Eco-Holistic Soil Conservation to support Land Degradation Neutrality and the Sustainable Development Goals

Juan Albaladejo*[1], Elvira Díaz-Pereira[1], Joris de Vente[1]

[1] Soil and Water Conservation Research Group. (CEBAS-CSIC), E-30100 Murcia, Spain.
*corresponding author: jalba@cebas.csic.es

https://doi.org/10.1016/j.catena.2020.104823

ABSTRACT

Soil degradation continues to be of the major threats for sustainable development and human well-being. Despite the advances in research, there is still a gap between research and effective conservation. To fill this gap, a change is needed in the paradigm of soil conservation research. Therefore, this paper aims to: (i) introduce the concept of Eco-Holistic- Soil Conservation (EHSC) to support the Sustainable Development Goals, (ii) present a framework for the implementation of EHSC, and (iii) show practical examples and recommendations of EHSC. The theory behind the concept of EHSC builds on a critical review of the main causes for success or failure of previous conservation projects and evaluation of latest holistic concepts and visions on conservation of soils and socio-ecosystems. The key principles underlying EHSC are: 1) perception of soils as living-systems, 2) holistic ecosystem approach, 3) central role of soil conservation for climate change mitigation and adaptation, and 4) ethical behavior in soil use. Implementation of EHSC requires a transdisciplinary approach involving a range of actions in three iterative phases: 1) diagnosis of the causes and processes of land degradation and the socio-economic context, 2) integrated assessment of the interactions and synergies between the factors and actors involved and the selection of EHSC actions, and 3) participatory evaluation and monitoring of impacts. Successful conservation requires more research on the resilience and adaptation of soils to climate change, integrated economic valuations of soil conservation, and protection of native peoples right to land in international legislation.

Keywords: soil health-holistic approach-soil living system-climate change adaptation-soil ethics-land stewardship, participatory monitoring.

1. Introduction

Soil degradation has been a key factor in the collapse of various civilizations throughout history (e.g. Diamond, 2005; Minami, 2009; Lal, 2015a). Many parts of the world have witnessed severe deterioration of land and soils in the last century which is globally ongoing due to unsustainable land use, deforestations and climate change. About 23% of the globe's terrestrial area is already degraded and the estimated current rate of arable land loss due to land degradation is 30 to 35 times the historical rate (UNCCD, 2012). Latest estimates indicate that land degradation negatively affects the well-being of least 3.2 billion people world-wide (IPBES, 2018). The challenge of land degradation is particularly important in developing countries and has potential strong links with conflict and population migration (McLeman, 2017). It is estimated that land degradation costs the global economy between 18-20 trillion USD annually (UNCCD, 2019). Being aware of these challenges, the United Nations have given priority to combating land degradation and aims at achieving Land Degradation Neutrality (LDN) by 2030 as reflected in Sustainable Development Goal 15.3 that focuses on the achievement of LDN by introducing land management practices that prevent the loss of healthy land and maintain or improve the land's productivity (SDSN, 2015). Moreover, soil conservation contributes directly and indirectly to achieving multiple other Sustainable Development Goals (SDGs), such as SDG 1 (no poverty), SDG 2 (zero hunger), and SDG 6 (clean water and sanitation) by maintaining or improving the lands productivity and its positive effects on water management. Soil conservation also has strong potential to contribute to climate change adaptation and mitigation (SDG 13: climate action) and to SDG 15 (life on land) through emission reductions, carbon sequestration, ecosystem restoration and biodiversity protection (Bouma, 2019).

Despite advances in scientific knowledge and extensive local knowledge regarding soil conservation, soil degradation continues and soil conservation programs do often not reach expectations (Bouma, 2019). Social awareness that we stand at a critical moment in Earth's history when humanity must choose its future is increasing (Earth Charter Commission, 2000). Effective design and implementation of land degradation prevention, mitigation and restoration programs to protect our natural, economic, and social capital requires transdisciplinary collaboration between environmental and social scientists, representatives from civil society organisations, sustainable business initiatives, and local, regional and national policy makers (Bouma, 2014; Sanz et al., 2017).

Most of the present soil conservation approaches are mainly focused on the prevention of soil erosion and soil fertility losses and a huge number of scientific articles is published annually on soil erosion (Dazzi and Lo Papa, 2019), often neglecting the many other critical roles soils play in natural and agricultural socio-ecosystems (Engel, 2009; Bouma, 2019). Likewise, there is an increasing awareness regarding the close linkages between soil degradation and food security, loss of biodiversity, reduction of environmental security, destabilization of societies, poverty and conflict (Keesstra et al., 2016), as is also evident from the previously mentioned central role of soils in the Sustainable Development Goals (Bouma, 2019). To deal with these concerns, we need a shift in the approach towards soil conservation to support sustainability of global socio-ecosystems.

Due to the close connection between soil and climate, through the carbon, nitrogen, and hydrological cycles, the changes in climate will affect soil processes and properties and vice versa (FAO, 2002; Álvaro-Fuentes et al., 2012; Albaladejo et al., 2013; Lal, 2018). Large impacts from climate change on physical, chemical and biological soil properties are expected in many areas due to rising temperatures and changing precipitation regimes that will affect microbiological communities and turnover rates. Increased frequency of extreme precipitation is expected to lead to higher erosion rates (Eekhout et al., 2018). Rising temperatures and soil degradation will increase GHG emissions from soil fluxes, potentially accelerating climate change (Conant et al., 2011; Curtin et al., 2012; Garcia-Franco et al., 2015a). On the other hand, soil conservation practices provide a unique opportunity to mitigate climate change by decreasing GHG emission and increasing carbon sequestration from the atmosphere into vegetation, soils and sediments (Garcia Franco et al., 2015b; Lal, 2016; Almagro et al., 2016; Sanz et al., 2017).

Soil degradation occurs through a set of physical and biochemical processes which, generally, are caused by human actions and socioeconomic, political and cultural direct and indirect drivers. The lack of consideration of socioeconomic and cultural conditions has often resulted in little acceptance of soil conservation measures by farmers and other land-users and low interest from governments, stakeholders and society in general (Montanarella and Panagos, 2015; Mozzato et al., 2018). While it is important to understand biophysical and biochemical processes of soil degradation, it is also vital to understand the socioeconomic and cultural drivers and potential barriers for adoption of conservation measures (Dumanski, 2015, Sanz et al., 2017)..

Advocates of soil conservation often isolated the values of land care from other great questions of global ethics such as poverty, human rights, and military conflict. As Pope Francis (2015) claimed, we must "speak the language of fraternity and beauty in our relationship with the world…, if we feel intimately united with the environment then sobriety and care will well up spontaneously". If the land is not treated with respect and affection, an ethical relationship with the land cannot be established, and we will not have a truly living relationship with the land (Minami, 2009). The global implementation of ethical principles in soil conservation, instead of using natural capital merely for economic interest, seems of paramount importance for preventing land degradation and achieving social justice and peace.

This paper aims to demonstrate why and how an eco-holistic approach, integrating biophysical, social, political, cultural and ethical factors is fundamental to identify effective conservation options to achieve LDN and support multiple SDGs. We define Eco-Holistic Soil Conservation (EHSC) as the "*sustainable and ethical protection and stewardship of the soil and its interactions with other living organisms and with their physical and social surroundings, to support ecosystem functioning and human well-being for present and future generations*". The purpose of this study is to: (i) highlight key principles of EHSC, (ii) present a framework for the implementation of EHSC, and (iii) show practical examples and recommendations for application of EHSC to achieve LDN and multiple SDGs.

2. Methods

This study is based on a critical review of published literature and the authors own expertise obtained during more than three decades working in soil science, to identify research gaps, advance the research agenda and implementation of effective soil conservation programs. A selection of relevant literature from the past decades (>1950) was made to identify and assess: (i) the main causes for the success or failure of previous conservation projects, (ii) the new concepts on soil and its environmental services, and (iii) the emerging holistic ideas on global conservation of socio-ecosystems. In our literature search we used various bibliographic databases (WoS, Scopus and Google Scholar) and a wide range of combinations of search terms (i.e. success/failure in soil/land conservation, soil conservation approach, land degradation control, soil living-system, soil health, soil and global change, economics of soil conservation, soil and ecosystem approach, soil and ecosystem services, soil policy, soil stewardship, soil conservation and land tenure, land rights, soil ethic). To make a selection of relevant literature we further searched the reference list of selected articles and publications and reports of international institutions and organizations involved in sustainable land management (i.e. UNCCD, CBD, UNFCCC, IPCC, IPBES, SPI, FAO, GEF, NRC, European Commission-DG XII, EASAC, GTZ, IUCN, Cambridge Conservation initiative, Institute for Human Rights and Business). Assessment of all these literature sources formed the basis for the identification of main causes for success and failure of past soil conservation programs and for development of the concept and practical implementation guidelines of Eco-Holistic Soil Conservation.

