CORE organic II

FERTILCROP

A European Network

Deliverable 7.1. Scientific assessment of farmer-oriented indicators and tools for the diagnosis and design of soil and crop management strategies in organic farming systems.

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Scientific assessment of farmer-oriented indicators and tools for the diagnosis and design of soil and crop management strategies in organic farming systems.

Pacini, G.C.[a], Antichi[b], D., Peigné, J.[c], Celette, F. [c], Doltra, J.[d], García-Méndez, E. [d], Hansen, S.[e], Kadziuliene, Z.[f], Barberi, P.[g], Askegaard M.[h], Sans Serra, F.X. [j], Blanco-Moreno, J.M. [j], Romanyà, J.[j], Fliessbach, A.[k], Gary, C.[l]

[a] Department of Agrifood Production and Environmental Sciences, University of Florence, Italy

[b] Centro di Ricerche Agro-ambientali "Enrico Avanzi" (CiRAA), Pisa, Italy

[c] Institut supérieur d'agriculture et d'agroalimentaire Rhône-Alpes (ISARA-Lyon), Lyon, France.

[d] Cantabrian Agricultural Research and Training Centre , CIFA, Muriedas, Spain.

[e] Norwegian Centre for Organic Agriculture (NORSØK), Tingvoll, Norway

[f] Lithuanian Research Centre for Agriculture and Forestry (LAMMC), Kė�dainiai, Lithuania

[g] Scuola Superiore Sant'Anna (SSSA), Pisa, Italy

[h] SEGES, Aarhus, Denmark

[j] University of Barcelona (UB), Spain

[k] Research Institute of Organic Agriculture (FiBL), Frick, Switzerland

[l] Institut National de Recherches Agronomiques (INRA), Montpellier, France

Preamble

This Deliverable is the result of the activities carried out under Task 7.1 "Indicators and tools for the assessment and design of organic soil and crop management strategies".

Regarding task 7.1 a major effort was done in Summer 2015 in order to develop a conceptual model to select and systematise indicators for the assessment and design of soil-crop systems. Starting from an already existing concept for sustainability assessment of agroecosystems, a Fertilcrop model as well as case-study specific models were developed. In order to do that partners were supplied with a tutorial to guide them in the building-up process of case-study specific conceptual models of local soil-crop systems. Information on the tutorial was supported by scientific articles previously published on the topic. Both the tutorial and the articles were also made available on the FertilCrop intranet. Contents and applicability of the tutorial were explained in detail in one-day long learning session during the Montpellier meeting (17-18 September 2015).

The use of the conceptual model was anticipated to supply two main functions: i) selection and assessment of indicators under a systems (holistic) perspective, and ii) systematisation of indicators under sustainability dimensions of soil-crop systems in order to guide following aggregation for integrated assessment of the various ecosystem services expected from organic soil management, to be carried out in following tasks.

Regarding function i), during Autumn 2015 case-study specific conceptual models were produced and refined with continuous exchange among partners. In December an overall list of Fertilcrop indicators was devised that was later (spring 2016) crosschecked with tools for practical assessment of soil quality as identified in Task 3.3. As a result of this process, M7.1. "First list of indicators and tools for assessing soil quality" was achieved.

The drafting oft he Deliverable was carried out in Autumn 2016 and got to an end recently. This report is a Fertilcrop deliverable initially planned for month 24 of the project but, due to delays in receiving some of the partners' very last contributions, was finally moved to month 26.

Summary

1. Introduction

Indicators and assessment tools are needed to provide farmers with instruments for a better understanding of the functioning of soil, which often remains a "hidden compartment", and for an appropriate management aiming at improving yield level and stability and limiting the environmental impacts of agriculture. There is a plethora of indicators for soil quality assessment and methods to calculate them in the literature. In this paper we will focus on indicators and tools that can be directly applicable by farmers or that anyway can be used by other stakeholders (e.g., researchers, advisors) to support farmers' decisions.

The objective of this paper is to carry out a scientific assessment of farmer-oriented indicators and tools for the diagnosis and design of soil and crop management strategies in organic farming systems.

Sets of farmer-oriented indicators are evaluated based on a conceptual framework fostering the adoption of a holistic perspective for the design of soil and crop management strategies in organic farms. This holistic view should facilitate the inclusion of the various agroecosystems dimensions and properties in the process of indicator selection. Indicators of the physical and biological dimensions of soil quality are considered and related to other dimensions (productive and social) of sustainability. A conceptual model facilitates the identification and systematization of indicator sets needed for sustainability assessment (Pacini et al., 2010; El Hage et al., 2014). Finally, the list of indicators is crosschecked with a list of available tools for soil quality assessment as assembled by WP 3.3.

2. A conceptual framework to assess and systematise indicator sets for diagnosis and design of soil-crop management strategies

In this section we present a conceptual framework to systematically evaluate indicator sets for assessment of the sustainability of farming systems (Pacini et al., 2010; El-Hage et al., 2014). The framework is generic and so far has been applied in other projects to a number of case-studies, including the evaluation of indicator sets for diagnosis and design of organic and conventional farming systems (Pacini et al., 2010), use of pesticides at national and regional levels (Capri and Marchis, 2011), comparing alternative land management options in a FAO worldwide study (El-Hage Scialabba et al. 2012), community farming in urban areas (Altman et al., 2014), slow-food restaurant management (Callahan et al., 2014), on-farm closed loop management system for the production of organic bread and pasta (Landi, 2015), comparing alternative land use options (Pacini et al., 2016). During the course of FertilCrop the framework has been further developed to cope with specific requirements of diagnosis and design of soil-crop systems. This work has resulted in an upgraded version of the framework and became the subject of a chapter on the forthcoming Encyclopedia of Sustainable Technologies, including an example from FertilCrop case-studies (Pacini and Groot, 2017).

The conceptual framework

The aim of the evaluation of indicator sets as proposed in this paper is to check if all the domains of the problem under study have been included (or have been excluded for clear reasons), if contrasting interests and perspectives can be addressed, and if there are unintended unbalances in the indicator set. For this purpose, a set of views on the agroecosystem is defined. The main principles underlying the conceptual approach are as follows:

- Separate views are defined on the components and on their values in the system.
- Values can have a cultural or a financial dimension.

- The components are categorized in four different dimensions: physical, ecological, productive and social.
- Some indicators are used to quantify functional properties (capacity, stability and resilience), and contribute to the monitoring of agroecosystems, and can be used to inform policy and other decision-makers.
- Other indicators are more complex and quantify interrelations among components within the system and relations with the environment; these indicators address the structural properties (diversity, coherence and connectedness) and play an important role during the participatory diagnosis and modification of agroecosystems management strategies.

