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SOIL: The vision to a global challenge
Department of Agricultural and Food Sciences (DISTAL)
Alma Mater Studiorum – University of Bologna

Soil Thematic Group
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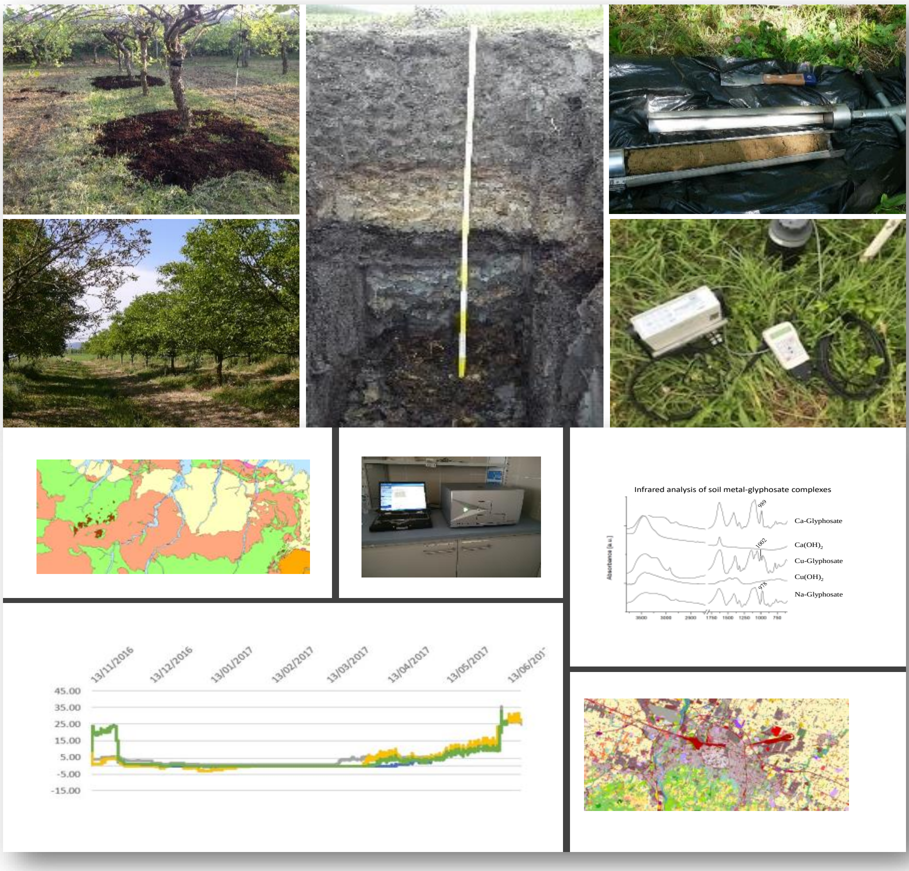

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Summary

Maintaining and improving the soil resource is crucial for the protection of the global environment, the sustainability issues, the human well-being, and the economic development. Soil is in fact a complex integrated system whose multitude of biotic and abiotic properties allows the provision of functions, which in turn deliver ecosystem services for human benefits.

The most widespread agrarian, forest and food production systems may have negative impacts on soil, thus exacerbating its degradation processes. There is an increasing awareness that improper use or poor soil management, together with the most recent events related to climate change, jeopardize the proper functioning of soils. The need to protect the soil resource is thus widely shared internationally.

One of the major challenges in the new growth EU strategy is to accomplish food security and to promote sustainable agricultural development, achieving the climate neutrality by 2050. Given the crucial role of soil for human activities, the Soil Thematic Group of the Department of Agricultural and Food Sciences (DISTAL), *Alma Mater Studiorum* - University of Bologna (Italy), states its position identifying the main challenges for the future growth of EU in:

- The organic carbon loss;
- Bio-technologies for agro-waste conversion into eco-efficient bio-based products;
- Soil biodiversity: preservation and restoration;
- The agroecological systems for supporting the farm to fork and ecosystems and biodiversity policies;
- Towards a soil sustainable and suitable farm and food system;
- Forest soil restoration;
- Next generation policy instruments for soil conservation and carbon sequestration;
- Soil as energy resource for sustainable rural facilities;
- Novel methodologies and approaches to multi-criteria landscape analysis, monitoring and planning.

1. Introduction

Soil is a simple word on which life of living organisms, including human beings, depends. The term soil defines the upper layer of the Earth's crust on which the different soil forming processes have driven its origin and development. Indeed, soil formation, as also called pedogenesis (from the Greek "pedon" which means soil and “genesis”), depends on five factors: climate (usually precipitation and temperature), topography (essentially slope and shape of landscape), time (elapsed time over which soil formation occurs), biota (plants, animals, and microorganisms) and parent material (igneous, sedimentary or metamorphic rocks, or unconsolidated sediments). Human activity can also affect the soil formation and, in some case, trigger and accelerate degradation phenomena.

The relationships among soil forming factors, including human activity, condition the processes of organic and mineral matter addition, losses, transfers and transformation occurring and forming soil, and allowing the organization of soil in layers roughly parallel to the ground surface (i.e., in soil horizons), which are distinguished on the basis of morphological, physical, chemical and biological properties. Different combinations of solid, liquid, and gaseous phases make soil as a unique resource characterized by high variability in time and in space, both at surface and along depth. Consequently, each **soil is a complex system.**

Soil solid components can be divided according to their physical size into sand, silt and clay particles, which regulate both physical and surface reactions. The particle size distribution affects, for instance, the soil structure and aggregation, porosity, water retention, redox potential and nutrient supply. However, also the nature of soil constituents is fundamental in defining soil properties. The soil solid phase, both in the organic and mineral horizons, is a complex mixture of inorganic and organic components, whose net physical separation can be often impeded by cementing agents. Silicate minerals, oxides, and carbonates form the largest part of the inorganic soil solid matrix, whilst living organisms, organic residues, both undecomposed and decomposed, and the most resilient humified organic materials account for the organic solid components.

Thanks to their high surface area and charged sites, humic substances and clay minerals mainly account for the soil ability to retain and supply nutrients and, together with carbonates, for the effective buffer capacity against possible pH changes in soils. In addition, these components provide adhesion to microorganisms, extracellular enzymes, and other compounds. Oxides, mainly Fe-oxides, affect several soil properties as anionic adsorption, soil aggregation and redox reactions. Additionally, the variety of soil constituents and the pore dimensions provide environmental niches for huge variety of soil-borne microorganisms and, more in general, for hosting most of terrestrial biodiversity. It is reported that, as far as the only bacteria are concerned, a teaspoon of productive soil generally contains 10^8-10^9 of them (Kennedy, 1999). Such a figure of living organisms in soil would not be possible in the absence of water. Soil water also drives many soil processes and soil solution plays an important role for life (plants, mesofauna and microorganisms). Besides, soil acts in biogeochemical cycle of elements (C, N, P and so on) by affecting their overall distribution among atmosphere, terrestrial, and marine ecosystems, as well as the rate of their flux among the different ecosystems.

