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Editorial

The interdisciplinary nature of *SOIL*

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Abstract. The holistic study of soils requires an interdisciplinary approach involving biologists, chemists, geologists, and physicists, amongst others, something that has been true from the earliest days of the field. In more recent years this list has grown to include anthropologists, economists, engineers, medical professionals, military professionals, sociologists, and even artists. This approach has been strengthened and reinforced as current research continues to use experts trained in both soil science and related fields and by the wide array of issues impacting the world that require an in-depth understanding of soils. Of fundamental importance amongst these issues are biodiversity, biofuels/energy security, climate change, ecosystem services, food security, human health, land degradation, and water security, each representing a critical challenge for research. In order to establish a benchmark for the type of research that we seek to publish in each issue of *SOIL*, we have outlined the interdisciplinary nature of soil science research we are looking for. This includes a focus on the myriad ways soil science can be used to expand investigation into a more holistic and therefore richer approach to soil research. In addition, a selection of invited review papers are published in this first issue of *SOIL* that address the study of soils and the ways in which soil investigations are essential to other related fields. We hope that both this editorial and the papers in the first issue will serve as examples of the kinds of topics we would like to see published in *SOIL* and will stimulate excitement among our readers and authors to participate in this new venture.

1 Introduction

In the current times of numerous publications in numerous journals, one can rightly ask whether a new journal, like *SOIL*, is necessary. We, the editors, asked that same question when approached by the European Geosciences Union to launch a new journal. Upon reflection, we decided that a "golden" open-access journal with a focus on the interdisciplinary aspects of soils would fill in a very much needed niche within the soil science publishing world. Within soil science, there are no fully open-access journals (referred to as "gold" in the publishing world) where the review process and publishing are conducted in an open forum where anybody around the world with access to the internet can participate in and learn from the communicated science of soil within an interdisciplinary context. Given the current and future global issues that are in need of a soils perspective, a journal like *SOIL* should be welcomed.

The study of soils naturally involves an interdisciplinary approach – a consequence of soils forming at the intersection of the atmosphere, biosphere, hydrosphere, and lithosphere. This interdisciplinary approach is reflected by the number of individuals who are famous for landmark accomplishments in other scientific fields who also made early contributions to soil science, such as Leonardo da Vinci, Robert Boyle, and Charles Darwin (Brevik and Hartemink, 2010). Many of the biggest names from the early days of soil science received their training in other disciplines because academic programs that provided training in soils had not yet been created; this was true in both the USA (Brevik, 2010) and Europe (Calzolari, 2013). Furthermore, as soils have become more prominent in addressing the many challenges facing our modern world, additional fields outside of the natural sciences, such as anthropology, arts, economics, engineering, sociology, and the medical fields, have also begun to take an interest in soil.

While narrow, very focused studies are abundant in soil science today and are of great value, a true appreciation of the role for soils in addressing current and future global challenges requires a broader view. Many of the current environmental, social, economic, geologic, and human health issues can be better addressed if soils are considered and paid due attention (e.g., Howitt et al., 2009; Brevik, 2013a; McBratney et al., 2014). To better appreciate the many ways that soils knowledge can enhance the study of other disciplines, as well as ways these other disciplines can augment the study of soils, an overview of some key examples is provided. This editorial will start by looking at examples of connections between soils and the natural sciences, will then consider connections with the medical sciences and the social sciences, and will conclude with a look at a traditional soil science topic that can be advanced through interdisciplinary investigations.

2 Soils and biodiversity

Soil habitats range in size from micro-niches to entire landscapes, while soil biodiversity includes all varieties of life dwelling in the soil habitat below- and aboveground. It is now acknowledged that soil biodiversity supplies many ecosystem services essential to humans and the environment, such as the support of primary production through organic matter (OM) and nutrient cycling; climate control through the regulation of C and N fluxes; control of pests and diseases for humans, animals, and plants; and decontamination of the environment. This puts soil biodiversity at the epicenter of cross-disciplinary research.

