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Soil quality indicators in a Rhodic Paleudult under long term tillage systems

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ABSTRACT

Many investigations have focused in defining soil quality indicator components. However, for understanding better the impact of soil tillage systems on soil quality, a broader approach is demanded, with simultaneous soil attributes evaluations, by using multivariate analysis. The objective of this experiment was to evaluate the long-term effect of two tillage systems on the soil C and N stocks in comparison to those of native grassland and to identify the most suitable soil attributes for characterizing soil quality. The experiment was established in 1988 at the Agronomic Experimental Station of the Federal University of Rio Grande do Sul, Southern Brazil. Treatments consisted of two tillage systems (no-tillage and conventional tillage) and a reference area under native grassland. Soil analysis was performed up to 20 cm. Soil organic matter, C and N, physical fractionation was performed and carbon management index calculated. Microbial biomass C and N was determined as well as soil aggregate stability. From soil aggregation, soil average diameters and mass were grouped, and classes determined to calculate mean weight diameter. After 18 years, conventionally tilled soil showed lower total C and N stocks in comparison to no-tilled soil, which did not differ from native grassland soil. Soil C stocks ranged from 44.3 to 34.1 Mg ha^{-1} for the native grassland and conventional tillage system and total nitrogen ranged from 5.2 to 4.1 Mg ha^{-1} for the native grassland and no-tillage system, in the 0–20 cm layer. Among the tested soil quality indicators, the microbial biomass-C, total and particulate C stocks, particulate C and N stocks, and mean weight diameter were the indexes that best indicated soil tillage system effects, and they are therefore recommended for future use in evaluating soil quality.

1. Introduction

The concept of soil quality has received special attention during the last few years, by the Brazilian and the international scientific community, because it is considered essential for sustainable agriculture (Warkentin, 1995). The importance of soil quality is reflected in many societal issues such as global warming, silting and water eutrophication (Bell and Lawrence, 2009). Therefore, soil has a high quality when it is able to develop its functions in plenitude as a result of interactions between its physical, chemical and biological attributes (Vezzani and Mielniczuk, 2009). To approach soil carbon (C) and nitrogen (N) dynamics, other soil attributes must be considered in order to better understand the soil system quality, yet, such subject demands more research (Bayer et al., 2004; Conceição et al., 2005; Carneiro et al., 2009).

Vezzani and Mielniczuk (2009) noted that many authors have tried to define which soil organic matter-related components fit best as soil quality indicator. According to these authors, the soil organic matter components that best express a consistent soil quality indicator are as follows: total soil C and N, particulate organic matter or light fraction C and N, mineralizable C and N, and microbial biomass C and N, as well as soil carbohydrates and enzymes. Gregorich et al. (1994) affirmed that time factor must be considered for an accurate interpretation.

Intense soil tilling for annual cropping accelerates physical, chemical and biological soil degradation processes, leading to decreased SOM stocks (Silva et al., 1994) from soil losses caused by erosion and oxidation by soil microorganisms, especially in tropical and subtropical climates (regions). In soil conservation management systems, such as no-tillage (NT), the substantial addition of surface residues and intense rooting (sub-surface) in parallel with low soil mobilization promotes increase organic

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matter stocks (Maia et al., 2010), which results from the physical protection of organic matter inside soil aggregates. Following this trend, Corazza et al. (1999) observed annual soil carbon losses from native grassland of approximately 0.69 Mg ha^{-1} when managed with intense soil tilling (heavy disking). By contrast, these same authors observed annual soil carbon increases of approximately 1.43 Mg ha^{-1} in NT, which represented an atmospheric C sink, thereby mitigating climate modifications resulting from greenhouse effects. These effects can increase over time, supporting the importance of long-term trials to enable an understanding of the time factor in ameliorating soil quality problems and in determining the soil variables with the best ability to express soil quality (soil quality indicators).

In addition to evaluating soil attributes, statistical tools (rather than Cartesian evaluations) that express the combined effect of these attributes are needed. Multivariate analysis has fulfilled the objective of simultaneously evaluating the relationship between numerous soil attributes (Gelsomino et al., 2006; Mariani et al., 2006). Multivariate analysis is more effective than univariate analysis in research on biological and soil organic matter issues because of the specificity of the latter method for particular production systems (Baretta et al., 200 5). According to Cruz-Castillo et al. (1994) and Baretta et al. (2005), the use of multivariate analysis provides a definition for the difference between attributes and distinguishes which of these factors contributes the most to data variability. Thus, a better definition of the main soil attributes as soil quality indicators is achieved.

Therefore, the hypothesis that soil conservation tillage systems (no-tillage) would yield higher soil C and N stocks relative to conventional tillage was tested. This expectation was even higher in the labile (particulate) organic matter fraction, which best reflects alterations resulting from soil management (Dieckow et al., 2006). The use of multivariate analysis was expected to provide a definition of the best soil management systems and the soil attributes that contribute the most in determining these effects. The objectives of this research were as follows: (1) evaluate the effect of two long-term soil tillage systems on soil C and N and the attributes related to these elements in comparison to these under native grassland and (2) identify best soil quality indicators using multivariate analysis.

