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A new definition of soil to promote soil awareness, sustainability, security and governance

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A R T I C L E I N F O

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A B S T R A C T

In these last decades, the awareness that soil is a very important resource for humans has noticeably increased. Many actions and initiatives to promote soil governance, aiming at sustainable soil management and soil security have been undertaken by several national and international institutions and in many countries. Analysis of the changes of soil perception over the centuries allows highlighting a perfect harmony between the evolution of soil awareness and the level of knowledge and technology achieved by humans during their history and evolution. Notwithstanding these many achievements, soils continue to be scarcely considered in politics and society. We suggest some thoughts and reflections that could lead to an up-to-date and effective definition of soil that directly focuses the public attention on its economic value. In our opinion, soil economic value could be the only aspect that truly attracts the attention of politicians and administrators, which could increase soil awareness and encourage soil sustainability, security and Sustainable Development Goals and finally promote soil governance.

1. Introduction

Soils are usually considered as non-renewable natural resources because their rate of formation over time is generally low or very low (Stockman et al., 2014) over a human lifetime. They are crucial to life on Earth and play a central role in many of today's environmental challenges (Weil & Brady, 2017). Even so, almost everywhere, soils show evident problems of degradation (Amundson et al., 2015; FAO, 2015, p. 650) due to several threats that undermine their ability to produce goods and services. In the last two decades, and, in particular, after the proposal to set up a World Soil Day celebration that was launched by the International Union of Soil Sciences (IUSS) during its 17th World Congress on Soil Science (Bangkok, Thailand, 2002), the awareness that soils are very important and multifaceted resources has noticeably increased. They are known to perform a leading role in ecological sustainability, climate change mitigation, ecosystem services, land use and planning as well as in food security (Adhikari & Hartemink, 2016; Bampa et al., 2019; Dazzi et al., 2019; Hou et al.. 2020; Yang et al., 2021).

Increasing soil awareness and governance can be seen as a common action that should involve civil society in all the world's countries. This is particularly true for the European Countries, where problems of soil degradation and desertification are evident and acute in many areas (FAO, 2015, p. 650).

At the international level, in 2011, FAO created the “Global Soil Partnership” (GSP), to promote sustainable soil management and soil protection. The 68th UN General Assembly declared 2015 the International Year of Soils, intending to increase awareness and understanding of the importance of soil for food security and essential ecosystem functions. Besides, to increase this momentum and the extent of the contributions of the civil society on these issues, the International Union of Soil Sciences (IUSS), at the end of 2015, proclaimed the International Decade of Soils 2015–2024.

At the European level, the 7th Environment Action Programme (EAP), which entered into force in January 2014, recognises that degradation, fragmentation and unsustainable use of land is consuming fertile soils, jeopardising the provision of several key ecosystem services, threatening biodiversity, exacerbating soil degradation and desertification and resulting in impacts on global soil and food security (European Union, 2014b, p. 87).

It is to underline these factors that the Common Agricultural

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Policy (CAP) also acknowledges that there is a strong feedback between the soil threats (FAO, 2017, p. 26) and stressors that a holistic and collaborative approach to soil management and governance is crucial, and it has put in place various instruments to promote sustainable use and management of soils (Pe'er et al., 2019). The European Green Deal (EGD), is a major policy step towards a sustainable society and acknowledges the central role soils play in solving or minimising most of the environmental problems of our time (Montanarella & Panagos, 2021).

For the same purposes, the European Commission (EC), has planned the achievement of several important goals in the Zero Pollution action plan (European Commission, 2020a) in the Biodiversity Strategy 2030 (European Commission, 2020b, p. 380), the Farm to Fork strategy (European Commission, 2020c), the European Climate Law (European Commission, 2020d), the Soil Health and Food Mission (European Commission, 2020e) and the Biodiversity Strategy (European Commission, 2020f). Soil is expressly cited in all the above-reported strategies and/or action plans and is indirectly relevant for achieving climate neutrality in 2050 (Montanarella & Panagos, 2021).

Always in the last two decades, together with the above-listed initiatives, specific concepts and ideas have been highlighted, aiming to increase the awareness of the soil's importance and role. We refer to the concepts of soil security, soil sustainability and soil ecosystem services (SESs), as well as the launch of the Sustainable Development Goals (SDGs). It is also important that several soil awareness and education initiatives were planned for informing decision-makers and working with stakeholder groups (Harrison et al., 2005; Towers et al., 2010).

Notwithstanding these various efforts and initiatives, until now, the wide range of soil functions and roles in ecological balance and human health/welfare are not completely fulfilled, even in top-level cultural and political contexts. The withdrawal of the Thematic Strategy on the Protection of Soil (European Commission, 2014) is one example, but we could also quote the peculiar case of the scientific and cultural panels listed by the European Research Council (ERC) in which the topic "soil science" does not appear with the importance that it deserves (Erdogan et al., 2021).