The multitude of soil properties allows the provision of **many important soil functions** (Table 1) among which we can highlight: (i) production of foods, wood and fibers; (ii) filtration, degradation and transformation of substances and nutrients; (iii) presence and conservation of biodiversity pools; (iv) platform function for most human activities; (v) supply of raw materials; (vi) function of carbon and nutrient storage; (vii) conservation of the geological and archaeological heritage. In turn, soil functioning determines the delivery of ecosystem services, thus the benefits that directly or indirectly derive from ecosystems (MEA, 2005) and arise from the analysis of the relationships between natural capital and the services produced (Costanza et al., 1997). Adhikari and Hartemick (2016) provided insight into the soil properties and their connection to provisioning, regulating, cultural and supporting ecosystem services, and highlighted their sensitivity to land use and soil management. Therefore, the maintenance and improvement of the world's soil resource is crucial in the global environmental protection and sustainability issues, human well-being and economic development.

Given the importance of soil, the Department of Agricultural and Food Sciences (DISTAL) of *Alma Mater Studiorum* - University of Bologna (Italy) presents this position paper developed after fruitful discussion by the members of the Soil Thematic Group. The overall objectives of this document are (i) to highlight the contribution of soil in the achievement of sustainable development into the new growth European strategy (2nd section), and (ii) to identify the main challenges which we consider crucial for the future growth of Europe and how to address them (3rd section).

Table 1. Key soil properties related to soil functions (modified from Adhikari and Hartemink, 2016)

Soil properties	Biomass production			Storing, filtering and transporting nutrients and water				Hosting biodiversity				Platform for human activity		Source of raw materials	Carbon pool	Storing geological and archeological heritage	
	provisioning food, fuel and fiber	regulating carbon sequestration	contributing to esthetic of landscape	Regulating water availability	regulating erosion and flood control	Regulating water purification	supporting nutrients cycling	provisioning gene pool	Regulating crop pollination, pests and diseases	Supporting mineral weathering and	supporting (micro-)biota habitat	contributing to recreation/ecotourism	supporting human habitat	provisioning minerals and soil organic materials	regulating gas emission (climate)	contributing to knowledge,	contributing and preserving of cultural heritage
Soil organic carbon	x	x	x	x	x		x		x	x	x	X		x	x	x	
Sand, silt, clay, coarse fragments	x	x		x	x	x	x			x			x	x	x	x	x
pH	x					x	x		x	x						x	
Soil depth				x	x	x										x	
Bulk density	x		x			x						X			x	x	
Available water capacity	x			x	x	x									x	x	
Cation exchange capacity	x						x									x	
Electrical conductivity	x		x				x									x	
Soil porosity	x			x											x	x	
Hydraulic conductivity	x			x	x	x									x	x	
Soil (micro-) biota	x	x				x	x	x	x	x	x	X			x	x	
Soil structure, aggregation	x			x	x					x	x				x	x	
Soil temperature	x						x		x	x						x	
Mineralogy							x			x				x		x	
Subsoil pans	x			x	x											x	

2. Maintenance and enhancement of soil functions in the era of intensive exploitation of agro-forest ecosystems – International state and outlook

The recent message from the President of the European Commission was loud and clear: "for Europe becoming the world's first climate-neutral continent preserving the natural resources is the greatest challenge and opportunity of our times". It involves taking decisive action now, being more ambitious and needing to invest in innovation and research, redesign our economy and update our productive policy (von der Leyen, 2019). The new growth EU strategy aims at transforming the EU into a fair and prosperous society, with a resource-efficient and competitive economy where there is no net emission of greenhouse gases (European Commission, 2019). The United Nations also recognize the need of a change in the growth strategies for the achievement of sustainable development, and the eradication of poverty in all its forms and dimensions (United Nations, 2015). This is the great global challenge announced by the UN.

Among the 17 Sustainable Development Goals (SDGs) formulated by the UN for the period 2015-2030 (United Nations, 2015), at least 9 are strongly related to the management of soil resource: end poverty in all its forms everywhere (SDG 1); end hunger, achieve food security and improved nutrition and promote sustainable agriculture (SDG 2); ensure healthy lives and promote well-being for all at all ages (SDG 3); ensure availability and sustainable management of water and sanitation for all (SDG 6); ensure access to affordable, reliable, sustainable and modern energy for all (SDG 7); make cities and human settlements inclusive, safe, resilient and sustainable (SDG 11); ensure sustainable consumption and production patterns (SDG 12); take urgent action to combat climate change and its impacts (SDG 13); protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (SDG 15).

In these ambitious and global challenges, soil and maintenance, or enhancement of its functionality are crucial. Soil is currently subject to a series of degradation processes, and the ability of soil to provide functions must be protected because of both their socio-economic and environmental importance. These challenges become more relevant keeping in mind that soil formation is an extremely slow process (from 100 to over 1000 years need to form 1 cm of soil, depending on climate, vegetation and other factors; Camps Arbestain et al., 2008), and, thus, soil must be considered essentially as a non-renewable resource. The protection of the soil functionality from the various events that threaten it is a priority for humanity, otherwise it would endanger its well-being and survival.

The need to **protect the soil and its functions** is widely shared at international level. There is, in fact, an increasing awareness that improper use and/or poor soil management, which have characterized the agro-forest ecosystems of the most developed countries in the last decades, together with the more recent events related to climate change, represent a real danger for the proper functioning of soils. Several documents released in the recent years by the international organizations point it out. These include: "Revised World Soil Charter" (FAO, 2015), "Voluntary Guidelines for Sustainable Soil Management" (FAO, 2017), "Threats to soils: global trends and perspectives (United Nations, 2017), "Opportunities for soil sustainability in Europe" (EASAC, 2018). These documents highlight the threats to which the functions of soils subjected to unsustainable management practices, are exposed, reporting recommendations, and suggest future actions to tackle them (Table 2).

The maintenance and improvement of soil functionality require actions at all levels: from governments, and public authorities, international organizations, scientific community, private sector, groups, corporations to all individuals using or managing soil (FAO, 2015; European Commission, 2019).

The scientific community, collaborating, can contributes to the achievement of a soil-degradation neutral world in the context of sustainable development. The scientific community has in fact a key role in the improvement and development of sustainable soil management (SSM) strategies able to maintain or enhance supporting, provisioning, regulating, and cultural services provided by soil without significantly impairing the soil functions that enable those services or biodiversity (FAO, 2015).

Table 2. Threats to soil, causes and their consequences on soil functions, and main technical recommendations and suggestions by international organizations