Dimensions of the soil-crop system

Separate views on the concrete components in the agroecosystem and on the values that can be associated with them were defined (Figure 1). A value system can be understood as 'the ordering and prioritization of a set of values that an actor or society of actors holds' (Abreu and Camarinha-Matos 2006). It reflects that components of the agroecosystem have a certain value attached based on societal priorities and rules, which can be expressed in a cultural (or socio-ethical) importance; besides, an economic or financial value can be attached to commodities that are traded in markets. The economic value depends on human demand and local supply of products and services.

The components of the agroecosystem are classified into four dimensions as a starting point of the assessment (Figure 1). In particular, the productive dimension is often omitted from evaluation frameworks used for sustainability assessment (Gómez-Sal et al., 2003). It includes not only products harvested from ecological systems, but also artefacts from industrial or human cultivation processes that use both ecological and physical resources. These products can be transformed into other products (milk into cheese; engines, dashboards and other components into tractors).

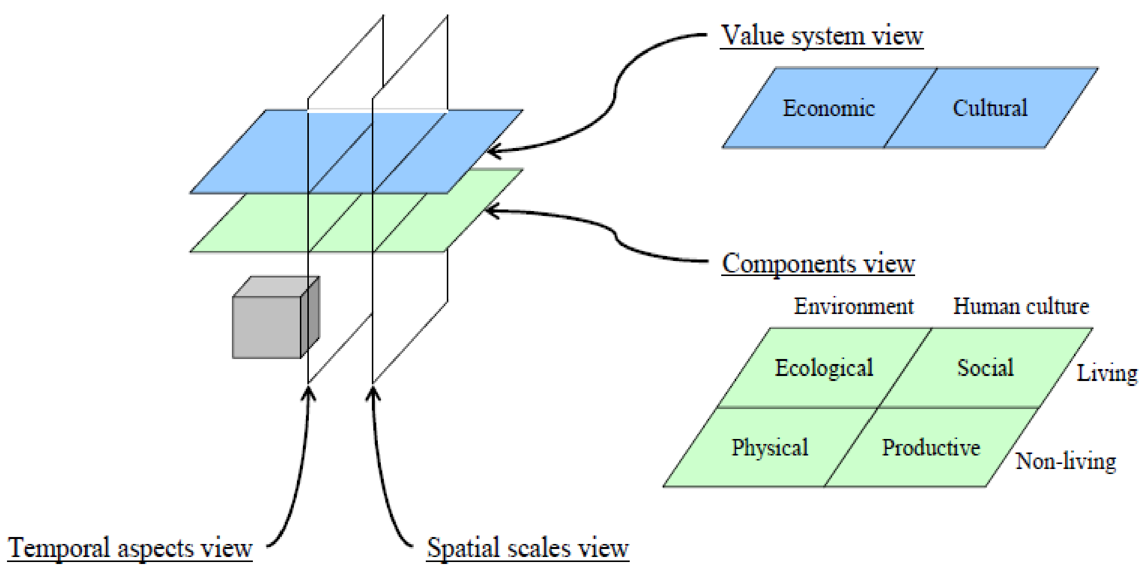

Figure 1. Views on an agroecosystem (grey box): the value systems view (blue) consists of two dimensions and the component view (green) comprises four dimensions. The value system reflects that components of the agroecosystem have a certain value attached based on societal priorities and rules, which can be expressed in an economic and a cultural value. Temporal aspects are included to take into consideration supposed preferences, short and long-term changes and the needs of future generations. Spatial scales are included to acknowledge importance to potentially heterogeneous impacts of management options at different hierarchical levels.

It can be argued that breaking the system and the problems of the system down in clearly distinctive dimensions will facilitate the identification of context specific problems. Subsequently, these dimensions can be translated into critical properties and relevant indicators in a rather straightforward fashion. In this manner the evaluation process is more concrete from the start and this would make the identification of the indicators less abstract, thereby increasing the opportunities for contributions of non-scientific stakeholders. These proposals do not imply that involved participants would immediately embark on mono-disciplinary approaches, since the dimensions are highly interrelated and adjustments with respect to one of the dimensions will have repercussions for other dimensions.

By overlaying the components in the dimensions with the perspective on the economic value system, indicators representing the financial values are identified. These are predominantly found in the productive, social and physical dimensions (prices of products and inputs, incomes). In all four dimensions, indicators that convey the cultural values of the system can be found. By overlying and combining views on the agroecosystem we can also specify questions such as: 'which ecological and physical components in the agroecosystem hold a cultural value (and should therefore be protected)?'; 'is as much attention paid to the physical as to the ecological dimension (or is one of the dimensions more important or problem-prone?)'; 'which components of the productive system provide the most economic benefit (and should these be prioritized or are other sources of economic benefit needed)?'.

Agro-ecosystem properties

Properties of agroecosystems can be classified into two main categories, i.e. functional and structural. Functional properties (capacity, stability and resilience) contribute to the monitoring of agroecosystems and can be used to inform stakeholders of the status of the system and the changes therein, while structural properties (diversity, coherence and connectedness) play an important role during the detailed scientific diagnosis to understand causal relations, and for the design of modifications to agroecosystems management strategies (Figure 2).

Structural properties

- *Diversity* is given by the number of different components and processes present in the system and their relative abundance. It includes among others biodiversity of genes, species and ecosystems, as well as the diversity of income sources and knowledge, traditional and scientific.
- *Coherence* provides measures of the numbers and strengths of the connections and flows among components and processes within the system. It considers ecological balance, economic integration and household labour, and seeks to minimize trade-offs and maximize synergies.
- *Connectedness* is similar to coherence, but concerns the connections with components outside the agroecosystem. It includes, among others, trans-boundary pollution and the production system connectivity with external waterways and habitats; integration of farm business in the supply chain and independence from exogenous factors; and the participation of producers in social networks and institutions.

Functional properties

- *Capacity* is the average performance level of a state variable in the system, e.g., the quantity of production of foods, biofuels, fibres, timber and other ecosystem goods and services that can be obtained from a unit of inputs (water, land, biodiversity, energy, nutrients and labour).
- *Stability* is the capability of the system to remain close to stable states of equilibrium when facing normal variations, and is reflected in the frequency and amplitude of fluctuations in the state variables.
- *Resilience* refers to the aptitude of the system to maintain its performance defined by capacity and stability after a disturbance or long-term or permanent changes in its environment or internal conditions, including both environmental and macro-economic risks.

Figure 2. Agro-ecosystem properties of the conceptual framework for sustainability integrated assessment of land use options (modified from El-Hage Scialabba et al., 2014).

The functional properties can be translated into corresponding indicators that are merely descriptive (e.g., like dashboard display in a car), can be used for monitoring of the sustainability of the agroecosystem, but are not useful to explain the underlying mechanisms or to design targeted adjustments aiming to improve the performance of the system and/or to innovate (redesign) the system.

