EIP-AGRI Focus Group

Protecting agricultural soils from contamination

MINIPAPER 2: Developing a soil quality toolbox for agricultural soil monitoring and assessment

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1. Introduction

Soil is a natural component of the ecosystems, made of both mineral and organic parts that develop particular physical, chemical and biological properties. Soil is a vital non-renewable resource providing numerous ecosystem services of crucial importance for human life and society and the sustainability of global natural resources. Essential environmental services delivered by soil include: nutrient cycling, carbon storage and turnover, climate regulation, soil retention, water retention and filtering, regulation of aboveground diversity, resistance to pests and diseases, degradation of organic and mineral contaminants (EC, 2006). Nevertheless, the most important role of soil is food production. (De Groot et al. 2002; FAO and ITPS, 2015). In view of this, it's of crucial importance for the ecosystems and society to assure the protection, quality and sustainable use and management of soil.

Good soil quality is of fundamental importance to both local and global food production, and to ecosystem resilience. Agricultural soils worldwide are subjected to threats and pressures and in almost all countries around the world, soil contamination is a widespread problem, creating a significant risk to human health. This way, soil monitoring is essential for the early detection of changes in soil quality. Such early detection and reliable knowledge and data enables land users (e.g., farmers) to make well-informed decisions about its use and the design and implementation of policy measures to protect and maintain the sustainable use of soil (Morvan et al., 2008). When information on alternative land use practices is easily available, it supports farmers to improve their land management.

Recognizing the importance of soil contamination and consequent need to halt further contamination and start cleaning the soil of European Union, the 7th Environment Action Programme of the European Union sets the aim to ensure that by 2020 "soil is adequately protected and the remediation of contaminated sites is well underway".

A soil monitoring "protocol" is of major importance since it can identify and describe options for harmonizing soil monitoring, including its coverage (in space and time), parameters to be analysed, sampling procedures and testing protocols. The coverage is very heterogeneous depending on the intensity and expansion of contamination. Indicators related to soil contamination are more often measured and there is generally a minimum set of mandatory parameters which are systematically measured (at least once) or monitored (with different frequencies).

Soil contamination could be caused by the accumulation of nutrients surpluses, metals or organic compounds leading to a reduction of the capacity of soils to deliver soil functions and services. Contamination may have a direct toxic effect on the plants, animals or humans living in or from that soil. Effects may appear indirect due to accumulation in the whole food-chain. Soil contamination leads to decreased biodiversity and it has effects on the resilience at farm level and in the whole food-chain. This mini-paper is a review of the on-farm level soil contamination threats and on monitoring of soil contamination by the farmer himself. **The main objective of the mini-paper is to recommend a soil monitoring system for implementation** (an integrated approach of physical, chemical and biological indicators for biodiversity and ecosystem functions across Europe) **in support on the farm level soil fertility, quality and contamination**.

2. Dissertation

Soil ability to full-fill its numerous functions depend on the biological, chemical and physical properties. Biological properties depend and are influenced from root development, extension and their secretions, macro and micro-fauna and organic matter content. Soil acidity, nutrient content, ability to preserve nutrients and salinity are some examples of chemical properties. Physical features depend on soil texture and structure that influence soil hydrology.