Threats	Main causes	Example of negative consequence on soil functions	Example of recommendations and suggestions
Loss of organic matter	Intense tillage, monoculture, lack of organic fertilization practices, agricultural intensive practices, removal of organic residues, fire, drainage of organic soils, forest disturbance	Decline soil quality and structure, increasing erosion, compaction, reduced water holding capacity, reduced soil fertility, emission of C into the atmosphere, loss of biodiversity	Using organic amendments like composts, applying carbon-rich waste, managing crop and forest plant residues, introducing reduced or no-tillage practices, providing soil with permanent cover, fire suppression
Nutrients imbalance	Inappropriate plant nutrition management, anomalous soil reaction degree, unavailability of mineral and/or organic fertilizers, overuse of inorganic fertilizers	Low production of food, fibre, feed and timber, low quality of food products, higher incidence of diseases with consequent further loss of products, worsening of the quality of surface and groundwater resources due to leaching of nutrient-excess	Balancing mineral and organic fertilizations, promote the use of innovative product like slow and controlled release fertilizers, manage time and rate of fertilization, soil and plant tissue testing should be used, biological fixation, improvements in soil health, maximization of return of plant nutrients to soil via crop residues and manures
Erosion	deforestation, lack of soil coverage, loss of organic matter, overgrazing, tillage, fire	Loss of surface soil layers, loss of mineral and organic nutrients pools, reduced water quality, environmental diffusion of contaminants, reduced water quality, siltation of reservoirs and lakes, alteration of landscape composition of vegetation physiognomies, hydrology, and biodiversity	Management of soil organic matter content, cover crop, mulching, minimum tillage, no till and direct seeding, agro-ecological approach could be encouraged, reforestation, fire-suppression by large-scale networking between individuals, organisations, and agencies
Loss of biodiversity	Intensive management practices, contamination processes, loss of soil organic matter, no rotation, use of pesticides, use of high levels of fertilization	Alteration of elements' cycle in soil-plant-atmosphere system, reduction of soil self-depurative ability, negative effect on soil C sequestration and, in general, on the detritus cycle, detrimental effect on regulating pests and diseases	Organic amendments, maintain an optimal nutrients' balance, minimizing soil disturbance, avoiding/limiting salinization, integrated or organic pest management should be encouraged
Acidification	Climatic effect, sulphur and nitrogen deposition, intensive management practices, overuse of ammonium-based fertilizers, burning of forests	Low crop production and plant growth, aluminium toxicity, loss of soil buffering capacity and cation exchange capacity, reduction of biological nitrogen fixation capacity	Use of proper amendments like lime, balanced fertilizers and organic amendment, adequate use of acidifying fertilizers, use of acid tolerant crops or cultivars

Salinization Alkalinization	High water evapotranspiration rate, inland sea water intrusion, improper irrigation and fertilization, climate change effect, primary salinization (weathering of salt-rich soil parent materials, wet or dry atmospheric salt deposition from sea)	Reduction of seed germination, plant growth and production, toxicity episodes, soil nutrients' imbalance, detrimental effects on soil structure in presence of sodium excess	Managing irrigation water quality, improve efficiency of water irrigation use, water desalination, adequate soil drainage, improve managing of soluble mineral fertilizers particularly in greenhouse cultivation, use salt resistant crop plants
Contamination	Industrial emissions and dispersion of contaminated materials, inadequate management/disposal of waste of various origins, improper use of agrochemicals	General negative effect on soil chemical, physical and biological properties, food products safety, water quality	Establishing background levels, governments could be implemented specific regulations, risk assessment and remediation procedure should be applied, appropriate attention should be given to reduce contaminants loads
Structure decline (includes soil compaction and surface sealing)	Wheeling (agricultural and forested regions), moist-to-wet pastures, animal trampling in combination with overgrazing are the main causes for soil compaction, chaotic urban expansion as a main cause of soil sealing	Compaction reduces soil space, with severe consequences for hydraulic, gas, and heat transport processes, as well as for nutrient storage and accessibility. The main consequence of structure decline are erosion, land-sliding, nutrient loss, water and air pollution, and yield uncertainty. Soil sealing affects fertile land, puts biodiversity at risk, increases the risk of flooding and water scarcity and contributes to global warming	Sustainable soil management practices (e.g., use of long-term reduced or conservation tillage). Land use planning based on land evaluation, adequate policies, legislation, funding schemes, local planning tools

3. New research, new data, new development

Soil should be considered as a complex integrated system made of abiotic and biotic components. For these reasons, soil science requires specific know-how resulting from the **combination of several expertises** of pedologists, soil physicists, soil chemists, biochemists, microbiologists, forestry, and agronomists. Moreover, the connection between the territory in which a soil develops and the resulting chemical, biochemical and physical soil properties regulates both soil vocationality and resilience with respect to specific use and management. Thus, there is a very strict linkage among territory, soil properties, soil functions, ecosystem services and sustainable development. Best management practices for soil conservation need to be developed in the specific context of agriculture and zootechnics (e.g. intensive or extensive management), forestry (e.g. management and policy of mountain lands) and in natural land (e.g. wetland, peat, high altitude grassland). DISTAL realizes this multi-disciplinary vision by a strong collaboration of many excellent scientists covering all the disciplines cited above. For this reason, DISTAL is as an ideal place where soil assessment can be conducted, based on a comprehensive view and effective solutions to soil conservation.

Understanding soil characteristics and functionality is hampered by our capability to assess all the components of this complex system. Thus, **integrated observation systems** are considered a key challenge for supporting soil assessment and provide effective solutions for soil conservation. DISTAL scientists tackle this challenge by sharing highly qualified laboratories with state-of-the-art methods and field equipments for characterizing the different components of soil systems. Considering that soil systems are also highly variable in time and space, particular attention is also paid on standardized measurements conducted at long-term experimental sites and in different agro-environmental conditions. Among some of them, we highlight that, since the 60s, DISTAL is in charge of one of the longest data-base collected on the effect on soil and crops of mineral fertilizers and organic amendments, crops rotation (Gioacchini et al., 2009; Giacometti et al., 2014; Triberti et al., 2016). Additionally, new non-invasive geophsyical method for soil-plant assessment have been developed (Stevanato et al., 2019). This method has shown excellent results in many conditions and it will provide a new observation system for supporting soil management in several agro-environment conditions.

This interdisciplinary approach and these state-of-the-art lab and field equipment provide the basis for advancing our current knowledge on soil system components and functions and on developing new innovative solutions for supporting soil management in the future agro-forest systems. According to this vision of DISTAL's researchers and soil scientists, the most relevant challenges concern on it are:

- The organic carbon loss;
- Bio-technologies for agro-waste conversion into eco-efficient bio-based products;
- Soil biodiversity: preservation and restoration;
- The agroecological systems for supporting the farm to fork and ecosystems and biodiversity policies;
- Towards a soil sustainable and suitable farm and food system;

- Forest soil restoration;
- Next generation policy instruments for soil conservation and carbon sequestration;
- Soil as energy resource for sustainable rural facilities;
- Novel methodologies and approaches to multi-criteria landscape analysis, monitoring and planning.

Detailed description of each new challenge, and the related scope and expected impacts, are reported in Table 3.

Table 3. The DISTAL'S vision to the new innovative solutions for supporting soil management in the future agro-forest systems.

