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Assessing microbial activities in metal contaminated agricultural volcanic soils – An integrative approach

C. Parelho[a,b,*], A.S. Rodrigues[a,c], M.C. Barreto[b,d], N.G.C. Ferreira[e], P. Garcia[a,b]

[a] Department of Biology, University of the Azores, 9501-801 Ponta Delgada, Portugal
[b] cE3c, Centre for Ecology, Evolution and Environmental Changes, and Azorean Biodiversity Group, University of the Azores, 9501-801 Ponta Delgada, Portugal
[c] CVARG, Center of Volcanology and Geological Risks Assessment, University of the Azores, 9501-801 Ponta Delgada, Portugal
[d] Department of Technologic Sciences and Development, University of the Azores, 9501-801 Ponta Delgada, Portugal
[e] CIIMAR, Interdisciplinary Centre of Marine and Environmental Research, University of Porto, Rua dos Bragas 289, 4050-123 Porto, Portugal

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ABSTRACT

Volcanic soils are unique naturally fertile resources, extensively used for agricultural purposes and with particular physicochemical properties that may result in accumulation of toxic substances, such as trace metals. Trace metal contaminated soils have significant effects on soil microbial activities and hence on soil quality. The aim of this study is to determine the soil microbial responses to metal contamination in volcanic soils under different agricultural land use practices (conventional, traditional and organic), based on a three-tier approach: *Tier* 1 – assess soil microbial activities, *Tier* 2 – link the microbial activity to soil trace metal contamination and, *Tier* 3 – integrate the microbial activity in an effect-based soil index (Integrative Biological Response) to score soil health status in metal contaminated agricultural soils. Our results showed that microbial biomass C levels and soil enzymes activities were decreased in all agricultural soils. Dehydrogenase and β-glucosidase activities, soil basal respiration and microbial biomass C were the most sensitive responses to trace metal soil contamination. The Integrative Biological Response value indicated that soil health was ranked as: organic > traditional > conventional, highlighting the importance of integrative biomarker-based strategies for the development of the trace metal "footprint" in Andosols.

1. Introduction

Soil is a dynamic living resource, vital to ecosystems functioning and represents a unique balance among physical, chemical and biological factors (Shukla and Varma, 2011). Soil microbial activity directly influences the ecosystem stability, fertility and sustainability, being widely accepted that a good level of microbial activity is essential for maintaining soil quality. Natural events, such as volcanism, and anthropogenic activities, such as long-term agricultural practices, continuously affect the quality of soil (Santos et al., 2011; Parelho et al., 2014).

Due to the complexity of soil structure and function, a good soil quality indicator must be integrative, combining a number of measurements into an easily understood and quantitative measure. Since soil enzymes and other biochemical parameters differ in origin, function and location within the soil matrix (Burns, 1982), and respond to different key environmental signals, it would be useful to combine the information they provide into a single numerical value. Complex indexes, such Integrative Biological Response (Beliaeff and Burgeot, 2002) have been developed as effect-based monitoring tools and may be used to integrate soil microbial responses into more simple and realistic stress model, providing a more complete status of soil quality.

The activities of soil enzymes, microbial biomass and soil basal respiration are important indicators of microbial and biochemical processes and functions, because of their role in soil organic matter (SOM) decomposition, carbon sequestration, nutrient cycling and availability (Dick, 1997; Caldwell, 2005). In addition, the efficient soil co-extraction of RNA and DNA makes possible to calculate the RNA:DNA ratio, which can be an important indicator of the metabolic status of soil microbial communities. These microbial activities can be used as indicators of soil quality to monitor soil metal contamination (Niemeyer et al., 2012; Xian et al., 2015) and agricultural soil management practices (Bowles et al., 2014; Pandey et al., 2015). Despite the numerous field

* Corresponding author at: Department of Biology, University of the Azores, Apartado 1422, 9501-801 Ponta Delgada, Azores, Portugal.
E-mail addresses: carolina.pf.parelho@uac.pt (C. Parelho), armindo.s.rodrigues@uac.pt (A.S. Rodrigues), maria.cr.barreto@uac.pt (M.C. Barreto), nuno.ferreira@ciimar.up.pt (N.G.C. Ferreira), patricia.v.garcia@uac.pt (P. Garcia).

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studies demonstrating the adverse effects of metal contamination on soil microbial activities (Kuperman and Carreiro, 1997; Antunes et al., 2011; Niemeyer et al., 2012), there is a lack of knowledge regarding the soil microbial responses to chronic metal contamination when soils are naturally enriched with trace metals and have been extensively used for agricultural purposes, such as in agricultural volcanic soils (Andosols). Due to their volcanic heritage, these soils are naturally enriched with a high range of trace metals (Doelsch et al., 2006; Parelho et al., 2014). In addition, allophanic ash volcanic soils are recognized for their abundance of neoformed amorphous aluminosilicates (such as allophane and imogolite) and organo-mineral compounds (Fontes et al., 2004), that confer unusual properties to soils, such as a very high binding capacity for metals (Sugiyarto, 2013). In the case of volcanic soils intensively exploited for agricultural purposes, the scenario is particularly aggravated, since the use of agrochemicals (pesticides and fertilizers) can contribute to the accumulation of trace metals in soil matrix, causing even higher negative impacts over the soil ecosystem (Parelho et al., 2014).