Soil biota have numerous and varied functions that play a significant role in determining the chemical, physical, and biological properties of soil (Table 1). Organisms not only contribute to total soil organic matter (SOM) formation, they also decompose SOM and transform nutrients (e.g., C, N, P, S), determining the chemical, and physical composition of their habitat. Finally, soil organisms perform a vital role in shaping the soil environment through formation and modification of the soil architecture with pores and tunnels, the transportation of soil particles, and the creation of new soil habitats through the weathering of rocks (Puente et al., 2004). While the diversity and abundance of soil organisms influence soil functioning, the diversity and activity of soil organisms also depend on soil properties (Bardgett, 2002).

Plants play an important role in shaping soil, from surface to depth, with the diverse architecture of their root systems. Plants are at the center of soil–plant–microbial interactions. The rhizosphere is rich with microorganisms (Cardon and Whitbeck, 2007) and nutrients, and exhibits a gradient in oxygen concentrations. Plant-growth-promoting rhizospheric (PGPR) microbes contribute to biofertilization, biocontrol, and phytostimulation (reviewed by Martinez-Viveros et al., 2010; Pereg and McMillan, 2015). The sustainability of crop production systems is a key issue for ensuring global food security. The links between human activity and soil biodiversity and thus soil function are illustrated in the influence agricultural management practices have on soil biodiversity (Berg and Smalla, 2009; Reeve et al., 2010). Natural diverse vegetation contributes to an increase in soil biodiversity, while intense mono-cropping supports the growth of only a subset of soil microbes, causing a decrease in biodiversity (Figuerola et al., 2014). Furthermore, increased use of fertilizers and pesticides might compromise both the activity and survival of certain microbes in the soil.

Due to the reliance of soil biological community structure and activity on the stability of abiotic and biotic soil properties, any change in these conditions may precipitate a shift in biodiversity. Climate change, land use change, pollution, invasive species, and any factor contributing to soil degradation can impact biodiversity. For example, agricultural dust has been shown to be a vector carrying terrestrial microbes into the ocean that are pathogenic to marine organisms, affecting ecological niches such as coral reefs and fish (Garrison et al., 2003). In recent years soil scientists have made enormous progress toward understanding soil organisms and their roles in ecosystems. Nonetheless, much remains to be discovered to allow the development of practices that will promote the sustainable use of soils. Understanding what causes changes in the belowground biodiversity and how diversity is linked to soil function, as well as how it influences aboveground diversity, would contribute to sustainability and restoration of ecosystems.

Biodiversity is evaluated using a myriad of methods that can be categorized as those that determine species abundance and diversity or those that measure functional diversity (Cooper and Rao, 2006). While the diversity and abundance of plants and macrofauna can be measured through direct sampling, microfauna is more complicated to assess due to the potentially enormous number of microorganisms that can be found in one gram of soil and that less than 1 % of the microorganisms can be cultivated or characterized

Table 1. Some soil organisms and the soil properties with which they are associated.

