Ecological Indicators 97 (2019) 100–110

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Biofunctool®: a new framework to assess the impact of land management on soil quality. Part A: concept and validation of the set of indicators

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A R T I C L E I N F O

Keywords:
Biofunctool®
Soil functions
Soil quality
Integrative approach
Indicators
Land management

A B S T R A C T

The assessment of soil quality is a scientific issue that has been widely debated in the literature for the last twenty years. We developed the Biofunctool® framework to assess soil quality based on an integrative approach that accounts for the link between the physico-chemical properties and the biological activity of soils. Biofunctool® consists in a set of twelve in-field, time- and cost-effective indicators to assess three main soil functions: carbon transformation, nutrient cycling and structure maintenance. The indicators were applied in a network of mostly rubber plantations compared with three other land uses in Thailand. We collected 1952 indicators values in 180 sampling points over a wide range of pedo-climatic and agronomic contexts in order to assess the validity of the indicators. A reliability, redundancy and sensitivity analysis was performed to validate the capacity of the set of indicators to assess the impact of land management on soil quality. The results showed the relevance and consistence of each of the twelve indicators to assess the soil functioning. Improvements are finally discussed to guide further implementation of the indicators in various contexts and build a soil quality index.

1. Introduction

Soils provide key ecosystem functions enabling essential provision, regulating, cultural and supporting services (Adhikari and Hartemink, 2016; Millennium Ecosystem Assessment, 2005). Human society is deeply relying on those soil ecosystem services (UNDP, 2015) but the current increase of anthropogenic pressure on soil has direct and considerable impacts on ecosystems and their functions (Gruver, 2013).

Land management was defined by van Oudenhoven et al. (2012) as "the human activities that can affect ecosystem properties, functions and services". In the present study, land management is defined as the comprehensive view of land use, land use change and management practices. On the one hand, land management was pointed out as one of the prominent factors responsible for soil degradation (Gruver, 2013). On the other hand, it was also stressed as one of the main drivers to mitigate this degradation (Minasny et al., 2017). In order to understand and regulate the impact of anthropogenic perturbations of the soil system, there is a strong need to develop and apply methods to assess this impact on soil quality.

Soil quality is defined as "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Karlen et al., 1997). Preserving soil quality is an issue that has always been

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https://doi.org/10.1016/j.ecolind.2018.09.023
Received 7 April 2018; Received in revised form 5 September 2018; Accepted 10 September 2018
1470-160X/

considered by land managers such as farmers who need to keep their long term soil fertility to sustain crop production. However, based on the integrative definition of soil quality, soils are no longer seen as a support for production only, but rather as a complex system interacting with the surrounding environment to provide various services (Keesstra et al., 2016; Vogel et al., 2018). This definition is nowadays well accepted in the scientific literature and stands as a basis for most of the studies dealing with the integrated view of soil quality.

In contrast to the consensus on the soil quality definition, the indicators and methods used to assess soil quality are continuously debated (Andrews et al., 2004; de Paul Obade and Lal, 2016; Obriot et al., 2016; Velasquez et al., 2007). This issue could be linked to the lack of consideration of the soil system complexity when selecting indicators, leading to the application of indicators not properly connected within a consistent conceptual framework (Vogel et al., 2018). Bockstaller and Girardin, (2003) underlined the importance to define a clear conceptual framework in order to construct relevant indicators. Indicators may be adapted to assess the soil quality in an integrative approach, provided that they are defined at sound stages from an initial anthropogenic perturbation to final responses, *i.e.*, along the DPSIR (driver–pressure–state–impact–response) pathway where changes in soil functions can be assessed (Bockstaller et al., 2008; Bünemann et al., 2018; Heink and Kowarik, 2010). This preliminary framework definition is lacking in most soil quality assessments, which may lead to biased results and erroneous conclusions (Olsson et al., 2009). Many studies aim at finding the best generic minimum data set of indicators to describe the physical, chemical and biological properties (Paz-Kagan et al., 2016). Those approaches reduce the complex soil system to the sum of its constituent properties. Kibblewhite et al. (2008) emphasised the need to change this "reductionist" paradigm to an "integrative" approach that takes into account the interactions between the soil constituents. It is paramount to account for those relationships between the soil physico-chemical properties and the biological assemblages that may considerably influence the system functioning through synergies or antagonisms (Karlen et al., 2003; Kibblewhite et al., 2008). Such an integrative approach may not enable the direct identification of properties or assemblages responsible for the soil quality state, but it can provide a direct assessment of this soil quality, *i.e.*, the soil functioning resultants, which is a strong requisite according to Karlen et al., (1997). Some studies noticed the relevance of this integrative approach (Idowu et al., 2008; Lima et al., 2013; Schimann et al., 2012; Vogel et al., 2018), but reductionist approach still largely prevails in the literature.