2. Materials and methods

This study was based on a long-term trial established in 1988 at the Experimental Station (30°05′22″ S latitude and 51°39′08″ W longitude) of the Federal University of Rio Grande do Sul, in Eldorado do Sul county, Rio Grande do Sul State (Southern Brazil). The experiment was performed on a Rhodic Paleudult clay loam soil (220, 140 and 640 g kg^{-1} of clay, silt and sand, respectively). The mean local annual rainfall is 1440 mm, and the climate is subtropical with a warm humid summer (Cfa), according to the Köppen classification. The experimental area was maintained under native grassland until 1974. During the two following years (1975/76), the soil was tilled (conventional tillage). The area remained fallow with native grassland until 1985, when black oat (*Avena strigosa* S.) was cropped under conventional tillage conditions.

In May of 1988, 3.4 tons of lime was broadcast-applied over the entire area and incorporated to a 15 cm depth by one-disk plowing and two diskings to reach a pH (in water) of 6.0 (CFS RS/SC, 1987). The liming was followed by black oat planting in October of the same year. After the oat harvest, experimental treatments were applied (soil tillage systems) before seeding the area with corn (*Zea mays* L.). Beginning in 1989, a mixture of black oat and vetch (*Vicia sativa* L.) was planted during the autumn–winter seasons. After the first black oat cropping, and before treatment applications, the soil chemical attributes in the 0–20 cm layer were as follows: water pH (1:2 soil/water ratio), 5.2; phosphorus (P) and potassium (K) (Mehlich 1), 2.5 and 132 mg dm^{-3}, respectively; and 30 g kg^{-1} of soil organic matter.

In this study two treatments were evaluated, a conventional tillage system (CT) and a no-tillage system (NT), both with row fertilization (5–8 cm depth during corn seeding). A third treatment, native grassland (NG), representing the Pampa biome, used as a reference area, without anthropic impacts, was also evaluated. The trial was carried out under a randomized block design, with three replicates.

The cropping sequence consisted of corn (irrigated, with 5–7 plants m^{-1} population and 1 m row spacing) during spring–summer seasons and black oat + vetch during autumn as cover-crops in the winter season. Nitrogen (N), P and K fertilizers were applied during corn cropping, with a goal of 8 Mg ha^{-1} yields (CQFS RS/SC, 1995, 2004), and they were supplied in the forms of urea (42% N), triple superphosphate (45% P_2O_5) and potassium chloride (58% K_2O), respectively. At 35 and 60 days after emergence, 60 kg of N was top-dressed as urea. Nitrogen fertilization (urea) during grass cropping (black oat + vetch) was intended to yield 4 Mg ha^{-1}, according to the CQFS RS/SC guidelines (1995, 2004). The total biomass for corn (summer) and cover crops (winter) in both tillage systems (conventional and no-tillage) is presented in Table 1.

After the corn harvest, three trenches per parcel were opened. Soil was sampled in May of 2007 from the 0 to 2.5, 2.5 to 5, 5 to 10 and 10 to 20 cm layers. In the Federal University of Rio Grande do Sul Environmental Biogeochemistry Laboratory, samples were air dried and passed through 2 mm mesh sieves. Soil organic matter (SOM) physical fractionation, according to Cambardella and Elliott (1994), was performed: 20 g of soil were put in 180 mL snap caps with 80 mL of sodium hexametaphosphate (5 g L^{-1}). Samples were shaken horizontally for 15 h. Suspensions were passed through 53 μm mesh sieves using water. Sieve-remaining material was dried at 50 °C until reaching constant mass weight, ground in porcelain mortar and pestle and soil carbon content was analyzed, representing the particulate organic matter carbon (POC). Total and particulate organic matter carbon were determined by dry combustion with a Shimadzu TOC-V CSH. Total nitrogen (TN) and N in the particulate organic matter fraction (POM-N) were determined with the Kjeldahl method, according to Tedesco et al. (1995). Soil C and N stocks were calculated using the equivalent soil mass method (Ellert and Bettany, 1995) by taking native grassland soil as reference of soil mass.

The carbon management index (CMI) was calculated on the basis of C stocks in the 0–20 cm section as proposed by Blair et al. (1995), with adaptations from Dieckow et al. (2006). Carbon management index (CMI) and its components were calculated according to the following equations: CMI = CSI × LabI × 100, where CSI, carbon stock index; LabI, tillage systems lability index; CSI, TOC treat/TOC ref, where TOC treat = soil tillage system total

Table 1
Corn, cover crops and native grassland residues in a Rhodic Paleudult under different tillage systems in the Southern Brazil.

Soil tillage systems[a]	Residues[b]			
	Corn	Cover crops[c]	Total $year^{-1}$	Total 18 years
	Mg ha^{-1}			
Conventional	7.8	4.4	12.2	219.6
No tillage	7.8	4.5	12.3	221.4
Native grassland[d]	–	–	2.4	43.2

[a] Conventional: plowing and two diskings; no-tillage: row corn seeding.
[b] Estimated from ten corn croppings and nine cover crops cycles.
[c] Vetch + black oat mixture.
[d] Data from Brambilla (2010).