Recovering soil structure by management practices in a sandy clay loam Acrisol degraded by agricultural use

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Abstract

Soil use for agricultural production may increase soil structure quality as long as conservation management practices are adopted. The aggregates and single particles distribution into diameter classes (9.51-4.76, 4.76-2.00, 2.00-0.25, 0.25-0.053, <0.053 mm) and carbon (C) stocks in the surface layer from 0-7.5cm were studied to evaluate the contribution of management practices in the soil aggregation recovery of a physically degraded soil. The management system was a degraded soil (cropping system), using the native condition (rangeland) as a reference in a sandy clay loam Acrisol in Rio Grande do Sul, Brazil. The intense tillage and the low addition of residues for 30 years decreased the proportion of aggregated soil (76.4% in the Rangeland to 49.9% in the Cropping system) and increased single particles (23.6% to 50.1%). C stock decreased from 20.0 Mg/ha in the rangeland to 11.8 Mg/ha in the cropping system. From a degraded soil condition, the no-till system with higher diversity of plant species and the addition of residues increased the proportion of aggregated soil from 49.9% (cropping system) to 70.7% over a 15-year period. The macroaggregates (>0.25 mm) also were increased from 22.8% to 53.5% and the C stock reached 17.9 Mg/ha building a complex soil structure with the capacity to increase soil quality.

Introduction

Aggregation is an essential property for the soil to be able to fulfill its roles and ensure quality (Doran and Parkin 1994). It is related to the soil's ability to offer an adequate balance between water and air for the development of plants and soil organisms and to regulate and compartmentalize the flow of water and nutrients in the biosphere. Soil aggregates are built in a combination of two processes involving the interaction between minerals, polyvalent cations, organic matter, microorganisms, plant fragments, and roots of living plants (Edwards and Bremner 1967; Tisdall and Oades 1982; Miller and Jastrow 1990; Golchin *et al.* 1998). In one processes, the construction of a hierarchy of structures occurs. First, the microaggregates (< 0.25 mm) are formed by the repeated interaction between organic molecules, polyvalent cations, and mineral particles from the clay fraction (Edwards and Bremner 1967). Next, the macroaggregates (> 0.25 mm) are formed by the mechanical union of microaggregates during the growth of roots of living plants and hyphae of rhizosphere fungi (Tisdall and Oades 1982; Miller and Jastrow 1990). Decomposing plant fragments and bacterial colonies build macroaggregates through the interaction with microaggregates and single particles (Golchin *et al.* 1998). Therefore, in addition to intrinsic soil characteristics (texture and mineralogy), agricultural management practices interfere directly with soil macroaggregate building by their influence on organic matter, microorganisms activity and plant root development.

Under native conditions, the soil becomes organized over time into well defined structures, due to its granulometric and chemical composition and to the action of biological agents. The conversion from native condition into conventional agriculture causes dramatic changes to that stable state, which result in losses of organic matter and water-stable macroaggregates. However, the adoption of conservation practices based on minimum till and adequate residues management may prevent organic matter degradation and maintain or recover soil structure. In this work, we study the recovery of soil structure by management practices in a sandy clay loam Acrisol degraded by intensive agricultural use by analyzing aggregates and single particles proportions and soil stock carbon.

Methods

The management systems studied are part of a long-term experiment conducted at the Agronomy Experiment Station, Federal University of Rio Grande do Sul, located at 30°50'52"S and 51°38'08"W (Weber and Mielniczuk 2009). The soil is classified as an Acrisol, with 300 g/kg coarse and medium sand (2.0 to 0.2 mm), 237 g/kg fine sand (0.2 to 0.06 mm), 211 g/kg silt, and 253 g/kg clay (Silva 1993); kaolinite (720 g/kg) and iron oxides (109 g Fe_2O_3/kg) are the dominant minerals in the clay fraction (Bayer *et al.* 2001).

Characterization of the experimental area and management systems
Originally, the experimental area was rangeland. From 1969 to 1983, *Helianthus annuus* and *Brassica napus* crops were grown using rotary tiller. In 1985, after liming and fertilization, an experiment was installed with three soil tillages and cropping systems in a randomized block design with three replicates. Four treatments without N application were studied: conventional tillage *Avena strigosa* / *Zea mays* (CT a/z), conventional tillage *Avena strigosa* + *Vicia sativa* / *Zea mays* + *Vigna unguiculata* (CT as/zu), no-till *Avena strigosa* / *Zea mays* (NT a/z), and no-till *Avena strigosa* + *Vicia sativa* / *Zea mays* + *Vigna unguiculata* (NT as/zu) (Table 1). In addition to the experimental plots, an adjacent area was sampled as a reference for maximum soil degradation condition (Cropping). This area had been cultivated since 1969 with cereals and conventional soil tillage, with plowings and disking conducted twice a year. The native condition (Rangeland) was sampled at three adjacent locations at the same elevation of the experiment area and the cropping area to serve as reference for the original condition (Table 1).

