submetido a sistema inovador de manejo, que utiliza gesso agrícola e braquiária na entrelinha de lavoura cafeeira, foi estudada a estabilidade de agregados e verificado o carbono orgânico total após dois anos da implantação de cafeeiros. Foram amostradas as profundidades de 5 e 15 cm na linha do cafeeiro em área experimental localizada na região do Alto São Francisco-MG. Os tratamentos foram: sem gesso na linha; doses de 7,0; 28, e 56 t ha^{-1} de gesso distribuído na linha; manejo convencional, sem gesso na linha e sem Braquiaria sp. na entrelinha do cafeeiro. Foram realizadas análises químicas para determinação dos cátions K^+, Ca^{+2}, Mg^{+2}, P e Al^{+3}, e do carbono orgânico total, além da análise física de estabilidade de agregados do solo. Determinou-se o diâmetro médio ponderado e o diâmetro médio geométrico dos agregados retidos em peneiras com diâmetro variando de 4 a 0,105 mm. Verificou-se que o carbono orgânico total do solo correlacionou positiva e significativamente com a agregação do solo, que as doses elevadas de gesso agrícola alteraram positivamente a agregação do solo na camada de 15 cm de profundidade e que a dose de gesso de 7 t ha^{-1} foi a melhor no que se refere ao aumento de carbono orgânico do solo na profundidade de 15 cm.*

Recebido: 05/09/2012
Aceito: 03/12/2012

1 Introduction

The different management systems significantly affect soil aggregates, mainly when these soils are used for long periods of time and with high input of organic matter (MATOS et al., 2008). In this sense, scientific results show that grasses in general, produce differential effects on the stabilization and aggregation of soils because of their aggressive root system, which promotes the input of large amounts of organic matter in the soil (LIMA et al., 2012). In this respect, high levels of organic matter when associated with root provide enhanced soil aggregation (CAMPOS et al., 1995) due to the physico-chemical bonding between organic colloids and the soil minerals (TERZAGHI; PERCL; MESRI, 1996). Thus, soil management with the use of grasses, whether in intercropping, succession, or rotation with diverse cultures, can minimize soil degradation due to the beneficial effect of grasses on the soil physicochemical properties, besides promoting increased stocks of soil organic carbon (SOC), with consequent reduction of greenhouse gas emission to the atmosphere. For the Brazilian agriculture, some authors such as Rosa Júnior et al. (2006), reported favorable results to soil aggregation with the use of agricultural gypsum (phosphogypsum), especially on the stabilization of aggregates larger than 1.0 mm in diameter. Phosphogypsum has lately been considered an important soil chemical physico-hydric conditioner because this input, besides favoring aggregation, also helps reduce the toxic effects caused by aluminum, and increases the levels of calcium and sulfur in the soil (RAIJ, 2008). From this perspective, we emphasize the important role of phosphogypsum as a calcium source in depth, conditioning greater growth of the root system and better water absorption by plants (SERAFIM et al., 2011; SILVA et al., 2012). However, the use of high doses of phosphogypsum in soil has caused very much controversy, since it is an input that promotes the leaching of some nutrients (RAIJ, 2008). Regarding the physical aspects of the soil, information available in the literature shows positive effects of the use of phosphogypsum (SILVA et al., 2012), especially those related to aggregation (ROSA JÚNIOR et al., 2006); however, there are no studies correlating aggregation with increasing doses of phosphogypsum. For this reason, management systems that use high doses of phosphogypsum (28 Mg ha^{-1}) and grasses – as the one adopted in the 'Alto São Francisco' region – need to be further studied. By recommending a set of differentiated managing practices compared to the conventionally used ones, in this system, considered innovative in the coffee crop, practices of deep soil tillage (plowing to 60 cm) are adopted, with early seedling planting; interrow grating operations previously cultivated with with grasses like Brachiaria decumbens are performed and this material is heaped in the row along with the gypsum (SERAFIM et al., 2011; SILVA et al., 2012). As demonstrated by authors such as Ferreira, Fernandes and Curi (1999), the stability of soil aggregates depends of the texture, clay fraction mineralogy, levels and types of cations, and organic matter, since these are the factors that determine the thickness of the diffuse double layer and that directly influence the dispersion and flocculation of particles.