Indicators that reveal the structural properties of diversity, coherence and connectedness express the composition of an agroecosystem in terms of components and processes and their interrelations or the relations with the environment outside the boundaries of the system under analysis. Structural properties determine the functional properties' responses of the system (like the engine of a car), and are particularly relevant to understand the mechanisms that govern agroecosystem performance (Ives and Carpenter, 2007), and to identify possible changes in the system to improve its sustainability.

In Figure 3 a generic application of the conceptual framework for diagnosis and design of farming systems is reported. In the next section the framework is applied for diagnosis and design of selected soil-crop systems of FertilCrop.

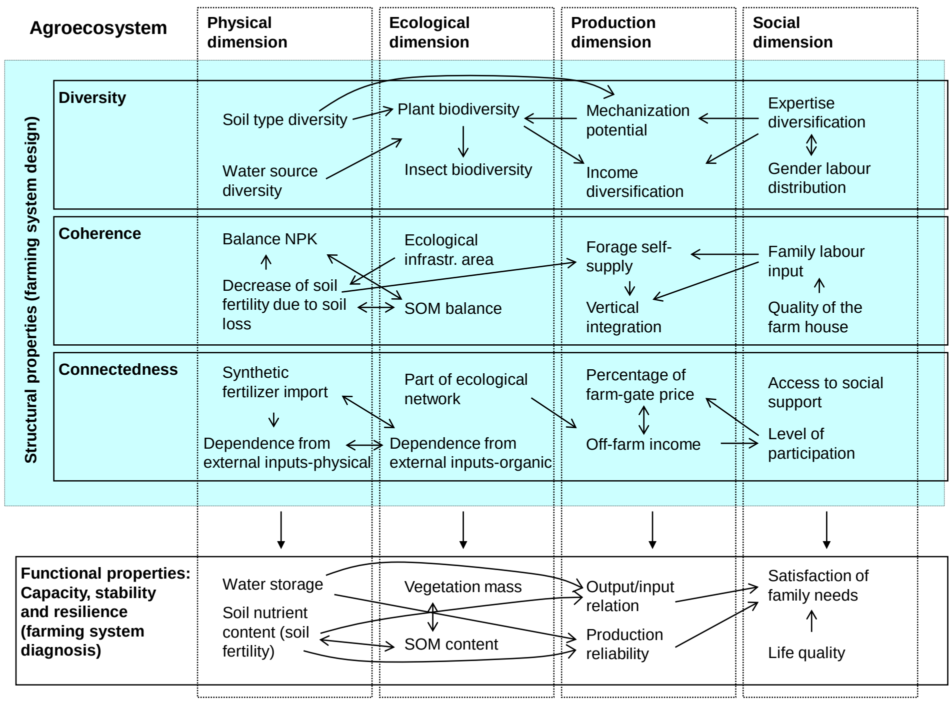

Figure 3. Generic application of the conceptual framework for diagnosis and design of farming systems. Note that the functional properties are combined in one row.

3. Application of the conceptual framework to assess indicator sets for diagnosis and design of soil-crop systems in FertilCrop case-studies.

The conceptual framework was applied to six case-studies in EU. Main features of case-studies are reported in Table 1. The selection of indicators in each case-study was based on expert judgement.

Table 1.
Case-studies

Case-study	Farm type	Research question
Denmark	Organic arable systems	How can yields be increased on organic arable farms with limited access to nutrients?
South-Eastern France	Organic arable systems	Is conservation tillage able to support soil fertility in organic intensive arable farming?
Tuscany, Central Italy	Organic arable systems	Is conservation tillage able to support soil fertility in arable farming systems without animal and green manure applications in inland hilly soils? To which extent?
Lithuania	Organic arable systems	Is the combination of legumes (as green manure) and organic fertilizers (cow manure pellets) able to positively affect productivity of spring cereals and soil fertility?
Catalonia, North-Eastern Spain	Organic arable systems	Is reduced tillage able to maintain soil quality in arable farming systems through the use of farmyard manure and the strategic deployment of green manures in a Mediterranean dryland/rain fed crop rotation?
Northern Spain	Organic arable systems	INPUT Jordi

Scientists responsible of each single case-study were trained in the application of the framework during a 2-day WP7 Methodological Workshop held in Montpellier, France, 17-18 September 2015, focusing on presentation of a proposal of conceptual model, discussion around a general framework of soil quality in FertilCrop and adaptation of the model to the context of each partner.

A tutorial was produced and disseminated among partners with corresponding literature to guide the application of the conceptual framework in case-studies. Finally, the methodological approach was rehearsed during specific sessions in the FertilCrop mid-term meeting held in Skara, Sweden, 29 June-1 July 2016.

Results are reported in the following paragraphs under the shape of case-study diagrams representing the set of indicators that local experts identified while applying the conceptual framework to their own case-studies. Diagrams are preceded by a short description of the corresponding case-study and a short illustration of the research question that supplied the motivation for it.

Case-study Denmark

A main challenge in organic arable farming, especially in Eastern Denmark, is that yields are way below potential. There are three significant reasons for this: 1) The availability of nutrient already present does not match plant needs due to lack of focus on importance of individual nutrients or poor synchronization in time, 2) lack of sufficient nutrient sources, and 3) existing knowledge is not sufficiently implemented in practice.

In coherence with production and environmental conditions and the research question, and following the tutorial guide, local experts developed the case-study diagram reported in Figure 4.

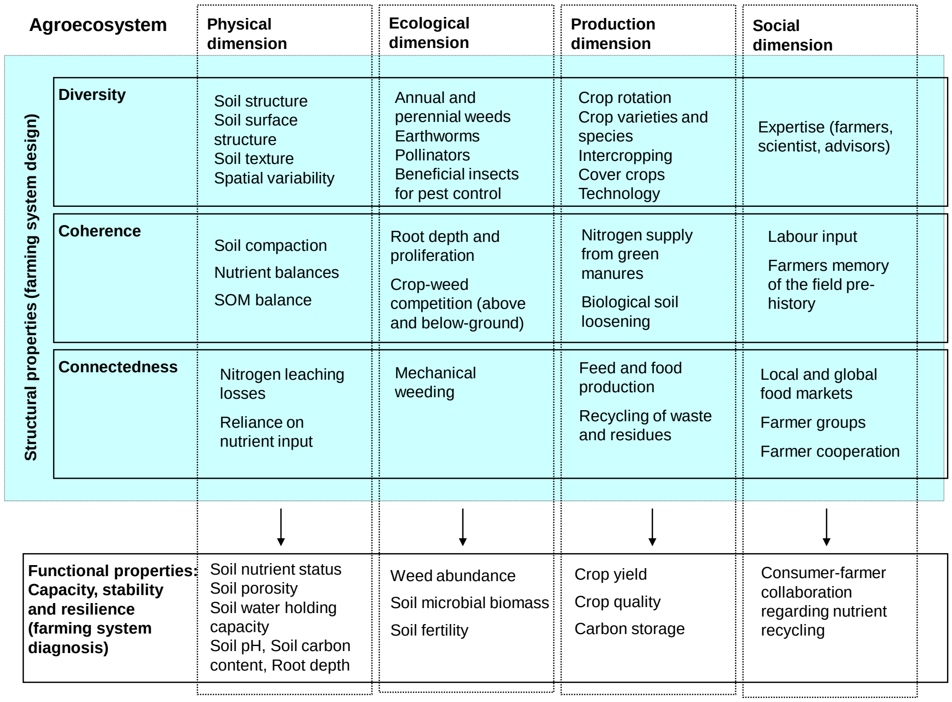

Figure 4. Application of the conceptual framework to assess indicator sets for diagnosis and design of soil-crop-farmer systems in organic arable systems of Denmark.

