The Open Soil Index 0.3

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1. Summary

Soils are not just a growing medium for crops but they also support other essential ecosystem services (ES), such as water purification, carbon sequestration, nutrient cycling and the provision of habitats for biodiversity (Bünemann et al., 2018; Rinot, 2019). Soils are a critical contributor to maintain local, regional and global environmental quality of the earth's biosphere. The quality of soils is not only affected by soil genesis and formation, but also by other factors such as land use and management. In order to improve and maintain soil quality, and subsequently all related ecosystems services, three companies in the Netherlands started a partnership in 2019. These companies are the Rabobank (one of the major banks in the Netherlands, who facilitates agronomic activities by financial support), a.s.r (a major insurance company, owning numerous hectares of arable land) and Vitens (the largest water winning company in the eastern part of the Netherlands, who focuses on improvement of water quality). They initiated a consortium of universities, consultancy companies and soil experts to develop Open Soil Index (OBI), a scientifically underpinned, open-sourced soil assessment framework. The current OBI uses existing soil measurements being available from routine agricultural laboratories and field properties from open data sources. Based on these measurements of various soil properties, the OBI calculates an index for each agricultural field, which tells what the soil quality is today and how it can be improved. With OBI, soil quality of a field can be monitored over time and can also be compared with other fields. OBI stimulates farmers to improve their soil management and monitors the evolution of soil quality and related ES, which ultimately promotes sustainable soil management. Its also easily scalable to other farming systems in Europe.

The OBI score is a number ranging between 0 and 10, that holistically represents the soil quality as well as its management. The score is field specific, accounting for the soil type, geohydrological site properties and the crop rotation sequence of the last decade. The OBI score can be decomposed to sub scores of different soil aspects (chemical/physical/biological/management), and these sub scores can further be decomposed to soil function levels. For each soil function, the OBI computes an indicator value ranging between 0 and 100 that reflects the current situation as well as its deviation from a target condition of that specific soil function. With this hierarchical structure, the OBI offers both integral assessment (i.e. whether a soil is overall good or not) and specific assessment (i.e. which soil functions are poorly evaluated and to what extent these soil functions need to be adapted to improve the overall soil quality to the "optimum situation"). The framework is additionally applicable on multiple spatial scale, supporting both field and regional assessments. When there are limitations in either soil chemical, physical or biological properties, relevant agronomic measures are recommended that solve existing deficiencies.

The OBI is developed in close collaboration with farmers, soil experts, agronomists and soil scientists. Through online collaboration everyone can in principle contribute to further development, practical testing and improvement of the OBI. All algorithms as well as underlying assumptions and references are published online to stimulate joint efforts between experts and to facilitate transparency.

2. Introduction

The soil is the basis of sustainable agricultural business and key to a healthy and productive agriculture for current and future generations. This also means that farmers want to take good care of their soil. To do that, it is important to know the limitations and production potential of their soil. Therefore, farmers regularly take soil samples to gain information about the vitality of the soil: are there sufficient nutrients available, can the crop take root easily and is there sufficient soil life? However, a simple measuring instrument to evaluate the soil quality at a glance is still not available today (Bunemann et al., 2016). Moreover, we all know that the soil is very complex. Various soil properties play a role in determining how much nutrients are available for crops and whether a plant can grow healthy, whereas these soil properties are influenced by all kinds of soil animals and chemical processes. As a farmer, how do you get an unambiguous and simple insight into the soil quality? How do you ensure that the soil remains healthy for future generations?

Soil quality monitoring tools can help. At the moment numerous soil quality assessment tools already exist (Bunemann et al., 2016; Molendijk et al., 2018) but there is no practical, cheap, and comprehensible tool to compare soil quality between fields or to monitor soil quality over time yet. It is also often unclear how soil quality can be further improved. The Open Soil Index (OBI) wants to help with this. This index provides simple and affordable evaluation on the soil quality of agricultural soils, and give recommendations for measures that can bring the soil back to top condition. The OBI version 0.11 is developed in 2019 in collaboration with all soil experts in the Netherlands. Farmers also participated in its development, because a soil index is only useful if it provides meaningful information for farmers and if they use it to improve or maintain the soil on their farms.