Soil properties	Mechanisms/organisms
Formation and structure	– Plant cover protects soil against erosion. Soil stabilization is also achieved through assembling organic matter (OM) mucus and soil by earthworms and polysaccharide-producing bacteria. – Creation of humus through the decomposition of dead OM. – Formation of pore, channel networks, root systems, and bioturbation by organisms such as earthworms, termites, ants, and other invertebrates that move through the soil, such as millipedes, centipedes, beetles, caterpillars, and scorpions. Other, temporary, soil residents (such as burrowing mammals) moving through the soil include snakes, lizards, mice, rabbits, and others. – Soil aggregation by fungal sticky glycoproteins, fungal mycelia attached to soil particles, bacterial exopolysaccharides and mucus produced by earthworms passing through the soil. – Ratio of macro- to micro-soil aggregates is influenced by earthworms ingesting and expulsing soil during feeding and burrowing. – Transport of soil particles and OM by nest builders (e.g., ants and termites) and burrowing organisms. – Cracking of rocky substrates by desert plants, such as cacti and trees, followed by production of weathered mineral matter or soil to support succession by other plants. – Microorganisms in the rhizosphere of desert plants (fungi and actinomycete) dissolve insoluble phosphates as well as rock, marble, and limestone.
Chemical properties and fertility	– Production of biomass from inorganic compounds by photosynthetic primary producers (plants, cyanobacteria). – Fertilization of top soils with litter and feces from soil temporary residents such as burrowing mammals (e.g., badgers, shrews). – Dispersal of OM and decomposers through feeding by protists, nematodes, and other macro- and mesofauna. – Direct processing (shredding) of OM by macrofauna, such as earthworms, ants, termites (digest cellulose), snails, and millipedes. – C transformation by decomposition of OM by meso- and microfauna, such as nematodes, mites and protozoa. The majority of mineralization is carried out by microorganisms (fungi and bacteria). – Nutrient cycling (e.g., N, P, S) and assimilation by microbes and plants. – Mineralization of substrates by microbes and root exudates. – Rate and extent of infiltration of nutrient-carrying water through to deeper soils are influenced by burrows, ant galleries, tunnels, and more.
Moisture and water distribution	– Water infiltration, underground water storage, and flow rate are influenced by plant cover; crust formation (by some algae); the creation of poles and tunnels (by organisms such as earthworms, ants, and termites); and burrows and tunnels of burrowing mammals, lizards, and others. – Compacting of the soil by the creation of micro- and macroaggregates by fungi, earthworm tunnel mucus, and bacterial polysaccharides. – Root uptake of water.
Oxygen levels and consumption	– Poles, channel, and burrow systems as well as roots allow soil aeration providing oxygen dispersal in the soil and around rhizospheres.
Health and pollution	– Decontamination of soil pollution by microbial biodegradation (bioremediation) or by phytoremediation, employing plants that can take up the pollutant and remove it from the soil.
Biodiversity	– All organisms through the food web (e.g., grazing, predation) and other interactions, such as competition and antibiosis, parasitism, pathogenicity, and symbiosis (e.g., *Rhizobium*-legume and mycorrhizal plants). – Through predation and fecal production, invertebrates, such as microarthropods and earthworms, contribute to the dispersion of microbes and activation of microbial processes. – Dispersal of plant seeds by burrowing animals.

References: Bardgett et al. (2001, 2005), Barrios (2007), Cerdà and Jurgensen (2008), Pimental and Kounang (1998), Bragg et al. (1994), Young and Crawford (2004), Hunt et al. (1987), Lavelle and Spain (2001), Rillig (2004), Purin and Rilling (2007), Swift et al. (1979), Jones et al. (1997), Lavelle et al. (1997), Puente et al. (2004), Bashan and De-Bashan (2010), Six et al. (2000, 2004).

(Torsvik and Ovreas, 2002). The development of culture-independent, molecular biology methods to assess biodiversity has revealed the hitherto unknown extent of microbial diversity, enabling the detection of 10–1000 times the diversity revealed by culturing techniques. The methods for the analysis of the genetic material, mainly based on the amplification of 16S (prokaryotic) and 18S (eukaryotic) rRNA encoding sequences, are varied (Cooper and Rao, 2006). While the diversity of microbes can be determined using DNA-based techniques, the activity of microbes under particular sets of conditions requires RNA technology to add breadth to the traditional analysis of microbial activity (e.g., enzyme kinetics), with techniques such as qRT-PCR and RNA sequencing becoming more widely used. The study of microbial diversity and function in the soil requires a good understanding of the biology of microbes and utilizes methods developed for biological and biomedical research, again emphasizing the cross-disciplinary nature of the study of soil biota and in general soils.

3 Soils and biogeochemical cycling

Soils are the recipients of major nitrogen (N) additions, from both organic and inorganic fertilizers and the atmosphere, which has led to a major change in the amount of N that soils store. Hence, there is a resultant flux of nitrogenous compounds to the atmosphere in the form of the greenhouse gas (GHG) nitrous oxide and to ground and surface waters in the form of nitrate (Fig. 1). The fact that soils are emitters of nitrous oxide has focused research on developing a better understanding of the microbiological pathways involved in denitrification (Baggs, 2011), but scaling this knowledge up to the landscape level is needed to better manage GHG emissions. Increasing evidence links soil N enrichment to a loss in biodiversity (Stevens et al., 2004) and N leakage to surface and ground waters is associated with eutrophication, anoxia, and human health issues. The increase in the soil N pool is thought to increase the soil carbon (C) pool by promoting plant growth (Zaehle et al., 2011). However, not only external additions of N may produce positive feedbacks: Melillo et al. (2011) showed that warming caused an increase in soil C turnover, but the resulting loss of soil C was more than compensated for by increased vegetative production due to increased N mineralization.