3. Success and failure in soil conservation projects

Numerous authors claim that successful conservation projects should relate to the three pillars of sustainability, including ecological, economic, and social goals (Brooks et al., 2012). Consequently, the planned achievements should not focus exclusively on the conservation of natural resources or agricultural productivity, but must also pursue improved livelihoods and well-being for local communities. To increase the chances of successful design and implementation of soil conservation measures, a combination of local and scientific knowledge is needed (e.g. Reed et al., 2011). Our review highlights three main reasons that explain the failure of previous soil conservation initiatives: 1) improper design, 2) lack of social and political awareness, and 3) lack of adaptation of soil conservation measures to global change.

3.1. Improper design or implementation of conservation measures

3.1.1. Frequently, soil scientists have addressed soil conservation from an individualistic and reductionist soil perspective, taking into account only those characteristics that gives it its fertility and agricultural productivity, but ignoring the interactions of the soil with other components of the socio-ecosystem, mainly biodiversity and humans (Bouma, 2014; Montanarella and Panagos, 2015). Soil science should provide the core for understanding soils and their central role in ecosystems services provision. In the last decades, many studies simplistically characterized soils by a single parameter (texture, bulk density, % organic carbon) rather than characterizing the whole soil body. Soil scientists should move away from reductionist or overly simplistic approaches by considering the entire soil profile according to the main soil classification systems (e.g. WRB for soil resources, Soil Taxonomy), which consider all the soil properties required to know its behavior under different conditions and to better prevent degradation. Likewise, soil scientists should pay more attention to promoting people's well-being and livelihoods through integrated studies and greater interaction with land users and social reality.

3.1.2. Neglecting the socioeconomic and cultural context. Increasingly, researchers, and people from different sectors of society, urge for the integration of socioeconomic and cultural issues in soil conservation and sustainable land management. Stocking and Murnaghan (2001) reported that although land degradation is a physical and biochemical process, its underlying causes are firmly rooted in the socio-economic, political and cultural environment in which land users operate. Doran (2002) stated the "vital importance of soil is related to the environment, society, and economics". Pope Franciscus (2015) claimed that "People are part of nature, included in it and thus in constant interaction with it". Indeed, it is essential to seek comprehensive solutions of soil conservation that consider the interactions between natural and social systems.

3.1.3. Non-involvement of local communities. Involvement of farmers and other land users from the early stages and throughout the design, implementation and monitoring of soil conservation projects is likely to foster acceptance and large scale adoption (de Vente et al., 2016). Nana-Sinkam (1995) also concluded that the key to successful implementation of soil conservation is participation, commitment and cooperation among all participants in the development of conservation strategies. Measures implemented by authorities through top-down approaches will not succeed if they are not understood and supported by the local community (Nana-Sinkam, 1995).

3.1.4. Lack of implementation and enforcement of a policy for the protection of land-user rights. The lack of an effective soil policy that guarantees long term land rights and a legal way to land tenure after land improvements following conservation measures is a main cause of failure of soil conservation projects (FAO, 2002; Weigelt et al., 2012; Ginzky et al., 2016).

3.1.5. Commitment to adopt an ethical soil use, dealing with local and/or global pressures and conflicts such as poverty, migration, and land rights. Soil is a finite common resource that provides livelihoods and well-being for humans and support the functioning of global ecosystems. The sustainability of the soil requires joint responsible and integrated stewardship by all individuals using or managing soil (FAO, 2015).

3.2. Lack of social and political awareness

The importance of soil protection for sustainable development has often failed to attract attention of policymakers and society at large (Bouma, 2001; Robinson et al., 2012). There is generally a limited social awareness that soil is vulnerable, that its capacity to produce goods and services is finite and can be drastically reduced by unsuitable use and management. There are also clear political barriers for implementation of an effective soil conservation policy. A clear example of this is the failure of the European Soil Thematic Strategy, due to the veto of some countries to the elaboration of the Soil Directive and to assign to the soil a legislation similar to that of other components of the biosphere such as air, water or biodiversity.

3.3. Lack of adaptation to global change

Climate change and changes in the use and management of soil and vegetation strongly affect soil degradation (Lal, 2015b). There are multiple interactions between soil conservation and climate change. Climate change has direct and indirect effects on the soil health and its capacity to produce goods and services and, likewise, the soil has an intrinsic capacity to act as a source or sink of GHG (IPCC, 2001). The impact of climate change on the occurrence and intensification of natural hazards (droughts, floods, landslides) depend at least in part on soil health (Gelybó et al., 2018, Eekhout and de Vente, 2019).

4. Key principals for Eco-Holistic Soil Conservation

This paragraph presents the key principals for Eco-Holistic Soil Conservation (EHSC) consisting of: 1) the perception of soils as living systems, 2) holistic, participatory ecosystem approach to soil conservation to achieve LDN and support the SDGs, 3) soil conservation for climate change mitigation and adaptation, and 4) ethics of soil use.

4.1 The soil as a living system

Soil is often perceived as something inert that supports plants and human activities, insensitive to human actions and environmental changes. To achieve soil conservation at the global level, it is crucial to change this perception and create greater social awareness that soil is a living, dynamic and highly sensitive system interacting with everything around it, and that human wellbeing depends on "the soils health". Increasingly soil scientists understand the soil as a living system (Doran et al., 1996; Sauer, 1999, Minami, 2009; Bockheim and Gennadiyev, 2010; Lal, 2015a; NRCS-USDA, 2018). Soils metabolize nutrients (Katznelson and Stevenson, 1956), breathe (Reichstein et al., 2003), are sensitive and react to external pressures to adapt their vital functions to environmental or anthropogenic changes (Saccá et al., 2017).

The hierarchical structure of soils, (i.e. aggregates, pores and distribution channels) allows the distribution and exchange of nutrients, oxygen, water, and energy along the soil matrix and with the environment. Fundamental differences exist in the physical laws between living soil systems and mechanical non-living systems. Soil evolves and functions by continuously taking free energy from the environment and returning degraded energy to their surroundings, so that soils “grow” and maintain their internal structural organization for sustainable functioning (Lin, 2014).

The main objective of soil conservation must be the protection and enhancement of all the soil functions and ecosystem services provided by soil. This involves soil health, which is defined as “the continued capacity of soil to function as a vital living system”

(Doran and Safley, 1997;) and its ability to provide ecosystems services (Dominati et al., 2010). The understanding of soil as a living system implies a need to increase the knowledge of the relationships of the soil with the other living organisms and their physical surrounding, the necessity to implement a suitable soil policy and legislation adapted to a living system, and the adoption of an environmental ethic. Understanding the relationship between humanity and soil as one between living organisms should make a fundamental change in our attitude and respect of the soil.

EHSC should enhance the global protection of soil health of all soil types as a vital subject in terrestrial biodiversity conservation. Each soil type, defined by the major soil classification systems, has a particular behavior under environmental and land use conditions, a particular resilience to drivers of change, and plays a different role in the functioning of ecosystems. The strong relation between soil diversity and biodiversity implies that effective biodiversity conservation requires an ecosystems approach involving conservation of soil diversity (Khaziev, 2011).

4.2. Implementation of a holistic, participatory ecosystem approach

Soils are in direct interaction with other ecosystem components to perform its functions, provide ecosystems services, and support humans livelihoods and well-being (Dominati et al., 2010; Bavey et al., 2016). Through their central role in ecosystems functioning, healthy soils are fundamental to food security, water availability and water quality, climate regulation, and protection of ecosystems and biodiversity. In addition, soils are closely connected with social, economic and cultural issues (Summers et al., 2012, Baveye et al., 2016; Small et al., 2017). These aspects link to a large number of Sustainable Development Goals related to ecosystem functioning and natural resources (SDG1; SDG2; SDG6; SDG 13; SDG14; SDG15) and to socioeconomic development, social equality, and human well-being (SDG3; SDG5; SDG8; SDG10; SDG11; SDG12). Consequently, both scientific aspects of soil and ecosystem protection, and legal, governance and property rights in soil use and land management are of paramount importance in the design of soil conservation practices and policies. Therefore, EHSC requires a holistic, transdisciplinary approach to overcome barriers for wide scale implementation of soil conservation (Box 1).

Research has provided extensive knowledge about the effectiveness of different soil conservation practices. Research has also demonstrated that the selection, design, and implementation of soil conservation practices have to be adapted to local environmental, socioeconomic, and cultural conditions since there are no one size fits all solutions. Therefore, there is urgent need for more case studies and 'living labs' in which different techniques are tested and demonstrated in close collaboration with stakeholders to facilitate knowledge exchange and find solutions to technical, cultural, economic, and institutional barriers for large scale adoption. The World Overview of Conservation Approaches and Technologies (WOCAT; www.wocat.net) is a good example of a network that facilitates global knowledge exchange regarding practical local experiences with sustainable land management practices and with creating an enabling environment for their implementation (Liniger and Critchley, 2007). To monitor the impacts of soil conservation efforts, preferably different analytical and visual methods are combined to assess soil quality and their potential to deliver ecosystem services and contribute to human well-being (Robinson et al., 2012). Barrios et al., (2006) proposed a widely applied framework to integrate local knowledge and scientific indicators of soil quality. There are several examples of Visual Soil Assessment (VSA) tools to facilitate the collection of soil and plant key performance indicators that can be used for self-evaluation, participatory monitoring and knowledge exchange purposes (Ball et al., 2017; Lujan-Soto et al, 2020).

