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EDITORIAL

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Editorial for special issue on "understanding soil functions – from ped to planet"

Soil functions are fundamental for solving the societal challenges of food security, climate action, biodiversity protection and environmental integrity. Yet, soils have suffered from the "Cinderella syndrome" for decades when it comes to the public perception of the relevance of natural resources for human well-being. Blum (1993) eventually "passed the golden shoe" with the introduction of the soil functions concept, which triggered public understanding of the potential of soils to store carbon, to host biodiversity, to transform matter into plant-available nutrients, to retain and purify water, and to contribute to plant growth. The soil function concept was further elaborated as a link between ecological processes and human well-being to support the science–policy interface (Bouma, 2010; Helming et al., 2018) the science–practice interface (Schulte et al., 2014) and a systemic approach to science-based decision support (Vogel et al., 2018). Still, at the European level, a soil policy framework failed to be implemented following multi-annual negotiations in the first decade of the 21st Century.

In policy regulations and strategies, such as climate strategies, biodiversity strategies, bio-economy strategies, and the agri-environmental and greening measures of the European Union Common Agricultural Policy, soils are treated implicitly as co-objectives or supporting measures rather than explicitly (Glæsner, Helming, & de Vries, 2014). Most of these policies and strategies are not legally binding or treat soil protection as an optional rather than mandatory instrument. A further boost to soil protection, and in particular to the carbon storage function of soils, emerged in the frame of the Paris Agreement on climate action in 2015, when the French Ministry launched the so-called 4 per mille initiative (Ministère de l'Agriculture, de l'Agro-alimentaire et de la Forêt, Hiver, 2015/2016), proposing that with an annual increase of 4 ‰ of soil organic carbon (SOC) stocks the annual increase of carbon dioxide (CO_2) in the atmosphere would be significantly reduced. However, the feasibility of the 4 per mille initiative under current conditions for agricultural management has been heavily challenged by some leading soil researchers (Baveye, Berthelin, Tessier, & Lemaire, 2018) and the Conference of the Parties (COP) to the United Nations Climate Change Conference (UNFCCC) in November 2017 had not taken the topic up (Rumpel, Lehmann, & Chabbi, 2018). Also as part of its climate protection efforts, the European Commission adopted the European New Green Deal in 2019, which aims to achieve carbon neutrality by the year 2050 through an ecological transformation of the economy. Therein, the Farm to Fork strategy lays the foundation for a sustainable food system, which considers soil functions not only as carbon reservoirs but also as key partners in the transition to agro-ecological economies with a strong reduction in pesticide use. With these strategies' efforts to return to a circular economy and to reduce the use of finite resources, the intrinsic potential of soils to deliver ecosystem services and to convert (solar) energy into plant biomass is ultimately regaining the fundamental importance it always had in pre-industrial times. Synergies, but also trade-offs and spill-over effects, in environmental and socioeconomic terms, might be associated with this endeavour (Fuchs, Brown, & Rounsevell, 2020), and have to be carefully revealed in scientific assessments.

This special issue of the EJSS presents contributions from participants of the Wageningen Soil Conference in August 2019 (https://wageningensoilconference.eu/2019/), which was held for the fourth time since its establishment in 2011, with a focus on "understanding soil functions – from ped to planet". The conference received over 250 participants and discussed a range of topics based around four key themes:

1. Soil functions for society
2. Innovative methods for measuring soil functions
3. Modelling and mapping of soil functions across scales
4. Can we understand synergies and trade-offs between soil functions?

Society is demanding more from our agricultural land in terms of ecosystem services and soil functions (Schulte et al., 2019). To support these societal demands on our soils, as scientists we are required to continuously improve our understanding of the soil system and strive to quantify the key mechanisms supporting soil functions over time and monitor changes therein. This requires innovation to take place across a range of scales, from the microscale (Aleklett et al., 2018; Soinne et al., 2020) to the application of appropriate measurements for soil monitoring and assessment for decision making and quantifying the effect of implemented land-management policies (Bünemann et al., 2018). For example, Zani et al. (2020) applied a set of seven soil quality indicators (chemical, physical and biological) to assess a range of farm management systems in the UK and concluded that the revival of mixed farming systems could be a key factor in ensuring multi-functionality in agroecosystems.