Topic	**THE ORGANIC CARBON LOSS**
Challenge	An effective contrast to soil organic carbon (SOC) loss needs a deep knowledge of the controlling factors of this complex process (Zdruli et al., 2004). These factors acting on SOC play different role depending on the scale of the study: global, continental, regional, etc. (Viscarra Rossel et al., 2019). At global scale, the main factor controlling SOC distribution and dynamics is the climate (Lal, 2004). Up to date, the climatic factors was assumed stable, but nowadays this statement has clearly changed. At continental scale, and even more specifically at regional scale, where the climate acts uniformly, region-specific controls affect local SOC distributions and dynamics. Consequently, when this regional specificity is not adequately considered, the real risk is in decreasing the global efforts to contain SOC losses. In other words, while problems are at global scale the solutions must be at local level. Researchers are called upon to find solutions, to contrast processes driving SOM decline that respond to the paradigm of sustainability based on social, economic and environmental components. Among the different possible solutions, stimulate recovery and recycle in soil of biosolids rich in organic carbon (OC) and nutrients coming from organic waste disposal chains is the most promising. In modern societies, characterized by a high degree of urbanization, organic wastes represent potential stock of OC and nutrients. However, to promote a rational, effective, and safe recycle of organic wastes, it is necessary to modify our development models by switching from linear to circular economy. In the four phases of the linear development model (take, make, use and dispose), the disposal phase, hamper the closure of the material cycle: residual OC and nutrients in wastes are landfilled or incinerated, and cannot return into the soil. On the contrary, the circular economy model involves the development of new production chains devoted to the recovery of organic matter and nutrients from the wastes, rather than its disposal, and conversion into bio-based ingredients and products. In the circular economy model, the fourth phase is switched on recycle and provides resource recovery as fertilizers promoting the closure of the cycles of C and nutrients in soil. At present, the most diffused types of biomasses produced are: sewage sludge (SS) from the urban wastewater treatment plants, and organic wastes from separate collection of the municipal solid wastes (MSW). European Union (EU) SS production in 2008 reached about 10 million tons (Mt) dry matter (Milieu, 2008). In Italy, Eurostat (2014) estimated a production of around 1.1 Mt dry matter. An Utilitalia survey (2017) reported that more than 50% of the SS analyzed had an OC content > 30%, N > 4.5% and P > 1.5%. These wastes are of great agronomical interest as a real source of OC and nutrients. The organic fraction of MSW (OFMSW) annually produced in the EU is estimated around 88 Mt, rising to 96 Mt in 2020. This fraction contains mainly carbohydrates, proteins and lipids, and is a good feedstock for aerobic (composting) and anaerobic digestion processes. A typical compost derived from OFMSW treatment has an OC content of 22%, N 2.2% and C/N 10 (Grigatti et al., 2014). These materials

	are agronomically suitable as a source of OC and nutrients, which can limit the soil progressive degradation and allow sustainable crops production. The amount of wastes yearly produced and potentially available suggests the opportunity of a sustainable and convenient plan to recovery and recycle these materials in agricultural soils (Clapp et al., 2007). However, many doubts still persist regarding the agronomic recycle of these biosolids, linked to their potential content of contaminants (EFAR, 2018). The content of potentially toxic elements, organic contaminants, micro and nano-plastics and microorganisms are the critical aspects to deal with a safe agronomic use of these biosolids.
Scope	The main objectives are: to recover OC, which lowers soil organic matter (SOM) decline, and recover nutrients, mainly N and P, in order to reduce our dependency on mineral fertilizers obtained from non-renewable resources. Only this way can contribute to the development of more sustainable agricultural systems. We are dealing with materials that certainly have significant agronomic characteristics together with potential contents of undesirable substances. Thus, the solution is not to counteract the use of these materials in agriculture, applying merely the precaution principle, but rather to equip ourselves with technical and legislative solutions which, intervening where necessary, ensuring the safety reuse of these biosolids in agriculture. The valorisation of resources available in the area of cultivation in which the inputs of the productive processes should be found inside the area itself, can also increase the environmental sustainability of the wastes recycle, taking into account regional factors regulating SOC dynamics in order to maximize the efforts in contrasting SOC losses.
Impact	The expected impacts are: - technologies capable of improving the quality of biomasses from the point of view of their safety and agronomic properties; - analytical protocols that guarantee the quality of the fertilizers obtained recycling the organic wastes; - to plan medium and long-term field trials to evaluate the effect of these materials on properties of soils and on quality of food products; - identification of the most suitable organic fertilizers and their optimal distribution protocol, to be used as alternative to mineral fertilizers; - reduction of nitrogen leaching and water table pollution; - reduction of gaseous nitrogen emissions in atmosphere; - increase of soil health and biological diversity; - improvement of soil fertility and water holding capacity; - promotion of the circular economy with the use of local waste-products; - climate change mitigation, through the improvement of soil carbon sequestration.
Topic	**BIO-TECHNOLOGY FOR AGRO-WASTE CONVERSION INTO ECO-EFFICIENT BIO-BASED PRODUCTS**
Challenge	Agriculture and sectors related to agri-food productivity are focal points in the European economy. The ongoing population growth, the reduced availability of cultivated land and water resources, the growing demand for biomass production (as a raw material for biofuels) and the continuing increase in global CO_2 emissions with its impact on climate change are all circumstances that urgently require innovative actions on land use, agricultural productivity and by-products and waste streams. Currently, they are not adequately managed for in both environmental and economic terms. Digestates generated, for example from anaerobic digestion of wastes, require sustainable use. The management of digestates is a challenge, particularly in industrial production systems as they can be sources of high value bioproducts. Digestates from agricultural wastes are frequently used as soil fertilizers but they are also a source of greenhouse gases (GHG) emission during their storage and when they are spread upon the field. Ammonia release and nitrate leaching are still a critical point with respect to N_2O and CH_4 emissions from digestates.

	Mushrooms are an attractive resource that allows the biotransformation of agro and urban wastes into a value-added bioproducts. Mushroom mycelium growth improves the degradation of more resistant macromolecules (lignin, hemicellulose and cellulose) and pollutants (pesticides, plastics, etc) by enabling a considerable reduction of waste volume residue. Moreover, the mycelium colonizing the substrate reduces greenhouse gas emissions, C losses and it is a nutrient for a vast range of fungi and bacteria driving the diversity and composition of microbial communities and increasing thus the biodiversity upon the transformed wastes reuse in soil. That could exhibits a potential plant protection against soil-borne fungal diseases. Mushrooms may be opportunities for new processes enabling innovative uses of these materials, also outside the agricultural sector. Also, the use of non-conventional yeasts such as *Yarrowia lipolytica* can represent a strategy to valorize agro-industrial by-products and waste. In fact, *Y. lipolytica* can be used to valorize the whey, having a high environmental impact, into safe and innovative bio-based microbial biomasses to be used in cheese sector as functional adjuncts, decreasing BOD and COD of the remaining whey, and accelerating the resulting cheese ripening profile.
Scope	The objective is to exploit the potential of agro and urban wastes to the full to create a new chain of products to ensure environmental and economic benefits which are based on technological innovation: i) Bioconversion of wastes into new bio-based by-products (eg. recovery of biopolymers, nutrients, enzymes); ii) Evaluation of nonconventional potential of wastes for the production of low-cost mushrooms; iii) Use of exhausted substrates as a source of organic C and to mitigate the impact of soil diseases in agriculture.
Impact	The expected impacts are: ✓ Minimize the impact of agriculture and food processing industry on the environment by reducing the amount of wastes that is not properly treated and by reducing the raw materials and fossil fuel usage; ✓ The overall environmental impact and greenhouse gas emissions (methane, nitrous oxide and CO_2) will be decreased along the new value chains; ✓ Produce economic benefits through the new business opportunities generated in the commercialization of the new products.
Topic	**SOIL BIODIVERSITY: PRESERVATION AND RESTORATION**
Challenge	According to the definition adopted by the Convention on Biological Diversity (CBD), biodiversity is "the variability of all existing origins between living organisms, including terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species and ecosystems". Soil biodiversity plays a significant role considering that soils present over a quarter of all living species on Earth. However, according to FAO, the loss of soil biodiversity is considered one of the main threats to this ecosystem in many regions of the world (see Table 2). Despite the enormous scientific progress made so far, the protection and monitoring of soil resources at national and global level face complex challenges, limiting the design and implementation of policies in the field. Soil biodiversity includes vertebrates, invertebrates, annelids, molluscs, nematodes, viruses, bacteria, fungi, lichens, bryophytes, and plants that provide a multitude of ecosystem functions and services and provide everyone with different social, economic, and environmental benefits. The essential services provided by this rich underground diversity include support for agriculture and food security; the regulation of nutritional cycles; control of the soil organic matter cycle; the implementation of carbon sequestration in the soil; the regulation of greenhouse gas emissions; modification of the physical structure of the soil and soil water regimes; the improvement of the quantity and efficiency of the acquisition of water and nutrients by the vegetation; as well as influencing the health of plants, animals and man.