Starting from the above concerns, and considering that some authors (Brevik, 2005; Brevik & Arnold, 2015; Brevik & Hartemink, 2010; Certini & Ugolini, 2013; Hartemink, 2016; Johnson, 1998) have called for a new definition of soil that could meet the needs of a world that is becoming more and more scientifically and economically interconnected (Lal et al., 2020), we would propose some ideas on how to define/consider the soil. These ideas would be for increasing soil awareness and encouraging soil sustainability, security and SDGs in a social and political arena that is increasingly economically oriented and dependent while promoting effective and concrete soil governance. We believe that soil governance is a very important point in soil science and particularly in pedology, because "*it is important to carefully consider the current pedological definition of soil and whether it can adequately address modern needs*" (Brevik & Arnold, 2015). Therefore, after considering the concern that researchers warrant for the main soil issues and the evolution that the idea of soil has had in time, we propose a definition of soil whose aim is to increase soil awareness among policy-makers and, consequently, to promote soil governance.

2. General concern on the main soil issues

In the last two decades, specific concepts and ideas have been stressed to highlight soil's importance and role in a healthy environment. These refer to the concepts of SDGs, soil ecosystem services (SESs) soil sustainability, soil security, soil awareness and soil governance. To have an idea of the attention that these concepts have in the scientific literature we did a systematic search in Scopus considering the "title, abstract and keywords". The review was limited to the number of scientific papers (Fig. 1) that have been published in the last 20 years (2001–2020) as reported in Scopus on the February 1, 2021. It emerges that in the past two decades, 64,669 papers have been published on the above-listed soil issue (Table 1). Most of them (31,635 = 48.9%) refer to SDGs. A very small amount (929 = 1.4%), however, deals with soil governance.

2.1. Sustainable Development Goals

Our survey shows that more than 31,000 papers (precisely 31,635) have been published in 20 years on the SDGs subject. The considerable appeal that the SDGs issue has had in the last decade (2011–2020) (see Fig. 1) relies on the fact that SDGs are an issue that shows objective importance not only for soil and food security but also for several social, cultural and economic goals. Soils play a key role that is evident for the SDGs 1, 2, 3, 6, 7, 11, 13 and 15 (Bouma & Montanarella, 2016; Keesstra et al., 2016) (Fig. 2). In particular:

Goal 1: No Poverty - Mainly in the rural areas of the world, people's incomes can be increased through suitable land use. Different soils need different management systems and different land uses. Therefore, detailed knowledge of the features and capabilities of the soil in each region will contribute to the achievement of this goal.

Goal 2: Zero Hunger - Keeping soils in good health and sustainably managing them allows for increasing food quality and quantity, thus ensuring food safety and food availability for an increasing population.

Goal 3: Good Health and Well-being – Humanity's quality of life depends on the quality of the soil on which they live and work. This is a consolidated axiom in soil science literature that dates back to the Roman classic time (Columella, De Re Rustica; 1st century).

Goal 6: Clean Water and Sanitation - Soils are a key element in the water cycle. Most of the freshwater quality for human consumption is directly or indirectly influenced by the soil, mainly through its cation exchange capacity.

Goal 7: Affordable and Clean Energy - Using the less productive soils to grow energy-crops could give a substantial contribution in alleviating the demand for energy from fossil or non-renewable sources.

Goal 11: Sustainable Cities and Communities - Urban soils play an effective role in increasing the aesthetics of cities due to the vegetation they sustain and in mitigating the " heat island" effect that characterises the urban areas as well as the well-being and social satisfaction derived from the management of the urban garden.

Goal 13: Climate Action - Soil is the largest organic carbon reservoir on earth and plays a key role in the global carbon cycle.

Goal 15: Life on Land - Goal 15 is based on the sustainable use of soil, which is the key element of the environmental ecosystem.

2.2. Soil sustainability

Our survey shows that 14,238 papers have been published in the last 20 years on the soil sustainability subject. According to Ludwig et al. (2018) over 100 different definitions have been proposed for soil sustainability. The most acknowledged, proposed by Abbott and Murphy (2007), considers soil sustainability as being "*soil management that meets the needs of the present without compromising the ability of future generations to meet their own needs from that soil*". Intuitively, sustainable soil management contributes significantly to the achievement of the SDGs, as highlighted also in SDG 2. The report on the state of soil resources in the world (FAO, 2015, p. 650), identifies 10 threats that hinder its achievement (Table 2). Sustainable soil management is achieved through mitigation or resolution of such threats. Shortly, therefore, it will be