Table 1. Characterization of the management systems studied.

Management System Code	Crop Types winter	Crop Types summer	Soil tillage	Time under current management at 2000 (years)	C added by plants (Mg/ha/y)
Rangeland	mixed native grassland(1) with moderate grazing		none	indefinite	N.D.
Cropping	*Triticum aestivum* and *Avena strigosa*	*Zea mays* and *Helianthus annus*	plowing and disking	30	3.0(2)
CT a/z	*Avena strigosa*	*Zea mays*	plowing and disking	15	4.23(3)
CT as/zu	*Avena strigosa* and *Vicia sativa*	*Zea mays* and *Vigna unguiculata*	plowing and disking	15	7.52(3)
NT a/z	*Avena strigosa*	*Zea mays*	no-till	15	3.92(3)
NT as/zu	*Avena strigosa* and *Vicia sativa*	*Zea mays* and *Vigna unguiculata*	no-till	15	6.90(3)

(1) Mixed grassland dominated by *Paspalum notatum* with *Desmodium spp.*, *Macroptilium spp.*, and *Stylosanthes spp.*
(2) Estimated value.
(3) Source: Lovato *et al.* (2004). Data already consider carbon added by roots.
N.D. = not determined.

Soil Sampling
Undeformed soil samples from the systems described in Table 1 were collected at a 0-7.5 cm depth in two seasons, September 1999 and September 2000. The soil samples were slightly broken with the fingers in order to obtain aggregates smaller than 9.51 mm in diameter. The aggregates were air-dried for 72 hours.

Distribution of Aggregates and Single Particles into Diameter Classes
The distribution of aggregates into diameter classes by wet sieving followed the methodology described in Carpenedo and Mielniczuk (1990). Single particles, which consisted of mineral quartz particles and concretions of non-associated minerals forming aggregates, were separated manually using a sharp instrument under the stereoscopic microscope at 2X (9.51-4.76 mm class), 10X (4.76-2.00 mm class), and 20X magnifications (2.00-0.25 mm class). The weights for each class were obtained. For the 0.25-0.053 mm class the aggregate and single particle frequencies within a 2 mm^2 field were counted under the stereoscopic microscope at 63X magnification. For the < 0.053 mm class, single particles were considered those with silt size (> 0.002 mm). The weights for those fractions were also obtained.

Carbon Stock Determination
Total soil carbon was determined by the Walkley-Black (Tedesco *et al.* 1995) and expressed as equivalent mass, so the soil density differences between treatments were compensated. The soil mass in each system was adjusted for soil mass in the native field, using the 1.50 Mg m^{-3} density determined in 1998 by Lovato *et al.* (2004).

Results

The native ecosystem (Rangeland) was predominantly covered with vegetation consisting of several grass species and a small frequency of winter legumes (Table 1). These systems had around 76.4% of aggregated soil and 23.6% of single particles, distributed among the various diameter classes (Figure 1a). From the aggregated soil, 51.7% were in classes > 2.00 mm, while single particles had their highest percentage in the 2.00 – 0.053 mm class, with 20.3% of the total soil. Such good structure is the result of a long and continuous action of the roots mainly of the grasses species (Bradfield 1937; Jastrow *et al.* 1998; Silva and Mielniczuk 1998) as well as the adequate carbon stock [20 Mg/ha in the 0 – 7.5 cm layer (Figure 1b)].