	The soil microbial community represents the greatest reservoir of biological diversity in the world (Compant et al., 2019). The rhizosphere is the soil region richest in microorganisms where microorganisms are under the selective control of plants roots. Plants excrete photosynthates and secondary metabolites in the rhizosphere that inhibit or stimulate the activity of targeted microorganisms. Plants may also secrete quorum sensing-interfering compounds that enable gene expression manipulation in soil community. The collective genome of the rhizosphere microbiome is much larger than that of the plant and it is referred to as “the plant second genome” (Berendsen et al., 2012). This genome has crucial function for the plant, ranging from the recruitment of essential nutrients to boosting the defensive capacity against pathogens. The rhizosphere population is composed not only of bacteria and fungi, which are the dominant microbiota, but also of Archaea, Protists and viruses. The number of viruses, for example, appears to be underestimated by massive soil sequencing techniques (Rodriguez et al., 2019; Pascale et al., 2020). The balance within the different components of the soil microbiome is strictly related to plant health and soil fertility and any factor hampering this balance is a risk for soil quality and function. The preservation of the integrity of the soil microbiome is impaired by several anthropogenic factors, such as antibiotics, heavy metals, pesticides and chemical fertilization (Christou et al., 2017; Woolhouse et al., 2015; Zhang et al., 2018) and new solutions need to be explored to counteract these threats.
Scope	Researchers should be conscious of soil microbial diversity objectives that are worldwide shared, and they should implement a research aimed at understanding the interactions between the various players of the soil ecosystem, the development of sustainable agronomic techniques, the development of bioremediation methodologies for the management of polluted soils, the preservation of biodiversity through the reduction of genetic erosion in the vegetable, microbial and animal fields and the diffusion of sustainable agricultural policies to make an important contribution to all research areas that aim to safeguard ecosystems and allow future generations to live in balance with nature and not at the expense of nature. Agronomic practices can also alter the balance of the soil microbiota, and studies are needed to clarify the best practices for soil microbiota preservation, not only to understand the impact on soil different taxa but to understand the impact on their functionalities. Moreover, the soil microbiome is a key player for conservation of soil health under changing environmental conditions and researcher must be aware that the preservation of the integrity of the soil microbiome is a priority goal in the preservation of the whole environment. For this purpose, target microbial groups essential for the soil functionality have to be selected and monitored as well as the whole microbiome composition and biodiversity through advanced sequencing tools. Moreover, more research is needed regarding all taxa that are not yet cultivable or that are in small proportions because could be important in maintain the balance of the ecosystem.
Impact	The concept of Planetary Boundaries (Rockström et al., 2009) clearly showed how biodiversity loss has already reached dramatic point. The theory stated that "transgressing one or more planetary boundaries may be deleterious or even catastrophic” at planetary scale. This concept clarifies the importance and the impact of the measures that world-wide must be implemented to protect, preserve and restore the biodiversity. The protection of soil organism will ensure storing and releasing of carbon, helping to regulate greenhouse gases, and so impacting on global climate systems. This also influence crop productivity, water resources, food security and human health. Moreover, soil organisms’ biodiversity ensures bioremediation of water and soil pollutants reducing their impact on ecosystems and human health, preserves soil structure and favours the control of pest outbreaks.
Topic	**THE AGROECOLOGICAL SYSTEMS FOR SUPPORTING THE FARM TO FORK AND ECOSYSTEMS AND BIODIVERSITY POLICIES.**
Challenge	Most of the planetary problems: energy shortages, water scarcity, environmental degradation, climate change, economic inequality, food insecurity, sanitary problems,

	poverty, obesity and others are clearly interconnected and their solution requires a novel vision, a novel education and a real change of paradigm. The coronavirus pandemic clearly highlighted the linkages among human, animal and ecological health and the tangible vulnerability of industrial agricultural and food systems as a consequence of extremely heavy losses of biodiversity and ecosystem services at planetary level. The EU Farm to Fork Strategy (*Area 6 European Green Deal call)* aims to "accelerate the transition to sustainable food systems, to ensure that the economic, social and environmental foundations of food and nutrition security are not compromised for current and future generations". Such a transition should be necessarily guided by AgroEcology, the science that applies ecological concepts and principles to the design and management of sustainable agricultural systems which is strictly linked to the need of restoring land and sea biodiversity and ecosystem services (*Area 7 European Green Deal call*). Soil care is the heart of agroecological transition. Soils are threatened by multiple factors that generate adverse effects on soil functions (see Table 2) and the increasing urban population exacerbates the fragility of the food system, particularly in large cities. The adoption of agroecological principles is essential to preserve soil health and also to counteract socioeconomic problems (i.e. migration and abandonment of lands) and poverty that affect many areas. Agroecological lighthouses, that means agroecologically-managed farms, able to demonstrate that is possible to reduce the intensive agricultural practices and alleviate their impacts on the environment, animals and humans, are strongly required in order to radiate the pathway of transition to communities and regions. The capability of catching the connectivity between agricultural and natural systems adopting a multidisciplinary approach and synergistic actions is essential. A comprehensive agroecological strategy offers the improvement of soil conservation and biodiversity, increases carbon sequestration and storage, reduces both non-renewable energy and GHGs emission for achieving climate neutral farms, develops intercropping strategies with proper species, reduces the use of machineries and practise rational pasture, consequently valorises the rich biodiversity of agroecosystems, which often remain unexploited. Participatory actions are undertaken to control soil threats (e.g. decline organic matter, biodiversity, compaction, erosion and desertification) in agricultural systems. Relevant agroecological strategies are intercropping, crop rotations, using dry-resistant crops, agroforestry systems, including integration of animals in the farming systems.
Scope	Research objectives should move forward with the development of agroecological strategies and agroecosystem designs considering: - intercropping with specific plants which can act as biological controls, attractants of beneficial insects, serve in the improvement of nutrient and water availability, physical soil conditions, increase the presence of functional mychorrizal-based soil networks. Higher biodiversity in the agricultural systems and surrounding landscapes will generate benefits on agricultural products and worldwide communities. In this context, volatile organic compounds (VOCs) play important roles on plant communication, activation of defence mechanisms, biological control effects and signalling between organisms. The potential of VOCs as a sustainable strategy able to limit the use of pesticides, fertilizers and water, protecting the complexity of our environment and our communities should be further explored. Site-specific agriculture and advanced analytics can greatly contribute to these achievements and consider the terroir; - the presence of animals in agricultural systems, because silvo-pastoral systems, based on agroecological principles, which ensure healthy animal production, in addition, restore landscapes and are less conducive to promoting epidemics. - site-specific agroecological management strategies and systems which contribute effectively to preserve natural resources, biodiversity and promote productive capacity and resiliency. The promotion of agroecological strategies and systems, as soil health defenders, require a deep comprehensive analysis at territorial levels, including social, economic and cultural

