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Global Soil Science Education to Address the Soil – Water – Climate Change Nexus

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SOIL is a vital compartment of the ecosystem that supplies us with food, feed, fiber, and fuel. This system is very dynamic, open, and complex, and requires special care for its protection and conservation. Soil has several nexuses that include water, food, energy, ecosystems, and climate change. Soil consists of a unique natural organization, which forms the basis of any water–energy–food nexus system. The soil – water nexus, like other nexuses, includes many interdependent and complex relations and its investigation requires content-specific approaches and concepts (e.g., sustainable development, climate change, governance, resilience, and security of water, food and energy). The management, conservation and maximizing the potential of each component of any nexus is considered a major global concern that have many challenges to be faced in the 21st century. Therefore, the general components of such nexus including health of soil, plants, water, animals, people, and ecosystems is one and indivisible. Therefore, there is an urgent need for a nexus approach with a strong focus on soil and water as quite literally the foundation of humanity's future. Indeed, soil and water sciences are the key foundation of several nexuses due to their strong potential in determining the quantity and quality of foods, water, and energy. There is an urgent need to sustain the human life through the intensive productivity of our managed ecosystems. Therefore, the importance of soils as a nexus tool in addressing many global issues, which investigate soil-water dynamic under climate change, to identify strategies of using them for addressing the issues within a multidisciplinary research program should be taken into account through conceptual modelling.

Keywords: Social media, Universities, Scientific centers, Research center, Geology, Geography

Soil Science Education

Among the various environmental compartments, soil holds a unique and special place in our lives. Soil is the substrate for all bio-geophysical and biogeochemical processes. Soil is the main habitat for billions of diverse macro-, meso-, and micro-fauna and flora and is essential for many ecosystem services that provide food, feed, fiber, feedstock and fuel that are critical to human well-being (Lal et al. 2017; Brevik et al. 2019a, b, 2020c). Soil is the main source of plant nutrients, their transformations, and determines their bioavailability, the renewability and quality of water, and transportation of pollutants in groundwater (Lal 2015). Many human needs could be produced through the soil. This unique natural positioning of soil makes it the foundation of any nexus related to the food–water–energy system (Lal et al. 2017).

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Therefore, soil science education is very important for preserving the soil and its resources, which starts in general with understanding soil, its properties, uses, and research history (El-Ramady et al. 2019). Several groups and places are interested in teaching soil science, including universities and institutes, schools of agricultural sciences, and many different organizations that deal with soil science like research centers and global soil science societies (**Table 1 and Fig. 1**). National and international conferences, annual meetings of soil societies (**Fig. 2**), exhibitions (**Fig. 3**), and other activities like field excursions (**Fig. 4**) are important opportunities to share ideas and update information on soils.

Soil science, as an academic discipline, has been taught at institutions of higher education in a wide variety of disciplinary departments (Brevik et al. 2014; 2021b). Many academic fields have a strong connection to soil science, including agriculture/agronomy, biological sciences, chemistry, crop and plant sciences, earth and geosciences, engineering, environmental sciences/studies, forestry, and land and natural resources (Brevik and Vaughan 2020; Brevik et al., 2021b). The ability for teaching soil science may depend on the availability of funding from sources such as grants and scholarships for students (Brevik 2019, Brevik et al. 2021b). Under the COVID-19 pandemic, teaching soil science forced many educators to change their mode of teaching to online delivery (Mahler et al. 2021), including online laboratories (Brevik et al. 2021a). Some of the changes made may be incorporated into future soil science courses (Brown and Krzic 2021). Soil management will play a role in recovering from the COVID-19 pandemic (Lal et al. 2020), again emphasizing the importance of soil science education.

Fig. 1. Soil science education can take many forms. Top left – a university soil science student teaches elementary school students how to texture by feel. Top right – university students learn about the rocks that form parent materials in an indoor lab. Bottom left – university students learn about soils in a field lab. Bottom right – university students work with a researcher to collect soil biology data in the field (Photos by Eric Brevik).