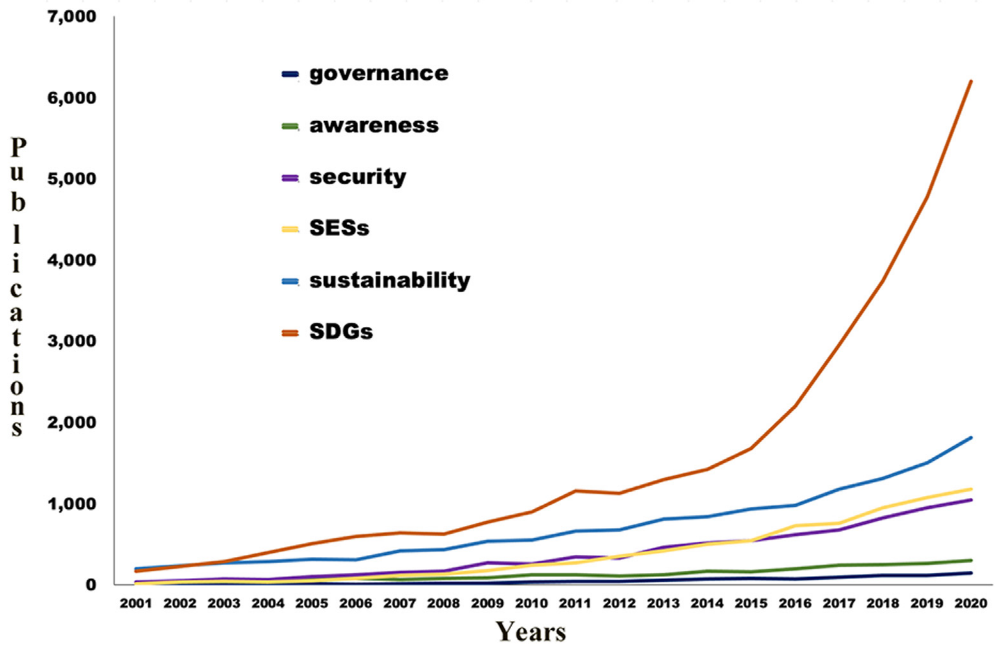

Fig. 1. Trend from 2001 to 2020 of the scientific and technical publications for the research terms listed in table 1 (performed in Scopus.com on 1st February 2021 and considering "title, abstract and keywords").

Table 1
Number of results for the research terms: soil governance, soil awareness, soil security, SESs, soil sustainability and SDGs (performed in Scopus.com on February 1, 2021 and considering the "title, abstract and keywords").

Soil issue	Number of papers	%
Soil governance	929	1.4
Soil awareness	2598	4.0
Soil security	7585	11.7
SESs	7684	11.9
Soil sustainability	14,238	22.0
SDGs	31,635	48.9
Total	**64,669**	**100.0**

Fig. 2. Soil performs a central role in selected SDGs.

necessary (FAO, 2017, p. 26) to minimise soil erosion, enhance soil organic matter content, foster soil nutrient balance and cycles, prevent, minimise and mitigate soil salinisation and alkalinisation, prevent and minimise soil contamination, prevent and minimise soil acidification, preserve and enhance soil biodiversity, minimise soil sealing, prevent and mitigate soil compaction and improve soil water management.

2.3. Soil ecosystem services

Our survey shows that 7684 papers have been published in the last 20 years on the soil ecosystem services subject. Such issues gained a broader acknowledgment after the Millennium Ecosystem Assessment (MEA) (Costanza et al., 2014). As stressed by de Groot et al. (2002), a comprehensive definition of the goods and services provided by the soil, implies the translation of its ecological complexity into a more limited number of functions. Actually, there is a general agreement in grouping these functions into four main categories: regulation, habitat, production and information.

Regulation functions are related to the soil's ability to regulate several ecological processes that are at the basis of life, through the bio-geo-chemical cycles. Habitat functions are linked to the possibility of providing a vital environment for plants and animals thus contributing to the in-situ conservation of biological and genetic diversity. Production functions are related to the soil's ability to support and produce biomass. Information functions are based on the soilscapes ability in maintaining human well-being by providing opportunities for reflection, spiritual enrichment, cognitive development and aesthetic and recreational experience (Chan et al., 2016).

These four functions are the basis of the "value" of the soil that can be divided into three types: economic, socio-cultural and ecological. The economic value refers to the simple market valuation and its definition is quite simple. Concerning the socio-cultural value, it should be noted that in addition to the ecological criteria, social values play a considerable role in conditioning the importance of natural ecosystems and their functions for humankind. In

Table 2
The ten threats to sustainable soil management according to the Voluntary Guidelines for Sustainable Soil Management (VGSSS, FAO, 2017).

1. Water and wind erosion
2. Loss of organic carbon
3. Imbalance of nutrients
4. Salinisation and alkalisation
5. Contamination
6. Acidification
7. Loss of soil biodiversity
8. Sealing
9. Compaction
10. Submersion

particular, social values positively influence physical and mental health, education, diversity and cultural identity as well as the value of freedom (Costanza et al, 1997, 2014; Ives & Kidwell, 2019). The ecological value, in summary, the environmental importance of a given soil, is determined both by the integrity of its regulation and habitat functions and by those parameters that affect its diversity, complexity and even its rarity.

The soil social and ecological values represent the aggregate value of the ecosystem services provided by the soil (Fig. 3) that, as reported by McBratney, Morgan, and Jarrett (2017), are thought to contribute a bit less than $12 trillion worth (in 2017 dollars). Such figure ($\$12^{18} = \$12, 000, 000{,}000, 000, 000{,}000$), expressed in monetary accounting units is useful to highlight the magnitude of the eco-services provided by the soil (Costanza et al., 2014) and remains engraved in the mind of the readers (Berg and Zia. 2013; Evans, 2008).

