

Review Article

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Microbiological-Indicators with Potential for Evaluating Soil Quality

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ABSTRACT

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An understanding of soil microorganisms as part of soil system and interactions between the diversity of producers and of decomposers, have major consequences on the functioning of agricultural ecosystems. Soil microorganisms control the transformation and mineralization of natural compounds and xenobiotics. The soil micro biota, existing in high density and diversity, rapidly modify the energetic performance and activity rates to changing environmental conditions. Thus, microbial consortium possesses the ability to accommodate environmental constraints by adjusting biomass, community structure and activity rates. These parameters are particularly important to take into consideration when evaluating soil quality. The use of microbial diversity, structure, biomass as indicators to monitor soil quality is challenging due to little understanding of the relationship between microbial community and soil functioning. A simple overview about the possibilities of using microbial populations as quantitative indicators for soil quality evaluation is presented in this paper.

Introduction

Selection of indicators

Soil quality is the edaphic capacity to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health (Doran *et al.*, 1997). Soil quality (SQ) assessment has long been a challenging issue, since soils present high variability in properties and functions (Zornoza *et al.*, 2015). Soil quality indicators are physical, chemical and biological properties or processes that can be measured

to monitor changes in the soil and their effects on processes ecosystem (Brady and Weil, 2008), and the capacity to support crop production (Arshad and Martin, 2002).

Common approaches used for assessing the soil quality are either qualitative or quantitative. Qualitative indicators are often sensory descriptors (e.g. appearance, smell, feel and taste) (Dang, 2007). Quantitative indicators of soil quality involve more sophisticated analytical approaches (Harris

and Bezdicek, 1994) and include combined and integrated analysis of the physical, chemical and biological soil properties (He *et al.*, 2003).

The effective identification of appropriate indicators for soil quality assessment depends on the ability of any approach to consider the multiple components of a soil function for productivity in particular and environmental well being in general (Bloem *et al.*, 2003). The selection depends on the sensitivity of these properties to soil management or changes in climate, as well as the accessibility and usefulness to producers, scientists, conservationists and policy makers (Rezaei *et al.*, 2006, Zornoza *et al.*, 2015). Indicators should be limited and manageable in number by different types of users, simple and easy to measure, cover the largest possible situations (Doran and Parkin, 2000) including soil types and seasonal variation and be highly sensitive to environmental changes and soil management (Dick, 2000). Thus the selection of microbiological indicators depends on the soil and functions being assessed. Since soil microorganisms can respond rapidly, they reflect a hazardous environment and therefore considered when monitoring soil status (Morugán-Coronado *et al.*, 2013). Micro biological and biochemical indicators determine edaphic quality would be simple to measure, should work equally well in all environments and reveal, reliably, sites where problems exist. It is unlikely that a sole ideal indicator can be defined with a single measure because of the multitude of microbiological components and biochemical pathways. Therefore, a minimum data set, (MDS) is frequently applied (Sinha *et al.*, 2009, Carter *et al.*, 1997) for monitoring and measurement soil quality. Many countries have developed their own MDS of microbiological indicators for monitoring soil quality. In general microbial biomass and soil respiration are the most commonly used indicators. Furthermore,

some of the recent tools such as Biolog, PLFA, DGGE/TGGE have been recommended for microbial diversity assessment to monitor soil quality in some countries (Winding *et al.*, 2005, Chapman *et al.*, 2000). In India, MDS for monitoring soil quality has been recommended but soil enzyme activities, respiration and microbial biomass are being used widely (Sharma *et al.*, 2005, Ramesh *et al.*, 2004).

Microbial biomass

The soil microbial biomass can be defined as organisms living in soil that are generally smaller than approximately 10mm. Generally, microbial biomass can offer a controlled tool in assessing the soil quality in different vegetation types (Groffman *et al.*, 2001). Most attention is given to fungi and bacteria, being the most important to energy flow and control of major soil processes such as carbon and nutrient cycling (Milne and Haynes, 2004). Microbial biomass carbon particularly organic matter and hydrolysable carbohydrates typically comprising 1%–5% of the total organic matter content, are considered as biologically active fraction and are sensitive indicators of changes induced by management of soil (Lentzsch, *et al.*, 2005). The ratio of microbial biomass C to soil organic C (C mic: C org) reflects the contribution of microbial biomass to soil organic carbon (Anderson and Domsch, 1993). It also indicates the substrate availability to the soil microflora or, in reverse, the fraction of recalcitrant organic matter in the soil. In fact this ratio declines as the concentration of available organic matter decreases (Brookes, 1995). Microbial biomass is easily exchangeable; it is considered a sensitive indicator of alterations imposed by soil use and management (Brookes *et al.*, 2008). The microbial biomass is a living component of soil organic matter, responds more quickly to the changes in soil conditions

than Soil Organic matter (SOM) (Araujo *et al.*, 2010). Soil microbial biomass is an important ecological indicator and acts as a source and sink of available nutrient for plant growth. Little change in soil microbial biomass affects directly on ecosystem stability and fertility of soil (Feng *et al.*, 2004). Any changes in microbial biomass ultimately affect nutrient cycling of soil organic matter. Therefore, estimation of microbial biomass can provide useful information on the changes in soil biological properties (Jordan *et al.*, 1995).

