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Review

Three decades of soil microbial biomass studies in Brazilian ecosystems: Lessons learned about soil quality and indications for improving sustainability

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A B S T R A C T

Soil microbial biomass plays important roles in nutrient cycling, plant–pathogen suppression, decomposition of residues and degradation of pollutants; therefore, it is often regarded as a good indicator of soil quality. We reviewed more than a hundred studies in which microbial biomass-C (MB-C), microbial quotient (MB-C/TSOC, total soil organic carbon) and metabolic quotient (qCO_2) were evaluated with the objective of understanding MB-C responses to various soil-management practices in Brazilian ecosystems. These practices included tillage systems, crop rotations, pastures, organic farming, inputs of industrial residues and urban sewage sludge, applications of agrochemicals and burning. With a meta-analysis of 233 data points, we confirmed the benefits of no-tillage in preserving MB-C and reducing qCO_2 in comparison to conventional tillage. A large number of studies described increases in MB-C and MB-C/TSOC due to permanent organic farming, also benefits from crop rotations particularly with several species involved, whereas application of agrochemicals and burning severely disturbed soil microbial communities. The MB-C decreased in overgrazed pastures, but increased in pastures rotated with well-managed crops. Responses of MB-C, MB-C/TSOC and qCO_2 to amendment with organic industrial residues varied with residue type, dose applied and soil texture. In conclusion, MB-C and related parameters were, indeed, useful indicators of soil quality in various Brazilian ecosystems. However, direct relationships between MB-C and nutrient-cycling dynamics, microbial diversity and functionality are still unclear. Further studies are needed to develop strategies to maximize beneficial effects of microbial communities on soil fertility and crop productivity.

1. Introduction

Soil microbial biomass-C (MB-C) is the living portion of soil organic matter, constituted by archaea, bacteria and eukaryotes, excluding roots and animals smaller than 5×10^3 μm^3 (e.g. Jenkinson and Ladd, 1981). Fungi, bacteria and archaea represent 75–98%, protists 1–6%, and meso- and macro-fauna (microarthropods, macroarthropods, enchytraeids and earthworms) only a minor fraction of total living biomass in soil (Beare, 1997). The MB-C has been correlated with several functional microorganisms, such as ammonifiers and nitrifiers (Andrade et al., 1995), microbial diversity (Nogueira et al., 2006), legume-nodulating bacterial populations (Pereira et al., 2007) and enzyme activities in the soil (Matsuoka et al., 2003; Mendes et al., 2003; Balota et al., 2004b). Furthermore, the MB-C could be related to diverse soil processes, including decomposition of organic residues, nutrient cycling, solubilization of nutrients (particularly phosphates), degradation of xenobiotic compounds and pollutants, soil structuring, organic matter storage, and biological control and suppression of plant pathogens; and for that reason, it has often been indicated as an important component for maintaining soil quality and plant productivity (Nogueira et al., 2006; Roscoe et al., 2006).

Three decades after publication of the first method for MB-C evaluation (Jenkinson and Powlson, 1976), several studies have been made on MB-C in ecosystems in Brazil, most of which are published in national journals and proceedings in Portuguese. The purpose of this paper is to review many of these studies identifying patterns in MB-C responses to various land uses in Brazilian ecosystems, emphasizing gaps in knowledge to inspire future research.

2. Methods for evaluation of MB-C

Prior to three decades ago, MB-C could be estimated only by microscopic observations by trained personnel with sophisticated equipment. Then Jenkinson and Powlson (1976) described the fumigation–incubation approach (FI), a much less subjective method to evaluate MB-C, based on fumigation, re-inoculation with

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live microbial biomass, incubation under controlled conditions, and measurement of differences of CO_2 fluxes between fumigated and non-fumigated soils. Later, Vance et al. (1987) proposed the fumigation–extraction method (FE), a modification to extract contents of MB-C with chemicals, immediately after fumigation.

Initially, Jenkinson and Powlson (1976) assumed that 50% of MB-C is effectively mineralized during an incubation period of 10 days, resulting in a coefficient for conversion of $K_C = 0.50$. Later, Jenkinson and Ladd (1981) proposed $K_C = 0.45$ assuming a bacterial to fungal biomass of 1:3, which could be applied to different soils without serious error, and since then, this value has been widely accepted. Values of K_C could be slightly different under tropical conditions, and indeed, Sampaio et al. (1986) incubated known amounts of microbes in several Brazilian soils and concluded that a $K_C = 0.41$ was more representative for tropical soils. Furthermore, this value is in accordance with estimates obtained elsewhere [e.g. $K_C = 0.41$ by Anderson and Domsch (1978)] under temperate conditions.

With regard to the FE method, Roscoe et al. (2006) observed that evaluations of MB-C in Brazil were normally based on K_{CE} (which have similar meaning to K_C but is related to FE method) varying from 0.30 to 0.38, and suggested that values lower than 0.33, as utilized by Vance et al. (1987) under temperate conditions, probably overestimate MB-C under tropical conditions. Roscoe et al. (2006) calibrated the relationship between FI and FE methods with MB-C measurements in several Brazilian studies, and suggested that a $K_{CE} = 0.40$ was more appropriated for tropical conditions. Therefore in this review, the MB-C measurements from different studies are standardized by using K_C and K_{CE} of 0.40.