2.4. Soil security

In 20 years, 7585 papers have been published on the soil security issue. Soil security has been defined as "*the maintenance and improvement of the capacity of the world's soil resources to produce food, fibre and fresh water, contribute to energy and climate sustainability, and maintain the biodiversity and the overall protection of the ecosystem*" (Koch et al, 2012, 2013; McBratney et al., 2014). From this definition emerges that soil security depends on the soil's ability to provide goods and ecosystem services (Carter et al., 1997; Lal, 2010), and relies on a good soil's structure and form; on a wide diversity of soil's organisms; on the soil's ability to sustain plants, to store and filter water, to sequester carbon dioxide from the atmosphere (McBratney et al., 2014). In this sense, a "good" soil, i.e. a soil that can supply food, fibre, clean freshwater, to maintain biodiversity and to contribute to the protection of the ecosystem, is to be considered a secure soil (Dazzi et al., 2019; McBratney et al., 2014), and vice-versa, a "bad" soil is insecure. Five "Cs" need to be evaluated to decide if a soil is a "good/secure" or a "bad/insecure" soil (McBratney et al., 2014; Field et al, 2017). These are: 1) Capability that considers which function can perform a particular soil; 2) Condition that considers the ability of a soil to perform functions as a result of management practices); 3) Capital, that considers "the stock of materials or information contained within an ecosystem" (Costanza et al., 1997); 4) Connectivity that seeks to determine how society understands and relates to soil; 5) Codification that acknowledges the need for, and role of, government policy and regulation in ensuring that soil is cared for. A wide and exhaustive explanation of the five Cs is in Field et al. (2017).

2.5. Soil awareness

Few papers have been published on soil awareness issues in the

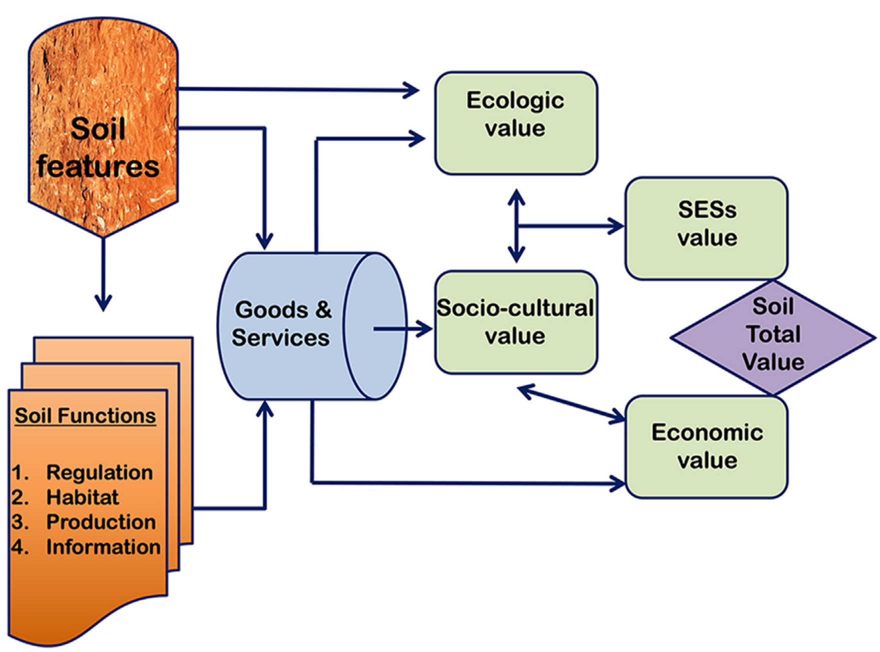

Fig. 3. The soil features influence the soil functions that through the production of goods and services determine the economic, socio-cultural and ecological value of the soils (based on de Groot et al., 2002).

last 20 years. They account for only 2598 of the papers. This is surprising if we take into consideration the plethora of initiative that has been and still are planned to increase and spread the awareness of the soil all over the world. Unfortunately, most of these (Table 3) occur at local/national scale, while only a few occur at the international scale (Towers et al., 2010; Harrison et al., 2005). Grunwald et al. (2017) state that the environmental crisis we face today is "due to a lack of awareness and understanding of prominent values and benefits soils provide to sustain humanity" while a coherent and adequate soil awareness should be a prerequisite to achieve the objectives of the new EU Soil Strategy (European Union, 2014b, p. 87). Indeed, in these last decades, particular attention was deserved in Europe to environment and environmental policy. Such attention is strongly supported by the European citizens who recognize that environmental problems go beyond national and regional borders and believe that the responsibility to protect soils should be shared among the industry, national governments, the EU and citizens themselves (European Union, 2014a).

2.6. Soil governance

Very few papers (only 929) have been published on soil governance issues in these last 20 years. FAO (http://www.fao.org/policy-support/governance/en/), defines governance at all levels as "*the process through which public and private actors articulate their interest, frame and prioritise issues and make, implement, monitor and enforce decision*". According to Juerges and Hansjürgens (2018), soil governance embraces "*all legal prescriptions, regulation, market incentives, rules, norms, habits, attitudes that concern soil-related decision-making processes of state and non-state actors' at all decision-making levels*". Consequently, soil governance should be the main tool through which politicians and administrators would regulate and control how soils are used and managed to avoid any environmental problems due to soil misuse and/or mismanagement (Montanarella & Vargas, 2012). As stressed in the introduction, within the EU, soil governance has gained increasing importance: particularly in these last 10 years, the soil has been considered in most of the strategies and/or action plans that were launched at the EU level. Moreover, the European Green Deal was proposed as a major policy step towards a sustainable society and acknowledges the central role soils play in solving or minimising most of the environmental problems of our time (Montanarella & Panagos, 2021). Notwithstanding all these proposals, all the initiatives that have been and still are planned to increase and spread the awareness of the soil all over the world, and despite the objective interest shown in issues such as soil security and SESs, not only on a European level but also on a world level, soil governance remains the Cinderella among the issues concerning the soil. Recently (April 28, 2021), the resolution on soil protection adopted by the European Parliament stresses that a comprehensive, adequate, coherent and integrated soil governance is a fundamental prerequisite "to achieve the objectives of the SDGs, the Paris Agreement and the European Green Deal, and in particular, the climate neutrality objective, the farm-to-fork strategy, the biodiversity strategy, the zero-pollution ambition, the bioeconomy strategy and other main environmental and societal challenges" (European Commission, 2021).

