Soil & Tillage Research 142 (2014) 42–53

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Soil structure and its influence on microbial biomass in different soil and crop management systems

Adriana Pereira da Silva [a], Letícia Carlos Babujia [a], Julio Cezar Franchini [a], Ricardo Ralisch [b], Mariangela Hungria [a], Maria de Fátima Guimarães [b,*]

[a] EMBRAPA Soja, Cx. Postal 231, 86001-970 Londrina, PR, Brazil
[b] Universidade Estadual de Londrina, Department of Agronomy, Caixa Postal 10011, 86057-970 Londrina, PR, Brazil

ARTICLE INFO

Article history:
Received 22 January 2014
Received in revised form 8 April 2014
Accepted 14 April 2014

Keywords:
Cultural profile
Soil tillage
No-tillage
Conventional tillage
Soil microbiota

ABSTRACT

Methods for assessment of soil structure in the field are useful for determining the sensitivity of soil to different management systems. Soil and crop management have a fundamental role in the maintenance and improvement of soil quality, as they have a direct influence its structure and on microbiota habitats. The aim of this study was to qualify and quantify homogeneous morphological units (HMUs) in a dystroferric Red Latosol, in a 22-year experiment with treatments consisting of a no-tillage planting system (NT), no-tillage with chiseling every 3 years (NTC) and conventional tillage (CT), using crop rotation (CR) [with five different crop species in 3 years] and succession systems (CS) [only two crop species]. The NT and NTC treatments presented HMUs with a continuous and cohesive structure and increased visible porosity at the surface, and continuous and cohesive units with lower porosity below this layer. The surface layer of the NT treatment presented free units made up of small and medium sized clods, and below this layer, compact, continuous units with little porosity. The soil management systems with crop rotation presented less compact units and roots with fewer morphological deformities than in the treatments with succession systems. Significantly higher levels of carbon and nitrogen microbial biomass (CMB and NMB) were observed in the HMUs in NT and NTC systems under both crop rotation and succession systems, and these had higher visible porosity than the units found in the CT system. On average, HMUs in the NT and NTC treatments presented 20% more CMB and 51% more NMB than in the CT treatment. NMB was the parameter most highly affected by the soil management. At depths of 0–20 cm, total organic carbon (TOC), was higher by an average of 21% than in the NT and NTC treatments. Total nitrogen (TN) was also affected by the soil management, increasing by an average of 50% in the NT and NTC treatments. This demonstrates how the tillage of the soil exposes the organic matter in the aggregates to oxidation and nitrogen mineralization.

Published by Elsevier B.V.

1. Introduction

The biggest challenge within modern agriculture is to find soil management systems that contribute to the economic and environmental sustainability of production systems. The no-tillage planting system (NT), in which the soil is not disturbed through tillage, reduces impacts on soil structure and has been indicated as an alternative means of sustainable soil management. Since this method was introduced in Brazil in the 1970s, studies have demonstrated the advantages of NT compared to systems involving tillage of the soil. The benefits of NT include the control it provides over wind and rain erosion (Barthès and Roose, 2002; Franzluebbers, 2002; Batey, 2009), better soil humidity conditions (Franzluebbers, 2002; Batey, 2009; Jin et al., 2011) and higher levels of organic carbon (Babujia et al., 2010; Jin et al., 2011; López-Fando and Pardo, 2011).

In addition, studies have indicated that NT has contributed to a reduction in carbon dioxide (CO_2) emissions (Ball et al., 1999; Bayer et al., 2002; Drury et al., 2004). In 2010, the Brazilian government introduced its Low-Carbon Agriculture Program (ABC), which aims to increase the current 26 million hectares of land under NT farming to 33 million hectares, with the objective of

* Corresponding author at: Universidade Estadual de Londrina, Department of Agronomy, Caixa Postal 10011, 86057-970 Londrina, PR, Brazil.
Tel.: +55 43 33714783; fax: +55 43 3371 4555.
E-mail addresses: drikapera@yahoo.com.br (A.P.d. Silva), leticiacb_@hotmail.com (L.C. Babujia), julio.franchini@embrapa.br (J.C. Franchini), ralisch@uel.br (R. Ralisch), mariangela.hungria@embrapa.br (M. Hungria), mfatima@uel.br (M.d.F. Guimarães).

http://dx.doi.org/10.1016/j.still.2014.04.006
0167-1987/Published by Elsevier B.V.

reducing emissions by around 20 million tons of CO_2 by 2020 (MAPA, 2012). This combination of factors has contributed to the adoption of the NT planting system across approximately 100 million hectares of land (FEBRAPDP, 2012).

Soil preparation is the activity with the most influence on the physical properties of the soil, as it has a direct impact on its structure (Ralisch et al., 2010). On the other hand, cropping systems that involve crop rotation or succession have a fundamental role in the formation and stability of aggregates (Munkholm et al., 2013).

Performing qualitative and quantitative evaluation on soil structure in the field in order to verify the effect of soil use and management on the morphology of the soil is challenging. The French cultural profile methodology (Gautronneau and Manichon, 1987), modified by Tavares Filho et al. (1999) for tropical conditions, has proved to be promising in this area. This methodology identifies soil volumes that are affected by the intervention of agricultural tools, root systems and natural factors, providing a differentiated picture of the effects of agriculture on the conservation and quality of the soil. Tamia et al. (1999) use the term Homogeneous Morphological Units (HMUs) to describe the soil volumes in the cultural profile affected by soil use and management activities.