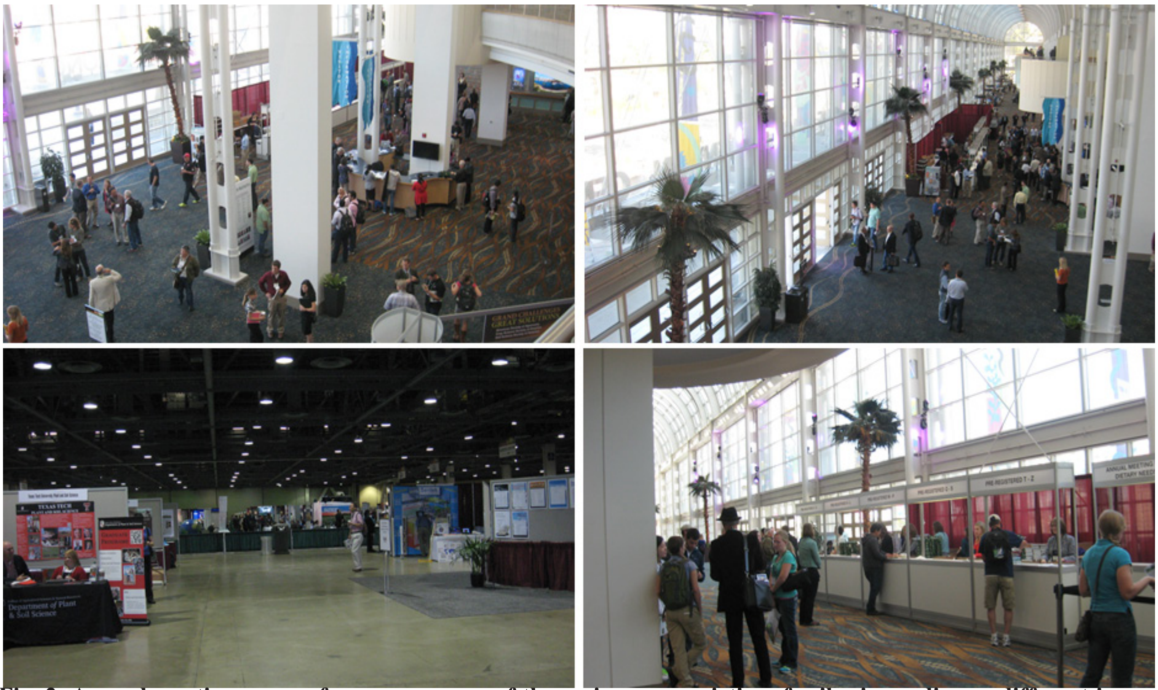

Fig. 2. Annual meetings or conferences are one of the main ways societies of soil science discuss different issues and exchange ideas related to soil sciences (Photos by H. El-Ramady during the annual meeting of the Soil Science Society of America in Long Beach, CA, USA 2014).

Fig. 3. Exhibitions are important activities at many soil science conferences. These exhibitions present many resources essential to understanding and studying soils, include new books, instruments, information on different universities and institutions, etc. (Photos by H. El-Ramady during the annual meeting of the Soil Science Society of America in Long Beach, CA, USA 2014).

TABLE 1. A list of some published articles about different resources for soil science education.

Source for soil science education or teaching	Reference(s)
Social media (online and its uses)	Brevik (2020); Krzic et al. (2020)
Universities (under-graduate and post-graduate students)	Brevik et al. (2018a, 2020a, b); Brevik and Vaughan (2020); Smith et al. (2020)
Schools (from KG to secondary schools)	Mori et al. (2020); Lal (2020)
Scientific institutes	El-Ramady et al. (2019)
Scientific meetings (conferences, symposia, workshops)	Lefevre et al. (2020)
Scientific exhibitions	Botelho and Brilha (2022)
Research centers	El-Ramady et al. (2019)
Global Soil Science Societies	Mataix-Solera et al. (2020)
General citizens or the public	Brevik et al. (2019b); Sánchez (2020)

Fig. 4. Field excursions that expose participants to a variety of soils are a major activity at many global soil science conferences (Photos by H. El-Ramady during the annual meeting of German Society of Soil Science, DBG, in Göttingen, Germany 2017).

The importance of soil education has led several scientists to work on raising public awareness of soil utilizing themes like global concepts of soils education (Takashi et al. 2020) and the framing of soil science education (Field 2020). Soil science education case studies have been discussed from many different countries including Austria (Sandén et al. 2020), Australia (Field et al. 2020), Brazil (Muggler et al. 2020), Canada (Krzic et al. 2020), New Zealand (Smith et al. 2020), India (Prasad et al. 2020), Spain (Mataix-Solera et al. 2020), and the USA (Brevik et al. 2014). An important lesson to consider is the role of soil as an integral tool to achieve the global sustainable developmental goals, which were announced by the United Nations (Lal et al. 2021). The ten main threats that represent a serious barrier to sustainable soil management include (1) water and wind erosion, (2) loss of organic carbon, (3) imbalance of nutrients, (4) salinization and alkalization, (5) contamination, (6) acidification, (7) loss of soil biodiversity, (8) sealing, (9) compaction, and (10) submersion (Dazzi and Lo Papa 2021). Therefore, great efforts are needed to educate people about these aspects of soil so that sustainable management practices can be identified and undertaken.