	interactions with local communities. Local communities should be more involved in projects and participate actively to the recognition, transmission and amplification of the cultural, scientific and practical value of agroecology as an effective combination of tools to manage natural resources and achieve sustainable crop production and healthy quality food. - participatory events on agroecological and rural development and strengthens international collaboration focused on AgroEcology to promote the creation of a trans-frontier Joint Lab, innovations of the teaching offer, improvement of students' soft skills and empowerment of the presence of University in the Society, in the area of AgroEcology (e.g. Participatory AgroEcology School System, PASS), also by testing, demonstrating and scaling-up of agroecological systems.
Impact	The expected impacts are: - Knowledge-based agroecological designs and practices will enhance soil, plant, animal and human health, the efficient use of natural resources, the sustainability and the resilience of production systems and food security providing safe, nutritious, and affordable food for all. - Participatory actions guided by AgroEcology will contribute to decreasing the dependency on the use of contentious pesticides, antimicrobials and fertilizer use and overcome "animal deficiency" conditions in agroecosystems. - Agroecological approach, in research and teaching, will be able to stimulate scientific curiosity in students and people, and the ability to grasp the essence of processes, the complexity of the world, ability, unfortunately affected by serious erosion phenomena, which the Higher Education has a duty to counter. - Actions stemming from these cultural jumps will breathe the Soil and the Hearth.
Topic	**TOWARDS A SOIL SUSTAINABLE AND SUITABLE FARM AND FOOD SYSTEM**
Challenge	The current farm system and food business still have negative impacts on water and air quality, biodiversity and climate change, and put pressure on agricultural soil exacerbating degradation processes (see Table 2). One of the major challenge in the new growth EU strategy is to accomplish food security and promote sustainable agricultural development achieving the climate neutrality by 2050. As reported by FAO, the global population growth and the increase food security cannot be supported by the current soil quality. It is urgent thus the development of sustainable agriculture able to increase soil carbon sequestration, reduce GHGs emission and soil erosion, which is one of the main threats leading to soil loss. Food security can be thus achieved through sustainable agriculture (Akpoti et al., 2019), and it requires a successful approach that maximises synergies and minimises trade-offs between the three dimensions of sustainability, including social and health, climate and environmental, and economic. This can be achieved through the assessment of soil quality and land suitability evaluation based on soil physical, chemical and biological characterization and their spatial analysis carried out by geographic and pedological information system (GIS). European agriculture is well-known for production safe, nutritious and high quality food, but also cultural and esthetical landscape in a managed territory. This must be face however to climate and economic challenge to become the global standard for sustainability. From this perspective, the knowledge of specific pedo-climatic conditions and territory vocation can help to identify the best solutions for farmers (Bonfante et al., 2018) driving their decisions to maximise social and economic benefits and avoiding negative climate and environmental impacts. In fact, the research of the territory vocation is one of the most effective means for quality and typicality protection of the production and, at the same time, to limit soil degradation, to enhance emissions mitigation and to have important repercussions for farmers' incomes, which of course depend not only upon crop yields, but also on the quality of production (Costantini and Bucelli, 2008).
Scope	The following urgent and pressing farm and food systems' challenges should be faced to: 1) Increasing of the knowledge of suitability and capability of soils by relating together pedological and climate information (defining pedoclimatic conditions), eco-

	functional processes driven by soil microbial biomass (e.g. terroir of crops), defining synthetic and descriptive soil health indices. This knowledge must be supported by a suitable geographic and pedological information system (GIS). 2) Achieving of soil degradation neutral farming by reducing intensity of soil threats (erosion, loss of organic matter and biodiversity, salinization, contamination, nutrient imbalance, structure decline) though the best practices linked to land suitability and capability. 3) Use biopreservation approaches, based on the use of lab bioprotective cultures in fields, to increase sustainability, safery and shelf-life of derived food products
Impact	The research is expected to: 1) Improving of soil quality and strengthening of its resilience against environmental and climate stressors; 2) Valorisation of quality, safety and typicality of the production; 3) Increasing of social and economic sustainability of production; 4) Defence of territory though the increasing of resilience, and social and economic sustainability of production also in marginal areas
Topic	**FOREST SOIL RESTORATION**
Challenge	In Europe, forest ecosystems cover more than one billion hectares (FAOSTAT, 2020) and they provide numerous services to human such as supply of raw materials and food, protection of biodiversity, regulation of climate, preservation of landscape. In this context, forest soil has a key role because, beyond to support the aboveground biomass functions, it preserves watersheds, hosts a huge biodiversity, regulates the biogeochemical processes of nutrients, storage carbon pool and regulates gas emissions (Bünemann et al., 2018). One of the main pressure that affects Europe's forests is degradation, mainly due to abandonment or overuse, that may threaten health of forest ecosystems in term of functionality of their components, such as soil. Soil properties and functionality are in fact highly influenced by the forest management systems, and the restoration forest practices can affect soil quality creating a healthy ecosystem able to cope with stress, to recover from the impacts of disturbance, and to adapt to stress and change. There is currently the need to gain knowledge on the best forest restoration practises able to improve the forest ecosystems functioning, and in particular forest soil functioning relation to biophysical properties, such as soil organic matter pool, microbial activities and soil aggregation, crucial for services for human well-being (Adhikari and Hartemink, 2016).
Scope	The research should demonstrate how restoration of unmanaged forests can be extended in areas with severe degradation, so that opportunities for substantial soil ecosystem services gains will be realised, which in turn enhance forest services for the human benefits. This will test and assess the effect on soil properties of different forest recovery strategies, put attention on the short and medium term consequences non-based exclusively on biomass production, but also on soil constituents regulating the nutrients cycling which will build up the soil fertility, the carbon pool dynamics which will support the microbial activities and regulate the biogeochemical cycle of elements, the soil structure and aggregation which will regulate the water availability, control erosion and, together with soil organic matter dynamics, regulate gas emissions.
Impact	The evaluation of forest recovery strategies will improve the living conditions of human communities in abandoned areas by restoring their forest environment, and reducing soil erosion and gas emissions as well as increasing soil carbon and nutrients storage. The research, based on a good knowledge of soil forest properties, lad suitability and their spatial analysis out in GIS environment, will diffusion of the best recovery management practises avoiding negative soil consequences and allowing their transferability of other similar forest ecosystems across the EU.

