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# Soil Agrobiodiversity Measurement indicators

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**ABSTRACT:** Soil is one of the most diverse habitats on earth and contains the most diverse assemblages of living organisms. Agricultural biodiversity includes all components of biological diversity of relevance to food and agriculture: the variety and variability of plants, animals and micro-organisms at genetic, species and ecosystem level which are necessary to sustain key functions in the agroecosystems, its structures and processes. Much work has already been done in the world on indicators of soil biodiversity. A rather large number of papers and books show the usefulness of most soil organisms as indicators of soil agrobiodiversity. To measure soil biodiversity, many different aspects need to be assessed, which requires the use of a set of various indicators. As a result, investigators have tried to design comprehensive indicators that combine a number of indicator parameters such as individual densities of indicator species or physico/chemical soil parameters. But for reasons of efficiency, data quality and repeatability, the number of indicators should be limited. Thus, the aim is to select the minimum set of indicators that adequately characterize soil biotic properties. Given the complexity of soil biota, indicators are useful to translate trends in soil biodiversity and related services in a simple and clear manner, and therefore sustainable use of soil should be indicated by an ecological indicator, based on a holistic approach that integrates data on physical, chemical and biological characteristics of the soil.

***Keywords*:** Soil agrobiodiversity, Indicator, Habitat

## INTRODUCTION

Agricultural production practices need to change. They need to become increasingly sustainable at the same time as meeting societal goals of access to sufficient, safe and nutritious food (Baulcombe, 2009; IAASTD, 2008; World Bank, 2007; Nellemann, 2009). Damage the environment (biodiversity decreasing), lead to reduced function of essential ecosystem services, result in the loss of biodiversity (MEA, 2005) and undermine the nutritional and health value of foods (IPCC, 2007). The soil system is dynamic, highly heterogeneous and extremely complex. Soil itself consists of a mineral portion containing mainly silica and a mixture of trace metals, and an organic matter portion containing a large variety of different organic compounds, as well as water and vast array of different organisms. Soil can exist as a variety of textures; with the texture being a product of changes in the relative proportions of sand, silt and clay. It can contain areas of relative dryness, and includes micropores which are almost always water filled apart from in times of extreme drought. The proportion and type of organic matter varies both with depth, and spatially. Much work has already been done in the world on indicators of soil biodiversity. A rather large number of papers and books show the usefulness of most soil organisms as indicators of soil biodiversity (Paoletti, 1999).

### *1.1. What is biodiversity?*

Biodiversity has different meanings depending on the situation being discussed and the target audience. For example, the *Oxford English Dictionary* defines biodiversity as being "The variety of plant and animal life in the world or in a particular habitat". This is definition is clearly sufficient for non-specialists. However, when looking more specifically at biodiversity, it becomes evident that thought needs to be given to other groups such as fungi, bacteria and archea, and therefore Biodiversity is defined as:

"the variability among living organisms from all sources including, *inter alia*, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems. As soil is such as diverse system when considered biologically (as well as physically or chemically) it is necessary to include all taxonomic groups. "Soil biodiversity" it will be in reference to the variety of *all living organisms* found within the soil system. Another definition is agrobiodiversity, where:

Agricultural biodiversity includes all components of biological diversity of relevance to food and agriculture: the variety and variability of plants, animals and micro-organisms at genetic, species and ecosystem level which are necessary to sustain key functions in the agroecosystems, its structures and processes.

Soil is one of the most diverse habitats on earth and contains the most diverse assemblages of living organisms. Biological activity in soils is largely concentrated in the topsoil. The biological components occupy a tiny fraction (<0.5%) of the total soil volume and make less than 10% of the total soil organic matter. This living component consists of plant roots and soil organisms. Soil microorganisms are responsible for a large part of biological activity (60-80%) which is associated with processes regulating nutrient cycles and decomposition of organic residues.

### *1.2. Microbial biodiversity in agriculture*

Microbial biodiversity has been neglected over the years but is now a topic of global attention. This is due to the realization that microbes contribute a wealth of gene pools that could be a source of material for transfer to plants to achieve traits such as stress tolerance and pest resistance, and large-scale production of plant metabolites. Of more immediate significance to farmers' production systems, microbes play varied roles in plant development and agriculture. Microbial interactions with plant communities range from disease-producing pathogens to associations with plant rhizosphere, phyllosphere and spermosphere as free living entities or in well-associated symbiotic associations for nitrogen fixation or as mycorrhiza. Seed-borne microfloras are instrumental in seed transmission of disease and thereby important in plant quarantine. Micro-organisms as food sources of 'neutral insects' support these alternative food sources of natural enemies of plant pests as described in the next section.