The OBI was initiated by the companies asr, Vitens and Rabobank. A team of soil experts from Wageningen University, Nutrient Management Institute and Farmhack lead the development of this index. The intention is to include all relevant aspects of the soil that facilitate and promote the growth of healthy crops. So not only nutrients, but also soil life, soil structure, location of the field, and landscape characteristics are taken into account. This is because the quality of the soil not only depends on the properties of the first centimetres of the topsoil (where soil is sampled by agricultural laboratories) but also on the subsoil properties, the geohydrological conditions and the availability of water.

The OBI is an open framework, being continuously improved as soon as new measurement methods or evaluation protocols have been developed. New insights and results from applied and fundamental science can easily be incorporated. The OBI version 0.11 has been published in the spring of 2020 and will be further improved in the coming years.

The assessment of the index is derived from the following data:

- Analysed soil properties (usually done by routine agricultural labs, so no additional samples have to be taken)
- Field properties like drainage systems, soil type, and ground water dynamics (all available as open data) and
- Soil management measures (like crop rotation plan, crop residue incorporation, catch crops and ploughing intensity, most indirectly derived from satellite imagery)

The algorithms to evaluate and assess the quality of the soil originates from field experiments and evidence from fundamental as well as applied research. This means that the OBI builds on the current state-of-the-art knowledge from universities, advisory companies as well as farmers themselves. All algorithms as well as underlying assumptions and references to original research are published online, being publicly available.

From 2020 onwards, the OBI will be owned by an independent entity (possibly a foundation) yet to be established. In this way, the data will not end up in the hands of market parties, who may use the information for purposes that conflict with the farmers' main objective to maintain soil quality for sustainable crop development.

3. Definitions and Requirements

All kinds of concepts and definitions are used interchangeably within the field of soil quality assessments. A clear definition of concepts is therefore important. The following definitions are used within the context of the OBI:

- Soil Quality : the capacity of a soil to fulfil the desired soil functions under varying conditions for a combination of purposes (and services) such as food production, efficient nutrient cycling and preservation of biodiversity.
- Soil ecosystem services : the different ecosystem services that soil can provide. These include primary (agricultural) crop production, carbon sequestration, water purification and nutrient retention in the soil, biodiversity and maintaining nutrient cycles..
- Soil functions : the role of soil in fulfilling certain objectives and soil services. A distinction is made between different types of soil functions: production, support, regulation and information functions. For example, delivering nutrient supply, soil structure and soil disease suppressiveness are important soil functions for the realisation of the ecosystem service 'primary production'.
- Soil indicators : an instrument or index that can be used to assess the contribution or relevance of a soil function. In practice, this is often done via qualitative categories (low to high) or numeric grades (1-10). This also means that a soil measurement as such is not a soil indicator. A soil measurement can be used as input for the calculation of a soil function, and this soil function can then be used as an indicator. Hence, an indicator is an evaluation or judgement score given a foreseen function of the soil.
- Soil properties : a characteristic of a soil that may be indicative of one or more soil functions. These characteristics may have been analysed in the laboratory as well as those resulting from the location of the field in the landscape. For example, the groundwater level, the variation in ground level, the slope, and the presence of drainage are also soil properties, similar to the organic matter content, pH and clay content.
- Soil management : all measures the land user or farmer can take to improve or adapt soil quality for a specific purpose. This has a direct influence on (measurable) soil properties. Sustainable soil management can be defined as the use of soil for the production of goods to meet changing human needs, while at the same time ensuring the long-term productive potential of this resource and the maintenance of its environmental functions.

The OBI is being developed in an open way (see section 4) so that everyone can see how knowledge of practice, mechanistic processes and empirical field research can be combined into an instrument that provides simple, -based insight into all kinds of aspects of soil quality. Because the OBI has a modular structure, new research results from national or international research programmes or practical experiences with the application of the OBI can easily be embedded to further improve the OBI. The required method of quality assurance and content control for this open process is still under development.