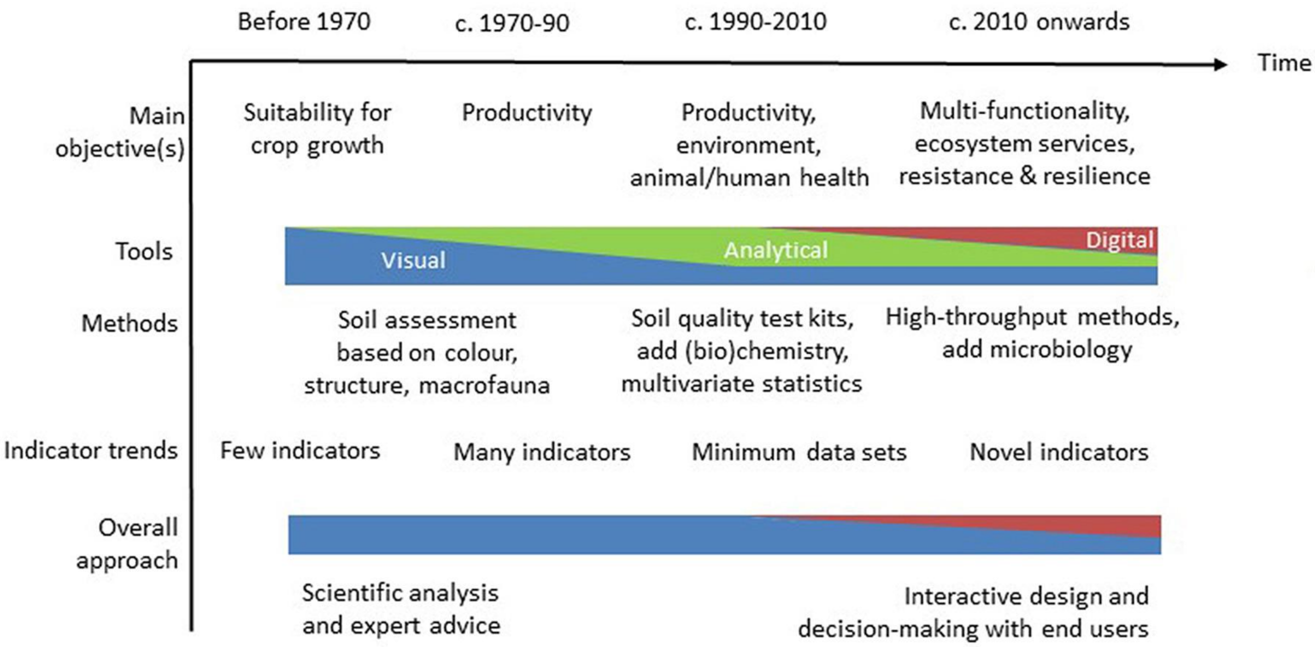

Figure 1. Historic timeline of objectives, tools and approaches of soil quality assessment (Bunemann et al., 2018)

Before 1970 the main objective of soil monitoring was the suitability for crop growth (Figure 1.). The tools to assessment of this were few and they were based on visual evaluation like soil colour and structure. Later on, productivity aspect got more value and analytical indicators were taken into account. At the end of 1990s, environmental and both animal/human health factors increased their importance. Soil monitoring was based on minimum datasets that were gathered from biochemistry multivariate statistics and soil quality test kits. The overall approach to soil quality was still based on scientific analysis and expert advisory services for farmers. From the beginning of the 2010s the soil role in the multifunctional ecosystem services and functions as a resistance and resilience aspect was noticed. Novel indicators were established based also on digital soil monitoring. The approach to maintain and improve the soil quality through monitoring is changing towards interactive design and decision-making with end-users. (Bunemann et al., 2018.)

A particular recommendation that needs to be taken into consideration is to focus on soil use rather than soil functions, so that the responsibility to maintain the quality of the soil can be clearly assigned to the user of the soil. Soil quality assessment then provides the scientific tools for the management of soil resources, considering also the societal demands of the various benefits that soils, if managed well, can provide to humankind. The evaluation of soil quality hence becomes connected to the valorisation of the ecosystem services provided by soils (Haygarth and Ritz, 2009, Dominati et al., 2010, EEA, 2015, SOER). A further benefit of such a soil quality concept is that it raises awareness and enhances communication between stakeholders regarding the importance of soil resources (Karlen et al., 2001).

Soil quality impacts human health in various ways (Pepper, 2013), through direct benefits from food and nutrition, living and recreational space for optimal lifestyles, physical exercise and for mental health. The mineral content of soil has strong effects on human nutrition and health. As an example, the minerals such as iron, zinc and selenium enter into the food web system from the soil, if a child has suffered deficiency of these micronutrients in uterus or during the first couple of years of life, he or she will never attain his or her cognitive and physical potential (Barret et al, 2015).

Soil quality involves various characteristics that summarize the inherited value of the soil, which is a very dynamic and complex eco-system regulated by the interaction of physical, chemical and biological processes acting simultaneously. Although a final consensus on the definition of soil quality is yet to be reached, one of its most prominent indicators is related to SOM content otherwise described as the *elixir* of soil's life having a paramount impact on all soil ecosystem services from biomass production to climate regulator (FAO and ITPS, 2015).

