Aggregation and morphological properties of a degraded Oxisol receiving organic amendments

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Abstract
Continuous soil use and inadequate conditions in urban or rural zones cause soil degradation. This study aimed to investigate the recovery of a degraded Oxisol. The research was installed in 2004 in a degraded area by the removal of a 8.60 m layer soil for civil construction. The site is located in Selvíria, Mato Grosso do Sul, Brazil. The experimental design was a randomized blocks with three treatments, two depths and three replicates. The treatments were: degraded soil; native vegetation and *Astronium fraxinifolium*+*Brachiaria decumbens*+sewage sludge. Undisturbed soil samples were collected in soil layers: 0-5 and 5-10 cm. The aggregate soil morphology, physical and chemical properties analyzed were: images of the aggregates, aggregate stability, projected area, carbon, nitrogen, iron and aluminum. The conclusions were: aggregate morphology showed that sewage sludge associated the tree savannah species and grass contribute to soil re-structuring; the aggregate morphology analysis image was a indicative of structure quality.

Key Words
Organic matter, aggregate stability, structuring, soil degradation, carbon, sewage sludge

Introduction
Many tropical soils are degraded or at risk for degradation due to human activities, which diminishes their capacity to produce food, fiber and fuel. Natural rangelands and savannahs are particularly vulnerable for soil degradation because they may be perceived as having low value, compared to cultivated agricultural lands. The construction of a hydroelectric power station, led to the removal of a big layer of topsoil for building earthworks and foundations. Topsoil removal exposed subsoil with low fertility and poor physical structure, which poses a major constraint to natural revegetation of plants from the surrounding native savannah. Organic amendments such as sewage sludge could be used to rehabilitate this degraded site. Indeed, the application of 60 t ha^{-1} of sewage sludge, improved the growth of trees and leguminous crops planted on this degraded Oxisol (Alves *et al*., 2007; Campos and Alves, 2008). Sewage sludge can enhance plant productivity as it contains a considerable amount of N, P and traced elements. Organic matter from the sewage sludge, plant roots and microbial cells (e.g., extracellular polysaccharides, fungal hyphae) is essential for binding and forming soil aggregates, fundamental for the eventual development of soil structure and physical properties that resemble the natural soil conditions. The purpose of this study was to evaluate the aggregation of a degraded Oxisol that was restored with organic amendments or left in the degraded state, compared to natural soil conditions, using an approach based on micromorphology imaging and soil chemical analysis. This study was development in Selviria, Mato Grosso do Sul, Brazil.

Methods
The experiment was conducted at the Teaching and Research Farm of the Faculty of Engineering, Ilha Solteira Campus, Universidade Estadual Paulista (UNESP), located in Selvíria, Mato Grosso do Sul, Brazil (51^o 22'W, 20^o 22' S) at an elevation of 327 m above sea level. The annual average temperature is 23.5°C and the Köppen type climate is Aw (humid tropical climate, with rainy season in summer and dry in winter). Annual rainfall is 1370 mm, relative humidity is between 70 and 80% year-round. The soil under native savannah is a Typic Haplortox or an Orthic Ferralsol according to the FAO classification (FAO, 1998), and a clayey-loam texture (200-350 g kg^{-1} of clay). Clay mineralogy is dominated by gibbsite and kaolinite.
The soils selected for this study came from experimental plots established on degraded soils in 2004 (two treatments selected) or from an adjacent area under native savannah that was not impacted by soil excavation in the 1960s. The experimental plots were laid out in a completely randomized block design with five soil restoration treatments and untreated, degraded soil as a control. Each plot was 150 m^2 (15 m x 10 m) and the experimental treatments were replicated in five blocks in a total of 30 plots. One restoration treatment was used in this study, namely the *Astronium fraxinifolium- Brachiaria decumbens*-sewage sludge treatment.