### *1.3. Agricultural biodiversity and ecosystem functions*

Historically, the focus in agricultural biodiversity work has been on characterizing and conserving species and genetic diversity. Now, however, there is increasing realization of the importance of agricultural biodiversity at the ecosystems level, consistent with the 'ecosystem approach' as promoted by the Convention on Biological Diversity. An ecosystem consists of a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit9. Thus agroecosystems need to be considered at several levels or scales, for instance, a leaf, a plant, a field/crop/ herd/pond, a farming system, a land-use system or a watershed. These can be aggregated to form a hierarchy of agro-ecosystems constitutes the global biosphere. Ecological processes can also be identified at different levels and scales.

## *2. Soil Biological Indicators*

Soil microorganisms (fungi and bacteria) and other fauna (e.g., earthworms, insects, and arthropods) influence the availability of nutrients for crop growth by decomposing soil organic matter and releasing or immobilizing plant nutrients. Biological activity improves soil aggregation through the secretion of soil binding mucilages and hyphal growth. Improved aggregation, in turn, increases water infiltration and the ease of plant root penetration. Soil biological activity is considered an integral attribute of a healthy soil.

In this article, we try describe the assessment tools that can capture the trends in soil agrobiodiversity. Unfortunately, direct measurements are often impossible to perform, due to methodological problems or practical reasons of cost and time. Simulation models which are developed as an alternative to direct measurements are also often highly impractical (Bockstaller and Girardin, 2003). Therefore, there is a need for indicators to assist us in establishing baseline conditions and trends. Indicators also allow to establish threshold effects and to know the acceptable level of pressure exerted on soil, but in this paper we show the best methods to agrobiodiversity measurement.

Indicators are a way of presenting and managing complex information in a simple and clear manner. Essentially, ecological indicators have two main functions: an informative function, i.e. to decrease the number of measures and parameters that would normally be required to represent a complex situation (e.g. an agro system). Many indicators relating to some aspect of biodiversity exist but none of them capture biodiversity in its entirety. Despite the need to agree and implement a method for measuring biodiversity status, no scientific consensus measure exists. The main difficulties in establishing operational indicators are due to the multidimensional nature of biodiversity which can be defined in terms of composition, structure and function at multiple scales (Noss, 1990). For instance, while indication methods have been proposed that combine a number of factors related to biodiversity status (Jenkins, 2003; Scholes and Biggs, 2005), these methods allow for comparisons on large changes on the global biodiversity between different environments but may be insensitive to diffuse impacts like for instance the long term effects of habitat fragmentation, climate change or pollution.

To measure soil biodiversity, many different aspects need to be assessed, which requires the use of a set of various indicators. As a result, investigators have tried to design comprehensive indicators that combine a number of indicator parameters such as individual densities of indicator species or physico/chemical soil parameters. But for reasons of efficiency, data quality and repeatability, the number of indicators should be limited. Thus, the aim is to select the minimum set of indicators that adequately characterize soil biotic properties. The choice of these indicators varies across a range of temporal and spatial scales and can be based on the following criteria:

1- *Meaningful*: indicators must relate to important ecological functions and use good surrogates (e.g. recognized high value organisms as indicator groups). This ensures the indicators will serve their purpose accurately, i.e. monitor trends in soil biodiversity.

2- *Standardized*: the selected parameters should be readily available and (almost) standardized. This ensures the comparability of data among sites.

3- *Measurable and cost-efficient*: the selected parameters must be easy to investigate in the field and to sample, affordable, and must not be restricted only to experts or scientists, but should also be assessable by interested public (e.g. citizens). This ensures the indicators will be used in practice, and can be routinely collected. Other relevant criteria for the selection of core set of indicators that accommodate environmental agencies and management practices needs as well as environmental experts, have been put forward (EEA, 2005) Convention on Biological Diversity, Montreal, 2003):

4- *Policy-relevance*: the selected parameters should be sensitive to changes at policy-relevant spatio-temporal scales, enable to capture progress towards policy targets, and allow for comparisons between a baseline situation and a policy target.

5- *Spatio-temporal coverage*: the selected parameters should occur in the different soil types and land uses, e.g. at natural and managed sites. They should also be amenable to aggregation or disaggregation at different spatial scales, from ecosystem to national and international levels.

6- *Understandability*: the indicators should be simple and easily understood (avoiding contradictory messages)

7- *Accuracy*: the value of the indicators should reflect precisely and robustly the changes they monitor.