The Earth Critical Zone (ECZ) is defined as the external terrestrial layer extending from the outer limits of vegetation down to and including the zone of groundwater (NRC, 2001). Complex interactions, among all the components of this layer, regulate the natural habitat and determine the availability of nearly every life-sustaining resource. Soil is the central interface of ECZ and its role in the processing of energy, material, and biodiversity is essential to the provisioning of life-sustaining resources (Banwart, et al., 2019). However, the interactions of soils with other components of the Earth system are often underestimated (Bockheim and Gennadiyev, 2010) because soil scientist have often taken a reductionist rather than integrated interdisciplinary research approaches. In contrast, an ecosystem approach aims at integrated management of soil, water and living resources that promotes conservation and sustainable use in an equitable way. Likewise, the design and planning of EHSC programs must be undertaken in a transdisciplinary way, recognizing that we are dealing with coupled socio-ecosystems and multiple disciplines like soil science, ecology, biology, hydrology, climatology, geology, sociology, and economy.

Desertification, biodiversity loss and climate change were outlined as the three main drivers of global environmental change during the 1992 Rio Earth Summit. There is increasing recognition about the interlinkages between these three drivers of global change (Gisladottir and Stocking, 2005). Fig. 1 illustrates how the soil plays a key role in the linkages, synergies and feedback processes between the three main drivers of the environmental changes. Knowledge of these interlinkages is crucial for the development and implementation of soil and ecosystem conservation approaches.

Although land degradation is a physical process, its main drivers are rooted in the socio-economic and political environment (Boardman et al., 2003). Reliable integrated economic assessment of costs and benefits related to land degradation and soil conservation are highly needed to foster implementation of soil conservation measures. Initiatives such as The Economics of Ecosystems and Biodiversity (TEEB) and The Economics of Land Degradation (ELD) focused on "making nature's values visible", are crucial to incorporate them into decision-making. The development of EHSC also requires quantification of these multiple values of nature.

A key issue to take in consideration in soil conservation frameworks is whether land property regimes are appropriate for sustainable land management. Land tenure systems cannot be isolated from their social and cultural context (FAO, 2002). An EHSC program should ensure that property systems are supported by certainty in the law and the rule of law and human rights. Conflicts related to land property are often very complex and have strong implications for the success or failure of soil conservation and sustainable management plans. To solve them, a coherent and transparent soil policy is needed. Soil policy should be integrated in a broader natural resources policy, and developed and implemented considering opinions, knowledge and active participation from local stakeholders. The three pillars of any land policy must be: 1) efficiency and promotion of economic development, 2) equity and social justice, and, 3) protection of the environment and sustainable land use for present and future generations (FAO, 2002).

4.3. Adapting to climate change

Globally, the soil plays a crucial role in regulating the Earth's climate by controlling the concentration of carbon dioxide and other GHG in the atmosphere. To promote a positive balance in the terrestrial carbon cycle is a key issue to enhance soil health and to increase its resilience and adaptation to climate change. Table 1 shows how this synergistic relationship between soil health and carbon cycle can be encouraged.

At present, there is insufficient knowledge about how climate change will impact soil organic matter, nitrogen and many physical and biological soil properties (Brevik, 2013). This impact could be different geographically, depending on the environmental characteristics of each area. In humid and subhumid areas, the increased atmospheric CO_2 concentration might lead to a gradual improvement in soil fertility and physical conditions (Brinkman and Sombroek, 1996; FAO, 2002). However, in drier ecosystems, the decline in plant primary production, due to increases in evapotranspiration and reductions in soil moisture caused by higher temperatures may lead to increased soil degradation and desertification (León-Sánchez et al., 2016). There is evidence that this impact may vary according to the land uses and with geographic latitude (Albaladejo et al., 2013). The indirect effects of climate change on soils through climate-induced changes in vegetation cover may well be greater than direct effects due to changing temperature and precipitation characteristics or changing atmospheric CO_2 concentration (Brinkman and Sombroek, 1996; Ziadat et al., 2017).

Many studies have demonstrated the potential capacity of soils to contribute to climate change mitigation through carbon sequestration (Srinivasarao et al., 2011; Lal, 2018). The annual carbon sink capacity of world soils is estimated at about 1 Pg carbon, which can annually off-set 0.47 ppm of CO_2 increase in the atmosphere (IPCC, 1999). On the other hand, the atmospheric carbon pool has increased from 280 ppm in around 1750 to over 400 ppm in 2019, and is increasing at the rate of 3.3 Pg carbon per year (IPCC, 2001). It is estimated that 30% of this increase is due to the land use and land-use change, and for the most recent decade (2003–2012), land-use change was responsible for 10% of total anthropogenic carbon emissions (Canadell and Schulze, 2014). Soil conservation approaches can have the double effect of reducing atmospheric CO_2 concentration, through soil carbon sequestration, and reducing emissions and losses of soil organic carbon. Moreover, irrespective of the climate change debate, increasing the soil organic carbon stock has multiple additional benefits in terms of soil conservation, biodiversity protection, and food security (Lal, 2004).

4.4. Embracing a soil ethic

When we speak of the "environment", we refer to the relationship between nature and the society that lives in it (Pope Francis, 2015). Humans, as part of socio-ecosystems, must determine why and how we should address our relationship with the soil. Ethical considerations regarding our responsibilities to soil include the following: i) soil degradation reduces its capacity to produce goods and services currently affecting the livelihoods of at least 3.2 billion people (IPBES, 2018) (SDG2; SDG3), ii) soil protection is strongly linked with eradication of poverty (SDG1), equitable economic development (SDG10), respect for human rights (SDG16), migration and peace, iii) the interactions of soil degradation with global climate change, loss of biodiversity, and reduction of ecosystems services (SDG13; SDG15), iv) land is the source of the spiritual, cultural and social identity of many populations, and, v) "soil stewardship" is key to address environmental and social issues together (SDG17).

To guarantee sustainable development, soil conservation should include an ethical framework regulating human-soil relationships. The role of soil ethic must be to set our moral obligations regarding the environment and more particular in human-soil relationships, avoiding actions damaging soils, and assuming that there are ethical decisions humans must consider. We can distinguish two types of response: 1) optimize the direct benefit of soil conservation for human beings, without endangering present survival but with little respect for the global environment, and 2) preserve the integrity, stability, and beauty of the natural environment and promote the well-being for future generations. The first response applies an anthropocentric ethic, while the second response applies a holistic or eco-centric ethic (Leopold, 2013). If soil conservation is to contribute to global sustainability, climate change mitigation and social stability, we strive for an eco-centric conception of soil ethic. The moral duty of soil ethic must be to guarantee the ecosystem services of the soil, for present and future generations, above partial or temporal benefits.

5. Framework for Eco-Holistic Soil Conservation (EHSC)

This section schematically describes the framework for implementation of EHSC. Planning and implementation of EHSC requires a transdisciplinary team representing all biophysical and socioeconomic disciplines, land users and stakeholders involved. The framework involves a range of actions in three iterative phases (Fig. 2). The first phase includes the interdisciplinary analysis for the diagnosis of the causes, processes and present state of the land degradation and its socio-economic environment based on local and scientific knowledge and including a stakeholder analysis. The second phase involves integrated studies to determine the interactions and synergies between the factors and actors involved in soil and land conservation, while the third phase consists of participatory evaluation and monitoring of the effectiveness and impacts of the soil conservation program. Findings from the evaluation phase may lead to adjustments, moving back to phase 1 and phase 2.

Phase 1: This phase consists of an initial analysis for the characterization and diagnosis of the soil and its environmental, socio-economic and cultural context involving scientists, farmers, land-users and other stakeholders. This phase includes the assessment of soil health and degradation risk, current status and risk of biodiversity loss, past and projected climate change and impacts on soils and biodiversity, availability of water resources, social structures, markets and economic sectors, soil policy and legislation on soil use and protection, land tenure, gathering opinions and involvement of land users and local communities, including cultural idiosyncrasy, customs and traditions.

Phase 2: This phase consist of detailed integrated analysis of data from soil, biodiversity, water resources, and climate change for the selection and implementation of conservation techniques. This analysis should lead to so-called "Biophysical conservation", comprising a set of technical actions and management practices able to reduce or prevent land degradation, and restore already degraded land by enhancing soil health, avoiding loss and enhancing biodiversity, and increasing the resilience of the ecosystem to climate change and contribute to climate change mitigation. At the same time, the integrated analysis of the social, economic, cultural and political characteristics, along with the opinions and preferences of all stakeholders provides so-called "socio-economic conservation", comprising of a set of priorities, opportunities and barriers for implementation of soil conservation measures. The ultimate design of the EHSC strategy will be obtained by integration of biophysical and socio-economic conservation.