3. The evolution of the idea of soil

A reflection on the relationships that in many cultural traditions link humanity to the soil and the analysis of the changes that the idea of soil has undergone over the centuries (Arnold, 1983; Hillel, 1992, p. 352; Krupenikov, 1992; Yaalon & Berkowicz, 1997; Sandor et al., 2006; Brevik & Hartemink, 2010; James et al., 2014), allows highlighting a perfect harmony between the evolution of such ideas and the level of knowledge and technology achieved by humans during their history and evolution. Such a relationship, idealised in Fig. 4, looks like a parabolic function. From time-to-time soil has been considered as (Buol et al., 2011): 1) inert support, 2) a tool for agricultural and forestry production, 3) an element of tax assessment, 4) a source of raw materials, 5) a place of urban and infrastructural settlements, 6) a dynamic system, 7) an organised natural body, 8) a base of physical, chemical and biological processes, 9) a seat of ecosystem functions and 10) support for human activities. Nowadays, most people consider the soil as support for man's activities as did the ancestors of humans in the Palaeolithic.

It is likely that during the Palaeolithic, the soil was considered as inert support that allowed humans to move from one place to another looking for food. It was during the Neolithic that humans, changing their nomadic habits towards a sedentary way of life, needed to use rudimentary tools to carry out simple farming practices (Diamond, 1997; Harari, 2014). The transition from a nomadic life (hunter) to a sedentary life (farmer) was surely

Table 3
A list of most known organization and/or initiatives planned in the last decade to raise awareness and understanding of the importance of the soil (we do not pretend to be exhaustive).

Web page
http://www.fao.org/global-soil-partnership/en/
https://esdac.jrc.ec.europa.eu/event/european-network-soil-awareness-ensa
https://www.iuss.org/
https://www.un.org/en/observances/world-soil-day
https://www.4p1000.org/
https://www.globalsoilbiodiversity.org/
http://saveoursoils.com/
https://alpinesoils.eu/soil-awareness/
http://www.soilconservation.eu/
http://www.waswac.org.cn/waswac/index.htm
https://www.un.org/sustainabledevelopment/sustainable-development-goals/
https://www.unccd.int/
https://www.unep.org/
https://www.ipbes.net/
https://www.sciencedaily.com/news/plants_animals/soil_types/
http://www.soil-net.com/
https://www.hutton.ac.uk/learning/dirt-doctor
https://www.museum-am-schoelerberg.de/
http://fondazionemida.com/museo-del-suolo

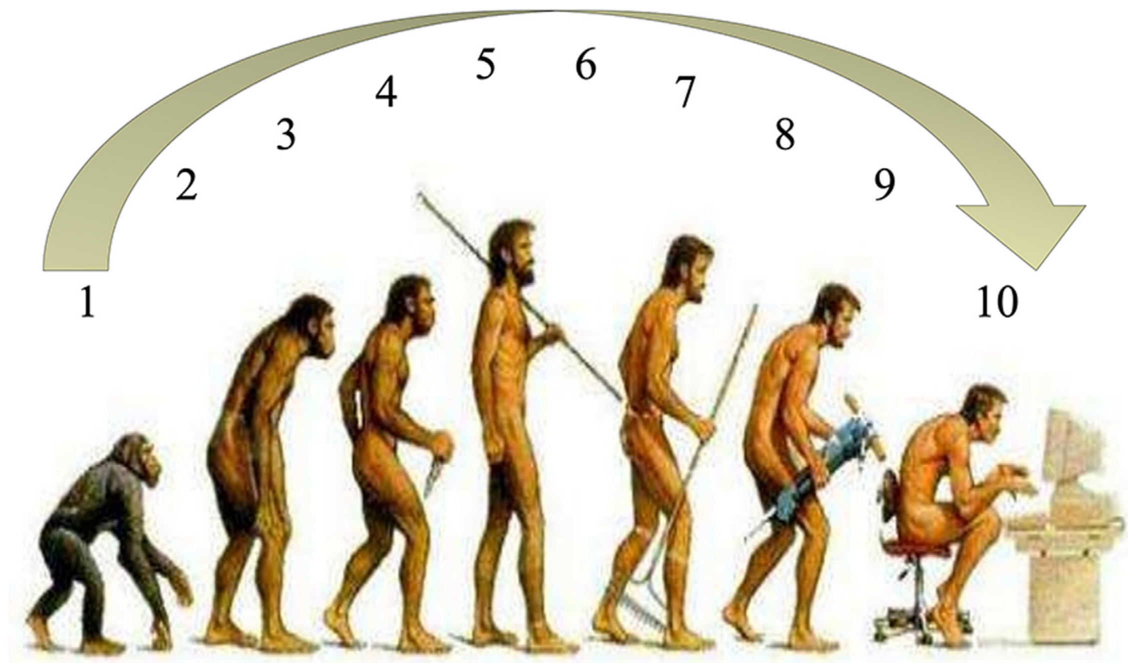

Fig. 4. The grey parabolic arrow represents an idealisation of the close relationship between the evolution of human knowledge and technology and the evolution of the concept of soil. Humans started their evolution from a prone position and reached again a prone position (the figure is a free elaboration starting from a drawing in https://www.uv.es/jgpausas/he.htm).

followed by a changed idea of soil: even in an embryonic form. It was clear that soil was not an inert material but that it hides some productive capacities that change from place to place (Miller & Schaetzl, 2014). Soil knowledge and its relationship with human practices, developed in parallel with agriculture (Desruelles et al., 2016) and humans realised that there is not only one type of soil but many different types that show different levels of fertility and different productive capacities.