Topic	**NEXT GENERATION POLICY INSTRUMENTS FOR SOIL CONSERVATION AND CARBON SEQUESTRATION**
Challenge	A key challenge for the conservation of soil and soil related ecosystem services is the misalignment of its private and social benefits. Soil conservation measures are typically characterized by large *social* benefits (biodiversity conservation, climate change mitigation), while their costs are mostly beard by landowners. With this incentive structures, free-riding issues lead to the under-provision soil conservation measures with respect to what would be their optimal level. Hence public policies, such as the Agri-Environmental Schemes (AES) of the EU Common Agricultural Policy (CAP), are potentially crucial in correcting these market failures. However, while surely improving the situation, AES have not fully achieved their promises. As the financial support is mostly based on the average costs of the implementation of the implemented practices, AES scheme do not ensure a proper delivery of the agri-environmental public goods provided by soil conservation measures. Moreover, at the same time, private initiatives have been also launched to so that consumer preferences are translated in price premiums to farmers along the value chain. There is the needs to provide adequate incentives to farmers for the conservation of soils and provision of soil-related ecosystem services.
Scope	Policy instruments should be upgraded so that they effectively deliver soil and soil related ecosystem services. Efforts should be spent on analysis of the shift from the traditional AES design towards payment-by-results schemes, in which the budget is effectively spent only upon the observation of the delivery of the promises service. While such a shift seems a natural step, its practical implementation poses several challenges that should be balanced against the status-quo. Among the others, the uncertainty of the reward could strongly reduce the enrolment rate of the farmers in the schemes, monitoring could entail significant costs that should be weighted with the potential benefits, the length of soil processes supposedly implies long term commitments of both farmers and public administration. Moreover, these measures should be addressed within the greater pictures that include the presence of green markets, so that public and private incentives, and their respective costs and benefits, should be assessed.
Impact	The direct impact of the research is an improved design and hence an increased effectiveness and efficiency of agricultural policies related to soil and public goods provision in general. Better effectiveness and efficiency, in a context of high stakeholder engagement and participatory governance, will also contribute to better policy acceptance and public awareness. Indirectly and in the longer term, the research will allow an increased production of public goods from soil and reduction of trade offs with the production of private goods. This will also contribute to more competitive farming systems, better dialogue with citizens and consumers and more vital rural areas.
Topic	**SOIL AS ENERGY RESOURCE FOR SUSTAINABLE RURAL FACILITIES**
Challenge	As all other sectors, agriculture expects to increase its energy need and consumption. Besides the field activities, a large amount of energy is required for rural facilities where the production can be processed, transformed, and stored. One of the goals of recent policies concerns the promotion of intensive and sustainable food production. To achieve this result, the increase of renewable energy use is considered necessary (Monforti-Ferrario et al., 2015). Besides the widespread renewable energy sources (such as photovoltaic panels, biogas, biomass, wind energy, etc.), the soil exploitation as well can provide a solid contribution to the energy need reduction. Since ancient times, in agricultural activities, the ground has been used both as thermal storage and thermal exchanger for food process and conservation (food storage, ice-storage, etc). Even nowadays, the well-known soil thermal properties can be used for several processes that require thermal control such as winemaking and ageing, and more. More recently, thanks to the developments in low-enthalpy geothermal energy systems, the exploitation of soil

	thermal properties has increased its efficiency and can be extended to other agricultural processes such as greenhouse production, milk cooling, fruit cooling, food drying, etc. Since the agricultural facilities can take advantage of large ground areas, the shallow systems can provide a large amount of cost-efficient energy.
Scope	The efficiency of ground energy system depends on several factors such as system configuration, soil stratigraphy and properties (such as density, thermal diffusivity, humidity content, aquifer, etc.), environmental conditions, and more. A general characterization of the energy potential, that can be exploited in agricultural contexts, can provide useful information for all farmers in order to achieve energy sustainable solutions overall when temperature-controlled processes are involved.
Impact	The expected impact is the reduction of both the rural building energy needs and increasing of the exploitation of renewable energy source, taking advantage of soil properties and its thermal stability.
Topic	**MULTI-CRITERIA LANDSCAPE ANALYSIS, MONITORING AND PLANNING THROUGH NOVEL METHODOLOGIES AND APPROACHES**
Challenge	It is well known that the various territorial and landscape planning choices play a crucial role in determining the level of environmental sustainability of the consequent models of development of rural areas, with particular reference to the efficiency in the use of resources, the direct and indirect impact on the agro-ecosystems deriving from land use transformations, in particular those that are scarcely or not at all reversible connected to settlement systems, as well as the influence on the potential of rural landscape resources to provide ecosystem services. In relation to the increasing pressure on soil resource and large-scale and rapid changes in land-use, providing new insights to enable more effective soil and land-use management, addressing climate change, sustainable development and crop production intensification challenges, is more and more crucial, also in relation to the growing demand for evidence-based policy making. Therefore, preserving the soil resource and planning its efficient and sustainable use requires the development of integrated and multidisciplinary methodologies and systems for analyzing and monitoring land use and landscape capable of addressing spatial and time variability of the various landscape features and to identify the peculiar characteristics, the critical issues and the opportunities of the various regions, in order to support the correct allocation of resources and the enhancement of both the natural and cultural components of the territory.
Scope	The research goal is to advance in the field of multicriteria and multi-scale land analysis and monitoring powered by GIS models and methodologies, aimed to lend support to rural planning and landscape management, focusing on the identification of landscape features and structures and high resolution tracking of their spatial and time trends, including soil sealing monitoring through accurate and efficient long-term approaches. Rural areas advanced spatial analytics, including modelling and machine learning approaches, would contribute to knowledge advancement in the following research domains: • GIS models and areal sampling strategies for spatial analysis and land-suitability assessment; • high spatial and time resolution land-use change and soil sealing analysis, monitoring and modelling; • study of the land-use change/soil quality and soil carbon stock nexus; development of multicriteria indicators/models for rural land analysis, classification, modelling and planning, through cost-effective and reliable multi-scale methodologies based on GIS, remote/proximal sensing, and field survey/mapping, also through participatory and ICT-enabled bottom-up approaches.
Impact	The research outcomes would allow to lend support to the definition of smart and site-specific agricultural practices and integrated spatial planning and rural development policies and their implementation and impact monitoring, fostering more resilient agro-forestry, settlement,

	and natural systems, a sustainable intensification of food, feed and fiber production, and the enhancement of ecosystem service provisioning and social functions. The research would also contribute to address climate-change trends and scenarios, also allowing to define mitigation and adaptation strategies through specific land planning strategies aimed at carbon stock optimization. Last but not least, the research can support the definition of performance and evidence-based references for rural and green areas planning, in relation with trends in soil and land-use conversion, promoting models aimed at maximizing ecosystem service performances.

REFERENCES

Adhikari K., Hartemink A.E. (2016). Linking soils to ecosystem services — A global review. Geoderma, 262: 101–111.

Akpoti K., Kabo-bah A.T., Zwart S.J. (2019). Agricultural land suitability analysis: state-of-the-art and outlooks for integration of climate change analysis. Agricultural Systems, 173:172-208.

Bonfante A., Monaco E., Langella G., Mercogliano P., Bucchignani E., Manna P., Terribile F. (2018). A dynamic viticultural zoning to explore the resilience of terroir concept under climate change. Science of the Total Environment, 624:294-308.

Bünemann E.K., Bongiorno G., Bai Z.G., Creamer R., de Deyn G.B., de Goede R.G.M., Fleskens L., Geissen V., Kuijper T.W.M., Mäder P., Pulleman M.M., Sukkel W., van Groenigen J.W., Brussaard L. (2018). Soil Quality - a critical review. Soil Biology and Biochemistry, 120:105-125.