### *2.1. Measuring soil agrobiodiversity*

A huge number of methods exist to measure the activity, biomass and biodiversity of soil organisms. Some methods directly count the number of species and individuals present in a sample to calculate diversity, while others are based on a community approach, and rather estimate the activity of soil organisms, or of specific functional groups. In the past few years, considerable efforts have been made towards the standardization of some methods. A working group of the ISO Technical Committee 190 Soil Quality reviewed appropriate candidates and proposed five methods for inclusion within the working program, covering the main classes of soil invertebrates. The methodology used to estimate species diversity varies depending on the soil organism considered. The largest organisms are directly observable with the naked eye or with a microscope, while the presence of the smallest can only be estimated by complex molecular techniques.

Several indicators, based on individual organisms groups or taking into account the whole soil community have been used to characterize soil biodiversity (Table 1). These indicators are directly based on the different measures available. Concerning chemical engineers, for example, the characterization of microbial communities has been mainly based on the determination of fungal or bacterial biomass (Beare, Neely *.,* 1990; ISO 1997) or on functional variables (Table 1). Sometimes, indices are calculated based on microbial activity, to assess the values determined with respect to soil quality. Some examples are the quotient of microbial carbon in the biomass to organic carbon content (Cmic / Corg) as an indicator for carbon dynamics in soil (Kaiser, Müller*,* 1992); the metabolic quotient as an indicator of energetic efficiency (Insam and Haselwandter, 1989); or the respiratory activation quotient as an indicator of the presence of contaminants (ISO, 2001). The pattern of degradable carbon sources is applied for the comparison of sites with respect to their microbial communities. Recently, efforts have been spent on using structural aspects for the characterization of the microbial community diversity. Different molecular methods (Lukow, Dunfield, 2000) as well as the determination of single microorganisms or microbial groups using cell components have been successfully applied (Frostegard, Baath, 1993; Waite, O'Donnell, 2003). These methods usually have good measurability (Table 1), and some have been proposed for use in assessment systems (Mulder, Cohen ., 2005).

But also, there are compound indicators. In the last decades, a considerable number of compound indicators related to soil biodiversity or using concepts based on soil communities have been developed. However, these indicators have usually been developed with the intention to assess soil health status and to establish ecological soil classifications for the purpose of soil quality assessment, rather than with soil biodiversity assessment as an aim per se. As a result, these soil biodiversity indicators typically encompass multi-factorial aspects of soil, including biotic to abiotic conditions, which makes them more meaningful indicators of soil agrobiodiversity (Table 1). Each proposal has its own advantages and disadvantages. Most indicators are based on benchmarks, where soil biodiversity in the sampled site is compared to that in a reference, baseline site. The reference sites are typically defined based on expert assessments, and only the most recent integrated indicators propose more robust, objective assessments. Moreover, few indicators actually propose an integrated measure, that is easy to use and report, most are based on complex multi-factorial representations. The main compound indicators for soil agrobiodiversity are detailed in table 2.

Table 1. Some simple indicators of soil biodiversity. Meas.= measurability

| Functional group | Organisms | Indicator | Method | Meas. |
|---|---|---|---|---|
| Microbial Decomposers | Microorganisms | Biomass / activity | SIR, fumigation-extraction<br>ATP concentration, initial rate of mineralization of glucose | Good |
| | | Activity | Respiration rate/quotient/ratio,<br>Nitrification, N mineralization, C mineralization<br>Denitrification<br>N-fixation<br>Mycorrhiza (% of root colonized) | Good |
| | | Enzymatic activity | Dehydgenase activity<br>Other enzymatic activity tests: phosphatase, sulphatase, etc.<br>Enzyme index | Good |
| | | Diversity | Culture-dependent methods: direct count, community-level<br>physiological profiles<br>Culture independent methods: fatty acids analysis, nucleic acid analysis | Good |
| Biological regulators | Protists, Nematodes | Abundance and Diversity | Culture-dependent methods: direct count (diversity index, functional or trophic diversity)<br>Culture independent methods: fatty acids analysis, nucleic acid analysis | Low |
| | Microarthropods (springtails, mites) | Counting | Litter-bag technique (colonization capacity)<br>Soil coring | Low |
| | | Abundance and Diversity | Community composition, ecological groupings | Low |
| Soil ecosystem engineers | Earthworms, isopods | Abundance Diversity | Species richness, diversity, evenness | Good |