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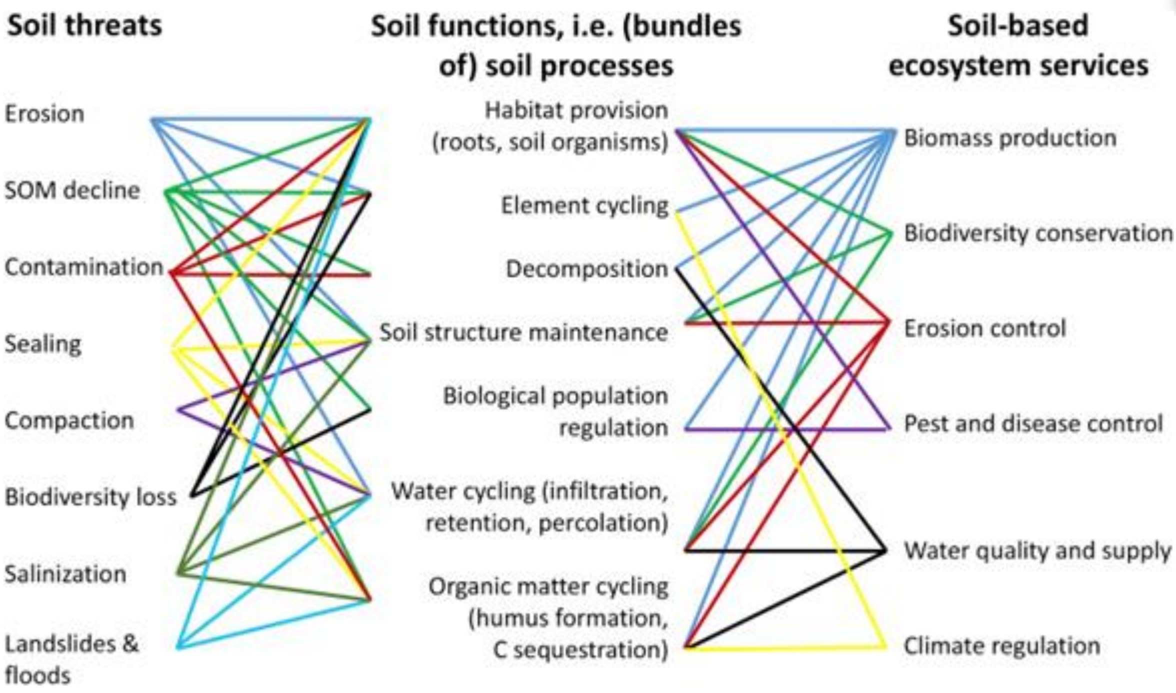

Figure 2. Linkages between soil threats, soil functions and soil-based ecosystem services (MEA 2005, further developed from the scheme presented by Kibblewhite et al. (2007) and modified by Brussaard (2012). and Bunemann et al. (2018).)

In this section are gathered examples for on farm level monitoring of soil contamination. The focus is to help the "farmer as a user" to implement orientated solutions. To fulfil this goal a set of already existing reliable databases of soil quality chemical, physical and biological indicators are needed. They could be identified by visual field soil assessments as indicators of genuine good operating practices.

2.1 European level soil monitoring

"Soil monitoring is the systematic determination of soil properties that can detect and record spatial and temporal changes" (FAO/ECE 1994) and a soil monitoring network (SMN) is a set of sites/areas where this periodic assessment is carried out and documented" (Morvan et al 2008). Monitoring of the soil resources has been implemented to facilitate the effective management of the soil and to support the delivery of its multiple soil functions. The focus of a SMN is on soil features that can be readily measured and can be used to detect changes over time.

Several EU funded research projects have reviewed SMNs in Europe for assessing soil quality. Good examples are the **ENVASSO** project and the Forest Soil Condition Database. National SMNs are available and running across Europe, but those are mostly providing only a set of very limited attributes. These properties are mainly unbalanced, focused mostly towards the chemical properties while both biological and physical attributes are severely under represented. The wide range of methods used in national SMNs for soil sampling and analysis also limits the harmonization possibilities of these datasets.