Phase 3: This phase consists of the design and implementation of an evaluation and monitoring system including qualitative and quantitative biophysical, social, political and cultural information representing the impacts and effectiveness of the selected conservation measures (Catizzone and Muchena, 1994; Stem et al., 2005). Preferably, stakeholders should participate in the monitoring and evaluation activities combining scientific, analytical, and Visual Soil Assessment tools (Luján-Soto et al., 2020) to foster ownership and knowledge exchange between stakeholders involved, which is often related to higher implementation levels by stakeholders (de Vente et al., 2016). Examples of typical EHSC indicators are soil health, carbon balance, biodiversity index, biomass productivity (biophysical indicators), per capita income, employment rate, food security, human well-being (socio-economic indicators), and government stability, legislative strength, public support, capacity building, education (political and cultural indicators).

6. Practical recommendations for the implementation of EHSC

6.1. Examples of management practices to enhance soil health

With respect to technologies for soil health management, three aspects should be considered: (1) find synergies and tradeoffs between the different techniques, (2) undertake conservation in a practical way, based on proven efficient technologies, and (3) co-develop soil conservation with all stakeholders to increase acceptance and chances for large scale implementation.

There is extensive information in the literature on innovative technologies and practices to protect and enhance soil and ecosystem health (Doran, 2002; Stocking, 2009; Delgado et al., 2011; Lehman et al., 2015; Lal, 2016). The challenge is to make better use of the diversity and resiliency of the biological community in soil to maintain a healthy ecosystem, thus fostering sustainability (Doran, 2002). Since soil health depends strongly upon the soil food web (NRCS-USDA, 2018), strategies of soil management for protecting or enhancing soil health should mostly focus on maintaining a suitable habitat for the huge number and diversity of microorganisms making up the soil food web (Lehman et al., 2015). The following practices contribute to protect soil and ecosystem health and increase resilience to climate change.

1 Enhancement of quantity and quality of soil organic matter through organic amendments. The amount and stability of soil organic carbon (SOC) pools is critical for soil health and the foundation of many ecosystem services

2 Minimum soil disturbance. Conservation tillage adapted to local climate and surface soil conditions.

3 Maintaining soil cover through crop rotations, cover crops, planting trees (agroforestry) and allowing cover residue to decompose on the soil.

4 Diversify soil biota through higher diversity in the crop rotation and cover crops. Biodiversity plays a key role in the sustainable productivity of any agricultural system (Altieri, 1999; Lal, 2014; Lehman et al., 2015).

5 Adoption of Integrated Nutrient Management (INM) practices based on the combined use of organic, biological and mineral resources (Gruhn et al., 2000; Wu and Ma, 2015).

6 Rhizosphere management to increase nutrient use efficiency and crop productivity (Ryan et al., 2009; Zhang et al., 2010).

7 Prevent and mitigate soil salinization, alkalinization, acidification and contamination.

8 Manipulation of soil biology. Novel technology such as selection of specific disease resistant plants and/or cultivars with desired exudates able to influence soil microorganisms, or more general approaches based on a shift of the global population of the microorganisms (Lehman et al., 2015).

9 Minimize the use of fossil fuels and petrochemicals through a better use of renewable resources instead of synthetic fertilizers.

10 Monitoring the effectiveness of the implemented techniques through the use of soil health indicators in collaboration with land users.

There can often be barriers for implementation of certain techniques depending on local conditions, since many of these technological options may incur considerable costs to land users in terms of labour or access to materials, and frequently crop residues and other organic sources are not easily available for soil management since they are already used for other purposes like fuel or feeding livestock (Stocking, 2009; Sánchez-Reparaz et al., 2020).

6.2. Recommendations to enhance transdisciplinarity, social awareness and soil ethic

Some guidelines for the integration of socioeconomic, policy and cultural aspects in the EHSC approach include:

1 Foster transdisciplinary co-development and evaluation by scientific, technical experts, land users, and other stakeholders. Conservation programs must be implemented in agreement with farmers and other land users, (Werner et al., 2017).

2 Develop integrated models through participatory modelling at multiple scales, to highlight the interrelationships between biophysical, social and economic processes reflecting the central role of soils and consider impacts on crucial SDG progress indicators, including, but not limited to Land Degradation Neutrality.

3 Build on the indigenous traditional methods (Mulat et al., 2013).

4 Land tenure must be guaranteed. Both the farmers who rent the land and the owners should be confident of holding the same conditions after the improvement due to conservation programs.

5 Since benefits of soil conservation measures often affect the whole of society, external funding and incentives from governments, private institutions, and NGOs and other support mechanisms are required to support large scale implementation of soil conservation. Examples of economic support range from the development of sustainable business models to Payments for Ecosystem Services schemes and subsidies like those from the European Common Agriculture Policy.

6 Capacity building. The efficient implementation of sustainable land management technologies and policies requires education and training and the translation of science into practical guidelines (e.g. Voluntary Guidelines for Sustainable Soil Management; FAO, 2017) that can be used by land users and policy makers (Doran and Safley, 1997).

7 Increase social awareness of the value of soil to prevent conflict and foster human well-being. This requires active dissemination and outreach, connecting science and technology to farmers and land managers and society as a whole.

8 National and international soil legislation frameworks should be developed (Hannam and Boer, 2004). As soil conservation is a global problem, this legislation should be recognized by the international community.

9 Respect for human rights and common property of natural resources. The principle of the subordination of private property to the universal destination of goods, and thus the right of everyone to their use, is a golden rule of social conduct and "the first principle of the whole ethical and social order" (Pope Francis, 2015).

10 Recognition that soil is part of the social, cultural and spiritual identity of local communities. Native inhabitants cannot be stripped of their soil by buying and selling land between countries.

11 Poverty and soil degradation are interrelated, self-enforcing processes (Barrett and Bevis, 2015). An ethical consideration of sustainable soil management, must address the inequalities in access to soil resources and help to ensure the livelihood of the poorest populations.

7. Conclusion

A more holistic vision of soil conservation is needed, considering biophysical, socioeconomic, cultural and ethical aspects to foster large scale adoption of effective soil conservation programs. This study highlights the need to undertake transdisciplinary case studies in close collaboration with land users and other stakeholders in the field, paying special attention to the central role of soils in the functioning of socio-ecosystems and to support multiple Sustainable Development Goals under present and future climate conditions.

This holistic perception of soil protection asks for more research and social, economic, political, cultural and ethical changes in soil conservation programs. Emphasis is required for the following aspects:

1 Policy makers at all levels as well as the scientific community should understand soils as living-systems that have critical interactions with all other ecosystem components. Further research is needed to increase the knowledge of interlinkages between the soil, plants, water, climate and organisms, in order to develop innovative technologies that promote: a) soil health and resilience, b) synergies between soil and other ecosystem components, c) food security, and, d) biodiversity. The SDGs can be guiding in the design of this future research.

2 Climate change is one of the main drivers of land degradation affecting health of soils and ecosystems. Increasing the resilience and biological adaptation of soils and ecosystems to the local trends of climate change is one of the main challenges in soil and environmental sciences at present. We need further research regarding interactions and feedbacks between soil health, water availability, biodiversity, and climate change to deal with this challenge.

3 Economic valuation of ecosystem services and of landscape restoration efforts are needed for greater awareness and acceptance of the importance of conservation of natural resources. This awareness is crucial to achieve land degradation neutrality and preserving the resources necessary to support life on the planet.

4 At present, the universal right to land is not explicitly reflected in international human rights law. In order to reach a better contribution of soil and ecosystem conservation to social stability and the reduction of poverty and inequalities, the right of native people to the land should be globally recognized and supported in the local, national and international legislations.

Given the central role of soils in the context of the three environmental Rio Conventions on Biodiversity (CBD), Climate Change (UNFCCC) and Desertification (UNCCD), further integration and collaboration between these three conventions will be an important step at a political level towards more effective and efficient implementation of soil conservation and protection of ecosystem services for the benefit of nature and human well-being.

Acknowledgments

This study was supported by the Spanish Ministerio de Economia y Competitividad (CGL2013-48753-R co-funded by European Union FEDER funds) and Fundación Séneca (20917/PI/18). We thank Andrés Marín for his assistance with the graphical editing.

Orcid
Juan Albaladejo: https://orcid.org/0000-0002-9603-3864
Elvira Díaz-Pereira: https://orcid.org/0000-0002-7459-5137
Joris de Vente: http://orcid.org/0000-0001-7428-0621

References

Albaladejo, J., Ortiz, R., Garcia-Franco, N., Ruiz Navarro, A., Almagro, M., Garcia Pintado, J., Martínez-Mena, M., 2013. Land use and climate change impacts on soil organic carbon stocks in semi-arid Spain. J. Soils Sediments 13, 265-277. https://doi.org/10.1007/s11368-012-0617-7.

Almagro, M., de Vente, J., Boix-Fayos, C., García-Franco, N., Melgares de Aguilar, J., González, D., Solé-Benet, A., Martínez-Mena, M., 2016. Sustainable land management practices as providers of several ecosystem services under rainfed Mediterranean agroecosystems. Mitig. Adapt. Strateg. Glob. Chang. 21, 1029–1043. https://doi.org/10.1007/s11027-013-9535-2.

Altieri, M.A., 1999. The ecological role of biodiversity in agroecosys-tems. Agric. Ecosyst. Environ. 74, 19–31. https://doi.org/10.1016/S0167-8809(99)00028-6.

