WUR Student Challenge

iSQUAD:

Integrated Soil QUality and Awareness Diagram for overall soil health assessment

by Team TERRApist

Wageningen University & Research Student Challenge:

Make all soils healthy again!

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Contents

1 Introduction

What is soil health? It might seem a bit strange to attribute health to something that is seemingly lifeless. Soils, however, are far from being just a non-living entity as they house millions of organisms, from micro to macro. Humans —similarly to most organisms (Berne et al, 2014)— depend deeply on soils, although most of us might not be aware of it. In this section we would like to reflect on the meaning of soil health, and its connection with today's environmental demands and the UN Sustainable Development Goals (SDGs). The section intends to boil down the concept of soil health as it is present today, to connect it with the design directives we took to build our proposition for the WUR student challenge.

To start with, soil health within the WUR student challenge is defined as *"the capacity of a specific kind of soil to function, contributing towards achieving the UN Sustainable Development Goals (SDGs)"*. We will stick with this definition, since a formal definition lacks for the European Union. In the upcoming EU-wide program Horizon Europe, however, one of the five missions prioritized reads *"Soil health and food"* (EU, 2020). This mission aims to *"provide a powerful tool to raise awareness on the importance of soils, engage with citizens, create knowledge and develop solutions for restoring soil health and soil functions"*. Since the mission's aim motivated WUR student challenge, we used it together with the challenge's definition of soil health to render the design principles that guided us when we conceptualized the tool now proposed in Section 2.

From the definition of soil health and the EU mission's aim, the concept of soil health can be thought of as a status which renders its capacity or incapacity to carry out its designated functions. In this regard, seven soil functions has been identified by the EU:

- biomass production, including in agriculture and forestry;
- storing, filtering and transforming nutrients, substances and water;
- biodiversity pool, such as habitats, species and genes;
- physical and cultural environment for humans and human activities;
- source of raw materials;
- acting as carbon pool;
- archive of geological and archeological heritage.

The list above demonstrates the EU concerns and recognition on the importance of soils in several aspects of human and environmental well-being. By these means, the EU recognises the crucial role of soils for the ecosystem. This echoes scientific concerns (Keestra et al., 2015). In other words, our existence and way of life is tightly bound to soils and we depend on them for several reasons not necessarily bound to soils as source of food or raw materials. Therefore, we should safeguard the overall health of soils urgently to ensure the well-being for generations to come. Ensuring that soils are healthy would only have beneficial consequences to society. In other words, securing healthy soils would pave the way to improving the quality and leading to a better life.

Achieving the aim of the upcoming EU mission on soil health and food demands to build "a powerful tool" that must relate to all soil functions. Further, a sufficient solution to the EU mission's aim must involve a multidisciplinary approach in order to cater to the multi-faceted nature of soil functions. In this regard, the "powerful tool" should be flexible enough to integrate or merge existing frameworks that have been developed for a wide-range of related disciplines.

The EU mission aims to "create knowledge and develop solutions" for soil health and food. This presents an avenue to advance scientific research and to develop novel ideas and enhance our knowledge on various disciplines. Reinforcing stakeholder involvement is implicitly a requirement in order to transform these scientific knowledge into solutions that will be relevant to society. The EU mission uses the verbs "to create" and "to develop" to define its aim, which evoke the idea of potentiality and dynamic states. The verb choice reinforces the idea of soil health as status, and thus it conveys another requirement for the tool: it must be reusable for different statuses of soil health and allow future re-assessments. Assessment of soil health should then follow a cyclical pattern, and not a linear approach, such that new knowledge can be used to update the status of soil health through new or repeat soil assessments. With all said, we set out five design principles to lead our proposition:

- The tool should be applicable now, without further research;
- It should involve a multidisciplinary assessment, encompassing socio-ecological factors as well as soil physical condition;
- It should collapse all the information into a one index easily understandable by all actors, facilitating social engagement.
- Its use should diagnose knowledge gaps, and propose improvements;
- Its application should lead to an improved version of itself usable in subsequent assessments.

Using this guidelines, we propose an integrated framework that builds on EU aspirations and combines existing methods to assess soil quality and societal perceptions as a tool to measure overall soil health. We argue that this framework will be equally beneficial to society, managers, policy makers, and the scientific community. The addition of a socio-ecological dimension, on top of soil quality assessment, will only result in beneficial consequences for soil health and is therefore considered as the missing piece in solving the challenging soil health puzzle.

2 Integrated Soil QUality and Awareness Diagram (iSQUAD)

We present a new framework which combines technical/scientific and societal dimensions for a complete assessment of soil health. This integrated approach will allow active participation of different sectors and is seen to benefit all stakeholders. The following sections provide a detailed description of the proposed framework. Two major elements —soil quality and societal perception assessments are first described since they provide the building blocks for the proposed approach. Followed by a section that describes how these two concepts can be connected within iSQUAD. The last section lists examples of studies that were deemed to be naively fitting the proposed framework.

2.1 Why do we need an integrated approach for soil health assessment?

Similar to mental health, there are different facets of soil health. Such as in an assessment of medical health, different tests are needed in order examine the "overall" health of one person. In the last decades, an intangible aspect of one's health, mental health has taken some serious attention after being ignored or set aside from the long standing frameworks for medical health assessment. Similarly, soil health needs to be treated in an integrative approach. It is imperative to change the existing frameworks to include other external dimensions to strengthen future methods for soil health assessment. We propose that this can be done by integrating the scientific and societal dimensions for soil health.

Soil and land management practices have been tightly connected with agricultural production and resource management (Bouma, 2002), including yield, greenhouse gases, recycling of nutrients, amelioration or water cycle management. However, the objective of sustainable land management (SLM) is to harmonize the goals of the sustainability pillars: environment, economic and social dimensions (Wood & Dumanski, 1994). While guaranteeing the access of present and future generations to the essential land resources, SLM practices aim to meet, continuously changing, human needs (such as agriculture or forestry).

The pillars of SLM are then the basic principles for the sustainable development and the foundation for the practices of land managers and decision-makers. These can be operationalized through different tools, frameworks, technologies, policies or activities, with the purpose to achieve a balanced use of the land resources. In a SLM approach, one pillar (environment, social and economic) cannot be prioritized over the other, as they are intrinsically dependant on each other (Boyer, Peterson, Arora, & Caldwell, 2016; Kidd, 1992). For example, the protection of a certain natural resource should consider not only the economic consequences but as well the social acceptability of measures. The definition and pillars have been field tested in several countries, and they were judged to provide useful guidance to assess sustainability.

The lack of a comprehensive, quantifiable definition for SLM is sometimes considered to be a serious deficiency. Yet, as argued by Gallopín (1995), a research model for sustainability has to be more flexible and therefore less easy to quantify than a research model for chemistry, physics, or classical agronomy. At the same time, use of indexes to quantify SLM, while not fully comprehensible, have been widely successfully used for many years now (Bierkens & Burrough, 1993). They can easily convey a message to a multidisciplinary audience and contribute positively for awareness raising of key aspects. Currently, most innovation in science is led by societal impact (Bornmann, 2013). However soil science, due to soil system complexity, still needs to improve quite significantly the perception and understanding that society has towards the functions and importance of soil.