The Eurostat run the Land Use and Coverage Area frame Survey known mostly as **LUCAS**, which is an EU level monitoring system that "focuses on the state and the dynamics of changes in land use and cover in the European Union". The survey is carried out in-situ; a large number of observations are made and registered throughout the EU. In 2012, all 27 EU countries have been covered and over 270,000 points have been analysed on different land cover types (cropland, grassland, forest, built-up areas, transport network, etc.). On these points, the surveyors have examined the land cover and land use, irrigation management and structural elements in the landscape. In addition, a 500 g top-soil sample is taken in one out of 10 points. These samples are analysed in a laboratory and used for purposes related to assessing environmental factors, such as updating European soil maps, validating soil models, and measuring the quantity of organic carbon in the soil which is an important factor influencing the climate change(**https://land.copernicus.eu/imagery-in-situ/lucas**). The LUCAS 2015 soil analysis included mostly physical-chemical properties such as: pH, organic carbon, nutrient concentrations and cation exchange capacity.

In 2018 a new set of maps of baseline topsoil chemical properties at high resolution (500m) is available for the European Union. The derived maps can be baselines to monitor soil quality and provide guidance to agro-environmental research and policy developments in the EU (Ballabio et al., 2019). The 2018 LUCAS survey includes laboratory data that were enriched extended also to soil biodiversity and bulk density, while field surveys included a visual assessment of erosion and measurement of the thickness of organic layer in organic-rich soils (classified as Histosols). These LUCAS updates are described below.

Soil biodiversity analysis: The most extensive EU assessment of soil biodiversity, based on DNA metabarcoding will be included as part of the LUCAS Soil Survey. For this, 1000 points were selected. Analysis will target the following attributes: Bacteria and Archaea (16S rDNA), Fungi (ITS), Eukaryotes (18S rDNA), Microfauna (nematodes), Mesofauna (arthropods), Macrofauna (earthworms), Metagenomics.

Bulk density will be measured at 9,000 points. Points were selected from the total set based on the heterogeneity of soil texture and organic carbon content, land use and land cover, topography and soil type. A CLHS approach was used to select candidate points, as for the biodiversity. Bulk density data points coincided with soil biodiversity points to explore possible correlation between these properties.

Visual assessment of erosion. Surveyors will provide a qualitative assessment of soil erosion by indicating the type of erosion (i.e. sheet, rill, gully, mass movement, re-deposition and wind erosion), and the distance and direction from the LUCAS point, together with an estimate of the number of rills or gullies observed.

Measurement of thickness of organic horizon in organic-rich soil. The thickness of the organic horizon in effectively or potentially organic-rich soil will be measured at 1,470 locations. (**https://esdac.jrc.ec.europa.eu/projects/lucas**)

Van Leeuwen et al (2017) concluded that although the previous and current LUCAS surveys had limitations in resolution, spatial cover and sampled attributes, the planned (and already conducted LUCAS 2018) survey broadens the scope for using the LUCAS database in the context of monitoring soil functions at the European level. This enables the monitoring of soil health on a European level, and the LUCAS SMN is a good example of a high-level monitoring system. Although due to its resolution and spatial coverage the derived conclusions and results are not necessarily informative on a farm level.

2.2. Chemical soil assessment methods

Some chemical properties of soils can be used as measurements-based indicators for the status of soils health and soil fertility, contributing this way to soil sustainability and associated biodiversity. Therefore, it is important to implement chemical monitoring surveys. The overall purpose of this subchapter is to provide simple, acceptable and adaptable information for the assessment of the chemical parameters (including sampling design, spatial and periodicity and analytical methods) that are deemed relevant for the agricultural soil quality. The objective is to propose a possible methodology or procedure for the selection of key chemical indicators (at least the most valuable) for the monitoring the soil status. However, it should also be adapted taking into consideration the agriculture management practices and the possible existing legislation in each country.

Soil sampling

Soil sampling at each agricultural field should comprise at least five topsoils (depending on the field size) to a depth of 0-20 cm, using a core (with a taken distance of 2 m from the first one following the four cardinal directions (De Gruijter et al., 2006; Tóth et. al., 2013; Orgiazzi et al., 2018). These five samples are mixed together and 500 grams of the mixture is taken to form a representative sample for each field. However, if the field has spots on which crops are growing differently compared to the rest of the field is advisable to take another sample separately from these" spots". Samples should be collected in plastic bags and air-dried before being transported to the laboratory for subsequent analysis. It is advisable to perform this survey every 3-5 years. Based on the year frequency of field soil sampling, by analysing the data is possible to monitor the changes in all the selected parameters. Attention should be placed however on repeating sampling in the same spots so that data could be checked and compared. To allow spatial comparison the use of GPS devices should be used together with the probe.