Soil and its different global nexuses

Soil is a complex, dynamic, and open system that allows a multitude of interactions with water, air, minerals and microbes. This soil system, or pedosphere, "is also in complete interaction with all other spheres including water or hydrosphere, living organisms or biosphere, and aerial environment or atmosphere, which are strongly interconnected to the human activities or anthroposphere" (Lal et al. 2017). Therefore, soil is a major factor mitigating changes in climate and securing water, food, and energy (McBratney et al. 2014). There is an urgent need for more interdisciplinary, post-disciplinary, and trans-disciplinary approaches to link soils with other ecosystem services, natural resources, and human social, individual, and environmental concerns (Weigelt et al. 2015). There is a critical need for innovative approaches to address complex global issues and achieve environmentally sustainable solutions. Generally, any strategy for sustainability must protect soil quality and renew its health, linking these system shifts with other resources through integrated methodological frameworks and conserving it to sustain life on earth (Lal et al. 2017). Thus, the nexus approach is a perfect solution to address complex global issues.

The soil-water system has several nexuses that include all agroecosystem compartments (organisms, air, water, and soil), ecosystem services, and natural resources (**Table 2**). There are multiple nexuses related to both soil and water including energy, food, wastes, climate, etc. The most important nexus may include the soil–water–food–energy–climate nexus, which is interwoven with ecosystem security and the functioning of Earth's four ecospheres (i.e., atmosphere, biosphere, hydrosphere, and lithosphere). Therefore, soil health and its relation to plants, animals, people, and ecosystems is one and indivisible (Lal et al. 2017; Brevik et al. 2020c). The energy-carbon-water nexus framework was applied to assess water utilization, energy flow, carbon emissions, and their links with agricultural production in China, using footprint analysis (i.e., carbon and water footprint), energy analysis, and a coupling model (Yu et al. 2022). They evaluated the footprints of agricultural activities at county scale on the Qinghai-Tibet Plateau (China), which might provide a systematic reference for energy-carbon-water nexus analysis and sustainable agricultural development policy for decision-makers in this area and this model may be applicable in many other areas around the world and this point requires further studies.

Soil for the global future

There is no future for humanity without conserving and managing all available resources including soil and water resources and related nexuses for future generations. Soil is the basic nexus tool, which is located at the center of several nexuses, especially the food–energy–water nexus (McBratney et al. 2014; Lal et al. 2017). Thus, our understanding of soils should focus on soil processes based on the nexus approach (Gu et al. 2021). Using the nexus approach, we should also consider human health, food safety, ecosystem sustainability, and crop productivity. The multiple goals of soil quality and health should be managed simultaneously, and more preventive measures should be implemented before soils become degraded. Urgent actions are required to manage soils from local to global scales involving multiple stakeholders from scientists to the public, farmers, and governments (Bouma et al. 2012; Gu et al. 2021).

TABLE 2. Different nexuses related to soil and water.

Different kinds of nexuses	Reference(s)
I. Water nexus group	
Water–food nexus	Corona-López et al. (2021)
Water – energy nexus	Panagopoulos (2021); Jian et al. (2022)
Water–energy–food nexus	Bian and Liu (2021); Correa-Porcel et al. (2021); Lazaro et al. (2021); Guerra et al. (2021); Yuan and Lo (2022)
Sustainable water–energy–environment nexus	Wan and Ni (2021)
Water–food–energy–climate nexus	Adebiyi et al. (2021)
Water-energy-waste nexus	Misrol et al. (2021)
Water- land — energy– food nexus	Psomas et al. (2021); Wolde et al. (2021)
Water –food–land–ecosystem nexus	Shi et al. (2022)
Water-food-ecosystem–livelihood nexus	Zhuang et al. (2021)
Water- energy – carbon nexus	Yu et al. (2022)
Water–waste–energy–food nexus	Couto et al. (2021); Lin et al. (2021); Xu et al. (2020)
Water–food–energy–health nexus	Slorach et al. (2020)
II. Soil nexus group	
Soil – water – waste nexus	Mannschatz et al. (2016); Avellán et al. (2017)
Soil-animal-human health nexus	Singh et al. (2017)
Soil security–food security nexus	Pozza and Field (2020)
Soil health–human health nexus	Rekik and van Es (2021)
Soil –vegetation nexus	Sun et al. (2021)
Soil fertility–crop productivity nexus	Mahmud et al. (2021)
Soil formation–geomorphology nexus	Yang et al. (2020)
Soil-food-environment-health nexus	Gu et al. (2021)

Great challenges face soil use and its nexuses, which include identifying effective strategies and policies to ensure global resources security for the healthy future of the planet. The world is faced with increases in both the frequency and amplitude of dynamic stresses, making the identification and implementation of such policies and strategies a great challenge (Lal et al. 2017). Thus, soil is the future of our world. Examples of this realization are shown in **Table 3**.