Case-study Rhône-Alpes region, South-Eastern France,

Organic arable farming in Rhone-Alpes region could be defined as intensive crop production, with a short crop rotation based on irrigated maize-soybean and wheat crops. Combined with soils sensitive to soil compaction, cropping systems present problem of soil structure and more globally soil fertility. According to surveys among organic arable farmers, conservation tillage practices such as shallow ploughing or reduced tillage could be introduced to solve soil fertility issues. Ten years ago, a long-term experiment was set up to compare several conservation tillage practices (shallow ploughing, reduced tillage and very reduced tillage) with traditional ploughing used by the farmers. The trial, called Thil trial, focussed on the effect of these practices on physical, chemical and biological soil components, and their impact on crop yields and weed control. Additionally to the trial, a network of field experiments in organic farms was also set up. The aim was to study conservation tillage on farm and extrapolate results obtained in the trial to organic cropping systems in different soil and climate conditions of Rhône-Alpes region.

In coherence with production and environmental conditions and the research question, and following the tutorial guide, local experts developed the case-study diagram reported in Figure 5.

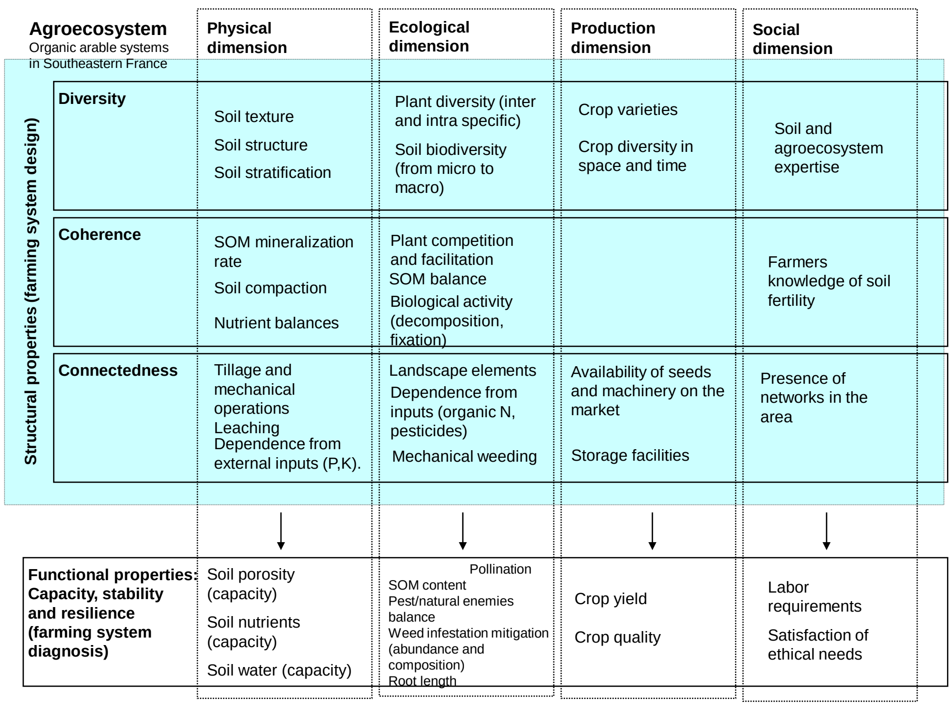

Figure 5. Application of the conceptual framework to assess indicator sets for diagnosis and design of soil-crop-farmer systems in organic arable systems of Southeastern France.

Case-study Tuscany, Central Italy

Arable systems in Tuscany are mostly featured by horticultural crops along the coast and cereals in rotation with grain legumes or, to a minor extent and usually in mixed farming systems, with fodder legumes, in inland hilly areas. The case-study considered in the present application focuses on the cereal-grain legume farming system of Tuscany inland. The Cereal-legume rotations have been the subject of the first Long Term Experiment confronting conventional and organic agriculture in the Mediterranean area, held since 1991 at the Florence University experimental farm of Montepaldi (named MOLTE, http://www.dispaa.unifi.it/vp-463-molte.html?newlang=eng). Climatic conditions of the experimental area are representative of Tuscany inland and are typical of the Mediterranean sub-Apennines zone with an annual rainfall of about 770 mm. Farmers of the area face soil fertility degradation problems due to relatively small presence of animal farms and consequent scarcity of manure availability. At the moment green manuring is not considered an option due to the combination of high seed prices, income loss and scarce availability of machinery and knowledge. The phenomenon of soil fertility degradation is mainly contrasted through the use of reduced tillage techniques, which was the subject of FertilCrop dedicated experiments at MOLTE.

In coherence with production and environmental conditions and the research question, and following the tutorial guide, local experts developed the case-study diagram reported in Figure 6.

	Agroecosystem	Physical dimension	Ecological dimension	Production dimension	Social dimension
Structural properties (farming system design)	**Diversity**	Soil texture diversity Soil stratification	Plant/Earthworms Carabids/Slugs diversity Organic and green manure potential	Mechanization potential for reduced tillage Crop diversity	Expertise potential
	Coherence	NPK balances Decrease of soil fertility due to soil loss	Ecological infrastr. area SOM balance Soil fertility with spade test	Forage self-supply Vertical integration	Family labour input Farmers knowledge of soil fertility
	Connectedness	Synthetic fertilizer import Depend. on ext.inputs-physic.	Part of ecological network Depend. on ext.inputs-org.	Percentage of expenses for organic and green manure and mechanization on gross margin	Presence of farmers groups in the area Level of participation
Functional properties: Capacity, stability and resilience (farming system diagnosis)		Soil porosity (capacity) Soil nutrients (capacity)	Root length Pest infestation SOM content Biological porosity	Crop emergence Crop yield	Satisfaction of family needs Life quality

Figure 6. Application of the conceptual framework to assess indicator sets for diagnosis and design of soil-crop-farmer systems in organic arable systems of Tuscany, Italy.