Table 2. Main compound indicators of soil biodiversity. Meas.= measurability

| Indicator | Functional groups | Soil biotic indicators | Soil abiotic indicators | Meas. |
|---|---|---|---|---|
| Benchmark indicators | | | | |
| BISQ (Biological Indicator System for Soil Quality) | -Chemical engineers<br>-Biological regulators<br>- Soil ecosystem engineers | - Microbial activity and biomass<br>- Diversity and abundance of nematodes, mites, earthworms | | Good |
| BBSK (Biological Soil Classification Scheme) | -Biological regulators | - Diversity of micro-arthropods morphotypes | pH, C/N ratio, soil moisture, soil texture | Good |
| BSQ (Biological Soil Quality) | Biological regulators | - Diversity of micro-arthropods morphotypes | No | Very Good |
| SOILPACS (Soil Invertebrate Prediction and Classification Scheme) | -Invertebrates | -Stress of soil communities | No | |
| Numerical indicators | | | | |
| IBQS (Biotic Indicator of Soil Quality) | - Soil ecosystem engineers | - Structure and abundance of macro-fauna | Physical classification of soil, based on routinely measured parameters (e.g. pH, cation concentration) | Good |
| (General Indicator of Soil Quality) | - Soil ecosystem engineers | - Diversity of macro-fauna | - Physical (porosity, moisture)<br>- Chemical (nutrient concentrations)<br>- Morphological (aggregation)<br>- Organic matter (C and N concentrations) | Good |

### *3. Effect of organic and inorganic fertilizer on the soil agrobiodiversity*

In comparison of organic and inorganic fertilizer, Evanylo and McGuinn (2009) show that, organic amendments improved soil physical properties (infiltration rate, water-holding capacity, and bulk density) and increased biological activity (respiration rate) more than the inorganic commercial fertilizer. The organic amendments also maintained the highest concentrations of nitrate-N in the topsoil despite the higher application rate of readily plant-available nitrogen from commercial fertilizer than from the other amendments. The slow-release nature of the organic N probably prevented leaching losses of the same magnitude as from the inorganic fertilizer. Soil infiltration rate, water-holding capacity, bulk density, and nitrate-N were increased by the organic amendments in the order of their expected carbon stability (i.e., cover crop < manure < cotton gin trash compost), while respiration rate was highest with the manure.

### *4. Conclusions*

A basic challenge in describing the contributions that soil agricultural biodiversity can make to improving food security over the next few decades is one of relevance and realism. While there are many possible ways in which agricultural biodiversity can improve food security, they may not all be feasible in production systems or they may prove uneconomic or too labor intensive for adoption by farmers. New approaches based on increased use of biodiversity may fit uneasily with production practices based on continuing simplification of agro-ecosystems. Identifying what works in practice, taking into account regional differences and different scales of farming, as well as supporting change, will therefore also be essential if diversity is to be used to improve sustainability and food security in the face of change. Successful approaches are likely to bring together positive aspects of sustainable intensification and multifunctionality in agriculture, to reflect the realities of small-scale farmers and to be supported by appropriate policy and economic frameworks. This acknowledgment of the importance of ecosystem services from agriculture constitutes a clear entry point for recognizing the specific contribution of biodiversity for food and agriculture to ecosystem function and to the ensuring the continued capacity of agricultural systems to providing food security in the face of global changes.

Given the complexity of soil biota, indicators are useful to translate trends in soil biodiversity and related services in a simple and clear manner. This is a key factor to communicate the value of soil ecological capital to decision-makers. Suitable indicators must be meaningful or clearly relate to an important ecological function, standardized, so as to allow comparisons among different sites, and easy to use, so as to ensure they can be routinely used.

To date however no reference set of indicators or synthetic indicators are available, despite the fact that a multitude of indicators estimating some specific aspects of soil activity or diversity, many of which ISO-certified, exist. But recently, much progress has been made in the development of compound indicators that account for both factors affecting soil biodiversity and soil biodiversity per se. The most promising avenue may lie in the development of numerical indicators which are objectively defined, such as GISQ and IBQS, since these do not rely on expert opinion or the definition of reference sites.

Sustainable use of soil should be indicated by an ecological indicator, based on a holistic approach that integrates data on physical, chemical and biological characteristics of the soil. Such approaches recognize the complexity of ecological interactions and the importance of ecosystem processes as a reflection of underlying functions, including soil characteristics. The combination of biotic and abiotic measurements leads to the possibility of deducing response models for individual indicators. With such models, predictions can be made concerning the effects of environmental and human impact scenarios. The relation between abiotic conditions, management practices and the composition and functioning of soil organisms offers opportunities to adapt political and management practices towards an optimal (sustainable) use of the soil biodiversity and the ecological processes that are governed by soil organisms. To establish the scale in which indicators fluctuate, it is necessary to make reference to descriptions and determine the effects of severe disturbance.

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