Many soils have also undergone considerable enrichment with phosphate (P) over recent decades. Much of this has been associated with mineral P fertilizer, but increased application of animal manures and slurries due to higher stock numbers has also occurred in many parts of the world (Bouwman et al., 2013). This over-application of P has been linked to the pollution and eutrophication of freshwaters. The transfer of P to surface waters has received considerable research attention challenging the long-held model of P as an immobile element in soils; recent data suggest that P leaching to

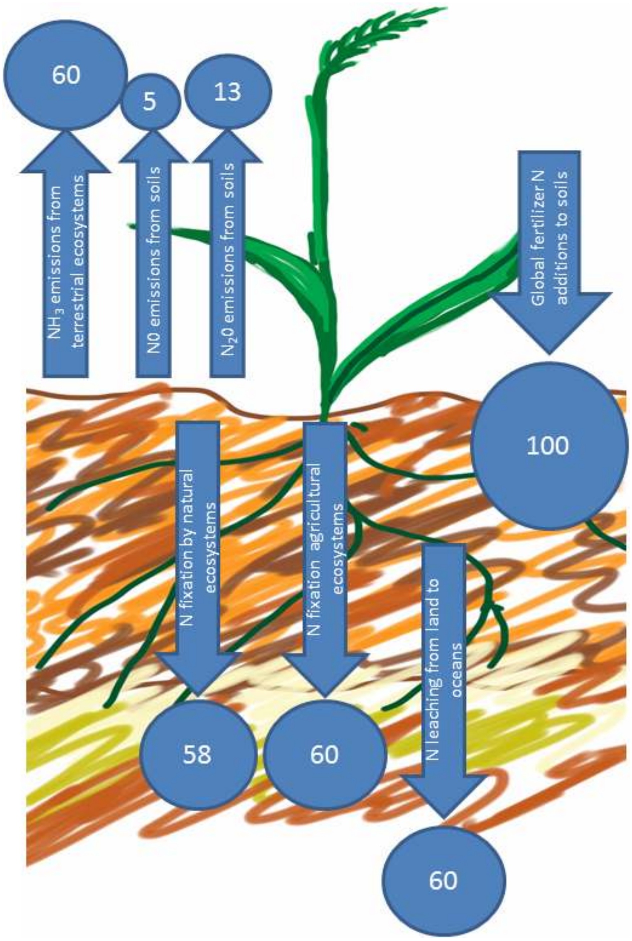

Figure 1. Global fluxes of N thorough soils (Tg N yr^{-1}). Based on data from Fowler et al. (2013).

groundwater may be a critical process (Sørensen and Rubæk, 2012). There has been considerable P deposited on soils from the atmosphere as well (Tipping et al., 2014), causing enrichment of soils and reducing nutrient limitations in natural and semi-natural systems. The P cycle in temperate soils is relatively well understood, but there is still a pertinent need to better understand P dynamics and availability in soils of the tropics, where the combination of variable charge clays and acidic pH have made managing P for crops a major challenge. The effect of P on C and N cycling in soils is still largely unknown.

The role of soils in the C cycle is well known and makes soils important in the study of climate change. Soils store more C than the atmosphere and vegetation combined, making them the largest terrestrial C store. This has focused attention on understanding the stores of C and C fluxes to and from soil. The fate of soil C is of global importance, and understanding where stocks are increasing and where they are decreasing is posing a major challenge to soil scientists, highlighting the difficulty of relying on the traditional, laborious methodologies for stock change assessments. There have also been major advances in our understanding of soil C dynamics, and particularly the role of soils as emitters of methane under a changing climate (van Groenigen et al., 2011); however, we are still searching for ways to manage soils that can lead to C sequestration. The use of minimum tillage has been promoted as a tool for C sequestration, although several researchers have recently raised questions about the value of this approach (Powlson et al., 2014). There has also been considerable interest in the addition of C-rich materials to soils to sequester C. These materials have included manures and industrial byproducts, but biochar has most recently caught the imagination of the public and academic communities. Studies of human-made Amazonian soils highlight the potential for building a new area of science based on indigenous knowledge (Sombroek et al., 2003).