Thus, the combination of organic matter provided by Brachiaria sp. with the calcium from the phosphogypsum applied may influence the aggregation quality, by causing interferences in the chemical properties and changes in the stock capacity of soil carbon, thereby promoting interaction, movement and complexation of flocculant cations (CREMON et al., 2009).

In this study, we aimed to analyze the aspects of soil structure and soil organic carbon, promoted by the addition of phosphogypsum associated with the management of Brachiaria sp. grown in the interrow of coffee crop Cerrado Latosol.

2 Materials and Methods

The study was carried out in an experimental area located in the municipality of São Roque de Minas, in the Alto do São Francisco physiographic region (20° 00' 00" S and 46° 00' 00" W), state of Minas Gerais, Brazil. According to Köppen's classification, the climate in the experimental area is as follows: Cwa type, mild temperate, with hot and humid summers, and dry winters. After morphological analysis of profile and laboratory analyses (Table 1), the soil under study was classified according to Embrapa (2006) very clayey Dystrophic Red Latosol and oxidic-gibbsitic mineralogy. We used a randomized block design with three replicates. The following treatments were used: conventional soil management, without gypsum in the row and without *Braquiaria* sp. in the interrow of coffee plants (CV-0); without gypsum in the row (G-0); 7.0 Mg ha^{-1} of gypsum distributed in the coffee plants row (G-7); 28 Mg ha^{-1} of gypsum distributed in the coffee plants row (G-28); and 56 Mg ha^{-1} of gypsum distributed in the row (G-56). In the deployment of crop, the soil was prepared in the months of July and August through the following phases: plowing and grating, liming, fertilization, and digging of soil furrows to 0.60 m depth with especial equipment, aiming structural relief and mixture of fertilizers. This deep soil tillage provides faster root growth and, therefore, rapid establishment of coffee plants.

The application of gypsum is performed on February or March, with the use of 28 Mg ha^{-1} along the coffee planting row. Phosphogypsum was applied on the side and along the planting row, followed by 'earth heaping at the foot of plants'

Table 1. Mean values for particle size analysis and sulfuric acid attack for the Ap and Bw horizons of very clayey Latosol.

Horizon	Texture			Sulfuric acid attack				Ki	Kr
	Clay	Silt	Sand	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5		
	g kg^{-1}								
Ap	763	198	39	102	355	157	1.32	0.49	0.38
Bw	819	148	33	105	392	169	0.98	0.46	0.36

Source: Silva et al. (2012).

with a mixture of soil and remains of brachiaria from the inter-rows.

As described by Serafim et al. (2011) and Silva et al. (2012), Brachiaria sp. planting is performed before deployment of crop. The grasses receives topdressing and, periodically, cuts are made using a mower pulled by a tractor. The residues of this process are placed in the planting row – these plant residues are a constant source of organic matter for the soil. The soil samples were collected on February 2011, when the coffee plants were in the second year of cultivation. The deformed samples were collected in the crop row at 5 and 15 cm depths. In the treatments G-0, G-7, G-28 and G-56, the samples at 5 and 15 cm depths were collected from the natural surface of the soil, that is, as from the non-dissolved gypsum layer. The determination of water-dispersible clay (WDC) was performed using the pipette method described by Embrapa (1997). The calculation of the flocculation rate followed the formula (Equation 1):

$$FR = [100*(TC - WDC)]/TC \quad (1)$$

where: TC = total clay in g; WDC = water-dispersible clay.