The microbial biomass estimation can be performed by several methods. The direct counting of microbial biomass in soil includes the use of staining techniques in conjunction with fluorescence microscopy or automated image analysis (Bloem and Breure, 2003). The most common indirect methods are chloroform fumigation and substrate-induced respiration (SIR) (Carter *et al.*, 1999). Soil microbial biomass is subsequently calculated using a conversion factor (Kaiser *et al.*, 1992).

Microbial diversity

Microbial diversity is a complex issue. Its measurement by diversity indices is usually less informative than qualitative community structure analysis. Most data suggests that community composition is more important than richness for specific microbial processes (Peter *et al.*, 2011 Bhat, 2013). Given the central role of microbes in ecosystem processes, soil microbial facets are at least as important as the physical or chemical edaphic parameters. Even though the relationship between microbial diversity and soil functioning has not been fully unraveled (Hooper *et al.*, 2005), these two facets should be regarded as intrinsically associated (Turbé *et al.*, 2010). Second, microorganisms rapidly respond to environmental stresses, as they have intimate relations with their

surroundings due to their high surface-to-volume ratio (Winding *et al.*, 2005).

The term microbial community adaptation (Wallenstein and Hall, 2012) relates to how fluctuations in specific microbial populations in response to changes in environmental conditions, affect the aggregate function of the community they belong to. Due to complicity of the whole microbial community it might be useful to look at indicator organisms only, which are correlated to soil quality, for example, beneficial microbes like *Rhizobium* or arbuscular mycorrhiza fungi. Arbuscular mycorrhiza are the most ancient and ubiquitous root symbioses, formed by fungi belonging to the order of Glomales (Zygomycetes) and 80% of terrestrial plants (Saif and Khan, 1975, Helgason and Alastair, 2009).

The occurrence, decline and infectivity of arbuscular mycorrhiza fungi in metal-polluted soils can be used as *bio-indicators* of soil contamination (Ibekwe *et al.*, 2001). Natural rhizobia populations are essential to increase the yield of leguminous crops. The importance of the interaction is based on the capacity of symbiotic *Rhizobium* strains to form nodules and fix atmospheric nitrogen (Zahran, 1999, Franche *et al.*, 2009). In recent publications, soil microbial biodiversity was also shown to influence global C (Nielsen *et al.*, 2010) and greenhouse gas budgets (Pritchard, 2011), enhance water quality, moderate soil organic matter decomposition, determine the susceptibility of soil to invasion by a pathogen (Van Elsas *et al.* 2012) and regulate nutrient retention and availability (Wagg, *et al.*, 2014).

Microbial activity

Microbial activity is the overall quantification of soil functioning, including C and N biogeochemical cycles, mainly via- soil organic matter decomposition. Microbial

activity leads to the liberation of nutrients available for plants, but also influences the flow of C, N, P, and S by their role in the processes of decomposition, immobilization and mineralization (Jordan *et al.*, 2005; Marcel *et al.*, 2008). Moreover, soil microorganisms also lead to the mineralization and mobilization of pollutants and xenobiotics (Reiger *et al.*, 2002). Thus, microbial activity is regulated by edaphic properties such as nutritional conditions, temperature and soil water availability and are of crucial importance in nutrient biogeochemical cycling (Harris, 2009).

Microbial activity in the soil can be assessed in a number of ways. Farmers can measure the status of either the total community of microorganisms or specific members of that community. The microscopic nematodes play numerous important soil roles, with both negative and positive effects. To the soil microbial activity estimation, two groups of microbiological approaches can be distinguished. First, experiments in the field that often require long periods of incubation (Alves *et al.*, 1993, Stenström *et al.*, 2001) before significant changes of product concentrations are detected -- (weeks for the estimation of net N mineralization. In this case, variations of soil conditions during the experiment are inevitable, such as aeration, and may influence the results (Madsen, 1996). In contrast short-term laboratory procedures that are usually carried out with sieved samples at standardized temperature, water content and pH value (Blagodatsky *et al.*, 2011). Such microbial activity measurements include enzymatic assays that catalyze substrate-specific transformations (Burns, 1977). This method may be helpful to ascertain effects of soil management, land use and specific environmental conditions (Burns, 1977). Taylor *et al.*, (2002) mentioned two main reasons for measuring soil enzymes. First, as indicators of process diversity, which