Álvaro-Fuentes, J., Easter, M., Paustian, K., 2012. Climate change effects on organic carbon storage in agricultural soils of northeastern Spain. Agric. Ecosyst. Environ. 155, 87–94. https://doi.org/http://dx.doi.org/10.1016/j.agee.2012.04.001.

Ball, B.C., Guimarães, R.M.L., Cloy, J.M., Hargreaves, P.R., Shepherd, T.G., McKenzie, B.M., 2017. Visual soil evaluation: A summary of some applications and potential developments for agriculture. Soil Tillage Res. 173, 114–124. https://doi.org/10.1016/j.still.2016.07.006.

Banwart, S.A., Nikolaos, P., Nikolaidis, N.P, Zhu, Y.-G., Peacock, C.L., Sparks, D.L., 2019. Soil functions: connecting Earth's critical zone. Annu. Rev. Earth Planet. Sci. 47, 333-359. https://doi.org/10.1146/annurev-earth-063016-020544.

Barrett, C.B., Bevis, L.E.M., 2015.The self-reinforcing feedback between low soil fertility and chronic poverty. Nat. Geosci. 8, 907–912. https://doi.org/10.1038/ngeo2591.

Barrios, E., Delve, R.J., Bekunda, M., Mowo, J., Agunda, J., Ramisch, J., Trejo, M.T.,Thomas, R.J., 2006. Indicators of soil quality: A South-South development of a methodological guide for linking local and technical knowledge. Geoderma 135, 248–259. https://doi.org/10.1016/j.geoderma.2005.12.007.

Baveye, P.C., Baveye, J., Gowdy, J., 2016. Soil "ecosystem" services and natural capital: Critical appraisal of research on uncertain ground. Front. Environ. Sci. 4, 41. https://doi.org/10.3389/fenvs.2016.00041.

Boardman, J., Poesen, J., Evans, R., 2003. Socio-Economic factors in soil erosion and conservation. Environ. Sci. Policy 6, 1–6. https://doi.org/10.1016/S1462-9011(02)00120-X.

Bockheim, J.G., Gennadiyev, A.N., 2010. Soil-factorial models and earth system science: A review. Geoderma 159, 243–251. https://doi.org/10.1016/j.geoderma.2010.09.005.

Bouma, J., 2001. The new role of soil science in a network society. Soil Sci. 166, 874- 879. https://doi.org/10.1097/00010694-200112000-00002.
Bouma, J., 2014. Soil science contributions towards Sustainable Development Goals and their implementation: linking soil functions with ecosystem services. J. Plant Nutr. Soil Sci. 177, 111–120. https://doi.org/10.1002/jpln.201300646.
Bouma, J., 2019. How to communicate soil expertise more effectively in the information age when aiming at the UN Sustainable Development Goal. Soil Use Manage. 35, 32–38. https://doi.org/10.1111/sum.12415.
Brevik, E.C., 2013. The potential impact of climate change on soil properties and processes and corresponding influence on food security. Agriculture 3, 398–417. https://doi.org/10.3390/agriculture3030398.
Brinkman, R., Sombroek, W.G., 1996. The effects of global change on soil conditions in relation to plant growth and food production, in: Bazzaz, F., Sombroek, W.G. (Eds.), Global climate change and agricultural production. FAO and Wiley, Chichester. pp. 49–6. https://www.fao.org/3/w5183e/w5183e05.htm.
Brooks, J.S., Waylen, K.A., Borgerhoff-Mulder, M., 2012. How national con-text, project design, and local community characteristics influence success in community-based conservation projects. Proc. Natl. Acad. Sci. U.S.A. 109, 21265–21270. https://doi.org/10.1073/pnas.1207141110.
Canadell, J.G., Schulze, E.D., 2014. Global potential of biospheric carbon management for climate mitigation. Nat. Commun. 5, 5282. https://doi.org/10.1038/ncomms6282.
Catizzone, M., Muchena, S.C., 1994. A holistic approach to sustainable soil use in SADC countries, in: Bridges, E.M., Muchena, S.C., Prasad, G., Williams, M. (Eds.), Proceedings of a Workshop Supported by the European Commission Directorate General XII and the Southern African Centre for Co-operation in Agricultural Research European Commission, Brussels xxv + 58 pp. https://library.wur.nl/isric/fulltext/isricu_i26539_001.pdf.
Conant, R.T., Ryan, M.G., Ågren, G.I., Birge, H.E., Davidson, E.A., Eliasson, P.E., Evans, S.E., Frey, S.D., Giardina, C.P., Hopkins, F.M., Hyvönen, R., Kirschbaum, M.U.F., Lavallee, J.M., Leifeld, J., Parton, W.J., Steinweg, J.M., Wallenstein, M.D., Wetterstedt, J.Å.M., Bradford, M.A., 2011. Temperature and soil organic matter decomposition rates - synthesis of current knowledge and a way forward. Glob. Change Biol. 17, 3392–3404. https://doi.org/10.1111/j.1365-2486.2011.02496.x.
Curtin, D., Beare, M.H., Hernandez-Ramirez, G., 2012. Temperature and moisture effects on microbial biomass and soil organic matter mineralization. Soil Sci. Soc. Am. J. 76, 2055–2067. https://doi.org/10.2136/sssaj2012.0011.
Dazzi, C., Lo Papa, G., 2019. Soil genetic erosion: New conceptual developments in soil security. Int. Soil Water Conserv. Res. 7, 317-324. https://doi.org/10.1016/j.iswcr.2019.08.001.
de Vente, J., Reed, M.S., Stringer, L.C., Valente, S., Newig, J., 2016. How does the context and design of participatory decision making processes affect their outcomes? Evidence from sustainable land management in global drylands. Ecol. Soc. 21. https://doi.org/10.5751/ES-08053-210224.
Delgado, J. A., Groffman, P. M., Nearing, M. A., Goddard, T., Reicosky, D., Lal, R., Kitchen, N.R., Rice, C.W., Towery, D., Salon, P., 2011. Conservation practices to mitigate and

adapt to climate change. J. Soil Water Conserv. 66, 118–129. https://doi.org/10.2489/jswc.66.4.118A.
Diamond, J., 2005. Collapse: How societies choose to fail or succeed. Viking Press, New York.
Dominati, E., Patterson, M., Mackay, A., 2010. A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecol. Econ. 69, 1858–1868. https://doi.org/10.1016/j.ecolecon.2010.05.002.
Doran, J.W., 2002. Soils health and global sustainability: translating science into practice. Agric. Ecosyst. Environ. 88, 119–127. https://doi.org/10.1016/S0167-8809(01)00246-8.
Doran, J.W., Safley, M., 1997. Defining and assessing soil health and sustainable productivity, in: Pankhurst, C., Doube, B.M., Gupta, V.V.S.R. (Eds.), Biological Indicators of Soil Health. CAB International, Wallingford, Oxon, UK, pp. 1–28. https://www.ars.usda.gov/research/publications/publication/?seqNo115=78601.
Doran, J. W., Sarrantonio, M., Liebig, M., 1996. Soil health and sustainability, in: Sparks, D.L. (Ed.), Advances in Agronomy, Vol. 56. Academic Press, San Diego, pp. 1–54. https://doi.org/10.1016/S0065-2113(08)60178-9.
Dumanski, J., 2015. Evolving concepts and opportunities in soil conservation. Int. Soil Water Conserv. Res. 3, 1-14. https://doi.org/10.1016/j.iswcr.2015.04.002.
Earth Charter Commission, 2000. The Earth Charter. San José: Earth Charter International Secretariat. https://www.environmentandsociety.org/node/2795.
Eekhout, J.P.C., Hunink, J.E., Terink, W., de Vente, J., 2018. Why increased extreme precipitation under climate change negatively affects water security. Hydrol. Earth Syst. Sci. 22, 5935–5946. https://doi.org/10.5194/hess-22-5935-2018.
Eekhout, J.P.C., de Vente, J., 2019. Assessing the effectiveness of Sustainable Land Management for large-scale climate change adaptation. Sci. Total Environ. 654, 85–93. https://doi.org/10.1016/j.scitotenv.2018.10.350.
Engel, J.R., 2009. Our Covenant with Earth: The Contribution of Soil Ethics to Our Planetary Future, in: Bigas, H., Gudbrandsson, G.I., Montanarella, L., Arnalds, A. (Eds.), Soils, Society and Global Change. Proceedings of the International Forum Celebrating the Centenary of Conservation and Restoration of Soil and Vegetation in Iceland, Selfoss, Iceland, September 2007. European Communities, Luxembourg. pp. 148-153. https://www.land.is/wp-content/uploads/2018/01/Soils-Society-Global-Change.pdf.
FAO, 2002. Land Tenure and Rural Development, FAO Land Tenure Studies No. 3, Rome. https://www.fao.org/3/a-y4307e.pdf.
FAO, 2015. Revised World soil charter. https://www.fao.org/3/a-i4965e.pdf.
FAO 2017. Voluntary Guidelines for Sustainable Soil Management Food and Agriculture Organization of the United Nations Rome, Italy. http://www.fao.org/3/a-bl813e.pdf.
Francis, P., 2015. Encyclical Letter. Laudato Si'. On Care for Our Common Home. Vatican Press,Vatikanen, https://w2.vatican.va/content/francesco/it/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si.html.
Garcia-Franco, N., Albaladejo, J., Almagro, M., Martínez-Mena, M., 2015a. Beneficial effects of reduced tillage and green manure on soil aggregation and stabilization of