For determining the aggregates stability, the samples was dried in the natural conditions and sieved through 7 and 4 mm sieves. The aggregates retained on the smaller diameter sieve were selected for laboratorial analysis. Thus, 25 g of soil from each sample were weighed and pre-moistened in according with the low-moistening principles described by Kemper and Chepil (1965). After 12 h, the wet sieving of the samples was performed using a set of sieves of 2.00; 1.00; 0.50; 0.25, and 0.105 mm diameters as described by Yoder (1936). After 15 min, the portions retained on each sieve were transferred to aluminum pots with the aid of water spray and were then oven dried at 105-110 °C for 24 h, they were then weighed. From the values of these masses and knowing the water contents of the soil samples subjected to sieving, the following data were calculated: 1- Percent of aggregates retained on each sieve; 2- mean weight diameter (MWD); and 3- geometric mean diameter (GMD), as described by Kemper and Chepil (1965). The values of MWD and GMD were calculated by the Equations 2 and 3, respectively, described by Castro Filho, Muzilli and Podanoschi (1998):

$$MWD = \sum_{i=1}^{n} (xi, wi) \quad (2)$$

where: xi = mean diameter of the aggregate classes; wi = percent of each class over the total.

$$GMD = \frac{EXP\ \sum_{i=1}^{n} wp.log\, xi}{\sum_{i=1}^{n} wi} \quad (3)$$

where: wp = weight of aggregates of each class (g); xi = mean diameter of classes; wi = percent of each class over the total.

For the chemical analyses, the samples pertaining to treatments CV-0, G-0, G-7 and G-28 were dried in natural conditions and sieved through 2 mm diameter mesh sieves in order to obtain air-dried soil (ADS). Subsequently, aliquots of these samples were taken to determine the levels of cations K^{+}, Ca^{+2}, Mg^{+2}, P, and Al^{+3}, according to Embrapa (2006). The dry combustion method was used for quantification of the total soil organic carbon (SOC). Soil aliquots of 10 mg, ground in mortar, from each treatment were used; they were oxidized at 900 °C using a 0.3 L min^{-1} oxygen flow. The amount of CO_2 emitted was estimated using non-dispersive infrared radiation. The stock of SOC of treatments CV-0, G-7 and G-28 was calculated by the following formula (Equation 4):

$$EstC = \frac{COS \times Ds \times e}{10} \quad (4)$$

where: StC = total carbon stock (mg ha^{-1}); SOC = total carbon content (g kg^{-1}); Ds = soil density (kg dm^{-3}); t = thickness of soil layer (cm).

The data were submitted to analysis of variance and means comparison by the Scott-Knott test ($p < 0.05$) using the Sisvar software. The dependence degree of the variables was assessed by the Pearson's test and the graphs were plotted with the aid of the Sigma Plot 11.0 software.

3 Results and Discussion

Some chemical properties of soil were altered by the application of different doses of phosphogypsum (Table 2). It is noteworthy that this was observed only at 15 cm depth, which can be justified by the fact that this input was incorporated in the soil during the heaping recommended in the management system. Corroborating the results by Ritchey, Belesky and Halvorson (2004), it is worth noting that the application of gypsum promotes the increase of Ca^{2+} contents in the subsurface, reflecting in the deepening of roots optimizin the water and nutrients uptakes (SILVA, 2012; SERAFIM, 2011). This occurs because calcium is the main component of the cell wall in roots, operating the elongation and multiplication of cells (MARSCHNER, 1995). In addition, the climatic conditions of the Alto São Francisco region probably have been contributing to of the gypsum and the consequent gradual release of Ca^{+2}. So, under these conditions, management systems with large amounts of gypsum, in the long term, are possibly capable of maintaining adequate contents of Ca^{+2} and thus promote flocculation of clays, improving soil aggregation. Over 90% of the aggregates found in all treatments belonged to the > 2 mm diameter class (Table 3), value mentioned by D'Andréa et al. (2002) as ideal for well managed soils. High values of aggregates in the 8-2 mm class, verified in all treatments at 5 cm depth, must be related to the continuous supply of organic matter resulted from the innovative management system of coffee crop (IMSC) adopted, noting that, in this system, the use of *Braquiaria* sp. in between row in the coffee plants of coffee trees with periodic mowing is recommended. These results corroborate those found by Mitsuiki (2006), who states that the uninterrupted supply of organic matter serves as energy source for microbial activity, mainly for bacteria that produce exopolysaccharides in their protective capsules, which act directly in the aggregation of microaggregates, forming macroaggregates. When the depth of 15 cm is analyzed, a clear effect of the high doses of phosphogypsum on soil aggregation is noticed. In the treatments where gypsum doses of 28 and 56 Mg ha^{-1} (7.0 and 14 kg m^{-1}, respectively) were used, incorporated in soil at approximately 10 to 13 cm deep, on both sides of the coffee plants row during heaping, a higher percent of aggregates with