In China, during the Vao Dynasty (2357–2261 BCE), Yu, a Chinese "engineer", arranged a soil classification system subdivided into nine soil groups based on their different capability. These classes were used to estimate potential different levels of income that, during the Jin dynasty (1115–1234), were taxed accordingly (GongZhang et al., 2003). With the same purpose, in ancient Egypt (about 3000 years BP), the "Kemet" soils (meaning alluvial dark and fertile soils), close to the Nile River, were separated from the "Deshret" soils (meaning desert red soils) (Bednarski, 2012; Jones et al., 2013, p. 176) found at a greater distance from the river and that rarely profited from the periodic flooding of the Nile. Besides, the Aztecs, a Mesoamerican people that flourished in central Mexico from the 14th to the 16th century, developed a soil classification system, with up to 45 classes, that was used for taxation (Williams, 2006).

Some indications on the concept of soil come from old Greece: "*soil serves to the plants as the stomach to the animals*", wrote Hippocrates about 2500 years B.P. (Saltini, 1979, p. 339). About 2400 years B·P., Teofrasto, Aristotle's pupil, called the soil "Edaphos" to distinguish it from the earth as a cosmic body. Teofrasto anticipated the soil profile concept of many centuries because in the edaphos he distinguished three layers: a surface one that was rich in organic matter, a subsoil as a dense layer able to supply nutrients to herbs and shrubs and a substratum able to provide a nutritional juice to the roots of the trees (Saltini, 1979, p. 339).

Marcus Terentius Varro, 2100 years B·P., defined the soil as *"the element in which the seeds are sown and germinate"* stating the importance of determining if the soils are rich, poor or discrete: the rich soils support all types of plants and provide good yields (a sort of Land Capability *ante litteram*). In the first century, Lucio Moderato Columella in the second book of "De Re Rustica" (i.e. On Farming), proposed a subdivision of soils into three types on a morphological basis: soils of plains, hills and mountains; each was further divided into six classes according to their quality: poor, fat, loose, hard, moist and dry.

In the Middle Ages, Ibn al-'Awwām, an erudite Arab scholar who lived in Seville and died in 1145, in his book Kitāb al-filāḥa (The Book of Agriculture), argued that: *"a sound and effective soil knowledge represent the basic point in agronomy"* (Ibn al-'Awwām, 1802) and acknowledged the soil had a crucial and active role for agricultural production (Saltini, 1979, p. 339). Nevertheless, at the beginning of the nineteenth century, several soil chemists denied any active role of soils, arguing that soil fertility actually depended on humus, since together with the water those alone provided nourishment to plants (Korcak, 1992; Moore, 1947; Hartemink, 2016).

The credit for recognising the soil as a natural body and worthy of a scientific survey is given to Vasily Vasilievich Dokuchaev (1846–1903) who is acknowledged as the founder of Pedology. Dokuchaev considered the soil as "*the fourth kingdom of nature*" and defined it as "*a natural and independent body resulting from the transformation of rock under the prevailing influence of the climate*". Focusing the attention on the soil features, Dokuchaev brought the soil surveys out of the confusion of the geologic, chemical and agronomic points of view (Hartemink, 2016; Marbut, 1936). Starting from the late 1800s, soil science became more systematically structured, leading in these last two hundred years to a plethora of definitions of soil that have been masterfully discussed and listed by Hartemink (2016), who also stressed, over time, the idea we have of the soil and its naming and definition has notably changed and that soil definitions could be clustered into six main typologies based on:

- material (organic, inorganic, clay, sand, etc.)

- composition (three-phase system, solids, liquids, gas)
- origin (broken down rocks, geology, diluvium, alluvium, etc.)
- behaviour (dynamics, changes over time)
- medium for properties and processes (C storage, water filtration)
- functions (biomass production, carbon pool, building material).

Soil is studied by very heterogeneous groups of researchers and means different things to different people with a very different cultural background. Starting from this consideration, Brevik and Arnold (2015) suggested that most of the soil definitions proposed in these last two hundred years can be clustered on the consideration that:

- soils are natural bodies;
- soils evolve in space and time;
- soils form at the surface;
- soils are the result of complex biogeochemical and physical processes;
- soils are capable of supporting life;
- soils are living systems.

Recent definitions as used by pedologists (Brevik & Arnold, 2015; Hartemink, 2016) consider the soils as:

- natural bodies;
- the weathering products of rocks and minerals;
- the medium for plant growth;
- environmental regulators;
- the result of complex biogeochemical and physical processes;
- the medium that supports life.

In the modern era, only in one case, i.e. around 100 years ago in Germany, soils were defined for land taxation purposes (Fackler, 1924) with politically agreed methods, definitions and interpretations (Landon, 1991).