The key issues in soil management include handling the following global issues: soil conservation, restoration, soil quality, monitoring, erosion, organic carbon loss, acidification, pollution, biodiversity loss, sealing, salinization and sodification, nutrient imbalance, compaction, and water logging (Vidar 2022).

Concluding statements

Timmis and Ramos (2021) raised some general points to improve our dealings with soils. These include: (1) we must develop the philosophy of handing our soil heritage over to the next generation in a better state than we received it in from the previous generations. (2) Protecting, conserving, and restoring of global soil heritage through international dialogue and policy development is needed. (3) Research programs on global soil biomedical issues are crucial in providing us more knowledge on soil health or deterioration indicators and their nature in soil-plant-microbiome partnerships. (4) The restoration or conservation of soil is needed for healthcare systems, which may include soil conservation agencies that are analogous to public health agencies and healthcare systems. (5) International agencies should establish globally accepted practices for soil restoration and conservation and be responsible for recommending incentives and disincentives for good/bad practices and monitoring their progress. (6) Soil stewardship and education should be advocated and implemented for all stakeholders including the concepts of soil value, health, and its loss. (7) Policies and practices to increase national and global food production based on sustainable soil management principles should be developed an incentivized.

TABLE 3. Some common information on soils and their nexuses based on different global issues.

Common concept (s)	Global issues	Reference(s)
"Soil is alive and a key enabler of life on land and in the air. The images of soil and of microbes need to change to reflect the benefits they bestow upon us and the rest of the biosphere, to promote humankind to embrace the policies and actions needed to repair, restore and maintain in good health soils that are currently unhealthy, and to attain soil sustainability"	Soil sustainability	Dazzi and Lo Papa (2021); Timmis and Ramos (2021)
"*Soil is a vital resource for agriculture and the feeding of the world population*"	Agricultural soil	Timmis and Ramos (2021)
"*Soil microbes, with their exceptional diversity of metabolic activities, use most organic wastes as food and, in so doing, both remove them from soil and recycle them into biomass that enters the food web. They are the great disassemblers, the soil recycling buffer which prevents the accumulation of biological wastes and most pollutants in the environment, and the great cleansers of water transiting through soil to aquifers and surface water bodies*"	Global wastes and soil pollution	Khan et al. (2021); Timmis and Ramos (2021)
"*Soil provides a multitude of goods and services that underpin ecosystem functioning, and are vital to human survival and wellbeing*"	Soil health and its quality	Rekik and van Es (2021); Timmis and Ramos (2021)
"*We outsource food production and lose control of food quality, diversity and security, and leave the fate of soil to others who may not be subject to considerations other than quick and maximal profit in the short term*"	Global food security	Timmis and Ramos (2021); Vidar (2022)
"*Soil is a major microbiome-provider and renewer of higher organisms in the biosphere*"	Soil biology	Timmis and Ramos (2021)
"*It is absolutely essential to transit from a linear pathway agriculture to a circular agriculture, analogous to the circular economy, with minimal inputs and wastes, and recycling of wastes. And not only with regard to phosphorus fertilizers*"	Soil and circular economy	Timmis and Ramos (2021)
"*Soils are alive but many are unhealthy and experiencing reducing fertility, others are dying, and most are suffering erosion*"	Soil erosion	Timmis and Ramos (2021)
"*Efforts to increase agricultural productivity involves farming practices that overexploit the capacities of soils, reduce the diversity of their biota, render them less resilient-more susceptible to erosion, and ultimately result in loss of soil essential for plant growth*"	Soil resilience	Hinge et al. (2021); Timmis and Ramos (2021)
"*The use of agrochemical fertilizers to increase food yields on terrestrial farms reduces soil microbial diversity, leads to eutrophication of aquatic systems, and can significantly reduce food fish yields, thereby off-setting some of the food production gains*"	Eutrophication	Häder et al. (2021); Timmis and Ramos (2021)
"*Current degradation and losses of topsoil constitute one of the major Grand Challenges of our times. Soil losses are losses of life that catalyzes the multitude of processes which sustain life on the planet*"	Soil degradation	Timmis and Ramos (2021); Saljnikov et al. (2022)

Prof. Aly A. Balbaa

(1938 – 2021)

Prof. Sarwat Youssef

(1948 – 2021)

Prof. Adel Abou El-Kheir

(1955 – 2017)

Prof. Samir Mashali

(1950 – 2013)

Several questions still need to be answered, such as where do we store water to be available for future generations? Which natural resources control the quality of soil and water? Where and how will we grow our food in the future? How can we balance the production of cultivated plants and edible crops that are used to produce both food and energy? Which natural resources will control the quantity and quality of food, energy, and water under a changing climate? When and how will we be able to achieve complete protection and conservation of soil? When will soil and water be considered important, priceless resources by all stakeholders? Providing a path to answering these questions is an important goal for soil education in the near future.

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