Table 2. Mean values of chemical properties at 5 and 15 cm depths.

Treatments	pH	P	K⁺	Ca^{+2}	Mg^{+2}	Al^{+3}	SB	t	T	V	m
Depth 5 cm											
	(H_2O)	mg dm⁻³		cmol$_c$ dm⁻³						%	
CV-0	5.1 a	2.8 a	177.8 a	2.0 a	0.9 a	0.1 a	3.4 a	3.5 a	7.8 a	43.7 a	2.9 a
G-0	5.1 a	2.0 a	147.6 a	2.8 a	1.0 a	0.0 a	4.2 a	4.3 a	9.1 a	45.8 a	0.0 a
G-7	5.4 a	3.2 a	163.2 a	3.4 a	1.2 a	0.0 a	5.0 a	5.0 a	9.4 a	53.5 a	0.0 a
G-28	5.6 a	3.3 a	170.5 a	3.2 a	1.3 a	0.0 a	5.0 a	5.1 a	8.8 a	56.8 a	0.0 a
Depth 15 cm											
Treatments	pH	P	K+	Ca^{+2}	Mg^{+2}	Al^{+3}	SB	t	T	V	m
	(H_2O)	mg dm⁻³		cmol$_c$ dm⁻³						%	
CV-0	5.5 a	3.0 a	108.6 a	1.6 b	0.6 a	0.1 b	2.5 b	2.6 b	6.4 c	32.4 b	7.4 a
G-0	5.3 a	3.2 a	109.2 a	2.7 b	0.9 a	0.0 a	3.9 b	3.9 b	8.3 b	47.1 a	0.0 b
G-7	5.4 a	3.4 a	74.8 a	5.3 a	0.4 a	0.0 a	6.0 a	6.0 a	9.8 a	59.2 a	0.0 b
G-28	5.2 a	5.1 a	94.1 a	4.8 a	0.8 a	0.0 a	5.9 a	5.9 a	9.8 a	59.8 a	0.0 b

Means followed by the same letters in the columns do not differ by the Scott-Knott test ($p < 0.05$).

Table 3. Mean percent of aggregates in different size classes (mm) at 5 and 15 cm depths in very clayey Cerrado Latosol.

Treatments	% Distribution of aggregates classes (5 cm)					
	8-2.00	2-1	1-0.5	0.5-0.25	0.25-0.105	< 0.105
CV-0	96.3 a	0.74 a	0.63 a	0.43 a	0.57 a	1.25 a
G-0	96.8 a	0.68 a	0.55 a	0.64 a	0.63 a	0.62 a
G-7	96.6 a	0.59 a	0.59 a	0.61 a	0.72 a	0.86 a
G-28	97.3 a	0.51 a	0.24 a	0.26 a	0.33 a	1.41 a
G-56	97.3 a	0.37 a	0.36 a	0.25 a	0.38 a	1.15 a
Treatments	% Distribution of aggregates classes (15 cm)					
	8-2.00	2-1	1-0.5	0.5-0.25	0.25-0.105	< 0.105
CV-0	91.5 b	2.29 a	2.46 a	1.42 a	1.49 a	0.73 a
G-0	93.1 b	1.04 b	1.21 b	1.78 a	1.93 a	0.89 a
G-7	93.4 b	0.97 b	1.06 b	1.56 a	1.66 a	1.34 a
G-28	97.1 a	0.16 b	0.35 c	0.38 b	0.36 b	1.57 a
G-56	96.3 a	0.72 b	0.33 c	0.79 b	0.81 b	1.01 a