4. Toward an economy-based idea of soil

From the above considerations, it emerges that soil can be synthetically conceptualised in three ways: in biophysical, societal and economic terms (Dazzi et al., 2019; McBratney, Field, & Jarrett, 2017). With the beginning of the Anthropocene (Crutzen, 2006), soil scientists have long been talking about the importance of soil in meeting our growing demands for food, water and energy, as well as in providing ecosystem services that affect climate change, human health and biodiversity.

The inter-relationships between soils and social issues, such as food safety, sustainability, climate change, carbon sequestration, greenhouse gas emissions, degradation by erosion, loss of organic matter and nutrients, are fundamental elements of the recently proposed soil security concept (Bouma & McBratney, 2013; Dazzi et al., 2019; Koch et al, 2012, 2013; McBratney et al., 2014) that relies on the soil's ecosystem services, i.e. the benefits that people derive from soils. Indeed, ecosystems provide a variety of services that are of paramount importance to humankind (Costanza et al., 2014) and have stimulated a strong interest in both the research and policy communities (Braat & de Groot, 2012; Costanza & Kubiszewski, 2012), mainly because the world's ecosystems provide goods and services worth about $60 trillion every year, as much as the gross national products of all the world's economies (Weil & Brady, 2017). Soils, as previously reported, are thought to contribute a little bit less than $12 trillion worth, nearly equivalent to the entire US economy (McBratney, Morgan, & Jarrett, 2017). According to McBratney, Morgan, and Jarrett (2017), who used data from Costanza et al. (1997) and de Groot et al. (2002), the contribution of soils represents the sum of the values of the four soil's ecosystem functions (regulation = 9752 billion USD year^{-1}; habitat = 10 billion USD year^{-1}; production = 1.143 billion USD year^{-1}; information = 476 billion USD year^{-1}). Dominati el al (2014) valued the ecosystem services provided by an alluvial soil from volcanic parent material under dairy in the Waikato region in New Zealand at US$16,390/ha/year on average over 35 consecutive years. According to Brevik et al. (2017), these values cannot be extended to soils and management systems that differ from that of the study area.

Considering that SESs are at the base of any other soil issues that recently focused the attention of researchers (as stressed in § 2) it is easy to realize that also in all those SDGs in which soils play a key role, an economy-based idea of soil could play a fundamental role in spreading soil awareness and in leading policy-makers towards an effective soil governance (Eisenmenger et al., 2020). Even if in this moment, there are not published papers on such issue, the statement of the economic role that soil performs in the SDGs (as well as in soil security), could be a win-win strategy to increase the perception of the soil's importance among politicians and in all sphere of the society and to stimulate a real soil governance on soil protection and soil conservation.

5. Labeling soil with a new definition for an effective soil governance

John Morton, an English farm-owner who in 1843 published one of the first book on soil science precisely 40 years before 1883 that is considered as the official birth-year of soil science (Boulaine, 1989, p. 285), argued that it would be very useful to have two definitions of soil: one for farmers and one for scientists. Starting from this consideration, Hartemink (2016) proposed two new definitions of soil by, which aimed at labeling the soil respectively for an audience made by experts on soil and for an audience made by laypersons (Table 4).

Labeling is a strategic tool that ascribes a label to a product both to identify it and to influence the opinion and behaviour of individuals by the terms used to describe or classify it (Morgan et al., 2017).

With the beginning of the Anthropocene, we started to live in a “global village” in which economic production and dissemination of knowledge plays a key role in the creation of wealth and where “money makes the world go round” (Derviş, 2012; Kander & Ebb, 1972). Such reflection leads to considering the soil on a broader and more appropriate scale, which is the main and only one that better reflects its importance for humanity and the same scale devoted to the soil in China 4000 years BP (GongZhang et al., 2003) in Egypt 3000 years BP (Bednarski, 2012; Jones et al., 2013, p. 176), in Mexico 500 BP (Williams, 2006) and Germany about 100 years ago (Fackler, 1924; Landon, 1991).

Thus, we face a dilemma: how to ensure an effective soil governance and to save soil ecosystem services in an era, the Anthropocene, characterised by the ever-prevalent influence of humanity on soil and a continuous lack of awareness from politicians and administrators concerning the importance of soils in the environmental equilibria? To ensure that concepts such as soil governance, soil awareness, soil sustainability, soil security and ecosystem services are not merely abstractions, we believe it mandatory to consider soils mainly as media producing and influencing economy. Such a consideration is not new in soil science (Costanza et al., 1997; de Groot et al., 2002; Dominati et al., 2010; Jónsson & Davíðsdóttir, 2016) and should be aligned with the need for policy to ensure soil security by encouraging sustainable soil management practices by a sound soil governance (FAO, 2017, p.

Table 4
The two new definitions of soil proposed by Hartemink (2016) for experts and laypersons.

