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# Microbial biomass under various soil- and crop-management systems in short- and long-term experiments in Brazil

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ABSTRACT

Management and cropping systems varying in soil mobilization rates and plant-residue inputs may have profound effects on the biological properties of soil. Therefore, the objective of this study was to quantify soil microbial biomass carbon and nitrogen (MB-C and MB-N)—by means of the fumigation-extraction method—under varied soil-management and crop-rotation/succession systems in southern Brazil, correlating the results with yields of soybean and maize crops. The microbial biomass and grain yields were examined at the 0–10 cm layer in four short- to long-term field experiments. Experiment 1 was a 26-year trial consisting of four soil-management systems: (1) no-tillage (NT), (2) conventional tillage [(CT) with disc plough], (3) field cultivator (FC) or (4) heavy-disc harrow (DH), each with a crop succession (CS) of soybean (summer) and wheat (winter). Experiment 2 was a 21-year trial consisting of one CS, soybean/wheat every year) and seven crop rotations (CRs) comprising soybean, maize, wheat and green manures (lupine, radish and black oat), under the NT system. Experiment 3 comprised a 14-year CT trial, and 4-year and 14-year NT trials, with both one CS and two CRs. Experiment 4, a 10-year trial consisted of CT and NT and three CRs. Analyses were performed during the summer and winter croppings. Differences in microbial parameters, as a function of crop succession and rotation, were not easily detected as they varied as a function of a complex combination of plant species and time of implementation of the experiment. In contrast, MB-C and MB-N values were consistently higher—up to more than 100%—under NT in comparison to CT and were associated with higher grain yields. Our results—from this wide range of experiments—suggest that MB-C and, particularly, MB-N are sensitive indicators of the effects of soil- and crop-management regimens.



## 1. Introduction

In Brazil, about 300 million ha, in varied ecosystems, have been converted to agricultural use (MAPA, 2008), with impacts on soil properties differing as a function of diverse management systems. Adoption of practices that minimize these impacts is fundamental to agricultural sustainability. For example, the soil environment is affected by return, or not, of plant residues, in terms of soil structure, temperature, moisture and aeration, which, in turn, affect soil microbial biomass. Microbes function as agents of transformation of organic matter, nutrient cycling, energy flow, among other functions (e.g., Wardle and Giller, 1996; Six et al., 2004) that impinge on sustainability.

According to Sparling (1992), changes in soil organic matter (SOM) are difficult to detect in the short term, necessitating long-term monitoring. In contrast, changes in microbial biomass carbon (MB-C) and nitrogen (MB-N) were found to rapidly reflect impacts of agricultural management (Carter and Rennie, 1982), before any changes in chemical or physical parameters are detectable (Franchini et al., 2007; Kaschuk et al., 2010). Accordingly, parameters associated with microbial biomass have been proposed as biological indicators of soil quality (e.g., Doran and Parkin, 1994; Hungria et al., 2009).

The no-tillage (NT) cropping system was introduced in Brazil in the 1970s, in the State of Paraná, for soil-erosion control, and has been increasingly adopted such that, according to estimates of the Brazilian Federation of No-Tillage, in 2005/2006 25.5 million ha were devoted to grain production under NT (FEBRAPDP, 2010). Among other benefits, NT increases water infiltration and retention

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and reduces soil-temperature oscillation (Castro-Filho et al., 2002). In addition, NT increases soil organic C content in comparison with conventional tillage (CT), which may contribute to sequestration of atmospheric C (Bayer et al., 2002; Pacala and Socolow, 2004).

It has been demonstrated that, in tropical soils, the inclusion in crop rotations under NT of nitrogen-fixing legumes, such as lupine (*Lupinus* spp.), and of green-manure crops such as black oat (*Avena strigosa* Schreb.) and radish (*Raphanus sativus* L.), increases soil organic matter and improves soil-chemical, -physical, and -biological properties (Franchini et al., 2007; Hungria et al., 2009). However, differential effects have been observed on the rate of residue decomposition and on microbial community composition according to the quantity and quality of plant residues added to the soil (Franchini et al., 2002).

Studies of microbial biomass may be valuable as an adjunct to research on the effects of agricultural practices on soil quality and crop productivity. In this context, the objective of the present study was to evaluate MB-C and MB-N in four short- to long-term field experiments under varied soil- and crop-management systems, correlating microbial parameters with soil productivity capacity, assessed as grain yield.

## 2. Materials and methods

### 2.1. Geographic location and general description of the field sites

The experiments were carried out at the experimental area of Embrapa Soja in Londrina, Paraná, Brazil, with an altitude of 620 m, latitude 23°11′S, longitude 51°11′W. Average annual temperature in Londrina is 21 °C, with an average high at 28.5 °C in February and an average low at 13.3 °C in July. Average annual rainfall is approximately 1651 mm, with 123 days of rainfall per year; maximum rainfall occurs in the summer (January–March) and the minimum in the winter (June–August). According to Köeppen's classification, the climate in Londrina is subtropical humid—*Cfa* type (humid, temperate, with hot summer). The soil (Latossolo Vermelho Eutroférrico, Brazilian classification; Rhodic Eutrudox, USA classification) is very clayey, averaging 71% clay, 16% silt, and 12% sand. The four experimental areas described below were selected for sampling.