Means followed by the same letters in the columns do not differ by the Scott-Knott test ($p < 0.05$).

diameter between 8 and 2 mm was observed (Table 3). In this case, it should be emphasized that the divalent cation (Ca^{+2}) must be acting in the flocculation of clays, contributing to greater soil aggregation. Significant differences were observed among treatments only regarding the weighted mean diameter (WMD). The results for CV-0 may have been influenced by the sampling, which was performed in the crop row. In this respect, coffee plant residues below the skirt of plants may have contributed to improve the soil aggregation properties, which explains the high GMD and WMD values (Figures 1 and 2) observed in this treatment, where Brachiaria sp. cultivation in the interrow or between row is not adopted. As previously mentioned, significant differences for WMD at 15 cm depth were found only in the areas where gypsum doses of 28 and 56 Mg ha⁻¹ (7.0 and 14 kg m⁻¹, respectively) were applied, heaped at approximately 10-13 cm depth on both sides of the coffee plants. The results show that the high doses of phosphogypsum used in the soil management system under study have contributed to the improved stabilization of soil aggregates at 15 cm depth.

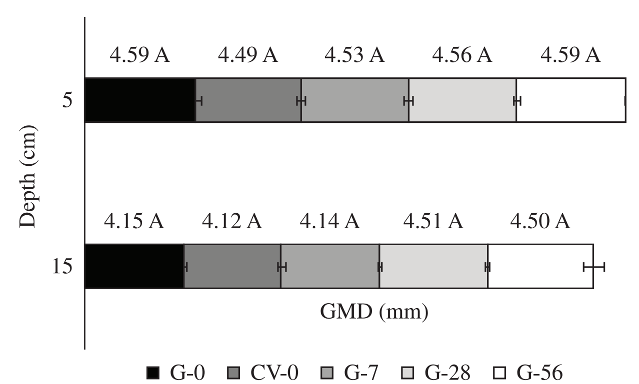

Figure 1. Mean values (mm) for the variable analyzed GMD at 5 and 15 cm depths in very clayey Cerrado Latosol. Means followed by the same letter in the line do not differ significantly by the Scott=Knott test at 5% probability level.