As soil health is then the status in which a soil can perform or not its functions, it is a concept that can be easily understandable by a broader audience. The focus on the capacity to perform well or not is easily graspable, whereas understanding the value of a quantifiable indicator can heavily depend on technical knowledge for interpretation. Therefore, having an integrated approach that can combine the knowledge from soil quality with societal perception is key for performing better SLM practices.

2.2 On the need to expand the soil quality concept

Researchers and managers have chased a silver hammer to convey soil value and potential in a "one fit all" index for decades. In this regard, the concept of soil health is not new and can be traced back to 1960s when the idea of "soil capability" aroused. The idea of soil capability mutated along the last decades, expanding to soil quality and now to soil health. We would like in this section to explore the connections between those closely related terms, setting the grounds for a what-is-new discussion in the following sections.

Back in 1961 the Soil Conservation Service of the US Department of Agriculture (USDA) published a handbook introducing the land capability concept. The idea behind it was to summarize soil properties by creating interpretative groupings *"to make possible broad generalization based on soil potentialities, limitations in use, and management problems"* (Klingebiel and Montgomery, 1961). The concept targeted primarily productive lands and, with such a scope, it was strongly connected with productivity as understood by agronomists. In a nutshell, the USDA concept aggregated soil units in an index from 1 to 8 according to their capability to produce common crops and pastures without deterioration over an extended period. It comprised both productivity potential and sustainability in one index intended for decision making. However, the connection with soil loss was abstract and it lacked other components to escalate the concept's use beyond crops to other productive schemes, such as tree orchards or forestry.

Due to these limitations, the Food and Agricultural Organization (FAO) expanded the soil capability concept broadening its scope and deepening the connection between soil potential, use, and sustainability (FAO, 1976). Mostly, FAO simplified the index binding it with the universal soil loss equation (USLE, USDA, 1965). By these means, FAO made tangible the connection between soil erosion and soil capability. They used a new term; land suitability, defined as *"the fitness of a given parcel of land for specific* *uses"*. This new term was also a new index, useful for agronomist to evaluate the viability of a given project. What was lost, however, was the independence of the index from the crop produced (*specific uses*), and its applicability at a broad scale (*given parcel*). The FAO framework expanded worldwide, and it is used until today to plan either land conservation strategies at basin scale (e.g. AbdelRahman and Arafat, 2020) or the placement of a given crop within a region (e.g. Sobczyński et al., 2020).

However, erosion is only one way of soil loss, and soil scientists and land managers knew it. In the 1990s a new term was born by the hand of the Dutch government: soil quality (see Howard, 1993 for a comprehensive narrative of the term origins). Although at the beginning it held a blurry definition, "soil quality" was understood as the capacity of a soil to function within ecosystem and land use boundaries. Moving away from its erosion constrains, the new index had to deal with summarizing several soil quality indicators. This was a titanic work, as each indicator had to be defined along with a method to aggregate all indicators into the final index.

After a few years, the USDA offered one of the first frameworks to assess soil quality (USDA, 2001). In it, they recognised that *"soils vary naturally in their capacity to function; therefore, quality is specific to each kind of soil"*. With such a premise, they had to drop the idea of a one fit all index considering it was impossible to achieve. They offered a method that used a subset of indicators for a given productive scheme to suggest best management practices for that given situation. It was not, therefore, an instrument for planning as much as it was an instrument for agronomists (e.g. Andrews at al., 2004).

Land managers had to apply the soil quality concept in a different way for it to be useful for planning in a broader geographical scale. They persisted in the idea of producing one final index that, once plotted in a map, would facilitate decision making. The approach that dominated was to combine the indexes using a weight function (Smith et al., 1993). The problem was, however, that the weigh function had to be defined for a certain area, as indicators' relevance change along with the physical environment that surrounds production (Oluwatosin et al., 2006). Moreover, to train a model, modelers needed a variable to regress, and they took crop yield as it was the best candidate. This represented an additional problem since they needed a standard way to represent yield. Although one way could be to use one (standard) crop, this approach is inconvenient as it can be applicable only at local scale where one crop dominates the market. This counteracts the intended purpose of use soil quality in a broader geographical context. Despite its limitations, this is the most common solution to date (see de Paul Obade and Lal, 2016 and de Paul Obade 2019).

Both approaches to present soil quality persist to date, and governments actively push them forward (see Karlen et al., 2019). However, they place the focus in productivity and cannot be used where land does not produce (direct) income. They are good indexes for managers to decide whether a practice would be beneficial and optimize sustainable production. However, they do not provide a tool for planning since they do not convey other relevant soil functions, such soils as physical and cultural environment for humans and human activities. In this regard, the integration of society to land management stands as a standalone discipline that deals the most with rural development and neglects a quantitative connection with soil quality. Here is where we would like to give our contribute.

Although the concept of soil quality is not new, we believe that future endeavours should expand the concept beyond its traditional link with productivity. It is now known that soils carry a variety of functions for society, and is not necessarily restricted to agricultural productivity. The new index should reflect this knowledge. Anyhow, the accumulate knowledge on soil quality should be the corner stone of a new and extended soil health framework. A framework that should encompass different soil functions.

As we review, the improvement of soil quality is not a trivial task. A framework that considers all soil functions while provides single numerical values to guide decision making might be only a dream. However, it can be —and surely is for the EU mission— placed as a final goal. A goal that demands continuous efforts to improve how we measure. In this regard, we believe that focusing on societal engagement and assessment of societal perceptions is one of the directions that need to be taken in this expansion of soil health towards other —non-productive— soil functions, as this will have positive cascading impacts for the improvement of the future environmental and human well-being.

2.3 On the challenges of societal perception assessment

Public perception describes the general appreciation, or lack thereof, of certain (environmental) issues that have direct or indirect impacts to society. Assessment of public perception can also reveal different perspectives of stakeholders or groups based on aspects that they deem is of most value. Consequently, public perception assessment identifies and highlights key variables that are potentially useful for researchers or policy-makers in addressing and identifying effective solutions.

Data on public perception are commonly obtained from detailed and targeted surveys that aim to extract information with specific goal in mind. Statistical methods are applied to the survey's results that identify important variables underlying the specific issue. Some of the techniques include using AHP, multivariate statistics or PCA analysis.

Measurement of public perception has been applied to medical, environmental and societal issues. For example, perceptions of behaviour or public reaction during an influenza's pandemic uncovered key variables that helped evidence-based decisions for both health experts and policymakers (Rubin et al, 2014). Within the energy industry, public perceptions for the natural gas industry uncovered that residents in areas with mature natural gas industry had more negative perceptions than those living in a n area where it is less established (Theodori, 2012). In ecological management, public perceptions about non-native evasive plant species in the Netherlands was investigated van Brugge et al. (2013) in relation to perceived risk, control and engagement. They concluded that lay public perceptions of non-native species have to be put in a wider context of visions of nature in order to gain public support for invasive species management. In the topic of climate change, a study conducted by Semenza et al (2008) indicated that while the awareness about climate change is virtually universal, they found that there are several cognitive, behavioural, and structural obstacles to voluntary mitigation. Individual-level mitigation can be a policy option under favourable contextual conditions, as these results indicate, but must be accompanied by mitigation efforts from industry, commerce, and government.