Case-study Lithuania

Green and animal manure fertilisers are tools for supporting nutrient cycling in low-input systems. Obviously, legume-based green manuring techniques are if possible even more important in stockless organic farming systems because they are the unique source of nitrogen for the crops. Indeed, yield benefits to subsequent crops are the major component of pre-crop value of legumes; however, management of legumes is complicated and their employment in crop rotations is insufficient in extreme Northern European environmental conditions. Furthermore, applying to crops only the nitrogen fixed by legumes is not sufficient to cover the nitrogen needs of following crops along the whole length of the vegetative cycle. It is therefore important to find out measures that may contribute to increase and stabilize grain yield, to support quality improvement and to foster soil fertility. Experiments of the Lithuanian case-study were carried out on a loamy Endocalcari-Ephypogleyic Cambisol and on a heavy loam Cambisol. The study aimed to combine legumes (as green manure) and innovative forms of organic fertiliser as cow manure pellets and to find out their impact on spring cereals productivity and soil fertility.

In coherence with production and environmental conditions and the research question, and following the tutorial guide, local experts developed the case-study diagram reported in Figure 7.

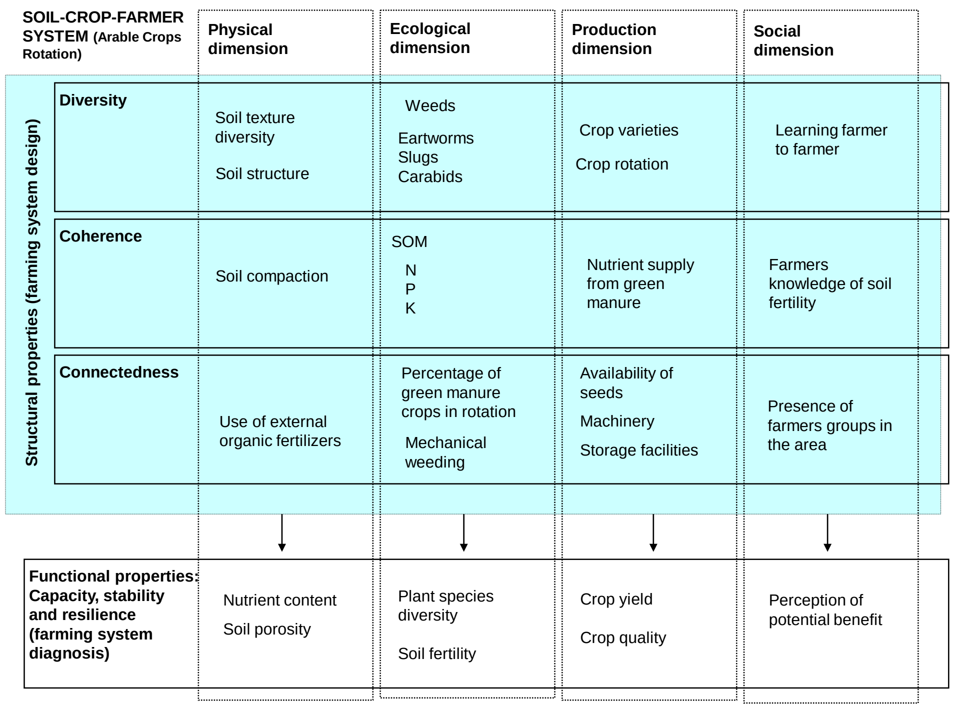

Figure 7. Application of the conceptual framework to assess indicator sets for diagnosis and design of soil-crop-farmer systems in organic arable systems of Lithuania.

Case-study Catalonia, North-Eastern Spain

Gallecs is a rural area in which organic farmers are constituted in a farmer's union. The environment is that of typical dryland rainfed arable fields, managed for cereal and legume production for human consumption. The farms are devoted to arable production, so all fertilizer must be imported, either in farmyard manure or other forms allowed by organic farming regulations. The farmer's union establishes a coordinated system of crop rotation, ensuring the overall supply of the different grains, and facilitating the short market channels for commercialization. Furthermore, the managing consortium has also been very involved in the crop rotation design, the consolidation and follow-up of organic farming implementation. Moreover, there is a food processing facility that operates in place, and sells directly to retail consumers. The whole project tries to become a keystone actor in local public life, as well as a reference for organic farming in Catalonia.

In coherence with production and environmental conditions and the research question, and following the tutorial guide, local experts developed the case-study diagram reported in Figure 8.

Organic arable system in Gallecs	Physical dimension	Ecological dimension	Production dimension	Social dimension
Structural properties (farming system design)				
Diversity	Soil texture Soil structure Soil stratification Carbonate content	Plant diversity Soil biodiversity (microorganisms & earthworms) Rooting	Potential for reducing tillage Crop diversity Crop rotation Crop mixtures	Learning farmer to farmer
Coherence	NPK balances Carbonate precipitation Soil compaction	SOM mineralisation Nutrient cycling	Seed self-supply Nutrient supply from green manures	SAT (Agrarian Trade Society) Farmers knowledge of soil fertility
Connectedness	Exogenous manure Soil loss Other organic fertilizer import	Landscape elements (field margins) Dependence on external organic inputs	Seed exchange Fodder production Market products Manure acquisition	School lunchrooms Environmental education Agroecological lighthouse Short market channels
Functional properties: Capacity, stability and resilience (farming system diagnosis)	Soil depth Water content at different depths Soil nutrients at different depths Bulk density at different depths	Rooting depth Weed abundance SOM content Microbial biomass MO decomposition (TBI) Crop growth	Crop quality Crop yield	Labor requirements Perception of potential benefits (Environmental & health)

Figure 8. Application of the conceptual framework to assess indicator sets for diagnosis and design of soil-crop-farmer systems in organic arable systems of Catalonia (NE of Spain).

Case-study Northern Spain

INPUT Jordi

In coherence with production and environmental conditions and the research question, and following the tutorial guide, local experts developed the case-study diagram reported in Figure 9.

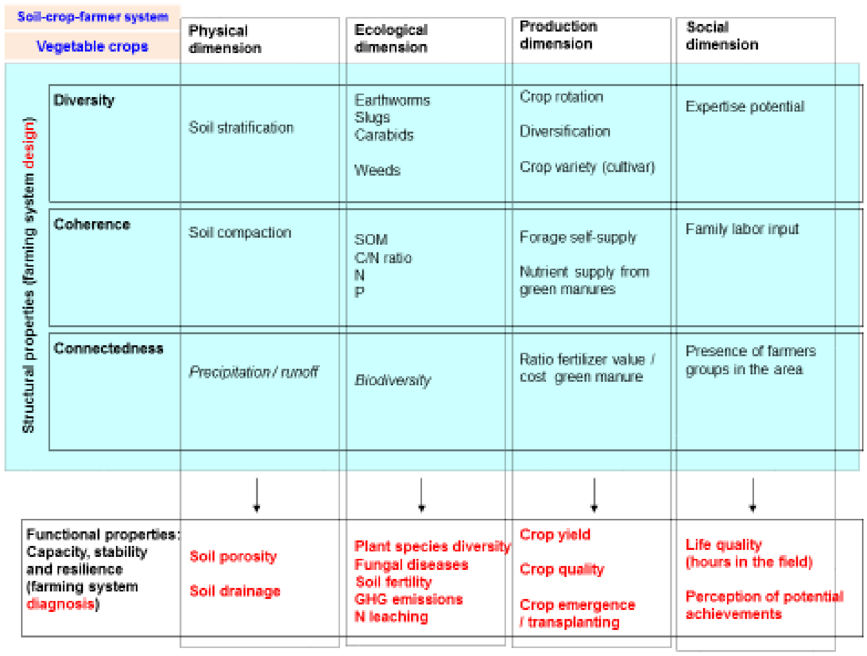

Figure 9. Application of the conceptual framework to assess indicator sets for diagnosis and design of soil-crop-farmer systems in organic vegetable systems of North-Spain.