Lower results for MWD were found in a similar study. Taboada-Castro et al. (2006) found MWD of 2.71 and 3.89 mm, respectively, for conventional and conservation soil managements; Torres et al. (2005) found values of WMD between 3.54 and 3.11 mm in a study on soil management systems that used cover crops such as sunnhemp and *Braquiaria* sp., respectively. This suggests, at first sight, that the system adopted by coffee growers in the Alto do São Francisco region fosters physical improvements in the soil. Regarding the differential effects found in treatments G-28 and G-56, with improvements in the MWD and percent of aggregates larger than 2 mm, they probably occur due to the higher concentration of calcium in the soil, since, according to Cremon et al. (2009), the Ca^{2+} ion promotes flocculation of soil clay fractions. Evaluating the contents of SOC individually by depth (Figures 3 and 4), it is possible to verify that there are differences between the treatments studied, demonstrating that phosphogypsum and *Braquiaria* sp. condition the increase of SOC contents. For the depth of 15 cm, it possible to observe that, under the innovative management system for coffee crop (IMSC), 7 Mg ha^{-1} is the best dose to be applied among all the gypsum doses tested. Thus, analyzing only from the standpoint of carbon sequestration, the management system used coffee crops in the Alto São Francisco region can be considered sustainable when associated with this dose of phosphogypsum, since it has promoted increased SOC contents, slowing carbon emission from the soil. Therefore, there is no need for gypsum doses greater than 7 Mg ha^{-1} aiming only at increased SOC contents at 15 cm depth. The higher contents of SOC found in treatment G-7 at 15 cm depth are related to the greater contents of Ca^{+2} (Table 2), reinforcing the comments by Amaral, Anghinoni and Deschamps (2004), who reported that plant residues release organic acids of low molecular weight, capable of forming organic complexes with aluminum, calcium and magnesium on topsoil. However, the Brazilian literature still lacks information on the magnitude of the plants residues effects when kept on soil surface under different management systems, particularly concerning the standardization of methodologies to assess the effect of these residues, singly or together with the application of phosphogypsum and/or limestone. The differences in SOC stocks among treatments to depths between 5 and 15 cm (Figure 5) were evident with the use of the Scott-Knott test ($p < 0.05$), which apparently evinces the effect of gypsum at the doses tested, given that this input was added at the depth of 10-13 cm, as already pointed out. The soil under (IMSC), when compared to the conventional treatment (CV-0), presented greater stocks of SOC, showing the system potential and highlighting that it

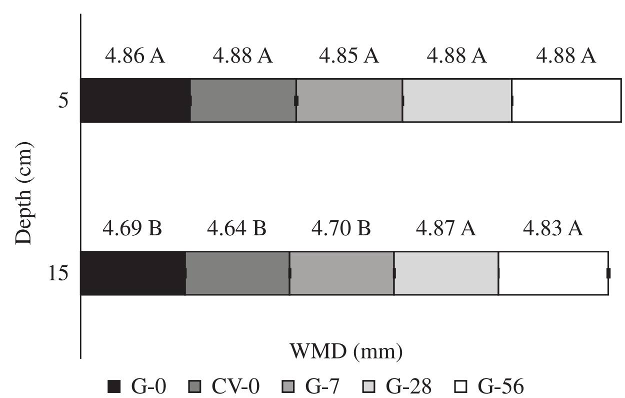

Figure 2. Mean values (mm) for the variable analyzed WMD at 5 and 15 cm depths in very clayey Cerrado Latosol. Means followed by the same letter in the line do not differ significantly by the Scott=Knott test at 5% probability level.

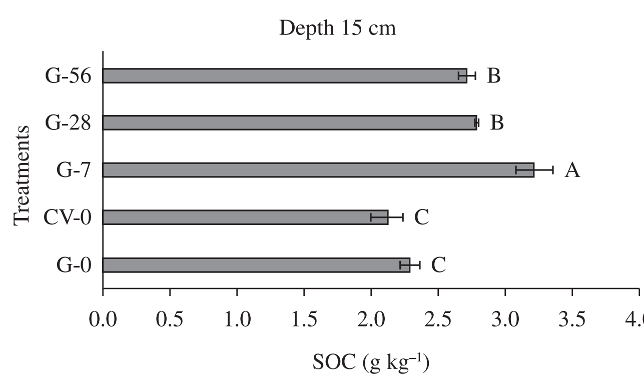

Figure 4. Total soil organic carbon (SOC) at 5 and 15 cm depths in very clayey Cerrado Latosol under the innovative management system for coffee crop (IMSC). Means followed by the same letter in the line do not differ significantly by the Scott=Knott test at ($p < 0.05$).