Besides the need for a proper conceptual framework, Van Oudenhoven et al., (2012) compiled four criteria for indicators assessing soil ecosystem services. Indicators need to be i) sensitive to land management, ii) temporally and spatially explicit, iii) scalable and iv) quantifiable. Griffiths et al. (2016) and Doran and Zeiss, (2000) also stressed the need of cost-effective and user-friendly indicators to meet the constraints of the land manager who is the ultimate driver of the soil quality.

This study presents a new framework to assess soil quality, namely Biofunctool® for "biological soil functioning assessment tool". Biofunctool® was developed to propose a way to assess soil quality based on an integrative approach such as defined by Kibblewhite et al. (2008) with a set of low-tech (time- and cost-effective as well as user-friendly) functional indicators that can be measured directly in the field. The aim of this study was to validate the relevance of the proposed new set of indicators when assessing the impact of land management on soil quality. The *a priori* selection of indicators was applied regarding the relevance, reliability and necessity of each indicator. Biofunctool® was first tested in tropical conditions. The main land management studied was rubber tree (*Hevea brasiliensis*) plantations complemented with a synchronic sampling of further land uses in neighboring land areas in order to examine the impact of land use changes. Large scale rubber tree plantations was a relevant study model, since it allowed for analyzing a soil disturbance gradient along the tree stand ages in various pedo-climatic contexts (Barrios et al., 2018). In this article (Part A), we investigated the relevance and consistency of Biofunctool® to assess soil quality and its sensitivity to land management along a chronosequence of rubber tree plantations. Finally, further improvement tracks and recommendations were proposed. In a second article (Part B), we applied a Biofunctool® soil quality index to investigate the impact of rubber tree land management on soil quality and to discriminate land uses and agricultural management practices.

2. Material and methods

2.1. Expert-based selection of the Biofunctool® indicators

According to the integrative view of the soil quality, the selected indicators should be the result of soil biota-physico-chemical properties interactions (Fig. 1).

Hence, the first and main filter to select the indicators was their ability to be the results of interactions between soil physico-chemical properties and the biological assemblages reflecting part of the overall soil functioning. In accordance with Kibblewhite et al. (2008), we selected indicators to represent the following three soil functions: carbon transformation, nutrient cycling and structure maintenance (Fig. 1). Pest regulation function was not included in Biofunctool® so far, as no ready indicators were available.

Second, the indicators should be measured on soil sample as intact as possible in order to reflect the interactions in the soil system with limited distortion. We therefore selected indicators that can be measured directly in the field or resulting from *in-situ* incubations, *i.e.*, limiting as much as possible extra disturbance due to the indicator measurement itself. Only for the nutrient cycling function, we needed to add two indicators requiring nutrient extraction in a laboratory.

Third, the indicators should not require specific skills and be cost- and time-effective, in order to ensure that sufficient indicators can be measured to have a comprehensive appraisal of the soil complex system (Gil-Sotres et al., 2005). This last requirement is a key to ensure an efficient and broad transfer to land managers, as low-tech tools can be more easily and repeatedly applied in the field.

The selection of Biofunctool® indicators was carried out ahead of field experiments through a "top down" approach (Griffiths et al., 2016) based on expert judgement (Bockstaller and Girardin, 2003). This selection makes the originality of the Biofunctool® approach compared to other existing methods; the latter rather assess the soil quality from indicators selected on a statistical basis (Minimum Data Set) (Rinot et al., 2019). This top down approach made it possible to define a consistent set of indicators according to an *a priori* conceptual view of the integrated soil functions rather than aggregating, *a posteriori*, indicators based on site-specific field results (Griffiths et al., 2016). The indicators were selected among peer-reviewed studies and sifted according to the purposes of the assessment and the monitoring (Stone et al., 2016). Only one indicator was newly developed to be used within Biofunctool®, the SituResp indicator. SituResp® method was developed to assess basal soil respiration in a time and cost-effective way. This method was adapted from a laboratory methodology, the MicroResp™ method, in order to be implemented in the field on fresh soil samples (Thoumazeau et al., 2017).

Twelve indicators that fulfilled the three criteria (*i.e.* integrated, in-field, low tech) constituted the novelty of the Biofunctool® approach. Ten of the twelve indicators define the core set of Biofunctool® indicators. The remaining add-on two indicators provide supplementary information for the specific case of perennial cropping systems (Table 1). In order to check the consistency of the indicator set within the Biofunctool® conceptual framework, we discussed the complementarity and potential redundancy of the indicators when applying them in field conditions.