organic carbon in a Mediterranean agroecosystem. Soil Tillage Res. 153, 66–75. https://doi.org/10.1016/j.still.2015.05.010.
Garcia-Franco, N., Martínez-Mena, M., Goberna, M., Albaladejo, J., 2015b. Changes in soil aggregation and microbial community structure control carbon sequestration after afforestation of semiarid shrublands. Soil Biol. Biochem. 87, 110-121. https://doi.org/10.1016/j.soilbio.2015.04.012.
Gelybó, G., Tóth, E., Farkas, C., Horel, Á., Kása, I., Bakacsi, Z., 2018. Potential impacts of climate change on soil properties. Agrochem. Soil Sci. 67, 121. https://doi.org/10.1556/0088.2018.67.1.9.
Ginzky, H., Heuser, I.L., Qin, T., Ruppel, O.C., Wegerdt, P. (Eds.)., 2016. International Yearbook of Soil Law and Policy 2016 Series. International Yearbook of Soil Law and Policy, Annual volumes 2016. Springer, Cham. https://doi.org/10.1007/978-3-319-42508-5.
Gisladottir, R., Stocking, M., 2005. Land degradation control and its global environmental benefits. Land Degrad. Dev. 16, 99–112. https://doi.org/10.1002/ldr.687.
Gruhn, P., Goletti, F., Yudelman, M., 2000. Integrated nutrient management, soil fertility, and sustainable agriculture: Current issues and future challenges. Food, Agriculture, and the Environment Discussion Paper 32. International Food Policy Research Institute Washington, DC. https://www.ifpri.org/publication/integrated-nutrient-management-soil-fertility-and-sustainable-agriculture-0.
Hannam, I., Boer, B., 2004. Drafting Legislation for Sustainable Soils: A Guide. IUCN. Gland. https://portals.iucn.org/library/sites/library/files/documents/EPLP-052.pdf.
IPBES, 2018. Summary for policymakers of the assessment report on land degradation and restoration of the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services. IPBES Secretariat, Bonn, Germany. https://www.ipbes.net/system/tdf/spm_3bi_ldr_digital.pdf?file=1&type=node&id=28335.
IPCC, 2001. Climate Change: The Scientific Basis. Cambridge Univ. Press, Cambridge, UK.
IPCC, 1999. Penner, J.E., Lister, D.H., Griggs, D.J., Dokken, D.J., McFarland, M. (Eds.) Prepared in collaboration with the Scientific Assessment Panel to the Montreal Protocol on Substances that Deplete the Ozone Layer Cambridge University Press, UK. Available from Cambridge University Press, The Edinburgh Building Shaftesbury Road, Cambridge CB2 2RU England. https://www.ipcc.ch/report/aviation-and-the-global-atmosphere-2/.
Katznelson, B.H., Stevenson, L., 1956. Observations on metabolic activity of the soil microflora. Can. J. Microbiol. 2, 611-622. https://doi.org/10.1139/m56-074.
Keesstra, S. D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., Montanarella, L., Quinton, J.N., Pachepsky, Y., van der Putten, W.H., Bardgett, R.D., Moolenaar, S., Mol, G., Jansen, B.,Fresco, L. O., 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.
Khaziev, F. Kh., 2011. Soil and biodiversity. Russ. J. Ecol. 42, 199–204.Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304, 1623–1627. https://doi.org/10.1126/science.1097396.

Lal, R., 2014. Soil carbon management and climate change. Carbon Manag. 4, 439–462. https://doi.org/10.4155/cmt.13.31.
Lal, R., 2015a. The soil–peace nexus: our common future. Soil Sci. Plant Nutr. 61, 566–578. https://doi.org/10.1080/00380768.2015.1065166.
Lal, R., 2015b. Restoring Soil Quality to Mitigate Soil Degradation. Sustainability 7, 5875–5895.https://doi.org/10.3390/su7055875.
Lal, R., 2016. Soil health and carbon management. Food Energy Secur. 5, 212–222. https://doi.org/10.1002/fes3.96.
Lal, R., 2018. Digging deeper: A holistic perspective of factors affecting soil organic carbon sequestration in agroecosystems. Glob. Change Biol. 24, 3285–3301. https://doi.org/10.1111/gcb.14054.
Lehman, R.M., Cambardella, C.A., Stott, D.E., Acosta-Martinez, V., Manter, D.K., Buyer, J.S., Maul, J.E., Smith, J.L., Collins, H.P., Halvorson, J.J., Kremer, R.J., Lundgren, J.G., Ducey, T.F., Jin, V.L., Karlen, D.L., 2015. Understanding and enhancing soil biological health: The solution for reversing soil degradation. Sustainability 7, 988– 1027. https://doi.org/10.3390/su7010988.
León-Sánchez, L., Nicolás, E., Nortes, P., Maestre, F. T., Querejeta, J.I., 2016. Photosynthesis and growth reduction with warming are driven by non-stomatal limitations in a Mediterranean semiarid shrub. Ecol. Evol. 6, 2725-2738. https://doi.org/10.1002/ece3.2074.
Leopold, A., 2013. A Sand County Almanac and Other Writings on Conservation and Ecology, Meine, C. (Ed.), Library of America, New York, NY, USA.
Lin, H., 2014. A new worldview of soils. Soil Sci. Soc. Am. J. 78, 1831–1844. https://doi.org/10.2136/sssaj2014.04.0162.
Liniger, H., Critchley, W., 2007. Where the land is greener. Case studies and analysis of soil and water conservation initiatives worldwide. Berne, Switzerland: World Overview of Conservation Approaches and Technologies programme.
Luján-Soto, R., Cuellar-Padilla, M., de Vente, J., 2020. Participatory selection of soil quality indicators for monitoring the impacts of regenerative agriculture on ecosystem services. Ecosyst. Serv., in press.
Minami, K., 2009. Soil and humanity: Culture, civilization, livelihood and health. Soil Sci. Plant Nutr. 55, 603-615. https://doi.org/10.1111/j.1747-0765.2009.00401.x.
McLeman, R. 2017. Migration and land degradation: Recent experience and future trends. GLOBAL LAND OUTLOOK WORKING PAPER. UNCCD. https://knowledge.unccd.int/sites/default/files/2018-06/8.%20Migration%2Band%2BLand%2BDegradation__R_McLeman.pdf
Montanarella, L., Panagos, P., 2015. Policy relevance of Critical Zone science. Land Use Pol. 49, 86–91. https://doi.org/10.1016/j.landusepol.2015.07.019.
Mozzato, D., Gatto, P., Defrancesco, E., Bortolini, L., Pirotti, F., Pisani, E., Sartori, L., 2018. The role of factors affecting the adoption of environmentally friendly farming practices: can geographical context and time explain the differences emerging from literature?. Sustainability 10, 1-23. https://doi.org/10.3390/su10093101.
Mulat, Y., 2013. Indigenous Knowledge Practices in Soil Conservation at Konso People , South western Ethiopia. J. Agric. Environ. Sci. 2, 1-10. http://jaesnet.com/journals/jaes/Vol_2_No_2_December_2013/1.pdf.
Nana-Sinkam, S.C., UNECA Joint ECA/FAO Agriculture Division, United Nations Food and Agriculture Organization, 1995. Land and environmental degradation and

desertification in Africa. Issues and options for sustainable economic development with transformation. Monograph (Joint ECA/FAO Agriculture Division); no.10, vii, Addis Ababa, UNECA. http://www.fao.org/3/X5318E/x5318e00.htm.

National Research Council (NRC), 2001. Basic research opportunities in earth sciences. National Academies Press. National Research Council, Washington, DC. https://doi.org/10.17226/9981.

NRCS-USDA, 2018. Principles high functioning for soils. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/soils/health/?cid=stelprdb1049236.

Reed, M.S., Buenemann, M., Atlhopheng, J., Akhtar-Schuster, M., Bachmann, F., Bastin, G., Bigas, H., Chanda, R., Dougill, A.J., Essahli, W., Evely, A.C., Fleskens, L., Geeson N., Glass, J.H., Hessel, R., Holden, J., Ioris, A., Kruger, B., Liniger, H.P., Mphinyane, W., Nainggolan, D., Perkins, J., Raymond, C.M., Ritsema, C.J., Schwilch, G., Sebego, R., Seely, M., Stringer, L.C., Thomas, R.J., Twomlow, S., Verzandvoort, S., 2011. Cross-scale monitoring and assessment of land degradation and sustainable land management: a methodological framework for knowledge management. Land Degrad. Dev. 22, 261– 271. https://doi.org/10.1002/ldr.1087.