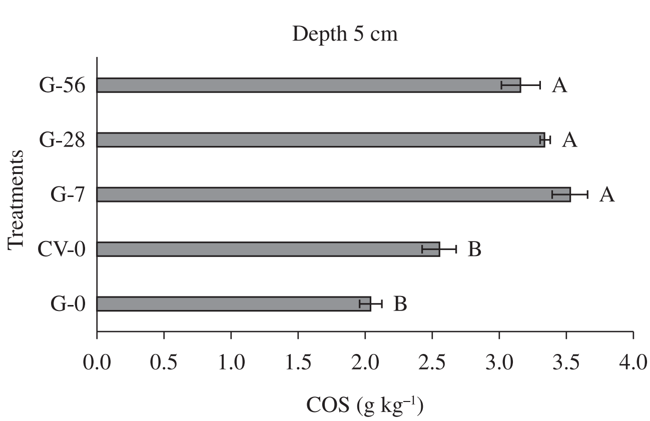

Figure 3. Total soil organic carbon (SOC) at 5 and 15 cm depths in very clayey Cerrado Latosol. Means followed by the same letter in the line do not differ significantly by the Scott=Knott test at ($p < 0.05$).

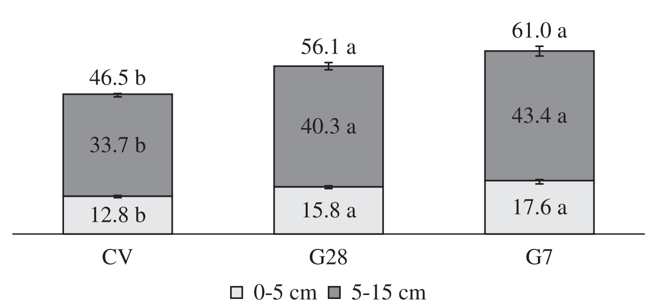

Figure 5. Accumulated carbon stock (mg ha^{-1}) in very clayey Cerrado Latosol under the innovative management system for coffee crop (IMSC). Means followed by the same letter in the line do not differ significantly by the Scott=Knott test at ($p < 0.05$).

had been implemented only two years and four months ago. It should be pointed out that the biomass from the mowing of *Braquiaria* sp. provides an homogeneous protection for the soil throughout the year, providing a microclimate similar to that found in the no-tillage system, where soil cover generates less oscillation in temperature, lower runoff, high water infiltration and, consequently, smaller losses of soil and water, besides the increase and conservation of the microbial community that inhabits the soil (PERFECTO; VANDERMEER, 2008). This way, the use of gypsum in soil associated with the planting of brachiaria in the inter-rows for the formation of coffee fields, favors greater resilience regarding the stocking of SOC, serving as an atmospheric carbon sink in the biomass of *Braquiaria* sp and coffee plant residues. The greater capacity of carbon stock in the management system can be related to the contribution of SOC from the roots of plants, once gypsum promotes root development in depth. Several authors suggest that the soil organic matter (SOM) is affected to a greater extent by the SOC contribution from the roots than from the surface plant residues. This efficiency of the root system in transferring organic carbon to the soil, probably derives from the fact that the roots are not exposed to climatic factors and their direct contact with the soil, allows their decomposition products to be absorbed to soil colloids, which results in the formation of clay-organic complexes less likely to be decomposed, in addition to the fact that microbial activity decreases with depth (LAL; KIMBLE, 1997). For annual crops, the contribution of the root system can be up to 1.8 times greater than that from the shoot area of plants (WILTS et al., 2004).