Soil chemical properties analysis

Most soil processes are mediated by soil biota in indirect relationship with the physical and chemical properties of their environment. Therefore, for monitoring of soil quality is essential to analyse the chemical properties of soil and a fundamental requirement is that the methods used to assess soil quality are robust and capable, within established degrees of confidence reproducing comparable information over extended spatial and temporal scales. As such, although each property has different methods that can be used, but it should be followed a standard protocol following the same procedure. If possible, farmers should perform the analysis using standard procedures.

Chemical properties of soil heath are correlated with the capacity to provide nutrients and/or retaining chemical elements or compounds harmful to environment and plant growth and thus the variations of a particular indicator are easily interpreted, and allow a quick improvement on the soil chemical properties liming and/or fertilization. These soil chemical indicators can also be useful in considering the soil's capacity for sustaining agriculture production and sustainability, maintaining nutrients availability and cycling and organic matter turnover (Guo and Gifford, 2002) and organic matter turnover. Hence, the monitoring of chemical parameters is essential to monitor soils fertility status.

The most important chemical parameters to be assessed are pH, electrical conductivity (EC), nitrogen (N), soil organic matter (SOM), soil organic carbon (SOC), phosphorus (P), calcium (Ca), sodium (Na), potassium (K), cooper (Cu), iron (Fe), manganese (Mn), zinc (Zn) and also some potentially toxic elements (PTEs).

Soil electrical conductivity (ISO 11265:1994) is a good indicator of salinity, which can cause fertility problems in soils and can affect crop productivity. Soil pH correlates directly with nutrients availability/solubility and also affects microbial activity. Thus, assessment of pH (H_2O; $CaCl_2$; ISO 10390:2005) allows to predict the potential for nutrient availability in a given production system since optimum plant growth varies among crops. A knowledge of the soil and the crops is important to manage soil pH for the best crop performance.

Soil organic matter (Weight-loss-on-ignition) and soil organic carbon content (ISO 10694:1995) are two crucial indicators to evaluate the quality and fertility of soils and are widely accepted as the most important chemical indicator of soil quality. Organic carbon is the primary constituent of SOM and affects, directly and indirectly many components of agro-ecosystems and their environmental functions (it is linked to provision of food, fibre and water). It affects important processes in soil like the storage of nutrients, mainly N, water holding capacity and stability of aggregates. In addition, also affects microbial activity. Several factors are responsible for their decline and many are related to human activity in agriculture, such as intensive tillage operations, high amount application rates of nitrogen containing fertilizers causing rapid mineralization of organic matter, crop rotation with reduced proportion of grasses, among others (Kibblewhite et al., 2007a). Therefore, it's important to measure SOC. Carbonate (CO_4^{3-}) content is also recommended to be determined (ISO10693:1994).

Nitrogen (ISO 13878:1998; ISO 14256:2005) is the most required plant nutrient, which is found in several chemical forms in soil, resulting in a very dynamic behaviour. Along with N, phosphorus (ISO 11263:1994) and K (ISO 11466:1995) are also key basic elements needed for crop growth in the soil. The results give a guidance for the amount of N, P and K that should be used for crop fertilization. Therefore, they are essential in assessment of soil quality, since it limits the agricultural yields. It would also be important to assess the Ca, Na, Cu, Fe, Zn (ISO 11466:1995) and the cation exchange capacity (ISO 23470:2007).

For example, to predict crop nitrogen requirements via soil analysis, a soil nitrate test (Pre-side dress nitrate test: PSNT) can be used to determine if additional nitrogen fertilizer is needed for corn. This test should be conducted on soil samples taken just before the period of major N demand by corn. This test is designated to estimate the soil´s nitrate supplying potential and decide if there is enough N to meet crop needs (Meisinger et al., 1992)

It would also be important that farmers consider doing surveys on soil contamination, since it can cause a deterioration or loss off soil fertility and one or more soil functions. The contamination is generally associated with atmospheric deposition, certain agricultural practices and inadequate waste and wastewater recycling as identified by the EU-funded ENVASSO project (Kibblewhite et al., 2007b).

There are two main classes of contaminants: inorganic (which include the potentially toxic elements (PTEs and some elements like N, P and sulphur (S)) and organic contaminants (which include pesticides, persistent organic pollutants, like polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), among others).