Briefly, plots were prepared by clearing the surface, subsoiling, plowing, harrowing and leveling, applying lime (2 t ha^{-1}) and sewage sludge (60 t ha^{-1}, from a city treatment station handling mostly domestic waste in Araçatuba, São Paulo State, Brazil) in February, 2004. The perennial grass *B.decumbens* was planted to promote soil restoration and eventually serve as forage for grazing animals. Samples collected for this study came from three replicate plots of the following treatments: (1) the *A. fraxinifolium- B. decumbens*-sewage sludge restoration treatment, and (2) untreated, degraded soil. Three representative samples were also collected from (3) adjacent native savannah.
Soils were collected in February 2008, four years after the establishment of the restoration treatment. Soil blocks (15 cm by x 15 cm) were removed from two layers: 0-5 and 5-10 cm. The initial size aggregates were passed in the 6 mm mesh and withheld the 4 mm. About 40 g of field-moist soil will be spread evenly on the largest sieve of a stack of sieves with openings of 4.0, 2.0, 1.0, and 0.25 mm. The soil properties were analyzed: total organic carbon and nitrogen (Skjemstad and Baldock, 2008) using the equipament NC Soil Analyzer – Flash 1112 Series EA; and analyzing surfaces aggregate image with scanning electron microscope-SEM (Goldstein *et al*., 2003).
Data were analyzed by one-way analysis of variance, followed by a post-hoc Tukey test ($P<0.05$) for mean comparisons, using SAS software (1999). Aggregate analysis data were transformed from % aggregate data before statistical analysis.

Results

The organic C content was greater in the natural soil than the degraded Oxisols, with no difference between restored and degraded treatments (Table 1). The total N content was similar in all treatments at the 0-5 cm depth, but the total N content followed the pattern natural > restored> degraded soils in the 5-10 cm depth (Table 1). It is hypothesized that C accumulation in organo-mineral complexes begins when N-rich, hydrophobic proteins bind to soil mineral surfaces (Klebber *et al*., 2007). If this is occurring in the 5-10 cm depth, then it suggests that the first steps leading to aggregate formation are underway in the restored soils. However although they are not visible in these black and white photos, the colour was slightly darker in aggregate fractions from restored and natural soils, suggesting more organic matter (Figure 1). Closer examination of the 6-4 mm aggregate size fraction revealed morphological differences under low magnification (10 x). Aggregates from the natural and restored soils appeared to have rough, uneven surfaces, compared to the smooth, flat surface of aggregates from the degraded soil (Figure 1, a, b, c). The mean surface area of this fraction was 10.11 to 11.10 cm^2 in the 0-5 cm depth and 10.27 to 11.5 cm^2 in the 5-10 cm depth. Although the size was similar, there were qualitative differences in surface morphology visible under higher magnification. The smooth surface of the 6-4 mm aggregate size fraction from degraded soils was particularly evident at high magnification (250 x), compared to the rough, bumpy surfaces of aggregates from restored and natural soils (Figure 1, d, e, f).
Restoration of these soils with organic amendments is expected to eventually increase the aggregation and soil organic C content. The visual observation of aggregate morphology coupled with soil organic-mineral analysis seems to indicate that changes are occurring in the restored soils. Further study is required to determine the length of time necessary to achieve a significant improvement in soil physical characteristics such as aggregation and soil structure, and if it is possible to return the soil to the same conditions as the natural site. In Figure 1, a, b, c one can observe the morphology aggregate characteristics for soil condition studied. The aggregate natural condition surface and the soil restoration (images with 25 and 50 magnifications) are more rough and one can that observe the micro-aggregates presence is better defined and intact. While the macro-aggregates in degraded soil surface are more smooth and with lower visual perception of the micro-aggregates, principally in the image with 50 magnification. Perception is better in the image with 250 magnification. In this case one can see different colors that probably indicate the organic matter present for the natural and restored conditions. A similar comportment can be observed to depth 5-10 cm, including the degraded soil which practically does not display roots or fungal hyphae. There is evidence in the images results scanning electron microscopy (SEM) of the differences between the aggregate morphology soil conditions for two depths. The observed comportment in analyzed images from SEM was also detected by other authors. Based on micro-morphological examination, the topsoil and subsoil, also SEM images, Kapur *et al*. (2007) concluded that SEM images showed considerable variation among the samples with topsoil samples of each rotation being different visually, and appearing more aggregated than subsoil samples. Mueller *et al*. (2008) concluded that method of visual soil structure evaluation was a feasible tool to provide fast semi-quantitative information on the status of physical soil quality.