With the purpose to establish the degree of dependence between physical and chemical indicators of soil quality, a few linear correlations were studied. In this study, the SOC presented significantly positive correlation with aggregates from the > 2.00 mm diameter class and the WMD (Table 4), suggesting that part of the positive effects to soil aggregation in the study area is due to the organic matter contribution promoted by the IMSC. Negative correlation (Table 4) was observed between the > 2,00 mm diameter class and the aluminum content (Al^{+3}) and aluminum saturation (m), which may be true, indirectly, noting that the presence of organic residues in soil acts in the complexation of Al^{+3}. These results corroborate Paladini and Mielniczuk (1991), who reported the existence of strong correlation between the > 2.00 mm diameter class and the SOC on the 0-2.5 cm layer. Several authors, such as Wendling et al. (2005), found correlation coefficients between the GMD and the organic carbon content in the 0 to 20 cm layer. The negative correlation between the 2.00-1.00 mm diameter class and water-dispersible clay (WDC) (Table 4) indicates that large aggregates are less dispersed in the water and, therefore, more resistant to erosion-promoting agents. On the other hand, the negative correlation (–0,54**) between aggregates from the 2.00-1.00 mm diameter class and potassium contents (K^+) may point to a higher concentration of this element in those aggregates, which should be further analyzed, since it may bring important information about soil management practices. In the positive correlation between aggregates from the 2.00-1.00 mm diameter class and Ca^{2+}, the participation of this element as a soil cementing agent became evident. The correlation between the GMD and Mg^{+2} contents was positive probably due to the chemical nature of $Mg^{+2,}$ which is a divalent cation that also serves as soil flocculant agent. The correlation between the WMD and the SOC was significantly positive due to the fact that increased organic matter in the soil directly reflects on the increased WMD. These results point to the protection afforded by organic residues in the soil. The positive correlation between the WMD and Mg^{+2} contents, as well as for the GMD, occurred because of the flocculant properties of $Mg^{+2.}$

Insofar as this soil was sampled 2.4 years after the IMSC implantation, it is important to highlight that a soil restructuration may have already occurred in this short period of time. This expected improvement in soil structure can be explained particularly by the efficiency of the thin abundant roots of grasses, because, according to Lima et al. (2012), soil management systems that use grasses have the ability to promote recovery, even in disaggregated soil. It is

Table 4. Correlation coefficients between size classes of aggregates and chemical properties in very clayey Cerrado Latoso under the innovative management system for coffee crop (IMSC).

	SOC	WDC	P	K^+	Ca^{+2}
	g kg^{-1}		mg dm^{-3}		$cmol_c$ dm^{-3}
>2.0	0.41**	0.02 ns	–0.01 ns	0.35 ns	0.15 ns
2.00-1.00	0.14 ns	–0.34***	–0.29 ns	–0.54**	0.44*
0.25-0.10	–0.38 ns	–0.12 ns	–0.19 ns	–0.49*	–0.00 ns
GMD	0.30 ns	0.03 ns	–0.17 ns	0.40*	0.04 ns
WMD	0.40*	0.02 ns	–0.03	0.37 ns	0.13 ns
	Mg^{+2}	Al^{+3}	SB	IF	m
	$cmol_c$ dm^{-3}			%	
>2.0	0.42*	–0.40*	0.29 ns	–0.00 ns	–0.53**
2.00-1.00	–0.35 ns	–0.12 ns	0.29 ns	0.34 ns	–0.08 ns
0.25-0.10	–0.26 ns	0.09 ns	–0.11 ns	0.09 ns	0.15 ns
GMD	0.42*	–0.25 ns	0.19 ns	–0.01 ns	–0.36 ns
WMD	0.42*	–0.37 ns	0.27 ns	–0.00 ns	–0.49*

*significant at 1%; ** significant at 5%; ns: non-significant.

also important to note that, besides the roots aggressiveness, these grasses are excellent nutrient recyclers, favoring the development of microbial life in soil by the increase of organic matter and, thus, improving soil aggregation.

4 Conclusions

Doses of phosphogypsum up to 56 Mg ha^{-1}, for the conditions of the experiment, positively alter soil aggregation at 15 cm depth, showing the potential of this input to promote physical improvements in soil, especially in management systems that use grasses in the interrow of coffee plants. The 7 Mg ha^{-1} phosphogypsum dose promotes significant increase in the total soil carbon content at 15 cm depth. The adoption of the innovative management system for coffee crop (IMSC) contributed to increased carbon stock up to 15 cm depth when gypsum was used.

Acknowledgements

The authors are grateful to the following funding organs for their financial support: Fapemig, CNPQ and EMBRAPA

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