Most studies of soil biogeochemical cycling are based on small-scale studies of soils in flat, experimental fields. However, soil scientists recognize that soils are connected entities exchanging matter and energy across a landscape over timescales from a few minutes to centuries or more. These exchanges and soils' intimate connection to the hydrological cycle have a major impact on the soil biogeochemical cycles. For example, recent work on soil erosion has highlighted how it may impact the C cycle by transporting C, N, and P across landscapes and preferentially depositing them in new locations (Quinton et al., 2010) and it is clear that nitrous oxide emissions at a landscape scale are closely related to landscape position (Corre et al., 1996).

4 Soils and hydrology

Soil water is a key component of the Earth ecosystem because it plays a vital role in determining the functioning of plants and other soil biota. Water conservation was a key topic in the 20th century that began in the USA due to the Dust Bowl in the American Midwest during the Great Depression (Helms, 2010). Other countries also established programs during the last century to fight against water and soil degradation and desertification. Conservation techniques such as mulches and cover crops have been tested on agricultural land (Jordán et al., 2010), fire-affected land (Fernández et al., 2012), afforested land (Jiménez et al., 2013), and road and railway embankments (Bakr et al., 2012).

Soil water analyses have seen major advances during the last century through techniques developed in other disciplines, e.g., soil water content measurements can now be done by in situ probes (Mittelbach et al., 2012) and remote sensing (Engman and Chauhan, 1995). Other advances include the use of time domain reflectometry (TDR) (Roth et al., 2006) and electromagnetic induction for mapping spatial changes in soil water content (Doolittle and Brevik, 2014). These new techniques have allowed for the collection of large soil moisture data sets across time and space, which are ideal for modeling and have greatly advanced our understanding of the role of soil water in the Earth system (Dorigo et al., 2011). Advances such as these are critical to tie the soil component into climate models and to improve agricultural production in support of food security goals.

Soil physics is largely related to the interactions between soil and water; therefore, the physical, chemical, and biological processes that take place in soil depend on the amount and composition of water. Infiltration determines the quantity of water that flows across the soil surface, reaches the soil profile, or, finally, percolates to recharge aquifers. This task of partitioning the processes of the hydrological cycle is essential to understanding the hydrological cycle and erosional response to it (Cerdà, 1999). Findings on preferential water flow in the soil system at the pedon scale contributed to better understanding of the flow of water and solutes in the soil and along slopes in watersheds (Jarvis, 2007). Those findings were soon modeled to better understand solute transport in soil under preferential water movement conditions (Gerke and van Genuchten, 1993). Understanding these processes is critical to advancing interdisciplinary topics such as human health through the supply of clean water sources and the modeling and prevention of soil erosion in support of food and energy security.

Water flows along preferential pathways because the matrix is hydrophobic (Dekker and Ritsema, 1994); this recognition has given rise to water repellency as a new research topic gaining attention within soil science and related disciplines. Soil water repellency (SWR) has been studied worldwide (Doerr et al., 2000), in both forest (Cerdà and Doerr, 2005) and cropped soils (Eynard et al., 2005). Repellency has become a soil property reported in many regions, whereas two decades ago it was thought of as more of an isolated occurrence than a widespread soil property.

The low affinity between water and soil particles and aggregates in water repellent soils results in decreased and uneven infiltration (Markus et al., 1994), poor and delayed seed germination and reduced yields (Abadi Ghadim, 2000), increased runoff and enhanced erosion (Doerr et al., 2000), accelerated leaching of agrochemicals (Taumer et al., 2006), and a decreased vegetative canopy, leaving bare soil that is prone to erosion (McKissock et al., 1998). On the other hand, soil water repellency can have some positive impacts: it has been reported that low levels of SWR may improve soil structure (Enyard et al., 2005) and soil C sequestration (Bachmann et al., 2008). Therefore, understanding water repellency is important for things such as agricultural production and understanding links between soils and climate. Water security depends on understanding soils and their place in the hydrologic cycle.