Reichstein, M., Rey, A., Freibauer, A., Tenhunen, J., Valentini, R., Banza, J., Casals, P. ,Cheng, Y., Grünzweig, J.M., Irvine, J., Joffre, R., Law, B.E., Loustau, D., Miglietta, F., Oechel, W., Ourcival, J.M., Pereira, J.S., Peressotti, A., Ponti, F., Qi, Y., Rambal, S., Rayment, M., Romanya, J., Rossi, F., Tedeschi, V., Tirone, G., Xu, M., Yakir, D. , 2003. Modeling temporal and large-scale spatial variability of soil respiration from soil water availability, temperature and vegetation productivity indices. Glob. Biogeochem. Cycle 17, 1104. https://doi.org/10.1029/2003GB002035.

Robinson, D.A., Hockley, N., Dominati, E., Lebron, I., Scow, K.M., Reynolds, B., Emmett, B.A., Keith, A.M., de Jonge, L.W., Schjonning, P., Moldrup, P., Jones, S.B., Tuller, M., 2012. Natural capital, ecosystem services, and soil change: why soil science must embrace an ecosystems approach. Vadose Zone J. 11, 6. https://doi.org/10.2136/vzj2011.0051.

Ryan, P.R., Dessaux, Y., Thomashow, L.S., Weller, D.M., 2009. Rhizosphere engineering and management for sustainable agriculture. Plant Soil 321, 363–383. https://doi.org/10.1007/s11104-009-0001-6.

Saccá, M.L., Caracciolo, A.B., Di Lenola, M., Grenni, P., 2017. Ecosystem services provided by soil microorganisms, in: Lukac, M., Genni, P., Gamboni, M. (Eds.), Soil biological communities in ecosystems resilience. Switzerland, Springer International Publishing AG. pp. 9-24.

Sánchez-Reparaz, M., de Vente, J., Famba, S., Rollin, D., Dolinska, A., Rougier, J.-E., Tamele, H.F., Barberá, G.G., 2020. Innovative Soil Fertility Management by Stakeholder Engagement in the Chókwè Irrigation Scheme (Mozambique). Irrig. Drain. 69: S1, 49-59. https://doi.org/10.1002/ird.2054.

Sanz, M.J., de Vente, J., Chotte, J.-L. , Bernoux, M., Kust, G., Ruiz, I., Almagro, M., Alloza, J.-A., Vallejo, R., Castillo, V., Hebel, A., Akhtar-Schuster, M., 2017. Sustainable Land Management contribution to successful land-based climate change adaptation and mitigation. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany. https://www.unccd.int/sites/default/files/documents/2017-09/UNCCD_Report_SLM_web_v2.pdf.

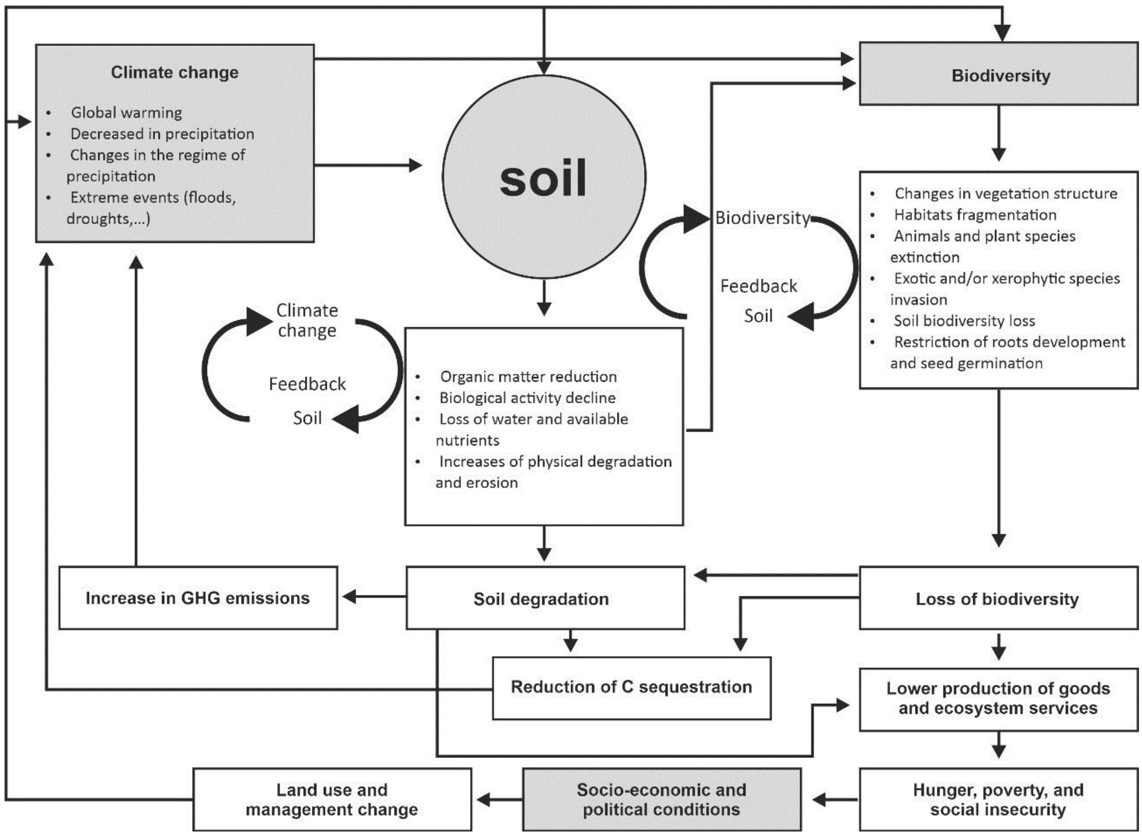
Sauer, L.J., 1999. Soil as a living system. Arnoldia. The Arnold Arboretum Harvard University 59, 35-43. https://www.ecolandscaping.org/12/soil/soil-as-a-living-system/
SDSN, 2015. Indicators and a Monitoring Framework for the Sustainable Development Goals: Launching a data revolution for the SDGs. A report to the Secretary-General of the United Nations by the Leadership Council of the Sustainable Development Solutions Network. https://sustainabledevelopment.un.org/content/documents/2013150612-FINAL-SDSN-Indicator-Report1.pdf.
Small, N., Munday, M., Durance, I., 2017. The challenge of valuing ecosystem services that have no material benefits. Glob. Environ. Change 44, 57–67. https://doi.org/10.1016/j.gloenvcha.2017.03.005.
Srinivasarao, Ch., Kundu, S., Jakkula, V.S., Reddy, S.B., Naik, R.P., Manideep, R.V., Veeraman, K.Ch., 2011. Soil carbon sequestration strategies in rainfed agriculture, in: Srinivasarao, Ch., Venkateswarlu, B., Srinivas, K., Kundu, S., Singh, A.K. (Eds.), Soil Carbon Sequestration for Climate Change Mitigation and Food Security. Central Research Institute for Dryland Agriculture, Hyderabad, India. pp. 46-56.
Stem, C., Margoluis, R., Salafsky, N., Brown, M., 2005. Monitoring and evaluation in conservation: A review of trends and approaches. Conserv. Biol. 19, 295–309. https://doi.org/10.1111/j.1523-1739.2005.00594.x.
Stocking, M., 2009. A global systems approach for healthy soils, in: Bigas,H., Gudbrandsson, H.G.I., Montanarella, L., Arnalds, A. (Eds.), Soils, Society and Global Change. Proceedings of the International Forum Celebrating the Centenary of Conservation and Restoration of Soil and Vegetation in Iceland, Selfoss, Iceland, September 2007. European Communities, Luxembourg. pp. 99-106. https://www.land.is/wp-content/uploads/2018/01/Soils-Society-Global-Change.pdf.
Stocking, M., Murnaghan, N. (Eds.), 2001. Handbook for the field assessment of land degradation. Earthscan, London. https://www.nhbs.com/handbook-for-the-field-assessment-of-land-degradation-book
Summers, J.K., Smith, L.M., Case, J.L., Linthurst, R.A., 2012. A review of the elements of human well-being with an emphasis on the contribution of ecosystem services. Ambio 41, 327–340 . http://doi.org/10.1007/s13280-012-0256-7.
UNCCD, 2019. Land-Based Adaptation and Resilience: Powered By Nature. https://www.unccd.int/.
UNCCD, 2012. Zero Net Land Degradation. A sustainable development goal for Rio + 20. UNCCD Secretariat Policy Brief, UN Convention to Combat Desertification, Bonn. https://sustainabledevelopment.un.org/index.php?page=view&type=400&nr=526&menu=35.
Weigelt, J. Beckh, C., Bose, P., Lobos Alva, I., Schmidt, O., 2012. Towards Integrated Governance of Land and Soil: Addressing Challenges and Moving Ahead (Issue Paper', Global Economic Symposium, 2012). https://pdfs.semanticscholar.org/24d6/fd2bd63257c8bf4511aad250b6051ee9dfda.pdf.
Werner, M., Wauters, E., Bijttebier, J., Steinmann, H., Ruysschaert, G., Knierim, A., 2017. Farm level implementation of soil conservation measures: Farmers’ beliefs and

intentions. Renew. Agr. Food Syst. 32, 524-537. https://doi.org/10.1017/S1742170516000454.
Wu, W., Ma, B., 2015. Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: a review. Sci. Total Environ. 512-513, 415–427. https://doi.org/10.1016/j.scitotenv.2014.12.101.
Zhang, F.S., Shen, J.B., Zhang, J.L., Zuo, Y.M., Li, L., Chen, X.P., 2010. Rhizosphere processes and management for improving nutrient use efficiency and crop productivity: implications for China. Adv. Agron. 107, 1–32. https://doi.org/10.1016/S0065-2113(10)07001-X.
Ziadat, F., Bunning, S., De Pauw, E., 2017. Land resource planning for sustainable land management. FAO, Rome. Land and Water Division Working Paper 14. FAO. http://www.fao.org/3/a-i5937e.pdf.