Based on ENVASSO project and Lucas Surveys, diffuse contamination by PTEs, like arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), mercury (Hg), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), antimony (Sb), vanadium (V) and zinc (Zn) are important to monitor in soils, as well as nutrients and pesticides since are strongly related to the impacts of agriculture. However, data availability is very limited for persistent organic pollutants.

Following the same pattern survey, levels of PTEs should be measured in farming soils every 5 years, unless some unexpected diffuse source contamination can occur. Although some of these elements, like Cu, Zn, Co and Ni are essential in small concentrations for normal healthy growth of organisms, at excessive concentrations all PTEs cause toxic effects like enzyme inhibition, the replacement of essential PTEs as cofactors and alterations in membrane integrity. The selected PTEs contents in soils are measured by ICP-MS (ISO/TS 16963:2013), ICP-AES (ISO 22036:2008) or FAA (ISO 11047:1998) after a aqua regia extraction (ISO 11466:1995). Mercury in soils should be determined by ISO 16772:2004 (cold-vapor atomic spectrometry or cold-vapour atomic fluorescence).

Agricultural management practices have also long-term effects on soil properties; therefore, the soil sampling indicators differ depending on the management practice that each farmer has chosen to use. The analysis and integration of the various parameters highlights the impact of soil mobilization on its quality, which is an important conditioning factor for soil dynamics.

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2.3. Biological soil assessment methods

Alongside chemical and physical, also biological indicators have a relationship to soil functions and can evaluate them to assess soil quality. Not so widely used as chemical and physical, biological indicators are providing insight into the living component of the soil and the diversity of organisms that are present in it.

Soil organisms play a central role in soil functioning. Therefore, adding biological and biochemical indicators can greatly improve soil quality assessments. Moreover, the assessment of biological indicators of soil quality is required to connect abiotic soil properties to (changes in) soil functions in terms of biochemical and biophysical transformations and (potential) aboveground vegetation performance. Nevertheless, soil biological indicators are still underrepresented in soil quality assessments and mostly limited to black-box measurements such as microbial biomass and soil respiration. Despite clear potential, more specific indicators such as those based on nematodes, (micro) arthropods or a suite of soil biota have rarely been suggested, possibly because they require specific knowledge and skills. This situation is unfortunate because soil biota is considered the most sensitive indicators of soil quality due to their high responsiveness to changes in environmental conditions.

A well accepted indicator has to be interpretable, correlate well with ecosystem processes, integrate different soil properties and processes, be accessible to many users and be sensitive to changes. Further on an indicator must have good reproducibility, low variability and simple testing and analytical methods.

There are myriads of organisms in the thin layer of the soil surface. They play key roles in the decomposition of soil organic matter, nutrient cycling, soil pollutant degradation and the formation and stability of soil structure. Soil biota also respond rapidly to soil management and land use changes and can be candidates for soil quality indicators. Some are listed in the table below (Table 1).

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Table 1: Summary of various forms of soil biota and their interaction with soil ecosystem services

Soil organism	Main soil functions	Mechanisms involved	Soil-based ecosystem services	Ease of application
Macroorganisms (fauna)				
Earthworms (macrofauna)	Soil structure maintenance, decomposition, organic matter and water cycling, habitat provision	Burrowing, fragmentation of litter, soil aggregation, humification, organic matter distribution	Biomass production, erosion control, water supply, climate regulation, biodiversity conservation	Easy to sample but not ubiquitous
Nematodes (microfauna)	Element cycling, decomposition, biological population regulation	Grazing on microorganisms, root herbivory, predation	Biomass production, pest and disease control	Identification only by specialists. Ubiquitous, easy to sample, abundant, sensitive.
Protists (microfauna)	Element cycling, biological population regulation	Grazing on microorganisms	Biomass production	Poorly defined taxonomically, difficult to isolate and identify. Variable in space and time.
Collembola (mesofauna)	Decomposition, element cycling, biological population regulation	Grazing on fungi	Biomass production, pest and disease control	Cumbersome to sample and isolate, difficult to identify
Enchytraeids (mesofauna)	Decomposition, soil structure maintenance	Burrowing, fragmentation of litter, soil aggregation, decomposition, humification	Water supply, climate regulation	Easy to sample but difficult to identify
Mites (mesofauna)	Decomposition, element cycling, biological population regulation	Grazing on bacteria and fungi, fragmentation of residues	Biomass production, pest and disease control	Cumbersome to sample and isolate, difficult to identify