Overall FertilCrop indicator diagram

Based on experiences of case-studies covering different areas in the EU, a Fertilcrop overall diagram was assembled, which is reported in Figure 10.

		Physical dimension	Ecological dimension	Production Dimension	Social dimension
Structural properties (farming system design)	**Diversity**	Spatial variability of soil texture, pH, electrical conductivity, temperature, total lime *Water source diversity* *Spatial variability of carbonate content*	Plant diversity (inter and intra-specific), Soil biodiversity (from micro to macro, including Earthworms, Carabids, Slugs) Organic and green manure potential Extra-soil biodiversity (pollinators, insects for pest control)	Mechanization potential for reduced tillage *Crop varieties* *Crop diversity in space and time* *Intercropping* *Cover crops*	*Soil and agroecosystems expertise potential (farmers, scientist, advisors)*
	Coherence	Soil permeability and water infiltration Soil organic matter mineralization rate Soil penetration resistance Bulk density Soil stratification *NPK balances* *Carbonate precipitation* *Decrease of soil fertility due to soil loss*	Soil fertility with spade test SOM balance, input C/N ratio Microbial actifvity (decomposition) Soil cover *Plant competition and facilitation* *Ecological infrastrastructure area* *Microbial actifvity (fixation)* *Root depth*	*Forage self-supply* *Vertical integration* *Nutrient supply from green manures* *Seed self-supply*	*Family labour input* *Farmers knowledge of soil fertility* *Farmers memory of the field history*
	Connectedness	*Synthetic fertilizer import* *Soil loss* *Precipitation / runoff* *Dependence from external inputs - physical (P,K)* *Nitrogen leaching* *GHG emissions*	*Part of ecological network* *Landscape elements* *Dependence from external inputs – organic (organic N, pesticides)*	*Rate of expenses for organic and green manure and mechanization on gross margin* *Availability of seeds, machinery and manure on the market* *Storage facilities* *Seed exchange* *Recycling of waste and residues* *Short chain and global market channels*	*Presence of networks, including educational, in the area* *Level of participation, including to farmer groups* *Farmer-to-farmer learning* *Farmer cooperation*
Functional properties: Capacity, stability and resilience (farming system diagnosis)		Soil moisture at different depths Soil porosity Soil nutrient contents (N,P,K,S) Soil mineral N spring Added available N *Soil water holding capacity*	Weed density, biomass & cover Root length and density Pest&natural enemies incidence SOM content Biological porosity Microbial biomass Habitat for above-ground organisms *Pollination*	Crop emergence Crop growth (water and nutrient uptake) Crop yield&density Plant sap nitrate Chlorophyl content on leaves Chlorophyl fluorescence Crop quality	*Labour availability* *Satisfaction of ethical needs* *Life quality* *Perception of potential achievements* *Perception of potential, environmental and health benefits* *Consumer-farmer collaboration*

Figure 10. Conceptual diagram including indicators for sustainability assessment of technology adoption in selected EU organic soil-crop systems. Note that the functional properties are combined in one row.

Legend: standard letter format, initial set of FertilCrop indicators; italic letter format, additional indicators identified by using the conceptual framework.

Overall, 51 indicators were considered for analyses in Fertilcrop. The application of the framework to Fertilcrop case-studies highlighted a sub-optimal coverage by Fertilcrop indicators of main structural properties (diversity and coherence) and functional properties concerning the physical (or abiotic) and ecological (or biotic) dimensions. Indicators of crop productivity were also highly considered. However, the application also highlighted opportunities for further improvement of the indicator set towards a properly holistic assessment of soil quality in soil-crop systems, which might be the subject of future research. Overall, 56 additional, potentially useful indicators were proposed by Fertilcrop partners while building the conceptual diagrams of corresponding case-studies.

Overall, no indicator was selected in the initial set of Fertilcrop (Figure 10, indicators in standard letter format) to describe social aspects that might have an impact on soil fertility management, such as soil and agroecosystems expertise potential, farmers' knowledge of soil fertility, farmer-to-farmer learning or labour availability.

No indicator was selected in the initial set of Fertilcrop concerning the structural property of connectedness, meaning that relationships with components outside the agroecosystem are disregarded, including e.g. the ability of ecosystems to supply important ecosystems services such as provision of beneficial insects and plants. This latter aspect was disregarded also at the level of agroecosystems, where no information was included on ecological infrastructure areas.

Regarding the production dimension of structural properties, it has to be noticed that it is poorly represented in the FertilCrop dataset (only one indicator, i.e. mechanization potential for reduced tillage), while it is widely considered with concern to functional properties.

4. Crosschecking indicators with tools and methods

In order to verify how FertilCrop would be able to approach indicator-based assessment of soil quality, we first crosschecked the overall set of indicators resulting from the combination of the initial set of FertilCrop indicators and of the set of additional indicators identified by using the conceptual framework (Figure 10), with the tools as presented in the document "Task 3.3. list of tools for practical assessment of soil quality". Next, the overall set of indicators of Figure 10 was crosschecked with measurement methods reported in D1.2 "FertilCrop handbook of methods". The final aim of crosschecking was to verify for which indicators among those selected for systemic assessment a tool for practical assessment or a measurement method was available, and for which not.

Results of crosschecking are reported in Figure 11. Practically, for each of the indicators listed in the initial set of FertilCrop a tool or a method of measurement was identified and reported either in M3.1 "Collection of tools for visual soil observation and interaction with crops" (also named "List of tools for practical assessment of soil quality") or in the D1.2 FertilCrop handbook of methods.