Within this particular context, the aim of this study is to determine the soil microbial responses and assess soil health status in naturally metal contaminated volcanic soils under different agricultural practices (conventional, traditional and organic farming systems). To achieve this goal, the study was based on a three-tier approach: *Tier* 1 – assess the biological effects of agricultural practices in soil microbial activities (β-glucosidase, acid phosphatase, dehydrogenase, microbial biomass carbon, basal soil respiration, metabolic quotient and RNA:DNA ratio), *Tier* 2 – link the microbial activity to soil trace metal contamination, and *Tier* 3 – integrate the microbial activity in an effect-based soil index (Integrative Biological Response) to score soil health status in trace metal contaminated agricultural soils.

2. Material and methods

2.1. Study area description, geology and soil trace metal loads

The study area corresponds to the Picos Fissural Volcanic System, located in the western half of the island of São Miguel, the largest (744.6 km^2 and 138.551 inhabitants) of the Azores archipelago.

According to Ricardo et al. (1977), two main associations of soil types can be observed in the studied area: (1) thin allophanic soils and thin Andosols, the latter over lava flows, and (2) thin allophanic soils and coarse Regosols, the latter mainly associated to basaltic pyroclastic deposits.

The selected farms (Fig. 1) correspond to the main producers of vegetables in the Island and are located in the same geological complex (Picos Fissural Volcanic System), ensuring the same bedrock and pedological conditions, being only differentiated by the type of agricultural soil management. The selected farms were all evenly distributed across the region of study and located at a similar altitude (50–100 m) to minimize the rainfall variability between sites and rain shadow effects.

Three types of farming systems (conventional, organic and traditional) were selected and compared to a reference soil. In the local context, a conventional system refers to farming practices in which the use of synthetic agrochemicals (both pesticides and fertilizers) is legally framed by European and national guidelines. Organic systems are certified by the European Commission, therefore the use of synthetic agrochemicals is prohibited and soil amendments are confined to organic fertilizers (compost and manure). Traditional practices represent the most common farming system in Azores, where in the past (last 150 years) synthetic agrochemicals were used in an uncontrolled manner and based

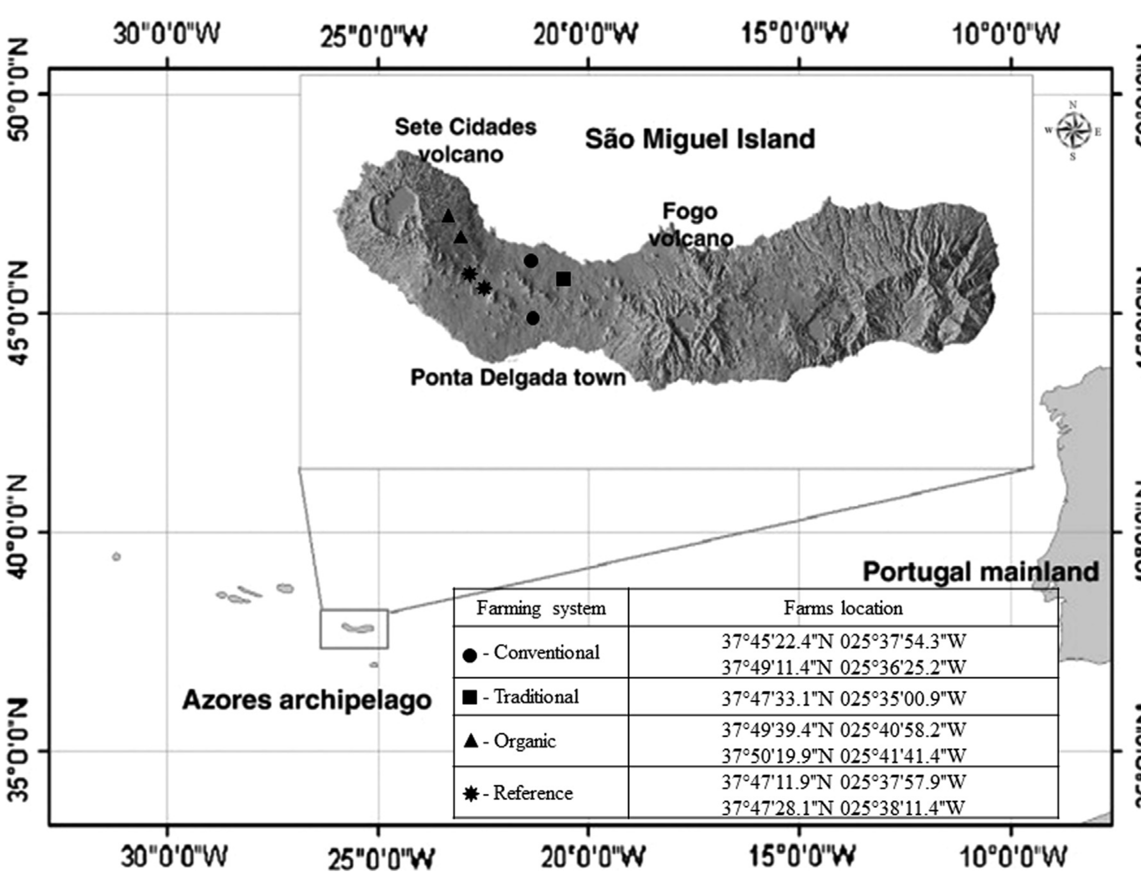

Fig. 1. Location of the Azores archipelago in the North-Atlantic Ocean. Inset: São Miguel Island with farms location (conventional, traditional and organic farming systems) and reference soil. Adapted from Cordeiro et al., 2012.