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Soil organism	Main soil functions	Mechanisms involved	Soil-based ecosystem services	Ease of application
		Macroorganisms (fauna)		
Macroarthropods (macrofauna)	Soil structure maintenance, biological population regulation	Burrowing, root herbivory, predation, grazing on bacteria and fungi	Biomass production, pest and disease control, biodiversity conservation	Relatively easy to sample, taxonomically very diverse
		Microorganisms (microbes)		
Bacteria	Element and organic matter cycling, decomposition, biological population regulation	Symbiotic association (nitrogen fixing bacteria), production of antibiotics, transformation and mineralization of organic material	Biomass production, pest and disease control, climate regulation	Spatially and temporally variable. Taxonomically very diverse and difficult to classify.
Fungi	Element, organic matter and water cycling, soil structure maintenance, decomposition	Production of antibiotics, transformation and mineralization of organic material	Biomass production, water quality and supply, erosion control, pest and disease control	

There are however limitations in directly using soil organism as indicators of soil quality (the exception here being earth worm density). Because of these biological dynamic properties are often selected as surrogates for measurement of processes mediated by soil biota. Some of these are: Soil respiration, microbial biomass, N mineralization, earthworm density, root health, enzyme activities, nematodes, microbial diversity, soil faunal diversity, etc.

Soil enzymes activities

Biochemical indicators such as soil enzymes can be useful indicators of soil health and quality because of the functions they play in soil cycles. Enzymes are involved in several metabolic processes and are also responsive to changes in soil use and management (Acosta-Martinez et al., 2007). Soil enzymes activities have been suggested as suitable indicators of soil quality because: (1) they are measures of soil microbial activity and therefore they are strictly related to nutrients cycles and transformations; (2) They may

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rapidly respond to changes in soil caused by natural and anthropogenic factors; (3) they are easy to measure (Sicardi et al., 2014). Soil enzyme activities may be considered early and sensitive indicators of soil alteration in both natural and agro-ecosystems, thus being suitable to measure the impact of use, management and contamination on the quality of soil (Nayak et al., 2007).

Among the several enzymes activities, the most important to analyse are the ones with functions in the cycles of carbon and nutrients (Schinner et al., 1996; Marx et al., 2001). Therefore:

1) Carbon cycling: Dehydrogenase, celullosa, invertase, amylase and β-glucosidade. The N- potential nitrification and N- mineralization are also important;
2) Nitrogen cycling: Urease, glutaminase and asparaginase;
3) Phosphorus cycling: Phosphatase;
4) Sulphur cycling: Arilsulphatase

2.4. Physical soil assessment methods

The sustainability of agricultural systems depends on the evaluation and monitoring of soil use and tillage in order to mitigate soil degradation. (Guimaraes et. al 2013). There are some questions that need to be considered when the aim is to monitor soil physical properties by visual assessment. First of all is the selecting the indicators for the targeted soil function and ecosystem services. There should occur a clear linkage between indicators and soil threats or functions. Understandable and visually determined effects from soil physical properties give motivation for farmers to start the changes in there farming practices. The standardization of visual assessment is another aspect, there should be constant circumstances for the sampling. The depth of sampling needs to be defined and critical limits of the sampling results need to be defined as well. Most known physical soil threat is soil compaction. But lately also soil contamination by plastics that are used in agricultural production and microplastics that are contaminating soils through sewage usage as fertilizers are new threats taken to account.

A promising method to evaluate physical soil properties is "Visual evaluation of soil structure". The visual evaluation of soil structure (VESS) was developed to provide a quick, simple and easily understood test to enable researchers, farmers and consultants to score soil quality. VESS (*S*q), is sensitive enough to identify differences in structure, resulting from soil management, in and between layers of topsoil (Guimaraes et. al 2013). VESS should be done when the soil is moist, spring and autumn are the best time of the year to do the VESS evaluation. The samples are are taken from the areas where the good soil structure is expected as well as from the areas where the soil structure is expected to be poor to allow to see of the changes in the soil different layers. The evaluation has three steps: soil removal, soil assessment and soil scoring.