Figure legends

Fig. 1. Synergies and feedback processes between the four main drivers (climate change, land degradation, biodiversity loss, and socio-economic and political environment) of the environmental change.

Fig. 2. Framework for the implementation of EHSC.



Climate change
Global warming
Decreased in precipitation
Changes in the regime of precipitation
Extreme events (floods, droughts,...)
soil
Biodiversity
Changes in vegetation structure
Habitats fragmentation
Animals and plant species extinction
Exotic and/or xerophytic species invasion
Soil biodiversity loss
Restriction of roots development and seed germination
Biodiversity
Feedback
Soil
Climate change
Feedback
Soil
Organic matter reduction
Biological activity decline
Loss of water and available nutrients
Increases of physical degradation and erosion
Increase in GHG emissions
Soil degradation
Loss of biodiversity
Reduction of C sequestration
Lower production of goods and ecosystem services
Land use and management change
Socio-economic and political conditions
Hunger, poverty, and social insecurity

Fig. 1

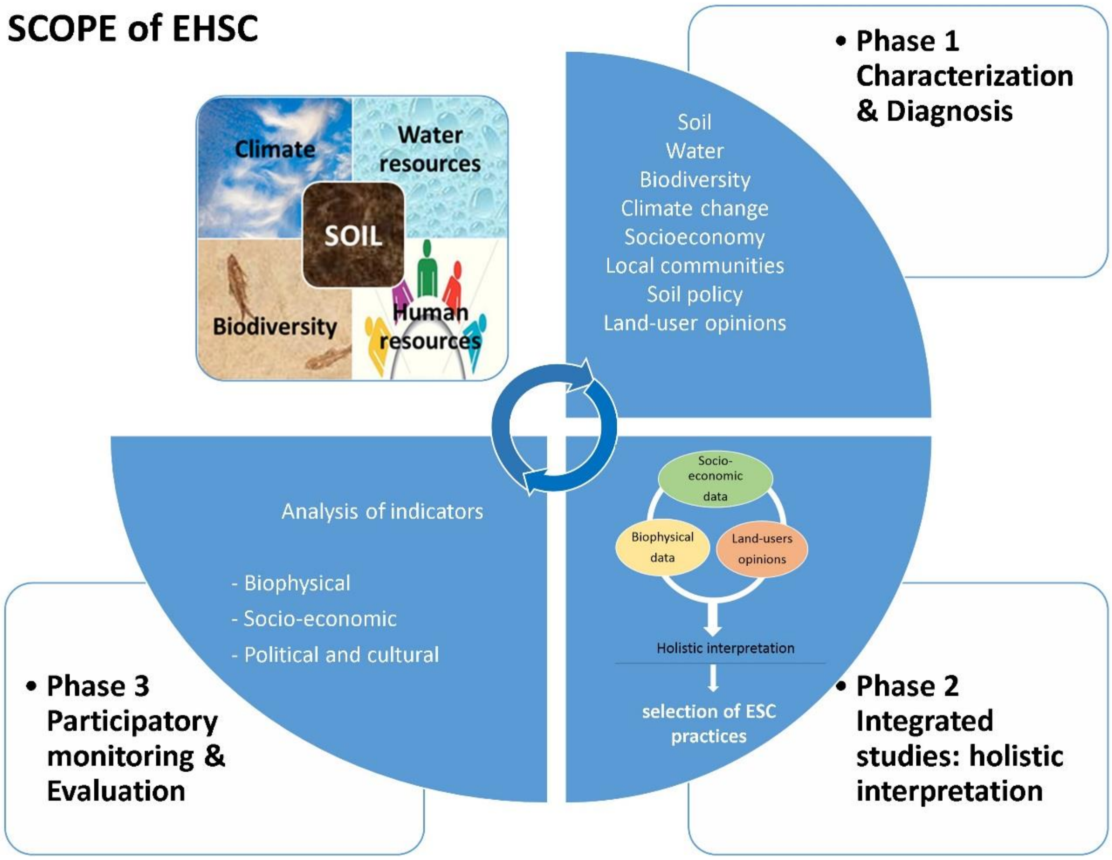
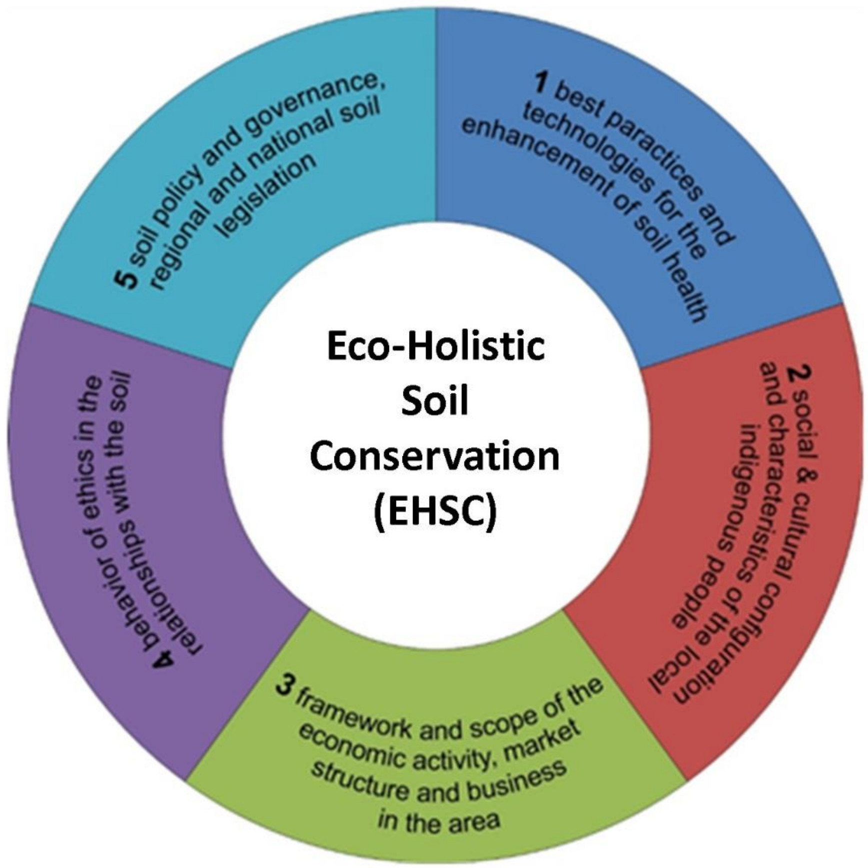

SCOPE of EHSC
Climate
Water resources
SOIL
Biodiversity
Human resources
• Phase 1 Characterization & Diagnosis
Soil
Water
Biodiversity
Climate change
Socioeconomy
Local communities
Soil policy
Land-user opinions
Socio-economic data
Biophysical data
Land-users opinions
Holistic interpretation
selection of ESC practices
• Phase 2 Integrated studies: holistic interpretation
Analysis of indicators
- Biophysical
- Socio-economic
- Political and cultural
• Phase 3 Participatory monitoring & Evaluation

Fig. 2

Table 1 The optimization of the terrestrial C cycle is key in enhancing soil health and increase its resilience and adaptation to climate change. Source: own elaboration.

How to enhance soil health optimizing the terrestrial C cycle		
1. Remove CO_2 from the atmosphere increasing biomass production:	2. Minimize the losses of C from the land	3. Increase the size and stability of OC pools in the soil
• Reforestation, afforestation, forest management • Sustainable grazing lands management • Ecosystems restoration • Optimize agricultural yield: environmentally adapted crops, crops rotation, cover crops • Plant breeding	• Implement the best soil uses and management practices, eradicate inadequate use changes and the abandonment of the land. • Control soil erosion. • Protection of forests, rangelands, wetlands and mangroves. • Responsible diet and consumption habits.	• Organic amendments • Improve soil structure • Enhance soil biology • Suitable management of soil microbiology



The whole target is the Eco-Holistic Soil Conservation (EHSC). The EHSC involves partial targets (1 to 5) and only can be achieved from the success of each of these partial targets. All these parts are in intimate interconnection, so that they only should be understood in reference to the whole target. The isolated achievement of partial targets is not a guarantee of the success of the EHSC. Only through the synergic interlinkages between all the parts involved it is possible to achieve the EHSC.

Box 1 The interdisciplinary character of Eco-Holistic Soil Conservation.