Soil definition for experts	The soil is a living, four-dimensional natural entity containing solids, water (or ice) and air. Most soils are outside and are open systems, but soils also occur in shallow lakes and underneath pavement. A soil can have any colour, any age, be very shallow or deep, and consists mostly of a structured mixture of sand, silt and clay (inorganics), rocks and organic material (dead and alive). The soil has one or more genetic horizons, is an intrinsic part of the landscape, and changes over time. Soils are distributed across the earth mostly in a systematic manner. Soils store and transform energy and matter. The soil often supports vegetation, carries all terrestrial life, and produces most of our food. It is an integral part of the natural world interacting with the climate, lithosphere and hydrosphere. Soils are often studied in combination with land-use, climate, geomorphology or the hydrology of an area.
Soil definition for laypersons	Soils are the thin layer covering our planet earth. They are complex blends of living and mineral materials. Just like birds or plants there are thousands of kinds of soil. Soil is a vital natural resource, it filters and stores water, and is an important part of the Earth system. Most of our food comes from cultivated soils.

26).

In our opinion, this would require that to go toward a real and shared soil governance, we should change our soil paradigm, labeling soil with an up-to-date and effective definition as that reported in Table 5.

Labeling soil as an “economic” resource that influences deeply the “social” and “political” systems, could be a win-win strategy in attracting the attention of people because such label recall a “fundamental aspect of mental experience with which people have the subjective sense of knowing or being conscious of something” (Siegel, 2012) that is of paramount importance for the people's everyday life, i.e. economy or, in a more explicit term, financial resources.

Such a definition, focusing the attention on the economic side of the soils, in our opinion the only feature that truly attracts the attention of politicians and administrators, could efficiently foster the linkages between soil science and society and turn soil science-policy-economy full circle, leading to real soil governance (Fig. 5).

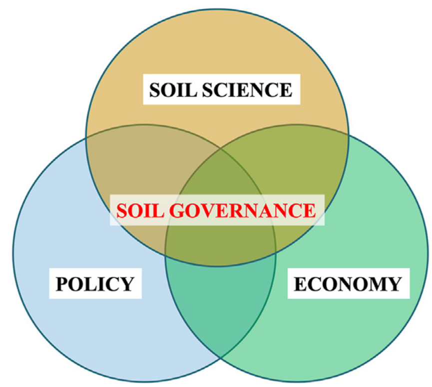

Fig. 5. Overlapping of soil science, policy and economy could effectively contribute to soil governance.

6. Conclusions

Soil scientists know and are aware that soils are natural resources but, nowadays, to communicate the importance of soils to others, they should put on one side mere scientific approaches and learn to understand people more than soils (Amundson (2017). Frequently soil data and information generated by scientists are only relevant to a very small scientific community and not of relevance to the public policy development process (Montanarella, 2017).

Amundson (2017) argues, “Scientists who do policy-relevant science typically are inexperienced and unproductive at communicating to the public and policy makers, the people who ultimately make the decisions that implement or ignore the science”. Surveys in the field of cognitive science (Brownell et al., 2013), highlights that people are “motivated reasoners,” who filter out information focusing only on those that are compatible with their, and their community's value system. Consequently, to perform policy-relevant science in an era with urgent and challenging issues mostly linked to economy, without effectively connecting to policy makers, can prove to be an unsatisfactory exercise.

Most of the soil definition proposed since the beginning of Pedology as an independent science, focus on biophysical attributes of soil. In some cases they are rather narrow in scope, in others rather vague. In order to meet the global environmental challenges, we need to identify the soil with a label that encompasses its economic, social and policy aspects. Such label must be clear and direct to push the civil society to consider the degree to which soil is being valued and cared for (McBratney, Field, & Jarrett, 2017). Recalling the attention of the general public and of the policy-makers by labeling the soil as an “economic” resource that influences deeply the “social” and “political” systems, could be a win-win strategy to go towards an effective soil governance that should be appraised as an economic investment.

Europe, in particular, is preparing a new future with ambitious challenges and goals identified in the EU Green Deal, while, at global level, the UN Sustainable Development Goals are assuming a strategic importance to set up a better and common future that must secure its roots into the soil. We cannot continue to lose time in the imperative quest to save our soils. The new “EU Soil Strategy - Healthy Soil for a Healthy Life” must be followed by effective and positive actions with the aim to conserve and enhance the multi-functionality of soil and promote the vital role of soil systems in enhancing environmental equilibrium and human health and welfare.

We live in an era and in a cultural system that pays particular attention to human rights but does not equally indicate duties and responsibilities. We can fight to defend our privileges but we skimp from our duties. Our relationship with the environment is characterised by a general indifference and widespread carelessness. The awareness of the role played by the environmental resources and by the soil, in particular, is lacking. Soil, being a “crypto-resource”, a hidden resource, is considered only after catastrophic events and when the failures are evident! So far, we have shown skills in getting out from situations that wisdom would have certainly avoided.

Now it is imperative to take a cultural leap. We all have to

Table 5
The soil definition that stressing immediately the economic importance of the soil, could effectively be appealing for politicians and administrators.

Soil definition for politicians and administrators	The soil is an economic resource that deeply influences the social and political systems.

consider the soil as a good for a human society that is continuously changing and in which the boost toward continued economic growth and rapid technological development, coupled with the progressive increase of the information, often causes considerable and unpredictable changes. The achievement of this goal is based mainly on the consideration that soil, since the beginning of the history of humans on Earth, has been primarily seen as an economic resource and as a source of wealth. Such an ancient but ever valid vision of soil, supported by a new soil paradigm, could also be useful for soil science because it could stimulate and lead to the genesis of a new discipline that, as a branch of bio-economics, we could call pedo-economy.

Declaration of competing interest

We declare that we do not have any competing interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.iswcr.2021.07.001.

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