Arguably, assessment of public's perception of soil health is less commonly determined. Although soil and environmental scientists have extensively shown the importance of soils to society, public perceptions of it is largely underrepresented. the scientific community In this regard and since soil functions are not limited to productivity, public perceptions assessments about soils should target all soil functions. This may be one of the key factors for overcoming the difficulty of assessing or further improving methods developed for soil health assessment. The lack of public concern about the on-going soil degradation is hindering science and policy makers in advancing the development of programs and research targeted to improve soil health assessment. After all, relevant scientific research with large societal impacts is one of the drivers future scientific endeavours. The grand challenge, therefore, is to obtain a comprehensive assessment of society's perspective of the overall levels of soil health.

2.4 iSQUAD matrix

2.4.1 How the framework works

Simply put, iSQUAD is a simple matrix that is used to connect the concepts of soil quality and societal perceptions for soil health assessment. We propose that results or outcomes from these two separate aspects need to be simultaneously addressed in order to arrive at a strategy for managers who are responsible for decision-making and implementation. The iSQUAD framework does not hinder or becomes incompatible with current frameworks. Its purpose is to build on existing knowledge and to integrate different dimensions. As most soil quality assessments rely solely on technical and/or performance data, the perception that society has over soil has been residual. Therefore, the iSQUAD framework is a two-dimensional matrix that aims to be easily and reliably understood by a wide range of stakeholders, including the general public (Figure 1).

The iSQUAD matrix operability is dependent on 2 concepts: (1) two-dimensional matrix and (2) use of categorical values. The first is displayed in the axis of the matrix and provides a quantified assessment of the soil health/quality and soil perception by the local stakeholders. These axis can be based on established frameworks and known methodologies to assess soil quality and perception. However, in order to fit the iSQUAD framework, values should be categorical variants. The use of categorical variants allows to compare the performance of both axis and facilitates the communication with stakeholders. Ideally, the approach should be based on quantifiable methods, but one can be applied even without a quantifiable methodology and used to place case studies within each quadrant (Figure 1). Making an effort to use the quadrants as reference from the starting point can help identify suitable actions to focus on and define target goals to ameliorate the current status. One example can be selecting adjusted activities that promote soil quality improvement for a community that is already motivated to preserve soil quality (moving from quadrant 4 to quadrant 1). The matrix's quadrants are the following:

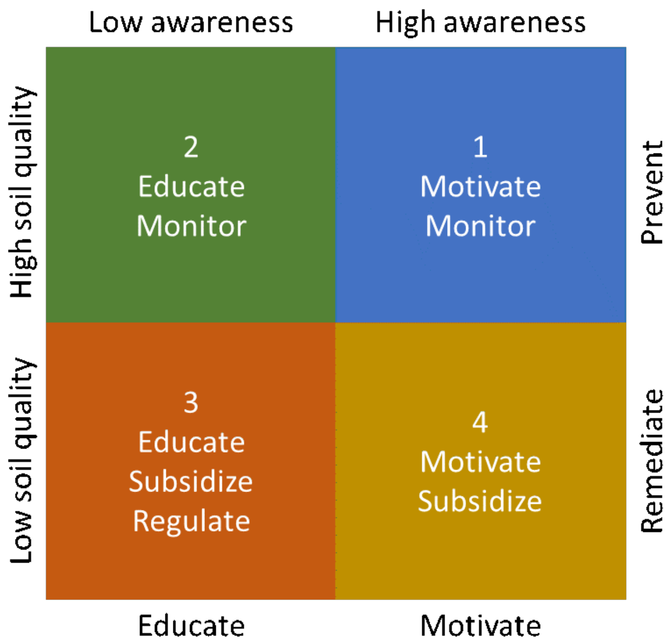


Figure 1: iSQUAD matrix for soil quality and societal perception assessment.

Low awareness and low soil quality. This is the worse quadrant, where the case study has low soil quality indexes and society does not acknowledge soil's relevance (and therefore, little community initiative can be expected). In this situation, there should be adopted mixed solutions that promote soil quality improvement and engage society in those activities. Local governments are the most likely entities to take the lead in this situation as local community might be little empowered to start their own soil quality improvement initiatives. Using regulatory policies that protect soil might be effective on the protection of sensitive areas and help increase awareness of those areas' relevance.

Low awareness and high soil quality. This is a good scenario as solutions should focus on awareness raising and monitoring as soil quality is already in good condition. Improving society awareness of soil's relevance might contribute to reduce costs on the long run with hard regulatory measures. Transparency and communication of monitoring results can play a key function in the promotion and education of the community towards the soil relevance.

High awareness and low soil quality. In this quadrant there is an urgent need to act rapidly towards improving soil quality, as high levels of society awareness towards the soil relevance might lead to discontent towards decision makers. Solutions in the scenario might focus on the empowerment of society to implement individual activities (reducing the burden of local authorities) through, for example, subsidizing or support to local initiatives. At the same time, transparency of progress is key to maintain society trust and motivation.

High awareness and high soil quality. This scenario is the ideal scenario where soil quality is already good and the community is aware of its importance. Nevertheless, there should be actions that stimulate society motivation and engagement, for example, through monitoring initiatives and open communication.

2.4.2 Dynamic soil health assessment with iSQUAD

Since soil health is considered as a status, implying its dynamic nature, a dynamic framework is needed to monitor changes through time because health can degrade or improve, depending on how it is being treated within the community. Regular "check-ups" are necessary to ensure that soils are still able to carry out societal and ecological functions. We can think of soil health assessment as a cycle with three important stages (Figure 2): assessment, decision-making, and action and implementation. The assessment step requires that soil quality and societal perception assessments to be presented together for a comprehensive treatment of soil health, as shown in Section 2.4.1. This stage requires active participation of both research institutes and society to gather sufficient data on soil health. The data will help researchers gain new knowledge about the status of soil health, and together with managers, they can formalize the new regulations or changes in existing ones within the decision-making step. Implementation of these regulations requires a tight cooperation between managers and society, because it is in this stage that the actual changes will take place. Both society and managers play major role in ensuring that the results from scientific assessments, which are translated to rules and regulations are strictly implemented to necessitate improvement in soil health.

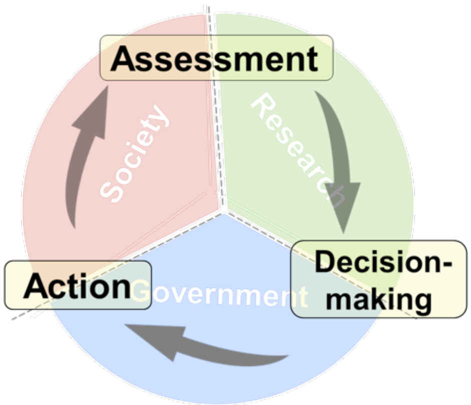


Figure 2: Cyclical soil health assessment showing the activities and which sectors of society are highly involved for each step.