informs about the biochemical potential, possible resilience and potential for manipulation of the soil system-Second, as indicators of soil quality, in the sense that changes in key functions and activities can provide information about the progress of remediation operations or the sustainability of particular types of land management. Mijangos *et al.*, (2014) observed that replacing meadows with pine plantations under a temperate climate influences enzyme activities and nutrient cycling. Moreover, enzyme activity was sensitive to human-induced alterations in a land use sequence from natural forest pastures and shrub lands in the Andes of southern Ecuador mineral top soils of Cambisols/Umbrisols (Tischer *et al.*, 2014). Similarly, in the reclamation of the pasture with *Panicum maximum*, as evidenced by improvements in the microbiological and biochemical soil health indicators, through CO₂ evolution decrease, whereas microbial biomass C increased, resulting in a lower metabolic quotient (qCO_2) that points to a decrease in metabolic stress of the microbial community (Santos *et al.*, 2015).

Soil organic carbon and total nitrogen

Soil organic carbon and total nitrogen reflecting the functional capability of soil to supply nutrients to plants, mitigate greenhouse gas accumulation, and provide organic resources for stabilizing the soil surface against erosion, filtering of water, and for promoting a biologically diverse and healthy microbial population (Brady and Weil, 2008). Soil organic matter is a key component of productivity, avoidance of synthetic inputs, healthy food supply, and environmental protection goals (Magdoff and Weil, 2004.) Soil organic matter (SOM) has been suggested as the most important single indicator of soil quality (SQ) for agricultural sustainability since it affects most soil properties (Arias *et al.*, 2005). Consequently,

SOM has been suggested as biological indicator of soil quality related to the sustainability of the production system (Bini, 2014, Cardoso *et al.*, 2013, Kaschuk *et al.*, 2010) and is more sensitive to indicate changes in soil quality (Cardoso *et al.*, 2013). Soil microorganisms divert more energy from growth to maintenance as stress increases and thus the ratio of respired C to biomass C can be a much more sensitive indicator of stress. The basal soil respiration / microbial biomass carbon (BSR/MBC) ratio indicates the carbon turnover rates in the soils, the importance of soil organic carbon in improving the overall soil quality (Debasish *et al.*, 2014, Fialho and Zinn, 2014). Microorganisms indeed make up the largest part of the total biomass in the soil (Winding *et al.*, 2005) and are key drivers in processes that contribute to the provision of essential ecosystem services, such as respiration, decomposition of organic matter and nitrification and other N-related processes (Barios, 2007). These compounds of soil are the main nutrition used for vegetation growth, and are also used as indexes of soil quality assessment and sustainable land use management (Liu *et al.*, 2011, Jiang *et al.*, 2007). The relationship between soil organic carbon and nitrogen represented as soil C/N ratio, is considered a sensitive indicator of soil quality and for assessing carbon and nitrogen cycling of soils (Zhang *et al.*, 2011). As the C: N ratio increases so N mineralization decreases, giving an indication of the potential activity of soil microbial populations (White, 1997). The ratio of C: N is relatively constant in temperate agricultural soils and falls between 10-12:1 (Kalinina *et al.*, 2010). The C: N ratio is particularly useful when looking at organic materials applied to soils; as values increase above 30, the soil biomass becomes limited by the quantity of N and will not be able to utilize the C. This reduction in available N is termed immobilization and can last a significant time (a growing season) depending on a range of

factors, but particularly the C: N of the added residue (Rowell, 1994). Therefore, through monitoring changes etc, in total N, an indication of potential N behavior in soil can be determined through nitrogen fractionation, mineralization kinetics, nitrogen isotope variation etc.

In conclusion, the great abundance and diversity of microorganisms in soil have high metabolic potentials. Since microorganisms have generally limited growth in soils, they may poorly exploit their capabilities. In contrast, soil microorganisms respond rapidly to stressors by adjusting activity rates, biomass, and community structure. Combining soil microbiological estimates seems to be of great relevance for evaluating soil quality. However, an improved understanding of microbial processes, community structure and natural temporal and spatial variation is needed. Further scientific knowledge should be developed through research activities included in the monitoring programme to provide a scientific base for new management policies. A scientifically sound mathematical modeling of data followed by qualified interpretation is the tools available today for quantification to develop a base line.

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