Table 1. Organic carbon and total nitrogen in the 0-5 cm and 5-10 cm depths of an Oxisol under native savannah (natural soil) and from a degraded Oxisol that received sewage sludge and were revegetated (restored soil) or left untreated (degraded soil).

Treatment	Total Carbon	Total Nitrogen
	g kg^{-1}	
	Depth – 0 - 5 cm	
Natural soil	9.13 A	0.78
Restored soil	5.44 B	0.54
Degraded soil	5.63 B	0.52
F – Test	13.9335*	3.7764^{ns}
V. C. - %	18.486	27.424
MSD – 5 %	3.14	0.30
	Depth – 5 - 10 cm	
Natural soil	7.61 A	0.66 A
Restored soil	4.00 B	0.41 B
Degraded soil	2.49 B	0.21 C
F – Test	33.7318*	56.1852*
V. C. - %	21.543	15.741
MSD – 5 %	2.55	0.17

Mean values followed by the same symbol in a column are not significantly different (5% level) according Tukey test. *= 5% significance, ns= no significance. MSD= minimum significant difference. V.C.= Coefficient of variation.

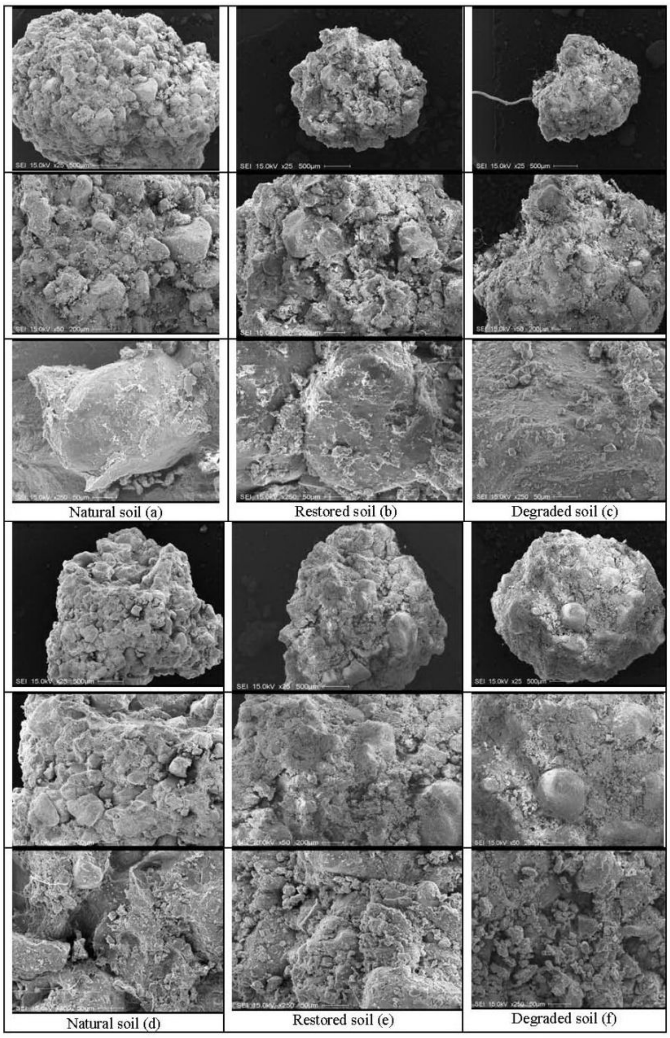

Figure 1. Scanning electron microscopy of soil aggregates (size between 6-4 mm) from the 0-5 cm depth (a, b, c) and 5-1- cm (d, e, f) of an Oxisol under native savannah (natural soil) and from a degraded Oxisol that received sewage sludge and was revegetated (restored soil) or left untreated (degraded soil). The magnification increases from top to bottom: 25 ×, 50 × and 250 ×.

Conclusion

After four years the visual evaluate restoration, by aggregates morphology of the degraded Oxisol, detected that sewage sludge associate the tree savannah species and grass are contributing to soil re-structuring. The aggregate morphology analysis image was more sensitive than the content of organic C and aggregate stability and is indicative of the structure quality evolution over a short time in the degraded Oxisol. Aggregate morphology can better express the restoration of this tropical soil.

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