3 illustrates the activities and information flows at each stage of a soil health assessment. At the initial stage of soil health assessment, a multitude of activities and datasets from different fields of research will be carried out and obtained. All these will be condensed into a few or a single qualitative or quantitative measure for soil health This step involves processing and integration of all information previously gathered and may require several iterations before suitable and applicable measures of soil health are derived. For the implementation stage, the amount of activities and information that will develop based on the soil health measures derived will again equal that of the initial

assessment stage. The regulations created can be as diverse as the methods identified to apply them in society.

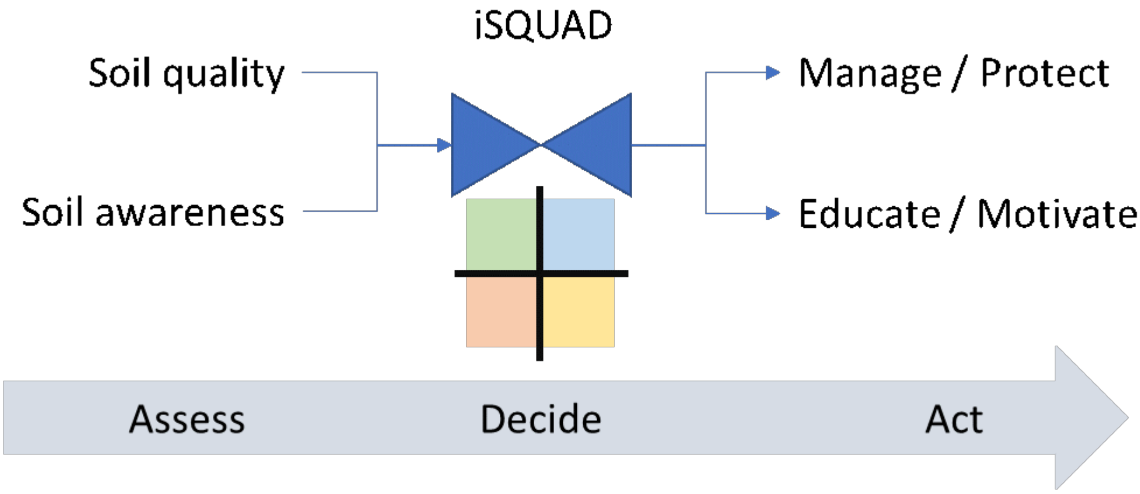


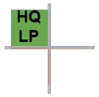
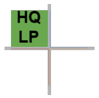
Figure 3: Information flow for each step in a soil health assessment.

A dynamic soil health assessment is at the core of the proposed iSQUAD framework. Each stage of the cycle described above is incorporated within the framework (Figure 1). First, to arrive at a soil health category, assessments of both soil quality and societal perceptions should be carried out. Once the overall soil health status or category is known, the suitable actions related to each category are identified. Although currently, the actions listed for each of the quadrants in Figure 1 are broadly-defined, these should be tailor made for each area or community. These actions will then serve as guides to managers so that the necessary actions can be implemented. By these means the iSQUAD framework can adapt to different scenarios with different requirements. Depending on the scale of the problem and solutions sought, the time frame from assessment to implementation can take a few years. At some future time, re-evaluation of the status of soil health should take place to check if the goals set in the previous assessment stage has been fulfilled.

2.5 Examples

In this section we offer a naïve implementation of the proposed framework to assess soil health. Naturally, since the framework we propose has not been implemented by any study so far, we have forced some studies to fit within the framework. The exercise's purpose is merely illustrative. It illustrates how, using current knowledge, the concept behind the framework could be applied by policy-makers and land managers to define priorities to improve soil health. Because of the naïve character of the proposed examples, we stopped after choosing a quadrant for each given example without venturing to propose action measures. Considering the limitations stated, Table 1 provide two examples per quadrant. The "reference" column leads to the original publication using a direct link.

Table 1: Examples —Ongoing soil health assessments in iSQUAD.

Category	Reference	Summary	Soil quality	Perception
	Farmers' knowledge, perceptions and management of chili pepper anthracnose disease in Bangladesh. Islam et al., 2020	• This study focuses on the problem of farmer's limited knowledge about the identity of plant diseases, transmission pathways and appropriate management methods in chili farms; • Results highlight that majority of the farmers are unaware of the fungal disease and almost all of them do not know how it spreads; • Capacity building to deal with diseases will improve chili productivity and the income and health of farmers.	Soils are highly productive in this area of Bangladesh.	Farmers overuse agrochemicals leading to soil pollution.
	Benefits over Threats: Understanding Community's Motivation to Participate in Restoration Initiatives in Gunung Leuser National Park, Sumatra. Khatimah et al. 2019	• The study is about the restoration efforts in one of Indonesia's most important conservation sites (GLNP) where a large extent of land is degraded because of human activity; • Results indicate that people living on these sites do not perceive any relations between forests, their livelihood, and threats due to deforestation; • Participants of the restoration initiatives were primarily driven by the opportunity to get additional income and improve their welfare.	The forest has a high soil quality but suffers from anthropic pressures.	Population disregard the connection between forest conservation and wellbeing.

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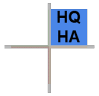
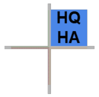
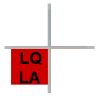
	Participatory agroforestry development for restoring degraded sloping land in DPR Korea. Xu et al. 2012	• The study analyzed long-term bottom-up agroforestry development processes influencing national policies today in Korea; • Broad support for agroforestry practices has now emerged within government ministries and research universities; • Further development will require increased engagement relevant agencies, while the social dimensions of participatory agroforestry continue to provide rich learning.	Soils in sloping lands have recovered from a dire past	Different actors are involved pushing forward agroforestry.
	Farmers consideration of soil ecosystem services (ES) in agricultural management-A case study from Saxony, Germany. Dietze et al. 2019	• This paper presents a theoretical framework based on (ES) is likely established in agricultural practices and policies in Germany; • Although the terminology for ES differs from research, authors found that there is inherent knowledge about ES in agriculture and farmers implement various ES in agricultural management.	Soils are highly productive in this area of Germany.	Farmers do use conservation practices based on ecosystem services.
	Bridging the gap of perception is the only way to align soil protection actions. Salhi et al. 2020	• The study investigates the importance of societal perception in solving land degradation issues; • The first and most difficult step to face soil degradation is to cultivate the right idea and develop it into a well-established community culture; • Confused perception of ideas results in inappropriate labor behaviors non-aligned with public actions; • A gradual change of perception and involvement based on a time-consuming culture of assimilation and acceptance will pave the wat to coordinated and aligned actions.	Soils are eroded by poor management practices, a situation that worsens every year.	Farmers unawareness worsens the problem as they do not align with public actions.