The OBI defines which soil parameters or analyses are needed to evaluate the different soil functions. The index is open to the use of measurements from any laboratory and is not limited to a (mandatory) collaboration with a single laboratory. However, we are actively working on automatic data links with existing agricultural laboratories in order to automate data transfer as much as possible.

For the time being, the OBI has a strong focus on field level. This means that spatial variation in soil properties within the field is not yet included. In 2019 a prototype instrument has been developed to show the principles of the soil assessment framework. This is done for all fields in the Netherlands. The OBI is applicable for all fields in the Netherlands without additional costs for the farmer, which promotes maximizing the use of existing data sources on farm. This choice was made because a large number of soil functions can already be quantified by smart integration of existing soil analyses and field characteristics. We also want to ensure an application (and method) that involves little additional cost. We are aware that this may possibly lead to less accurate estimate of soil functions (such as, for example, C storage in agricultural soils), and we are looking for alternative calculation methods in such situations. The framework is designed modular making it easy scalable to other countries and farming systems.

The OBI does not have the ambition to be used as a fertilizer planner, irrigation guide or as an advisory module for an optimal crop rotation plan. It is aimed at quantifying, evaluating and valorising soil quality and as such can provide valuable information for more sustainable fertilisation and soil management.

4. Soil Quality Assessment

Many attempts have been made to develop indices to assess soil quality (reviewed by Buneman et al., 2018; Rinot et al., 2019.). Ewing and Singer (2012) suggested that it is essential to establish a set of biotic and abiotic indicators to develop a feasible index and that existing interactions among the various indicators need to be used to provide a holistic overview. A multi-indicator index can subsequently be utilized to classify the full spectrum of soils. An integrated and holistic assessment of soil quality is therefore a challenge where various scientific institutions have been working on for years. To date, most of this knowledge has not been implemented in decision support tools assisting farmers for monitoring and evaluation of soil quality on farm and field level. In a recent review of all scientific soil quality assessment tools, Buneman et al. (2018) state that "*explicit evaluation of soil quality with respect to soil threats, soil functions and ecosystem services has rarely been implemented, and few approaches provide clear interpretation schemes of measured indicator values*". The main reason for this lack of valorisation is that soil is a complex interplay of chemical, biological and physical processes and that the objectives for which the soil is used for has an enormous influence on the evaluation of soil quality. However, there is broad consensus that soil chemistry, soil structure, as well as soil biology need to be considered for a good interpretation of soil quality. Organic matter plays a key role in this because it affects all three aspects. This is also reflected in the minimal data set as compiled by researchers at Wageningen University and Research Centre (Hanegraaf et al., 2019). The interpretation of soil analyses, however, is another challenge; a quality assessment is by definition linked to one or more objectives for which the soil can be used.

The OBI framework is based on the Soil Management Assessment Framework (Andrews & Carroll, 2001; Andrews et al. 2002, 2004; Karlen et al. 2001, 2003; Wienhold et al. 2004, 2009). Different steps are distinguished, as shown schematically below (Figure 1). In order to properly assess soil quality, it is first necessary to define which soil ecosystem services the soil is managed for. Although soil can be used for a variety of services such as agricultural production, carbon sequestration, or nature conservation, we focus, within the current OBI framework, on the objective of soil to maintain sustainable crop production.

More specifically, the soil should be able to maintain the current crop rotation plan and produce sufficient and healthy food. The soil should be managed in a sustainable way, in the sense that the soil quality facilitates crop production as much as possible and is (and will remain) sufficient to keep facilitating crop production in the future. Sustainable also means that the agricultural use of the soil should lead to minimal losses to ground and surface water. In this light, the OBI will (after 2019) also be used to provide insight into the contribution of the soil to the societal challenges to biodiversity and climate.