	Physical dimension	Ecological dimension	Production Dimension	Social dimension
Structural properties (farming system design)				
Diversity	Spatial variability of soil texture, pH, electrical conductivity, temperature, total lime *Water source diversity* *Spatial variability of carbonate content*	Plant diversity (inter and intra-specific), Soil biodiversity (from micro to macro, including Earthworms, Carabids, Slugs) Organic and green manure potential Extra-soil biodiversity (pollinators, insects for pest control)	Mechanization potential for reduced tillage *Crop varieties* *Crop diversity in space and time* *Intercropping* *Cover crops*	*Soil and agroecosystems expertise potential (farmers, scientist, advisors)*
Coherence	Soil permeability and water infiltration Soil organic matter mineralization rate Soil penetration resistance Bulk density Soil stratification *NPK balances* *Carbonate precipitation* *Decrease of soil fertility due to soil loss*	Soil fertility with spade test SOM balance, input C/N ratio Microbial actifvity (decomposition) Soil cover *Plant competition and facilitation* *Ecological infrastrastructure area* *Microbial actifvity (fixation)* *Root depth*	*Forage self-supply* *Vertical integration* *Nutrient supply from green manures* *Seed self-supply*	*Family labour input* *Farmers knowledge of soil fertility* *Farmers memory of the field history*
Connectedness	*Synthetic fertilizer import* *Soil loss* *Precipitation / runoff* *Dependence from external inputs - physical (P,K)* *Nitrogen leaching* *GHG emissions*	*Part of ecological network* *Landscape elements* *Dependence from external inputs – organic (organic N, pesticides)*	*Rate of expenses for organic and green manure and mechanization on gross margin* *Availability of seeds, machinery and manure on the market* *Storage facilities* *Seed exchange* *Recycling of waste and residues* *Short chain and global market channels*	*Presence of networks, including educational, in the area* *Level of participation, including to farmer groups* *Farmer-to-farmer learning* *Farmer cooperation*
↓	↓	↓	↓	↓
Functional properties: Capacity, stability and resilience (farming system diagnosis)	Soil moisture at different depths Soil porosity Soil nutrient contents (N,P,K,S) Soil mineral N spring Added available N *Soil water holding capacity*	Weed density, biomass & cover Root length and density Pest&natural enemies incidence SOM content Biological porosity Microbial biomass Habitat for above-ground organisms *Pollination*	Crop emergence Crop growth (water and nutrient uptake) Crop yield&density Plant sap nitrate Chlorophyl content on leaves Chlorophyl fluorescence Crop quality	*Labour availability* *Satisfaction of ethical needs* *Life quality* *Perception of potential achievements* *Perception of potential, environmental and health benefits* *Consumer-farmer collaboration*

Figure 11. FertilCrop coverage of tools and methods for measurement of indicators of soil quality assessment. Note that the present figure was obtained by superimposing information on availability of tools and methods on the indicator diagram reported in Figure 10. Legend: standard letter format, initial set of Fertilcrop indicators; italic letter format, additional indicators added by using the conceptual framework; green background, tools available in the list of tools for practical assessment of soil quality; orange background, methods available in the handbook.

In Table 2 the list of tools for practical assessment of soil quality is reported together with corresponding, potential target groups. Potential target groups were identified by local experts in order to understand which tools might be of interest for different types of farms (arable, grassland, vegetable, orchards), could fit different farmer attitudes (farmers oriented to short-term, to long-term, to cash-cropping, to support functional properties, or to invest in structural properties), and/or be attractive for other target groups, including advisors, policy-makers and scientists. For convenience of the reader, the tools were grouped by soil aspect assessed (i.e., soil chemical properties, soil texture, soil structure and other physical properties, soil stratification, soil biology, soil hydraulic properties, soil overall assessment).

The final aim of this table was to understand to which extent farmers, but also additional target groups, could perceive available tools as useful and viable and potentially apply them. In conclusion, first we identified indicators conceptually and theoretically important for systemic assessment of soil quality (Figure 10), secondly we verified if tools and methods exist that can be applied to measure those indicators (Figure 11), and finally we investigated with local experts to which extent the tools are useful for farmers and other potential target groups (Table 2).

In most cases, the tools identified had very broad field of application and thus resulted to be linked to many farm typologies. This was especially true for tools for soil chemical properties, texture biology, hydraulic properties and global assessment. The use of tools related to soil physics were much more restricted to the specific farm type for which they were intended and developed, due to presence/absence of limiting operative conditions (e.g. the usual presence of gravel and stones in orchards makes very hard to use penetrometers to assess soil compaction), but also to the specificity of the study conditions and aims (e.g., spade test as the VESS method were intended for assessing soil structure in the first 30 cm of depth, then they are not useful for deeper soils such as those grown with fruit trees or grasslands).

Concerning farmer attitude, according to the expert-based evaluations of the tools, none of the tool was retained to be uniquely related to one kind, due to the previous mentioned high versatility of the tools, which is definitively one of their main advantages. The same tool can be actually operated both for assessments led by short-term needs (e.g. to assess the effect on soil structure of a recent tillage operation) or longer term issues, such as the sustainability of a certain cropping system in terms of organic matter content and soil structural stability. Tools for assessing soil physical properties and overall soil quality were thought to be mostly related to long-term oriented farmer approach, considered that the soil physical quality is not always clearly perceived by farmers as a key element of soil fertility and, in particular for sustaining crop growth. On the opposite, measurements related to soil water content were much more based on short-term needs (e.g. the proper management of irrigation of a certain crop at a given time of the year). In these terms, water pool can be considered as a dynamic component of soil functional properties, whilst soil structure stability and porosity much closer to a structural property of the soil. This could be confirmed by the fact that this kind of tools also match needs of farmers much prone to cash crops, i.e. targeted to crop production and maximized income through the implementation of intensive cropping systems. Obviously, farmers oriented to invest more on functional properties than on structural properties would be more prone to use these kind of tools, whilst the other tools could be linked to both categories of farmers or only to farmers more focused on structural properties and long term sustainability (stability) of crop production.

Most of the tools could be brought to farms by the intermediation of advisors, i.e. operators who share practical implication of soil assessments with farmers (i.e. their customers) but at the same are also aware of the background of the tools like scientists are too. Only few of the tools selected and/or tested in Fertilcrop were for the exclusive use of stakeholders other than farmers (e.g. policy makers or scientists). Policy makers could be retained much more interested to tools able to cover wide portion of the land they manage and, at the same time, being very informative and easy/cheap to assess by public bodies/agencies. Examples of this kind are tools related to remote sensing (e.g. soil roughness or water content estimated through satellite imagery). On the other hand, scientists could be more interested to use much sophisticated tools able to predict very detailed aspects of soil fertility (e.g. X-ray tomography) or tools allowing them to obtain proxy measures of studied complex variables (e.g. visual soil cover could replace more costly biomass samplings or weed counts). What is clear from Table 2 is that collaboration with scientists is crucial for the proper application of many tools and for the useful interpretation of their results. Nonetheless, for a big portion of the tools the involvement of scientists could be much important only in the training phase, when end users have to acquire more skills in order to be able to operate the tools in complete autonomy. The role of scientists could be also crucial for the further development of the tools and for the intake of farmers' needs and perceptions.