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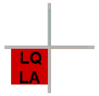
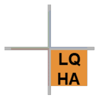
	Perceptions of integrated crop-livestock systems (ICLS) for sustainable intensification in the Brazilian Amazon. Cortner et al. 2019	• The study examines local perspectives of ICLS to better illuminate what might guide farmers' decisions to adopt agricultural intensification strategies in Brazil; • Results indicate that existing adopters perceived ICLS as a beneficial strategy for increasing the economic value and competitiveness of their farm, while most non-adopters did not; • There is a strong need to employ a more diverse set of policy tools (e.g. education programs) that can support intensification and help create a climate of innovation.	Poverty provokes and increase in ecosystems anthropic pressure.	Lack of education impedes the adoption of preventive measures.
	Adoption of technologies that enhance soil carbon sequestration in East Africa. What influence farmers' decision? Ng'ang'a et al. 2020	• The study sets out to understand factors that influence the adoption of technologies that enhance soil carbon sequestration among smallholder farmers in Kenya and Ethiopia; • The results show that positively perceived net benefits of the soil carbon enhancing technologies were more likely to adopt such technologies that enhance soil carbon sequestration; • Interventions aimed at addressing specific factors such as inadequate skills and knowledge, change in perception among farmers, and off-farm income are likely to have the greatest impact in deciding to adopt soil carbon enhancing practices.	The land undergoes a degradation process.	Improving perception motivates actions.

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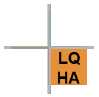	How to improve the adoption of soil conservation practices? Suggestions from farmers' perception in western Sicily. Fantappie et al. 2020	• The study focuses on farmers' perception about the value of natural resources in agricultural management din Western Sicily (Italy), which is one of the most important agricultural areas of Europe and is affected by soil degradation processes; • Farmers revealed an inclination to perceive the production benefits and management benefits, stronger than the environmental and aesthetic ones; • Effective profitability was the main efficient stimulus to the adoption of SCP, much larger than farmers' ecological attitudes, or the presence of subsidies.	The land undergoes a degradation process.	Farmers perceive the benefits of good management practices.

3 Discussion –SWOT analysis of the framework

We conceptualized the discussion as a SWOT matrix. This analysis coveys the Strengths, Weaknesses, Opportunities and Threats of the framework we proposed. To do the analysis, we first schematized the framework's stages and interactions as shown in Figure 2 and Figure 3. Figure 4 presents the framework's SWOT matrix. Afterwards, we reflect on the predicted impacts for the stakeholders using the iSQUAD framework.

Strengths	Weaknesses	Opportunities	Threats
Proposes an approach that **can start in short term**. Incorporates simultaneously **technical and social** aspects of the soil environment. Intends a **multi-disciplinary** approach. Defines soil health as a **dynamic** state. **Compares** soils under different environmental contexts, or land management scenarios.	Does not quantify soil health. Efforts to build or convey indicators presuppose **research efforts**. **Requires calibration** or adjustment of indicators for each soil context to be assessed.	Promotes the development of **perception index** for soils. Promotes the **expansion** of current scientific frameworks to assess soil quality outside productivity. Promotes the development **of key performance indicators** for stakeholders. **Builds on** existing scientific frameworks	Presupposes **multidisciplinary** collaboration that might not be welcomed. **Needs for research** and complex synthesis of indicators might demotivate users to adopt the concept.

Figure 4: SWOT matrix for the proposed framework. Each point should be read as "The framework...". The discussion of the report was articulated around this analysis.

3.1 Strengths

The framework's strongest facet is that policy makers and land managers can start applying it since the beginning of its proposal. This is a key difference that separates the "soil health" concept from its predecessors: soil quality, and land capability. So far, the development and proposition of concepts aiming soil status assessments supposed long research stages that delayed their application. Scientific committees have had to propose and evaluate long lists of indicators and criteria to select them to make possible the assessment of soil quality at any location (de Paul Obade, 2019). Our framework bridges this gap, as it builds on concepts already established and common to land managers. Although it might not have a strong numerical output at the beginning, it can be applied as an qualitative interpretation from an early stage in ongoing social-ecological situations (see Section 2.5 for examples of this use).

Because the framework proposed extends current methods, it combines technical and social aspect of soils in their role of physical support of terrestrial ecosystems. The framework takes this idea from the concept of social-ecological systems (SEs) well stablished in ecosystem sciences. Ecosystem scientists have implemented the SEs concept for more than 20 years along which the concept has gained more and more users (Colding et al., 2019). In its progression, the implementation of SEs has become from a mere abstract exercise to an output that makes scenario analysis and modelling possible (e.g. Janssens de Bisthoven et al., 2020). In its essence the SEs concept does not stablish a simplistic framework, but rather exposes the high complexity of its components (Ostrom, 2007). The motivation behind such unorthodox approach —traditionally, users favour small models (see Baartman et al., 2020)— lies in the empirical observation that reductionist dynamics give a misleading representation of how social-ecological systems work (Levin et al. 2012). Our framework takes all the knowledge about SEs and re-purposes it to soil sciences, but with one difference: it preserves complexity but has pivotal interpretation node that allows the different specialists involved in the assessment (e.g. land managers, the policy makers) to plan and prioritize strategies to improve soil's socio-ecological condition (see Fig 3). The requirement to work with different specialists gives our framework another considerable strength. Empirical evidence suggests that multidisciplinary approaches respond adequately when situations involve the interaction of different actors (Jaillot et al., 2020). In its intended application, the framework will allow the involvement of different disciplines in the assessment of soil health, adjusting the participating disciplines according to the situation's intrinsic characteristics. Specialists of each discipline will provide priorities and indicators in a nested fashion, that will be collapsed by land managers in the final index. By this means, the soil health assessment presents itself as a standalone and unique multidisciplinary indicator that summarizes the ongoing situation and held —in its internals— guidelines on how to improve on each contained discipline.

As a summary of an ongoing situation, our framework recognises soil health as a dynamic state. By these means, it provides a tool to assess temporal improvements while it allows a priori evaluations of tentative measures by scenario analysis. The opportunity to evaluate the impacts of possible measures saves time and efforts, since it prioritizes actions by cost or positive outcomes (Jerves-Cobo et al., 2020; Lemma et al., 2019). Policy managers could use this information at a larger geographical scale to orient goals and set actions.

Finally, when the output of the framework is interpreted in its descriptive form (i.e. in which quadrant a soil is given its social-ecological context) the framework allows to compare soil in different environments regardless its productive, economic, or ecosystem scenario (Section 2.4.2). We expect that policy-makers use the most this index's facet, as it allows prioritizing at a broad geographical scale. One of the draw backs of prior indexes as we discussed in Section 2.2 is that they are tied to a specific crop-production scenario, or productivity as net worth. Our framework bridges that gap as it provides common ground way of comparing —through a four-level ranking— the threats and to-dos of soils even if they are placed in contrasting scenarios.

3.2 Weakness

Within the proposed framework, the assessment of soil health is presented as a situation that is characterized by combinations of technical and societal assessment of soil health. As an output, a descriptive characterization of soil health is presented rather than a quantitative measure. Although a unique numerical value —as a x,y coordinate— can be reached for a particular area, the number will remain meaningless for large (geo)scale comparisons. In this regard, to offer a descriptive framework might find some resistance from scientists and some technical managers has their preference lies commonly in numerical values. Even for small areas, where the comparison between numerical values might have meaning, iSQUAD does not offer in its first implementations numerical outputs. This is because achieving a single numerical value for soil quality or societal perception is not a trivial task (see Section 2.2 and Section 2.3). Therefore, the implementation of iSQUAD is threaten as its requires to cover knowledge gaps that nowadays hinder the possibility to summarize both soil quality and societal perception to a single numerical value.