#### 2.1.1. Experiment 1—26-year trial

The area where the experiment was established had been cropped with coffee trees (*Coffea arabica* L.) for about 40 years. The experiment was set up in the summer of 1981, with a crop succession of soybean (*Glycine max* L. Merr.)/summer and wheat (*Triticum aestivum* L.)/winter every year. The experiment had a randomized complete block design with four blocks as replicates (Cochran and Cox, 1957), and four types of soil management as treatments: (1) no-tillage (NT) (sowing directly through the residue of the previous crop, with the opening of only a narrow furrow in the sowing row); (2) conventional tillage (CT) [soil is prepared with disc plough and heavy-disc harrow followed by light-disc harrow (DH)]; (3) field cultivation (FC) (with the subsoil scarified to a depth of 15–20 cm followed by light-disc harrow); and (4) DH. Field plots were 50 m in length x 8 m in width. Soil preparation of the winter crop in the CT and FC treatments was accomplished by DH, followed by light-disc harrow. Previously, other cultivars had been used, but in the summer of 2006/2007 soybean cultivar BRS 232 was planted, and in the winter of 2007 the wheat cultivar planted was BRS 208. In this experiment and in the other three (described below) herbicides were applied after the grain harvest, to desiccate crop residues. With NT, the crop residues were left on the soil surface, whereas, in the other soil-management systems, the residues were incorporated into the soil.

#### 2.1.2. Experiment 2—21-year trial

This area had also been cropped to coffee for about 40 years. The experiment began in the winter of 1986, and included one crop succession (CS) and seven crop-rotation (CR) systems under the NT system. The experiment had a randomized complete block design with four blocks as replicates (Cochran and Cox, 1957), and the field plots were 14 m in length × 5 m in width. Cropping effects were studied including grain crops [soybean, maize (*Zea mays* L.), and wheat)] and cover and green-manure crops [lupine (*Lupinus albus* L.), radish (*R. sativus* L.), and black oat (*A. strigosa* Schreb.)]. In southern Brazil more than 90% of the farmers plant exclusively the soybean (summer)/wheat (winter) crop succession and it has been a technical challenge to introduce other species into crop rotations. Few adapted species, with seeds commercially available, can usefully be included in crop rotations relevant to Brazil; the species were chosen accordingly. The sequence, shown in Table 1, represents various strategies for rotating legumes, grasses and cover crops. In the early years the cultivars were chosen according to annual recommendations, and in the 2006/2007 season soybean cultivar BRS 184 and maize cultivar BRS 10-30 were grown in the summer, whereas in the winter the wheat cultivar was BRS 208, black oat was BRS 139, and radish was IPR 116.

#### 2.1.3. Experiment 3—14-year trial

Again the area had been cropped to coffee for about 40 years. The experiment was set up in the winter of 1993, in a randomized complete block design in a factorial scheme with three soil-management and three cropping systems, each with four replicates (Cochran and Cox, 1957). Field plots were 38 m in length × 8 m in width. The following soil-management systems were compared: (1) CT, with disc plough in the summer and DH in the winter; it should be noted that this CT was slightly different from that of Experiment 1; in view of the benefits accruing from NT, the farmers started to reduce the soil-management operations also with CT; (2) old NT (NTo—named "old" because it was established in 1993); and (3) new NT (NTn) (where part of the area previously treated to CT was converted to NT at the beginning of October 2003). The experiment consisted of two crop rotations (CRs) and one crop succession (CS), which included grain crops [short-season maize ("safrinha") (the summer crop sown and harvested early followed by a "late" short-season maize) and cover and green-manure crops (lupine and black oat)]. Nine treatments were compared: CT (CR 1, CR 2, and CS), old NT (CR 1, CR 2, and CS), and new NT (CR 1, CR 2, and CS). The sequences of the crops in the soil-management systems are described in Table 1. In previous years, the cultivars were chosen according to annual recommendations, and in the 2006/2007 summer crop, both the CR and CS had soybean cultivar BRS 232, whereas, in the winter of 2007, wheat cultivar BRS 208 was used in CR 1 and CS, and the "short-season" maize cultivar BRS 10-10 in CR 2.

#### 2.1.4. Experiment 4—10-year trial

This site had been farmed with conventional tillage (CT), with the traditional practices of plowing and disking, and planted to soybean in the summer and to wheat in the winter over the previous 6 years. The experiment was set up in the summer of 1997/1998, with a randomized complete block design in a factorial scheme, with two soil-management systems [NT and CT (as described in Experiment 3)] and three CR systems (CR 1, CR 2, and CR 3), including soybean, maize, wheat, lupine, and black oat, each with four replicates. Field plots were 15 m in length × 8 m in width. Crop rotations are shown in Table 1. In the early years, the cultivars were chosen according to annual recommendations, and in the 2006/2007 summer, hybrid maize Pioneer 30 F 33 was planted, and in the winter of 2007 black oat cultivar Iapar 61 and wheat cultivar BRS 239 were used.