Given its utility and robustness, the FI method (Jenkinson and Powlson, 1976) became a standard procedure for measuring MB-C, and has been used to confirm the reliability of other methods for MB-C measurements, including FE. Roscoe et al. (2006) compiled several studies performed in Brazil (Pfenning et al., 1992; Rodrigues et al., 1994; Feigl et al., 1995; Geraldes et al., 1995; Oliveira et al., 2001), adjusted the MB-C measurements on the basis of coefficient values of $K_C = 0.41$ and $K_{CE} = 0.40$, and obtained a correlation of 92% ($P < 0.01$), with a regression of $y = 1.02x$, showing that both FE and FI are equally suitable to measure MB-C. However, it has also been shown that, under tropical conditions, FE in general is less variable than FI (Pfenning et al., 1992) and more sensitive to total soil organic carbon (TSOC) (Rodrigues et al., 1994; Oliveira et al., 2001); therefore, it has been recommended for MB-C measurements in Brazil by the Brazilian Soil Science Society since 2004 (Roscoe et al., 2006).

Some important parameters may be derived from MB-C, such as the ratio of MB-C to the TSOC, known as the microbial quotient (MB-C/TSOC) (e.g. Insam and Domsch, 1988), and the metabolic quotient (qCO_2), which is the ratio of basal respiration (BR) to the total MB-C (e.g. Insam and Haselwandter, 1989). The MB-C/TSOC gives insight into the capability of a soil to support microbial growth, and it is expected that soils with better quality will have higher ratios of MB-C/TSOC. The qCO_2 indicates the efficiency by which soil microorganisms use C-resources in the soil, and it is expected that stressed soils will provide higher qCO_2 values than less-stressed soils (Insam and Haselwandter, 1989).

The FE method has also been used to determine nutrients other than C in the MB, following the same principle of measuring flushes after fumigation and dividing by a conversion coefficient (K). Therefore, MB-N (nitrogen) has been determined according to Brookes et al. (1985) with $K_N = 0.54$, the MB-P (phosphorus) according to Brookes et al. (1982) with $K_P = 0.40$, and the BM-S (sulfur) according to Strick and Nakas (1984) and Chapman (1987) with $K_S = 0.35$. In fact, it is possible to determine the MB-N with the FI method as well, but the results should be interpreted with caution due to nutrient immobilization during the incubation period.

3. The MB-C as indicator for soil quality

Concerns about agriculture sustainability have inspired myriad studies on MB-C and related parameters associated with soil chemical and physical characteristics, biodiversity and crop productivity as indicators of soil quality. Soil quality was first defined as the continued capacity of the soil to function as a vital living system, within ecosystems and land-use boundaries, to sustain biological productivity, promote air and water quality, and maintain plant, animal and human health (Sparling, 1997; Seybold et al., 1999). The MB-C is one of the most promising indicators of soil quality because it responds promptly to environmental changes, often much earlier than physical and chemical parameters, including TSOC and even crop productivity, consistently over seasonal fluctuations due to climatic conditions (Sparling, 1997; Balota et al., 1998; Seybold et al., 1999; Nogueira et al., 2006; Roscoe et al., 2006; Franchini et al., 2007; Hungria et al., 2009).

Additionally, MB-C/TSOC and qCO_2 may be used to indicate the soil vulnerability to disturbance in terms of resilience and resistance (Seybold et al., 1999). It is assumed that soil MB-C has low resistance if MB-C is significantly decreased after disturbances, but high resilience if the MB-C/TSOC and the qCO_2 are barely affected. High resilience is advantageous because after a stressful event in the soil, the MB-C and its related soil quality may recover with time. However, it is necessary to measure MB-C of a given soil under several circumstances before defining the thresholds of MB-C for optimal soil quality, mainly because MB-C is vulnerable to pedogenetic and climate conditions, and often varies significantly from one environment to another (Table 1). Therefore, the response ratios of MB-C with various treatments should be used to compare different studies (Sparling, 1997). In the following sub-sections, we discuss many of the MB-C studies performed in Brazil aiming at identifying management practices with relatively little impact on MB-C or soil quality.

3.1. Conceptual model to understand the role of MB-C in studies of soil quality

As mentioned before, the MB-C is a useful bioindicator of soil quality because it is sensitive and responds more rapidly to soil changes than any other agronomic parameter (Sparling, 1997; Balota et al., 1998; Nogueira et al., 2006; Franchini et al., 2007; Hungria et al., 2009). Based on MB-C measurements, measures may be taken to avoid soil degradation and loss of the soil quality, and consequently avoid losses in plant productivity. Fig. 1 shows a conceptual model of the responses of yield as a function of MB-C. Small losses in the MB-C do not relate directly to reductions in plant productivity due to a buffering capacity through soil resilience (Box III). Further decreases in the MB-C result in losses in N_2-fixation and arbuscular-mycorrhizal activities; however, crop productivity may be maintained by application of increasing rates of fertilizers (Box II). However, further decreases in MB-C and in soil quality may lead to lack of crop-productivity responses to fertilizers (Box I). On the other hand, if management practices stimulate MB-C, then plant productivity may increase due to stimulation of nutrient cycling and beneficial plant–microbe symbioses (Box IV).

3.2. Soil-tillage systems

Conventional tillage (CT)—the traditional system of ploughing, disking and harrowing before cropping—has damaged soil quality and crop productivity for decades in Brazil (Derpsch et al., 1991); therefore, as soon as they were aware of its advantages, farmers adopted no-tillage (NT), a cropping system minimizing soil turnover. Today, NT covers about 25.5 million ha (FEBRAPDP, 2008) and is often assumed to play a key role in sustainability, favoring