Comparison of soil health may result in location-specific assessments because demographic and socio-economic factors may influence society's perceptions of soil. Similarly, soil quality indicators are, at present, not standardized globally. A unified framework incorporating different soil functions in assessing soil quality, and not only focusing on productivity, is one big hurdle that needs yet to be surpassed.

However, although a numerical measure for soil health is not yet achieved in the proposed framework, its utility for scientists and policy makers is undeniable. Each of the quadrants in the proposed soil health framework already enables soil health assessment which also allows identification of possible activities that will improve or maintain the current rating.

3.3 Opportunities

There are major opportunities to be considered in the adoption of this framework. In particular, the main opportunity identified is the possibility to contribute for a better understanding of the value and functions that soil has. Soil still has a residual understanding within society about its value and functions, however, the true societal awareness is hard to grasp and can only be indirectly estimated. This framework would add immensely to a better understanding of the gap that needs to be addressed by soil scientists and decision makers, while at the same time would contribute positively for a better understanding of soil perception.

Most of current soil quality assessments frameworks are based on productivity and agricultural performance (see previous explanation on 2.2), however, recent efforts have been made to further improve the current frameworks beyond the existing scientific knowledge (Bornmann, 2013). For example, the development of the Sustainable Development Goals (SDGs) framework by the United Nations has identified some gaps regarding the soil contribution. In this regard, this proposed framework not only can provide a positive input but it is introduced in a good timing frame.

Key Performance Indicators (KPIs) is a framework that aims to develop measurable performance of a particular activity or organization. While its origin is traditionally linked to the performance measurement of business, due to its flexibility and ease to communication, it has become more relevant for several organizations, such as local governments. The focus on categorical values in this framework makes it possible to link soil quality and health with KPIs of local organizations and, therefore enhance the transparency and performance of those organizations.

The use of categorical values in this framework is an added value to this framework as it makes it flexible enough to integrate different already existing scientific frameworks. There are several existing scientific frameworks that are well established and supported and the aim of our framework is to build on existing knowledge and further explore only missing knowledge gaps.

3.4 Threats

The proposed framework for soil health requires strong collaboration with different scientific fields. Researchers in both social and soil sciences need to overcome scientific and technical boundaries in order to harmoniously investigate different aspects of soil health. However, this potential drawback is only foreseen at the initial stages of collaboration. Nevertheless, it could potentially threaten the development of an integrated soil health assessment approach. Active participation and enthusiasm from researchers in different scientific fields are necessary in order to secure the success of the proposed framework.

As mentioned previously as one of the weaknesses identified for the soil health framework, assessment of soil quality and perception are, by themselves, already complex tasks. Research of soil quality has been for more than two decades (e.g. NRC, 1993) and is still continuously being developed and expanded over the years including, but not limited to, RUSLE (Renard et al., 1991), Cornell soil health assessment (Moebius-Clune, et al., 2017) , and Landmark project (Landmark, 2020). These are testaments to the large scope and scale of soil quality assessment. The complex assessment of soil quality may potentially result in a undirected endeavour if the current and future frameworks are not harmonized.

3.5 Impacts —How will our approach impact all stakeholders

3.5.1 Policy makers

This approach can have a significant contribute to the relevance of soil in the process of decision making. While decision makers are mainly involved as end users, the framework is designed to increase its adoptability by different types of stakeholders and decision makers. Decision making is a broad capacity that should consider the complexity of one system (such as economic, environmental and social and political implications), regardless of the scale of case study (local, regional or national). This framework focuses not only on the soil quality/health but also considers soils' societal perception —essential information in the process of decision making.

The success of the decision making depends on the transparency and the efficiency in the interpretation of the complex system. This framework is constructed to be a strong communication and interpretation tool. The focus on 4 quadrants and categorical values has a double added value for the decision makers. On one hand, it makes possible for different type of users to easily enact and operate the framework. The decision making stakeholders are normally people with multiple different background and different understanding of other disciplines methodological tools and knowledge. The use of categorical values is then an advantage over precise quantitative values has it removes technical interpretation of the values significance. On the other hand, the 4 quadrants framework is strong communication tools. The process of decision making is dependent of the transparency and communication to build trust. This framework makes use of the quadrants to better interpret ideal or less ideal situations and makes recommendations based on the decision goals (moving or keeping each case study in the quadrants). Therefore, the framework is well suited to be used as a communication tools with a with audience.

3.5.2 Researchers

In its first stage, the implementation of our framework will involve, above all, research. The construction of indexes that convey societal perception of soils should be one of the core activities of soil scientists who should work together with experts on other disciplines. Considerable efforts should be made at this stage to transfer the knowledge accumulated when the soil quality index was developed. Since our framework builds on concepts already developed, this knowledge transfer is crucial. Integrating and transferring what is known about social-ecological systems will be also an important task.

After its implementation and adoption, the research community will have a tool that will allow the assessments of soil health at a global scale. This is a powerful outcome for scientists, as soil health will serve as an instrument to understand the interconnection of different processes and propose new, undiscovered ways to prevent soil loss. To understand the importance of such a tool, we could revisit what happened with soil erosion and the universal soil loss equation (USLE), to predict what could happen with the soil health framework. The universal soil loss equation was proposed in the 60s (Ghosal & Bhattacharya, 2020). It has undergone a high number of modifications and adjustments, but after a general proposition was framed it has been used to evaluate the success of soil protective measures at global scale (Borrelli et al., 2017). Something similar could happen with soil health. It could be an index that provide information of how well we are acting today to prevent soil erosion tomorrow, and to adjust and fix intermediate goals to keep soils capable of supporting the United Nations sustainable development goals. In this sense, the development of a soil health index will convey the proposition of more ambitious hypothesis that will prevent hunger (Keesstra, et al., 2016).

3.5.3 Society

The framework we propose puts strong emphasis on the value of soils to society by incorporating an element that focuses on soil perception. In our view, this is vital in the agenda soil health going forward because it promotes societal engagement in what would normally be a scientific research endeavour. Soil serves different purpose to society and its health has been included in one of the five missions for Horizon Europe, the next phase of Horizon 2020 (EC, 2020). However, we argue that societal appreciation is, currently, largely unknown and perhaps this is due to soil's "invisibility" to society.

This approach will primarily develop a sense of societal awareness of the roles of soils that is currently ignored or deemed unimportant by a large part of the population. Within the 17 Sustainable Development Goals adopted by the United Nations in 2015 (UN, 2015), the word "soil" has only been mentioned 4 times within the whole document. This is an example that highlights the degree of importance (or neglect) that have been (unfairly) given to soils. It is somewhat ironic that society is concerned with the quality of air in relation to environmental pollution and climate change even though it is invisible. Soils, however ubiquitous and tangible they may be, have remained "invisible" or extraneous to society in general. As a response to the UN SDG, a collaboration of soil scientists have enumerated in detail the significance of soils in realizing most of the SGDs because they believe in the intrinsic value that soil's hold for a future sustainable society (Keesstra et al., 2015). Similarly, we are convinced about the essential role of soils and that engaging society in assessing soil health is the key that will unlock future efforts in quantifying and improving the current methods developed for soil health.