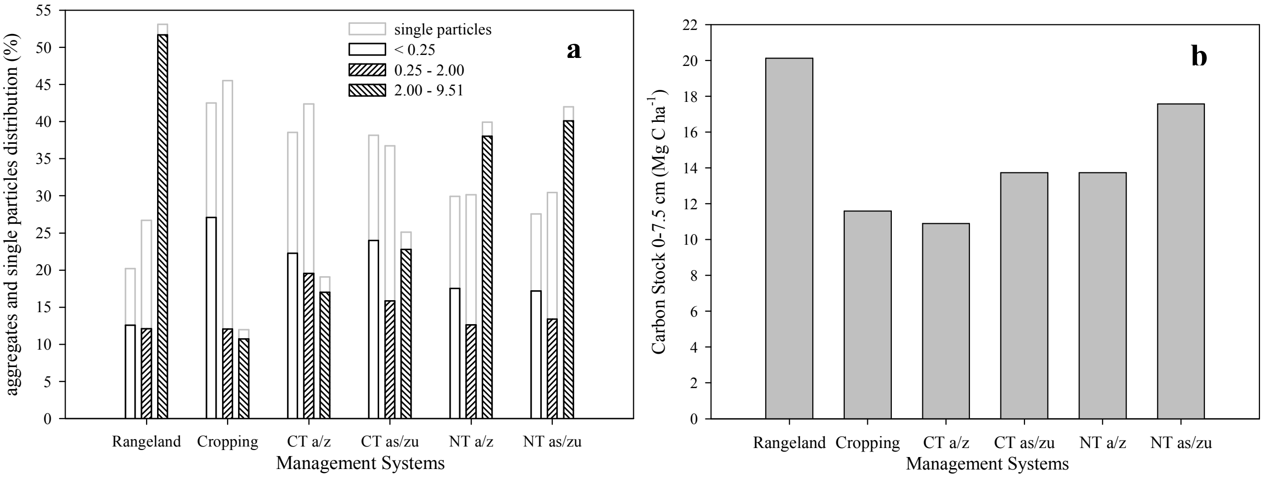

Figure 1. Aggregates and single particles distribution into diameter classes (a) and carbon stock (b) in the 0 – 7.5 cm layer in the management systems. CT = conventional tillage; NT = no tillage; a = *Avena strigosa*; z = *Zea mays*; s = *Vicia sativa*; u = *Vigna unguiculata*.

The inadequate soil tillage system used between 1969 and 1983 (Cropping) decreased the aggregated soil to 49.9%, and aggregates with diameter > 2.00 mm from 51.7% to 10.7% (Figure 1a), while single particles increased from 23.6% to 50.1%. From that degraded soil structure, management systems were implemented (Table 1) in order to restore the structure to its original condition. So the reduced soil tillage, the carbon added via plants and the number of plant species improved the soil quality. The CT a/z system represents a decrease in soil tillage to once a year and a increase of carbon added (Table 1) in relation to the initial degraded condition (Cropping). This condition provided an increase in the total proportion of aggregates and a change in the distribution (Figure 1a). There was a tendency for aggregates < 0.25 mm to become organized into larger aggregates, even incorporating single particles into the structure, a fact that was demonstrated by the difference in the distribution between CT a/z system and Cropping system for the 2.00 – 0.25 mm class. That behavior is a reflex of the organo-mineral interactions, due to the carbon added by the plants. The roots and hyphae of the rhizosphere fungi may also have contributed to improve soil macroaggregation in the CT a/z system. The CT as/zu system represents a improvement of the CT a/z system by the increase on plant species in each growing season and, consequently, the addition of carbon via plants cultivation. This practice increased the total proportion of aggregates by 3.8 % in relation to CT a/z. Aggregate distribution also changed. There was a tendency for aggregates < 2.00 mm to become organized into aggregates > 2.00 mm. The formation of those macroaggregates is the result of the mechanical action of roots, binding together microaggregates and smaller particles. In that process, single particles become part of the aggregates. The introduction of legume plants in both growing seasons in the CT as/zu system may have favored the process due to the better development of roots and hyphae of rhizosphere fungi in a condition of plant species diversity. Consequently, the proportion of single particles decreased in the 0.25 – 2.00 mm class in relation to CT a/z.

The NT a/z system represents the improvement provided by the no-till. This system shows the effect of the physical compression by the machinery traffic, in addition to the carbon added by plants and the action of the root system. The lack of soil tillage maintains the structures formed by compression; the added carbon favors organo-mineral interactions and consequently the formation of microaggregates, while roots provide the organization of smaller aggregates and single particles from classes < 2.00 mm into the 2.00 – 9.51 mm class. The resulting aggregation comes from biological action and has greater complexity. Also it increases the macro- and micropores and provides a suitable habitat for the development of organisms. The best management practice (NT as/zu) increased the number of plant species in each growing season and, consequently, increased the addition of carbon. Such improvement did not result in a difference in the proportion of soil aggregated and single particle distribution in relation to NT a/z. However, it is important to analyze the carbon stock over the development period of those systems. The NT as/zu system accumulated an additional of 3.9 Mg C/ha in the 7.5 cm surface layer in relation to NT a/z (Figure 1b). Therefore, both systems became organized with the same distribution of aggregates into diameter classes (Figure 1a) as a result of texture, mineralogy, presence of roots, microorganisms, and carbon, while a higher amount of carbon was found in the aggregate composition for NT as/zu. An equal distribution of aggregates with a higher carbon stock indicates that the structure of the aggregates is more complex and has more organic components, such as fragments of plant tissues and macroorganisms, hyphae and microorganism cells, and humic substances. The presence of carbon in the structure enables the soil to play its roles, ensuring soil quality, which makes a difference in favoring environmental sustainability by an agricultural production system.

Conclusion

Management practices with no-tillage increased the proportion of macroaggregates in relation to the initial condition. In the same way, the carbon added via complex cropping systems increased the proportion of macroaggregates. When those practices were applied jointly there was a significant increase in the proportion of macroaggregates in the soil mass and in carbon stock.

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