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Soil is removed to the depth of 20 cm. After that is taken a slice from the undisturbed face. Slice is opened the undisturbed side of the block like a book and started to break it up. After evaluating the different layers, the soil is scored. There is a simple spreadsheet that allows transfer of data from the field recording form and the calculation of overall block scores**.** Soil assessment goes though the degree of firmness, the shape and size of soil fragments (clods and aggregates), root density and distribution as well as any evidence of anaerobism (colour, mottles and smell) are all used to identify the contrasting layers in the block. VESS has showed similar results to bulk density and soil resistance. The effects of soil management are detected by VESS. (Guimaraes et. al 2013)

The most common extraction is extraction by floatation, it is easy, cheap but time consuming and prone to errors. It works with Light density plastics, but high density plastics are difficult to extract. A solution is to increase the density of the liquid for floatation, but it makes the process more complicated and less accurate. A promising method is using electrostatic behaviour.

An easy, cheap but time consuming and not very accurate method is the visual identification by optic microscope and heating process. The FTIR method is more expensive but more accurate and can identify the types of plastic. A thermal degradation method is possible with Py-GC-MS. There is a promising method without extraction, but so far it is not applicable for the concentrations that are commonly found in soils. These are the most promising techniques. They have to be improved and many more are investigated. All these innovations are very recent.

3. Conclusions/Key messages

When considering prevention and monitoring soil contamination on farm level there are three points that should be taken to an account

- sustainable benefits for farmers
- investments needed
- time needed

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Economic impacts should be positive: save money, increase income, save inputs. The soil contamination should be taken into account at an early stage to prevent excess costs to any partner in the agricultural chain.

The monitoring methods, results and frequencies should be standardized. Requirements for soil quality indicators, methods for selecting a reliable dataset, most important soil quality indicators are subjects to consider on farm level. It should be noted that farmers often know very well which specific soil parameters are the most relevant for their particular situation. Therefore, the view of land managers should be taken into account when evaluating various sets of indicators for soil quality (Lima et al., 2013; Palm et al., 2014), necessitating a transdisciplinary and participatory approach. Precision agriculture has grown to meet increasing worldwide demand for food using technologies that make it simpler and cheaper to collect and apply data, adapt to changing environmental conditions, and use resources most efficiently. Although large farms have been the first to adopt these technologies, smaller farms are now able to benefits as well, using tools built into smart phones, relevant applications, and smaller-sized machinery. What's more, these technologies are contributing to solutions that extend beyond farms, including pollution, global warming, and conservation.

Because the relevant actions are not the same for all farms, there should be a tool box where a farmer is able to choose the soil monitoring measures. Also, data sharing is an important part of soil monitoring, without comparable long-term datasets it is not possible to evaluate the significance of the changes detected. There is plenty of new research information available in the scientific literature on the soil health, but the practical application and testing is still lacking.

4. Research needs

- Development of smart sensors or tools (affordable, "fast determination methods" and with improving resolution and accuracy) to allow in-situ field monitoring of the fundamental parameters' contents [mainly the nutrients, (N, P and K) and carbon] by the farmers. It is needed to bear in mind that these procedures should be tested under practical conditions regarding their easy-to-use, compared with the standardized laboratory methods and validated individually;

- Establishment and setting up of a soil quality monitoring protocol which enables the farmers to assess the respective soil status at farm-level. This can be translated into a tool that will help farmers to improve the use and management of their soils;

- Although many technologies and solutions are already available, it is important the recognition of those alternative systems for soil scan and monitoring (besides the laboratory analysis), as for example remote sensing, which can foster the investment in those systems and decrease the cost involved with it;

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- Development of kits for the determination of soil enzymatic activities (low tech, easy-to-use and affordable) to monitor the soil quality health;

- Survey of farmers concerning their willingness and understanding the importance of soil monitoring and their management at the farm using practical tools.

5. Ideas for innovations

Time-lines for soil monitoring and for quality measurements on farm level are more needed than ever. Furthermore, technology is moving faster than ever and the private sector is heavily involved in the development of new devices that are quick, cheap and easy to use also for the average farmer. Using artificial intelligence and machine-learning techniques nowadays is possible to perform high accuracy crop modelling, resource-base management and weather forecasting for sustainable farming. Through these technologies, farmers are empowered to check and control the life cycle of their crops in terms of soil moisture stress, pest and disease indicators all functioning through a single device that can retrieve and disseminate data anywhere and anytime via the Internet. Furthermore, numerous Apps are becoming available at the hands of the farmer making modern farming easier and challenging in the same time[1].

Further research needs coming from practice, ideas for EIP AGRI operational groups and other proposals for innovation can be found at the final report of the focus group, available at the FG **webpage**.

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