Soil quality indicators have traditionally focused on the measurement of chemical and physical soil properties, due to a combination of methodological difficulties and limited fundamental understanding of the role of soil biodiversity in regulating soil functions (Lehmann, Bossio, Kögel-Knabner, & Rillig, 2020), but the biological perspective is increasingly gaining attention (Bongiorno, 2020). It is clear that multiple methods are required to investigate the contribution of soil biota to soil functioning; for example, Delgado-Baquerizo, Reich, and Trivedi (2020) showed a clear association between soil biodiversity and important soil functions such as nutrient cycling. Recently, a range of physical, chemical and biological soil quality indicators was used to define soil classes based on functionality rather than genesis (Seaton et al., 2020). Developing a classification system using dynamic soil properties can aid in linking the contribution of soil functions to the broader concept of ecosystem services that can be provided by the soil (Lilburne et al., 2020).

New methodological innovations in soil science, such as combining existing methods to allow for a high-precision visualization of internal soil structure (Han, Bai, Liu, Zhao, & Zhao, 2020), are steadily facilitating insights into the role of our soils in supporting a range of functions and wider ecosystem services, but these innovations also need to be reliable, reproducible and resilient to changes in equipment over time and as such should be standardized to ensure comparability across the soil science research domain. Standardization is also required for the use of soil-related indicators in ecosystem service assessments in order to allow for comparisons, upscaling and synthesis (Paul, Kuhn, Steinhoff-Knopp, Weißhuhn, & Helming, 2020).

In addition to the developments in the methodological assessments of soil functions, further insights have been achieved into the modelling of soil functions and were discussed in detail at the Wageningen Soil Conference. Modelling and mapping of soil functions combine soil properties with environmental and climate conditions (Vogel et al., 2018). Digital soil mapping (Minasny & McBratney, 2016) and machine learning (Khaledian & Miller, 2020) are increasingly used to model and map soil properties and functions (e.g., SoilGrids, https://www.isric.org/explore/soilgrids), or large-scale databases (e.g., LUCAS; Orgiazzi, Ballabio, Panagos, Jones, & Fernández-Ugalde, 2018; Dai et al., 2019). Kalumba et al. (2020) evaluated five pedotransfer functions, including three using machine learning algorithms, for soil hydraulic properties in the large Zambezi River Basin and their performance in the AquaCrop model. Within a landscape, multiple soil functions can co-exist in the same location and may be enhanced or diminished as a result of the land management. Vrebos et al. (2020) used machine learning techniques (Bayesian Belief Networks) in combination with soil function performance indicators to map and evaluate the soil function performance on agricultural land across Europe. Young et al. (2020) estimated the impact of agronomic measures on crop yield, SOC and nitrogen (N) surpluses, quantifying the trade-offs among sustainability indicators. The temporal aspect of soil functioning can be assessed on timescales ranging from hours to decades (Schulte et al., 2015; Vogel et al., 2018), whereas most soil functional maps are static glimpses of the functional capacity at a point in time. However, Heuvelink et al. (2020) show that machine learning can be used for space–time mapping of soil properties that contribute to the temporal assessment of soil functions.

The modelling and mapping of dynamic changes is a critical next step to define the potential synergies and trade-offs between soil functions for given land-management practices, as a basis for future spatial planning and policymaking (Lilburne et al., 2020; Schulte et al., 2019). Vazquez et al. (2020) identified such synergies and trade-offs in three soil functions studied at 52 farms across the Netherlands. Although most farms showed multi-functionality in achieving two out of three functions assessed, there was a clear trade-off between the function, biodiversity and habitat provision and both primary productivity and nutrient cycling. Zwetsloot et al. (2020) present a pan-European monitoring framework for assessing soil functions, with two main conclusions: (a) agricultural land can deliver multiple functions, with three out of five functions achievable at optimal levels, and (b) future research and policies should prioritise the functions: biodiversity and habitat provision, climate regulation and nutrient cycling. This is supported by the recent Horizon Europe framework programme for research, starting in 2021, which includes the mission on Caring for Soil is Caring for Life (Veerman et al., 2020). This mission sets the research agenda to conduct such assessments and develop the evidence base for implementing sustainable soil management practices and policies, with a spotlight on soil functions.

So much has been achieved in soil science in the last 28 years since Blum introduced the concept of soil functions. The journey was slow to begin with, but in recent years the recognition and understanding of soil functions in science, policies and society mean that soil functions have been affirmed as the foundation from which the European Commission Green Deal, the Farm to Fork strategy and the reformed European Union Common Agricultural policy can grow.

The Wageningen Soil Conference in 2019 had the opportunity to bring together scientists and stakeholders from all over the globe to discuss the role of soil functions from ped to planet. This was an inspiring conference with excellent outputs as shown in this special issue and we hope this special issue will provide a sound knowledge base for future research initiatives. We look forward to welcoming you in 2023 to Wageningen for another interactive and inspiring soil conference!

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DATA AVAILABILITY STATEMENT

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