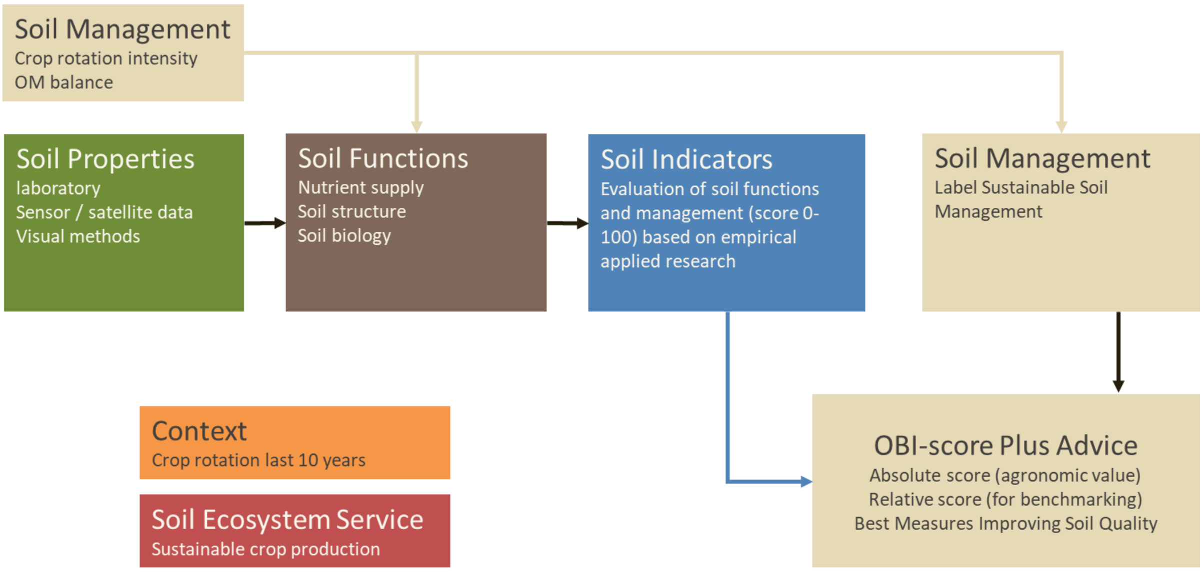

Figure 1. Soil Quality Assessment Framework of the OBI.

Within the boundary condition of context (i.e. continuation of crop rotation scheme in next decade) and objective (i.e. sustainable crop production), soil properties are quantified based on routinely available soil analyses, field properties and remote sensing data (Figure 1). The soil properties are in conjunction with each other used to quantify a number of soil functions (as listed in Figure 2). These functions can be clustered around the three relevant aspects of soil, namely i) chemistry and nutrient supply, ii) structure and root ability and iii) biology and disease resistance. Separately from these three aspects - each of which relies heavily on actual measurements - soil management is also evaluated. Furthermore, the soil's contribution to a sustainable living environment is first and foremost indirectly included as the following soil functions: the N buffering capacity for ground and surface water as well as for the potential to sequester carbon.

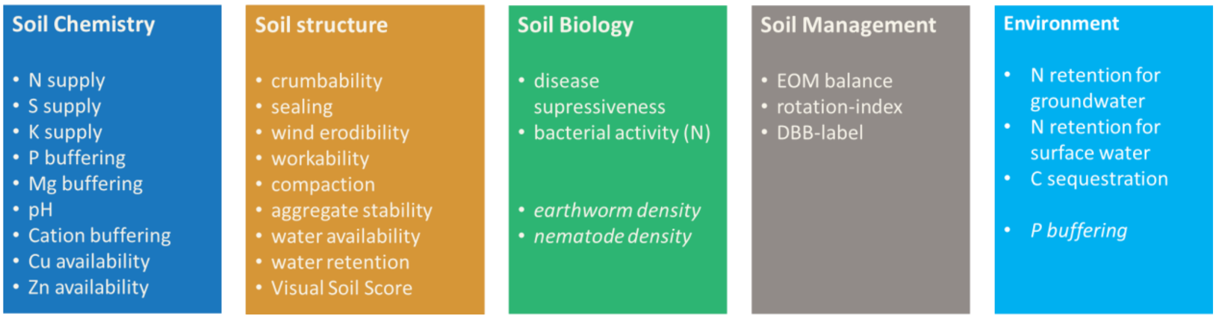

Figure 2. Detailed soil functions / indicators as embedded within the OBI, version 0.11. The functions / indicators shown in italics are described qualitatively, and are therefore not (yet) included. Soil functions are clustered into five aspects.