Changes in soil structure directly affect the habitat of microorganisms, which are considered to be critical components of natural and anthropogenic ecosystems as they regulate the level of decomposition of organic material and the cycling of nutrients (Barros et al., 2007). Due to the sensitivity of this parameter, microbial biomass has been used in studies as an indicator of changes provoked by soil and crop management and in the tropics (Franchini et al., 2007; Hungria et al., 2009; Babujia et al., 2010; Silva et al., 2010). Positive correlations between microbial biomass and crop productivity have been observed (Hungria et al., 2009; Silva et al., 2010).

The hypothesis raised in this study is that morphological alterations observed in soil structure may be related to modifications in microbial biomass, validating the cultural profile method as a tool capable of providing an indication of the microorganisms present in the HMUs found in soil profiles. Soil samples to evaluate microbial biomass are generally collected up to depths of 30 cm (Baker et al., 2007) and potential alterations to soil structure along the profile are not taken into account, meaning that they may not represent the actual conditions of the soil.

The aim of this study was to quantify carbon and nitrogen microbial biomass in the Homogeneous Morphological Units (HMUs) in a dystroferric Red Latosol, in a 22-year experiment with treatments consisting of a no-tillage planting system (NT), no-tillage with chiseling every 3 years (NTC) and conventional tillage (CT), using crop rotation (CR) and succession (CS) systems, in order to determine the relationship between alterations in soil structure and modifications in the contents of microbial biomass.

2. Materials and methods

2.1. Characterization of the experimental area

The experiment began in the summer of 1988/1989, in the experimental area of the Soybean Research Center at the Brazilian Agricultural Research Agency (EMBRAPA Soja) (23°11′ S, 51°11′ W), Londrina, in the state of Paraná in Brazil.

The local climate is classified according to Köeppen as Humid Subtropical (Cfa) and has an average annual temperature of 21 °C, with an average maximum of 28.5 °C in February and an average minimum of 13.3 °C in July. The average annual rainfall is 1.651 mm, with the highest rainfall in January (217 mm) and the lowest in August (60 mm). The altitude is 620 meters with a slope of 6%. According to the Brazilian classification system, the soil is a very clayey dystroferric Red Latosol, and according to the American classification system, it is a Rhodic Eutrudox with 710 g clay, 82 g silt and 208 g sand per kg^{-1} of soil.

Before the experiment, the area was cultivated for around 40 years with coffee (*Coffea arábica* L.). The area was split into experimental units of 7.5 m width by 30 m length (225 m^2), with four repetitions per treatment, distributed over randomized blocks in a factorial arrangement. The profiles were prepared and soil sampling was carried out 22 years into the experiment, in April 2010, after the maize harvest in the units under crop rotation and the soybean harvest in the units with crop succession.

The study compared the effects of three soil preparation systems: no-tillage planting (NT), where sowing is carried out on the residues of the previous crop and mechanical intervention is restricted to the digging of a narrow planting row (~4 cm deep); no-tillage with chiseling every 3 years (NTC), with the objective of breaking up the compact surface layer (~25 cm deep) but without the use of soil leveling operations; and conventional tillage (CT), where the soil is prepared every year with a disc plow (~20–25 cm deep), followed by a leveling harrow (~15 cm deep) before the planting of the summer crop, and a heavy harrow (~15 cm deep) followed by a light harrow (~15 cm deep) in the winter. The chisel plow used in the NTC treatment was last used 3 years before the soil evaluation took place.

In addition, each soil preparation system was submitted to the effects of crop rotation and succession. Six management systems were evaluated in total: NT (rotation and succession), NTC (rotation and succession) and CT (rotation and succession). The crop rotation (CR) consisted of five different crop species: white lupine (*Lupinus albus*)-maize (*Zea mays*), black oat (*Avena strigosa*)-soybean (*Glycine max*), wheat (*Triticum aestivum*)-soybean, every 3 years; and crop succession (CS) with soybean in the summer and wheat in the winter.

At the start of the experiment, the soil received two tons of limestone per hectare to achieve a base saturation of 60% and to adjust the pH to approximately 5.5, and maintenance was carried out every 3 years. Similar quantities of fertilizer were applied to all of the treatments. Along the 22 years of the experiment, an average of 47 kg P ha^{-1} (triple superphosphate) and 41.2 kg K ha^{-1} (potassium chloride) were added to the soybean culture, with no nitrogen fertilization being carried out. The soybean seeds were inoculated with *Bradyrhizobium japonicum* and *B. elkanii* before planting. After 10 years of soybean cultivation, 20 g Mo ha^{-1} (sodium molybdate) and 2 g Co ha^{-1} (cobalt chloride) were added to the soil every year. For the maize culture, an average of 19.2 kg N ha^{-1} (urea), 51.5 kg P ha^{-1} (triple superphosphate) and 47 kg K ha^{-1} (potassium chloride) were added every year.

The insects and diseases were controlled as necessary. The residues of previous cultures were desiccated using glyphosate. After planting, other herbicides were applied to the CT treatment as necessary.

2.2. Cultural profile

Two 1.0 m long × 1.0 m wide × 1.0 m deep trenches were dug for each treatment (two repetitions per treatment) in the middle of the experimental units and perpendicular to the direction of the agricultural machinery. The cultural profile method was used for the evaluations, as described by Tavares Filho et al. (1999). Cultural profile methodology classifies HMUs into two levels: (1) organization of clods in the soil profile (C – continuous; F – cracked; L – free and Z – laminar), and (2) internal state of the clods (μ – not compact; Δ – compact and $\mu\Delta/\Delta\mu$ – ±compact). For more details see Neves et al. (2003): L – Free soil volume – Loose soil and aggregates of varied sizes (0–10 cm) with no cohesion; C –Continuous