5. Conclusions

The objective of task 7.1 was to carry out a scientific assessment of farmer-oriented indicators and tools for the diagnosis and design of soil and crop management strategies in organic farming systems.

We decided to do it by applying a systems perspective to the soil-crop-farmer system and check if the initial set of FertilCrop indicators, the one that was anticipated to guide field experiments, was able to cover relevant system properties and dimensions. Although the set of indicators tested in FertilCrop experiment proved to be well-refined and robust concerning main properties and dimensions, our assessment revealed that there would be space for further extension of the indicator set towards properties and dimensions not directly connected to the soil-crop system but important in terms of the potential impact they could have on it.

It has to be noticed that many of the indicators added after assessment of the initial FertilCrop set could be already now calculated based on data collected for other indicators or from information collected with case-study surveys. Hence, no additional information would be needed; rather, we now have in disposal additional tools, i.e. the overall FertilCrop and case-studies' indicator diagrams, to guide further data processing, to systematize information and to communicate results.

The results of this conceptual effort constituted a consistent part, including an example of the FertilCrop indicator diagram, of an article accepted for publication by the Editorial Board of the Elsevier Encyclopedia of Sustainable Technologies (Pacini and Groot, 2017).

In Deliverable 7.1 we also verified coherence between the set of FertilCrop indicators and the tools and methods identified and tested in corresponding tasks and deliverables of other workpackages. Regarding tools, we also enquired on their potential adequacy for different farm types, farmers showing different attitudes and other target groups. We believe this work is propaedeutic to the next steps of FertilCrop concerning on-farm testing of tools and perception of the importance of the tools by farmers and other target groups in the course of soil quality evaluation exercises.

Table 2. List of tools with corresponding target groups

Tool[1]		Target Groups: Farmers: Farm Type[2]	Farmer attitude[3]	Other target groups[4]
	Tools for soil chemical properties			
A	Soil pH - Colorimetric test (1)	A	All	Ad
B	EC-probe for salinity measurements (28)	A	ST/LT, CC, FP	Ad, PM, Sc
C	Total lime content test (32)	A	LT/ST, CC, FP	Ad, Sc
D	Visual appreciation of soil $CaCO_3$ content in soil profiles (46)	A	LT, SP	Ad
	Tools for soil texture			
A	Soil texture feeling test (2)	A	LT/ST, SP	Ad
B	Texture by feel (18)	A	LT/ST, SP	Ad
C	Sieve - gravel content (25)	A	LT, CC, SP	Ad
	Tools for soil structure and other physical properties			
A	Penetrometer test (3)	Ar, V, G	ST/LT, CC, FP	Ad
B	X-ray Tomography (6)	A	LT, SP	Sc
C	Soil corer - Bulk density (15)	A	LT, SP/FP	Sc
D	Photogrammetric analysis of soil roughness (17)	Ar	LT, SP/FP	PM, Sc
E	Soil cylinder - Bulk density (24)	A	LT, SP/FP	Ad, Sc
F	Wet aggregate stability method (29)	Ar, V	LT, SP	Sc
G	Soil thermometer (31)	A	LT/ST, CC, FP	Ad, Sc
	Tools for soil stratification			
A	A spade method (4)	Ar, V	LT/ST, SP/FP	Ad
B	VESS (8)	Ar, V, G	LT/ST, SP/FP	Ad, Sc
C	SubVESS (9)	O, G	LT, SP	Ad, Sc
D	Soil profile method (11)	O, G	LT, SP	Ad, Sc
E	Spade test – qualitative method (13)	Ar, V, G	LT/ST, SP/FP	Ad, Sc
F	Assessing soil quality (40)	A	LT/ST, SP/FP	Ad
	Tools for soil biology			
A	Earthworm sampling with mustard (10)	A	LT, SP/FP	Ad, Sc
B	Soil respiration test (19)	A	ST/LT, SP	Sc
C	Soil color chart (30)	A	LT, SP	Ad
D	Soil organic matter - hydrogen peroxide test (33)	A	LT, SP/FP	Ad
E	Teabag test (45)	A	LT, SP/FP	Ad, Sc
F	Weeds as indicators of soil fertility (47)	A	LT/ST, FP	Ad
G	Weeds as bioindicators of soil fertility (48)	A	LT/ST, FP	Ad
H	Fertimeter® (49)	A	LT, FP	Ad, Sc
	Tools for soil hydraulic properties			
A	Infiltrometer (12)	A	LT/ST, CC, SP/FP	Ad, Sc
B	Infiltration test (20)	A	LT/ST, CC, SP/FP	Ad, Sc
C	Soil water content - Thermogravimetric method (21)	A	ST, CC, FP	Ad, Sc
D	Soil water content - TDR - Time Domain Reflectometry (22)	A	ST, CC, FP	Ad, Sc
E	Soil water content - Remote sensing (23)	A	ST, CC, FP	Ad, PM, Sc
F	Hydraulic conductivity test kit, model Hooghoudt (26)	A	ST, CC, FP	Ad, Sc
G	Guelph constant head permeameter (27)	A	LT, SP	Ad, PM, Sc
	Tools for global soil assessment			
A	VSA with spatial statistics (5)	A	LT, SP	Ad, PM, Sc
B	BoBi-MCA (7)	G	LT, SP	PM, Sc
C	VSA (14)	A	LT/ST, SP/FP	Ad, PM
D	Smell test (35)	A	LT, SP	Ad
E	Visual soil cover (36)	A	LT/ST, FP	Sc
F	Visual soil cover with imagery (37)	A	LT/ST, CC, FP/SP	Ad, PM, Sc
G	Cornell Soil Health Assessment Training Manual (38)	A	LT, SP/FP	Ad
H	World Reference Base for Soil Resources (39)	A	LT, SP/FP	Ad, PM, Sc
I	New Jersey Soil Health Assessment Guide (41)	A	LT/ST, SP/FP	Ad
J	Soil Management: Soil Health Check (42)	A	LT/ST, SP/FP	Ad
K	NASA's Globe soil characterization Centre (43)	A	LT/ST, SP/FP	PM, Sc
L	ThinkSoil (44)	A	LT/ST, SP/FP	Ad

Legend:
[1]Values within brackets are the original ID number of each tool in the D3.4 “Task 3.3. list of tools for practical assessment of soil quality”
[2]Farm type: A, any; Ar, arable; G, grassland; V, vegetable; O, orchards (including also vineyards and olive plantations).
[3]Farmer attitude: ST, farmers oriented to short-term; LT, farmers oriented to long-term; CC, farmers oriented to cash-cropping; FP, farmers oriented to support functional properties; SP, farmers oriented to invest in structural properties.
[4]Other target groups: Ad, advisors; PM, policy-makers; Sc, scientists.

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