Unlike other soil functions, soil management is hard to evaluate quantitatively. To take on this challenge, we introduced the expert-judgement driven framework of the Sustainable Soil Management label (DBB-label). The Sustainable Soil Management label was designed in 2016 by a group of soil scientists and consultancy workers in the Netherlands. A team of soil experts from research and practice made a selection of measurable and verifiable soil management measures that contribute to the ecosystem functions of the soil, and assessed their impact on the soil quality, separately for the arable and dairy farming sectors as well as for the various soil types. Using this expert judgement, the current soil management applied in a field can be systematically and quantitatively evaluated. Besides the current management practices, explicit attention is given to measures supporting soil organic matter build-up in soils (EOM balance, Figure 2), given the key role of soil organic matter controlling soil fertility. Because changes in the organic matter content are difficult to measure, an estimate is made of the net supply or removal of Effective Organic Matter based on the crop rotation plan and the current manure practices according the regulations present. This balance is indicative of the expected developments in the organic matter content of the soil.

Each soil function is quantified with its own unit, which makes the comparison between soil functions difficult. Therefore, soil functions are translated into a uniform evaluation system - the indicator - in which the relevance of the soil function is presented as a score between zero and one hundred (Figure 1). This translation from the soil function to the soil indicator was made by standardizing the effects of soil functions in terms of crop production, based on existing datasets and field trials. The indicator helps farmers to gain insight into the difference in soil quality between his fields, and identify specific aspects of their soils that need to be improved. Furthermore, the use of the uniform valuation system enables agricultural entrepreneurs to certify their positive contribution to a sustainable world, which helps them to valorise their efforts. The soil indicators of each soil function can be further translated into an integral assessment of the soil, the OBI score (Figure 1). The OBI score, which ranges between 0 and 10, is computed for each of the four aspects (chemical / physical / biological / management) separately, as well as for the soil as a whole. This integration takes explicit account of the current and desired (or achievable) soil quality as well as the uncertainty on the developed soil functions and indicators. This also means that the desired situation is adjusted depending on soil type and objectives.

Finally, for each soil function, recommendations are given for management measures that can be implemented to improve soil quality (Figure 1). For this purpose, a set of management measures were identified and their impacts on soil functions or soil indicators were evaluated based on scientific literature. Based on the matrix of measures and their effects on each soil function, a measure is chosen that improves poorly-scored soil functions most effectively.

5. Open Source Development

The ambition of the Open Soil Index is to make all calculation rules publicly available in order to facilitate transparency in soil valuation and to focus on unambiguity and scientifically underpinned algorithms to evaluate soil quality. In our view, both the scientific underpinning as well as the transparency is a prerequisite for any soil assessment tool used to reward sustainable soil management financially.

All algorithms are available at https://github.com/springgbv/Open-Bodem-Index-Calculator.

The underlying arguments, data used, and substantive underpinning are explained for each soil function in 'factsheets'. These are freely available and can be retrieved from the author of this document. These are also published online at the website www.openbodemindex.nl/documentatie (in Dutch for the moment). A prototype of the OBI currently runs on https://tools.wenr.wur.nl/obi/.

6. Version

Versie 0.1 20191004 prepared by Gerard Ros (NMI, WUR)

Versie 0.2 20200104 updated by Gerard Ros (NMI, WUR)

Versie 0.3 20200528 translated to English by Yuki Fujita (NMI) and Gerard Ros (NMI, WUR)

7. Literature

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