Camps Arbestain M., Macías F., Chesworth W. (2008). Soil. In: Encyclopedia of Soil Science, Chesworth W. (ed.). Springer, Dordrecht, The Netherlands. pp. 629-634.

Christou A., Agüera A., Bayona J.M., Cytryn E., Fotopoulos V., Lambropoulou D., Fatta-Kassinos D. (2017). The potential implications of reclaimed wastewater reuse for irrigation on the agricultural environment: the knowns and unknowns of the fate of antibiotics and antibiotic resistant bacteria and resistance genes–a review. Water research, 123:448-467.

Clapp C.E., Hayes M.H.B., Ciavatta C. (2007). Organic wastes in soils: Biogeochemical and environmental aspects. Soil Biology and Biochemistry, 39:1239-1243.

Compant S., Samad A., Faist H., Sessitsch A. (2019). A review on the plant microbiome: ecology, functions and emerging trends in microbial application. Journal of Advanced Research, 19:29-37.

Costantini E.A.C., Bucelli P. (2008). Soil, wine and other quality crops: introduction and practice of the “terroir” e “zoning” concepts. Italian Journal of Agronomy, 3:23-33.

Costanza R., d’Arge R., de Groot R., Farberk S., Grasso M., Hannon B., Limburg K., Naeem S., O’Neill R.V., Paruelo J., Raskin R.G., Suttonkk P., van den Belt M. (1997). The value of the world’s ecosystem services and natural capital. Nature 357: 253-260.

EASAC (2018). Opportunities for soil sustainability in Europe. EASAC policy report 36.

EFAR (2018). Public Health Risk Assessment of Sludge land Spreading. Final report N° DRC-07-81117-09289-C, INERIS, July 18th 2008, pp. 1-32.

European Commission (2019). The European Green Deal. COM (2019) 640, Brussels.

Eurostat (2014). Eurostat regional yearbook 2014. ISBN 978-92-79-38906-1.

FAO (2015). Revised World Soil Charter. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (2017). Voluntary guidelines for sustainable soil management. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAOSTAT (2020). Forest land. http://www.fao.org/faostat/en/. Accessed 29th June 2020. FAO statistics division.

Giacometti C., Cavani L., Baldoni G., Ciavatta C., Marzadori C., Kandeler E. (2014). Microplate-scale fluorometric soil enzyme assays as tools to assess soil quality in a long-term agricultural field experiment. Applied Soil Ecology, 75: 80-85.

Gioacchini P., Montecchio D., Baldoni G., Ciavatta C. (2009). Agricultural management practices and dynamics of C in a long-term field experiment followed by isotopic and thermal analysis, In: Proc. International Symposium on soil organic matter dynamics: land use management and global change, Colorado Springs (Colorado, USA), July 6-9 2009, pp. 6-6.

Grigatti M., Cavani L., C. Marzadori, Ciavatta C. (2014). Recycling of dry-batch digestate as amendment; soil C and N dynamics and ryegrass nitrogen utilization efficiency. Waste and Biomass Valorization, 5:823-833.

Kennedy A. (1999). Bug biography: bacteria that promote plant growth. USDA Agricultural Research Service, Pullman, WA

Lal R. (2004). Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science, 304:1623-1627.

MEA-Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Milieu Ltd, WRc, RPA and DG Environment (2008). Environmental, Economic and Social Impacts of the Use of Sewage Sludge on Land, Final report for the European Commission.

Monforti-Ferrario F., Dallemand J.F., Pinedo Pascua I., Motola V., Banja M., Scarlat N., Medarac H., Castellazzi L., Labanca N., Bertoldi P., Pennington D., Goralczyk M., Schau E.M., Saouter E., Sala S., Notarnicola B., Tassielli G., Renzulli P. (2015). Energy use in the EU food sector: State of play and opportunities for improvement. Eds. F. Monforti-Ferrario and I. Pinedo Pascua. European Commission, Joint Research Centre, Luxembourg: Publications Office of the European Union.

Pascale A., Proietti S., Pantelides I.S., Stringlis I.A. (2019). Modulation of the root microbiome by plant molecules: The basis for targeted disease suppression and plant growth promotion. Frontiers in Plant Science, 10:1741.

Rockström J., Steffen W., Noone K., Persson Å., Chapin III F.S., Lambin E., Lenton T.M., Scheffer M., Folke C., Schellnhuber H.J., Nykvist B., de Wit C.A., Hughes T., van der Leeuw S., Rodhe H., Sörlin S., Snyder P.K., Costanza R., Svedin U., Falkenmark M., Karlberg L., Corell R.W., Fabry V.J., Hansen J., Walker B., Liverman D., Richardson K., Crutzen P., Foley J. (2009). Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society, 14:32.

Rodriguez P.A., Rothballer M., Chowdhury S.P., Nussbaumer T., Gutjahr C., Falter-Braun P. (2019). Systems biology of plant microbiome interactions. Molecular Plant., 12:804-821.

Stevanato, L., Baroni, G., Cohen, Y., Cristiano Lino, F., Gatto, S., Lunardon, M., Marinello, F., Moretto, S., Morselli, L., 2019. A Novel Cosmic-Ray Neutron Sensor for Soil Moisture Estimation over Large Areas. Agriculture 9, 202.

Triberti L., Nastri A., Baldoni G. (2016). Long-term effects of crop rotation, manure and mineral fertilization on carbon sequestration and soil fertility. European Journal of Agronomy, 74:47-55.

United Nations (2015). Transforming our world: The 2030 agenda for sustainable development. A/RES/70/1.

United Nations (2017). Threats to soils: global trends and perspectives. A Contribution from the Intergovernmental Technical Panel on Soils, Global Soil Partnership Food and Agriculture Organization of the United Nations.

Utilitalia (2017). Utilizzo dei fanghi di depurazione in agricoltura. Indagine Utilitalia sui fanghi prodotti dal trattamento delle acque reflue urbane. Coordinamento scientifico, Giuseppe Mininni. Gruppo di lavoro Utilitalia, Paolo Giacomelli, Elena Mauro, Bernardo Piccioli. Roma.

Viscarra Rossel R.A., Juhwan L., BehrensT., Zhongkui L., Baldock J., Richards A. (2019). Continental-scale soil carbon composition and vulnerability modulated by regional environmental controls nature research. Nature Geoscience, 12:547-552.

von der Leyen, U. (2019). A European Green Deal. In: A Union that strives for more - My agenda for Europe. Political guidelines for the next European Commission 2019-2024. pp. 5-7.

Woolhouse M., Ward M., van Bunnik B., Farrar J. (2015). Antimicrobial resistance in humans, livestock and the wider environment. Philosophical Transactions of the Royal Society B: Biological Sciences, 370, 20140083.

Zdruli P., Jones R.J.A., Montanarella L. (2004). Organic Matter in the Soils of Southern Europe. European Soil Bureau Technical Report, EUR 21083 EN (2004), pp. 16, Office for Official Publications of the European Communities, Luxembourg.Berendsen, R.L., Pieterse, C.M., Bakker, P.A. (2012). The rhizosphere microbiome and plant health. Trends in Plant Science, 17:478-486.

Zhang P., Ren C., Sun H., Min L. (2018). Sorption, desorption and degradation of neonicotinoids in four agricultural soils and their effects on soil microorganisms. Science of the Total Environment, 615:59-69.