4 Conclusions

"Make all soils healthy again" is the motto for the challenge that frames this proposal. We have taken an approach that stimulates and emphasizes on the role that society should have in preserving soils. Realizing that the lack of a strong societal awareness about the role that soil's play in achieving social and environmental well-being, we focused on developing a conceptual framework that can establish a better bridge between research and society. We believe that raising awareness is facilitated when society is actively participating in environmental studies. Scientists are now more open and aware that their science should be closer to society, yet most scientific frameworks are still focused mostly on technical aspects. With iSQUAD we focus on how scientists, decision makers and society can collaborate together in a soil assessment framework to improve not only soil health information but also to increase societal perception of soils' inherent value.

In the context raised by the questions of this challenge, our framework defines soil health as a dynamic status around which all soil functions articulate together to support life on earth. The iSQUAD matrix was designed to make it possible to integrate existing scientific frameworks and be easily read and understood by different stakeholders (by using categorical values and 2 axis). This poses as an advantage as it allows a fast and flexible implementation of the framework even at early stages. We deem both these attributes fundamental to promote public discussion and identification of strategic goals. Moreover, the use of a 2-axis matrix is seen as a good communication tool with peers or different types of stakeholders due to the universal use of similar frameworks.

Within the soil health realm, we can think of soils as patients whose health is akin to the concept of medical health. The World Health Organization (WHO) defines health as: *"a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity"*. This expresses health is not only in terms of physical well-being but also including the intangible social and mental health aspects. In this regard, the aspects of soil health addressed within iSQUAD parallels the multi-faceted nature of medical health. As a metaphor, soil quality can be compared to a patient's physical condition, while societal awareness of soil functions' value can be compared to a patient's social and mental well-being.

The year 2020 started with a pandemic that has put health and medical field at the forefront of all the institutional agenda worldwide. Although a long-term solution is still to be developed and the world is still trying to adapt to a "new normal" situation, the pandemic has shown that collaboration between different sectors in society is vital in mitigating and containing the spread of Covid19 virus. For soil health, iSQUAD will be both a tool and a platform that will focus foremost on the collaboration of different sectors of society. While we might be facing a serious medical pandemic, other "environmental pandemics" might already be on-going (e.g. worldwide land degradation) and require urgent action. Realizing the urgency of addressing the issue of soil health requires raising societal awareness of soil's inherent value.

European Commission has a societal responsibility and the power to boast strategic research and innovation that focuses on improving citizens' lives. We see that scientists have been only focusing on their field of expertise and recent efforts to focus on societal impact of their research is not always welcomed or finds structural barriers. We think that creating and stimulating more flexible and interdisciplinary frameworks is key to step in the right direction to have a bigger societal impact. Our proposal was designed as well considering this vision as it relies more on communication and interdisciplinary, rather than further developing already existing frameworks or proposing new ones.

References

AbdelRahman, M.A.E. and S.M. Arafat. 2020. An Approach of Agricultural Courses for Soil Conservation Based on Crop Soil Suitability Using Geomatics. Earth systems and environment, 4:273-285. https://doi.org/10.1007/s41748-020-00145-x

Andrews, SS, DL Karlen and CA Cambardella. 2004. The Soil Management Assessment Framework: A quantitative soil quality evaluation method. Soil Science Society of America Journal, 68(6):1945-1962. https://doi.org/10.2136/sssaj2004.1945

Baartman, JEM, Melsen, LA, Moore, D, van der Ploeg, MJ. 2020. On the complexity of model complexity: Viewpoints across the geosciences. Catena 186:104261. https://doi.org/10.1016/j.catena.2019.104261

Berhe, A. A., Arnold, C., Stacy, E., Lever, R., McCorkle, E. and Araya, S. N. 2014. Soil erosion controls on biogeochemical cycling of carbon and nitrogen. Nature Education Knowledge 5(8):2 https://doi.org/10.1146/annurev-earth-082517-010018

Bierkens, M. F. P., and Burrough, P. A. 1993. The indicator approach to categorical soil data. Journal of Soil Science, 44(2):361–368. https://doi.org/10.1111/j.1365-2389.1993.tb00458.x

Bornmann, L. 2013. What is societal impact of research and how can it be assessed? a literature survey. Journal of the American Society for Information Science and Technology, 64:217–233. https://doi.org/10.1002/asi.22803

Borrelli, P, DA Robinson, LR Fleischer, E Lugato, C Ballabio, C Alewell, K Meusburger, S Modugno, B Schütt, V Ferro, V Bagarello, K Van Oost, L Montanarella and P Panagos. 2017. An assessment of the global impact of 21st century land use change on soil erosion. Nature Communications 8:2013. https://doi.org/10.1038/s41467-017-02142-7

Bouma, J. 2002. Land quality indicators of sustainable land management across scales. Agriculture, Ecosystems and Environment, 88(2):129–136. https://doi.org/10.1016/S0167-8809(01)00248-1

Boyer, R., Peterson, N., Arora, P., and Caldwell, K. 2016. Five Approaches to Social Sustainability and an Integrated Way Forward. Sustainability, 8(9):878. https://doi.org/10.3390/su8090878

Colding, J., and S. Barthel. 2019. Exploring the social-ecological systems discourse 20 years later. Ecology and Society, 24(1):2. https://doi.org/10.5751/ES-10598-240102

European Commission 2019, Orientations towards the first Strategic Plan for Horizon Europe. https://ec.europa.eu/info/files/orientations-towards-first-strategic-plan-horizon-europe_en

EU. 2020. Soil health and food. Retrieved June 17, 2020, from https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme/mission-area-soil-health-and-food_en

FAO. 1976. A framework for land evaluation. FAO Soils bulletin 32. Soil resources development and conservation service, land and water development division. Food and Agriculture Organization (FAO). United Nations. Rome, 1976. http://www.fao.org/3/x5310e/x5310e00.htm#Contents

Gallopín, G. 1995. The potential of agroecosystem health as a guiding concept for agricultural research. Ecosystem Health, 1(3). Retrieved from https://www.researchgate.net/publication/291842655_The_potential_of_agroecosystem_health_as_a_guiding_concept_for_agricultural_research

Ghosal, K and Das Bhattacharya. 2020. A Review of RUSLE Model. Journal of the Indian Society of Remote Sensing, 48(4): 689-707. http://doi.org/10.1007/s12524-019-01097-0

Howard, PJA. 1993. Soil protection and soil quality assessment in the EC. Science of the total environment, 129(1-2):219-239. https://doi.org/10.1016/0048-9697(93)90172-3

Jaillot, V, Istasse, M, Servigne, S, Gesquière, G, Rautenberg, M, and Lefort, I. 2020. Describing, comparing and analysing digital urban heritage tools: A methodology designed with a multi-disciplinary approach. Digital Applications in Archaeology and Cultural Heritage, 17:e00135. https://doi.org/10.1016/j.daach.2020.e00135

Janssens de Bisthoven, L, Vanhove, MPM, Rochette, A-J, Hugé, J, Verbesselt, S, Machunda, R, Munishi, L, Wynants, M, Steensels, A, Malan-Meerkotter, M, Henok, S, Nhiwatiwa, T, Casier, B, Kiwango, YA, Kaitila, R, Komakech, H, and Brendonck, L. 2020. Social-ecological assessment of Lake Manyara basin, Tanzania: A mixed method approach. Journal of Environmental Management, 267:110594. http://doi.org/10.1016/j.jenvman.2020.110594

Jerves-Cobo, R, Benedetti, L, Amerlinck, Y, Lock, K, De Mulder, C, Van Butsel, J, Cisneros, F, Goethals, P, and Nopens, I. 2020. Integrated ecological modelling for evidence-based determination of water management interventions in urbanized river basins: Case study in the Cuenca River basin. Science of the Total Environment, 709:136067. https://doi.org/10.1016/j.scitotenv.2019.136067

Karlen, DL, Veum, KS, Sudduth, KA, Obrycki, JF, and Nunes, MR. 2019. Soil health assessment: Past accomplishments, current activities, and future opportunities. Soil and Tillage Research, 195:104365. https://doi.org/10.1016/j.still.2019.104365

Keesstra, SD, Bouma, J, Wallinga, J, Tittone, P, Smith, P, Cerdà, A, Montanare, L, Quinton, JN, Pachepsky, Y, van der Putten, WH, Bardgett, RD, Moolenaar, S, Mol, G, Jansen, B, and LO Fresco. 2016. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. SOIL 2:111-128. https://doi.org/10.5194/soil-2-111-2016

Kidd, C. V. 1992. The evolution of sustainability. Journal of Agricultural and Environmental Ethics, 5(1):1–26. https://doi.org/10.1007/BF01965413

Klingebiel, A.A. and P.H. Montgomery. 1961. Land-capability classification. Agriculture Handbook 2010. Soil Conservation Service, US Department of Agriculture. https://play.google.com/store/books/details?id=gEDYBOzWTdcC

Landmark EU Project 2020, Retrieved June 22, 2020 http://landmark2020.eu/

Lemma, H, Frankl, A, van Griensven, A, Poesen, J, Adgo, E, and Nyssen, J. 2019. Identifying erosion hotspots in Lake Tana Basin from a multisite Soil and Water Assessment Tool validation: Opportunity for land managers. Land Degradation and Development, 30(12):1449-1467. https://doi.org/10.1002/ldr.3332

Levin, S., T. Xepapadeas, A.-S. Crépin, J. Norberg, A. de Zeeuw, C. Folke, T. Hughes, K. Arrow, S. Barrett, G. Daily, P. Ehrlich, N. Kautsky, K.-G. Mäler, S. Polasky, M. Troell, J. R. Vincent, and B. Walker. 2012. Social-ecological systems as complex adaptive systems: modeling and policy implications? Environment and Development Economics 18:111-132. http://dx.doi.org/10.1017/S1355770X12000460

Moebius-Clune BN, Moebius-Clune DJ, Gugino BK, Idowu OJ, Schindelbeck RR, van Es HM, Thies JE, Shayler HA, McBride MB, Wolfe DW, Abawi GS. 2017. Comprehensive assessment of soil health – the Cornell framework manual, edition 3.2. Cornell University, Geneva, in preparation, http://soilhealth.cals.cornell.edu/

National Research Council. 1993. Soil and Water Quality: An Agenda for Agriculture. Washington, DC: The National Academies Press. https://doi.org/10.17226/2132

Oluwatosin, GA, Adeyolanu, OD, Ogunkunle, AO, and OJ Idowu. 2006. From land capability classification to soil quality: an assessment. Tropical and Subtropical Agroecosystems 6, 49-55.

Ostrom, E. 2007. A diagnostic approach for going beyond panaceas. Proceedings of the National Academy of Sciences 104(39):15181-15187. http://dx.doi.org/10.1073/pnas.0702288104

de Paul Obade, V and Lal, R. 2016. Towards a standard technique for soil quality assessment. Geoderma, 265, 96-102. https://doi.org/10.1016/j.geoderma.2015.11.023

de Paul Obade, V. 2019. Integrating management information with soil quality dynamics to monitor agricultural productivity. Science of the total environment 615(15), 2036-2043. https://doi.org/10.1016/j.scitotenv.2018.10.106

Renard, K. G., Foster, G. R., Weesies, G. A., and Porter, J. P. 1991. RUSLE: Revised universal soil loss equation. Journal of soil and Water Conservation, 46(1), 30-33. https://www.jswconline.org/content/46/1/30.full.pdf

Rubin, G. J., Bakhshi, S., Amlôt, R., Fear, N., Potts, H. W., and Michie, S. 2014. The design of a survey questionnaire to measure perceptions and behaviour during an influenza pandemic: the Flu TElephone Survey Template (FluTEST). https://www.ncbi.nlm.nih.gov/books/NBK263566/

Semenza, J. C., Hall, D. E., Wilson, D. J., Bontempo, B. D., Sailor, D. J., and George, L. A. 2008. Public perception of climate change: voluntary mitigation and barriers to behavior change. American journal of preventive medicine, 35(5), 479-487. https://doi.org/10.1016/j.amepre.2008.08.020

Smith, JL, Halvorson, JL, and RI Papendick. 1993. Using multiple-variable indicator kriging for evaluating soil quality. Soil Science Society of America Journal, 57(3), 743-749. https://doi.org/10.2136/sssaj1993.03615995005700030020x

Sobczyński, G., Studnicki, M., Madry, W., Wijata, M., Gozdowski, D., Noras, K., Samborski, S., Rozbicki, J. 2020. Impact of cultivar and environment soil suitability on the contribution of yield components to grain yield variation in spring wheat. Crop Science, 60 (1), pp. 428-440. https://doi-org.ezproxy.library.wur.nl/10.1002/csc2.20065

Theodori, G. L. 2012. Public perception of the natural gas industry: data from the Barnett Shale. Energy Sources, Part B: Economics, Planning, and Policy, 7(3), 275-281. https://doi.org/10.2118/115917-MS

United Nations, 2015, Transforming our world: the 2030 Agenda for Sustainable Development. https://sustainabledevelopment.un.org/post2015/transformingourworld

USDA, 1965. Predicting rainfall-erosion losses from cropland east of the rocky mountains: guide for selecting practices for soil and water conservation. Agriculture Handbook 282. Agricultural Research Service, US Department of Agriculture. https://www.ars.usda.gov/ARSUserFiles/50201000/USLEDatabase/AH_282.pdf

USDA. 2001. Guidelines for soil quality assessment in conservation planning. United States Department of Agriculture, Natural Resources Conservation Service, Soil Quality Institute. 48p. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051259.pdf

Verbrugge, L. N., Van den Born, R. J., and Lenders, H. R. 2013. Exploring public perception of non-native species from a visions of nature perspective. Environmental management, 52(6), 1562-1573. https://doi-org.ezproxy.library.wur.nl/10.1007/s00267-013-0170-1

Wood, R. C., and Dumanski, J. 1994. Sustainable land management for the 21st century : proceedings of the International Workshop on Sustainable Land Management for the 21st Century, University of Lethbridge, Lethbridge, Canada, June 20-26, 1993.