5 Soils and human health

The idea that there is a link between soils and human health has been recognized for thousands of years; however, the scientific study of how soils influence human health is a recent undertaking (Brevik and Sauer, 2015). Contributions to this area come from a diverse array of fields, including soil science, agronomy, geology, biology, anthropology, and medicine. The French scientist André Voisin (1959) believed the medical profession had ignored soils in their efforts to improve human health, but that soils should be the foundation of preventive medicine.

Examples of common topics investigating how soils benefit human health include the transfer of nutrients from soil to people through plant (Kabata-Pendias and Mukherjee, 2007) and animal (Jones, 2005) sources as well as through direct ingestion (Brevik, 2013a). Exposure to soil microorganisms is thought to be important in the prevention of allergies and other immunity-related disorders (Rook, 2010). One prevailing theory about the practice of geophagy is that the consumed soil acts as a food detoxifier (Brevik, 2013a). Soils have the ability to clean water sources, thus improving human health (Helmke and Losco, 2013), and are an important source of medicines: 78 % of antibacterial agents approved between 1983 and 1994 had their origins in the soil (Pepper et al., 2009). Beyond antibiotics, approximately 40 % of all prescription drugs have their origin in soil, including an estimated 60 % of all newly approved drugs between 1989 and 1995, and 60 % of new cancer drugs approved between 1983 and 1994 (Pepper et al., 2009).

Exposure to soils has the potential to harm human health as well. A variety of materials found in soils can cause problems if present at toxic levels, including heavy metals, radioactive materials, and organic chemicals (Brevik, 2013a). In addition, soils can expose humans to pathogenic microorganisms (Loynachan, 2013) (Fig. 2). Geophagy is frequently responsible for negative health impacts because it can lead to exposure to hazardous materials and soil pathogens (Brevik, 2013a).

Figure 2. Ringworm on a woman's skin caused by *Trichophyton rubrum*, a fungus that lives in soil. (Courtesy of the Centers for Disease Control and Prevention, image #2909.)

Additional research is needed into almost all areas of soils and human health. One of the biggest research needs is an understanding of the complex interactions that take place between chemical species in the soil. For example, Burgess (2013) points out that it is not known whether the mixtures of organic chemicals that end up in soil are creating new, toxic xenobiotics that might be found at very low concentrations but have important health effects on humans and other organisms. Investigation is needed into the ecology and life cycles of human pathogenic soil organisms and the influence of climate change on soils and human health. Less traditional areas that require further investigation are the possible health benefits of contact with healthy soil (Heckman, 2013) and the possible links between organic farming and human health (Carr et al., 2013). In the modern world, the One Health Initiative (http://www.onehealthinitiative.com/) is seeking to create an environment of interdisciplinary collaboration between medical professionals and other relevant scientific disciplines to promote human, animal, and environmental health. Supporting organizations represent medical, natural, environmental, and animal scientists. Soil scientists and the organizations representing them would do well to also engage in this initiative. To meet future needs in soils and human health research, soil scientists will need to work with a wide range of other specialists, including medical professionals, agronomists, anthropologists, biologists, geologists, public health experts, and sociologists, among others.

6 Soils and social sciences

The application of soils to archaeological work is fairly new; by contrast, the application of geology to archaeological investigations is much more established (Holliday, 2004). Soils can provide valuable information to archaeologists, including the impact of human occupation on a site and the environmental setting at the time of occupation (Holliday, 2004).

Buried soils can be used as markers showing where artifacts are likely to be found, and in some instances the location of artifacts within a soil can be used to assign approximate dates to the artifacts (Homburg, 1988) (Fig. 3). The number of soils at a site and the degree to which each soil profile developed can provide important information about the time spanned by a given archaeological site, the integrity of the archaeological record, landscape evolution, and environmental change over time (Holliday, 2004). Soils have been useful in the study of ancient agricultural systems, providing insight into the diet (Sweetwood et al., 2009) and general land use of ancient people (Homburg and Sandor, 2011). Conversely, studies carried out on archaeological structures have been useful in soil research. Parsons et al. (1962) used soils formed in dated archaeological features to estimate rates of soil formation, while archaeological sites (Sandor and Eash, 1991) and features (Brevik and Fenton, 2012; Brevik, 2013b) (Fig. 4) have been used to investigate long-term effects of human activity on soil processes and properties. Archaeology could benefit from more research into soil magnetic methods (Herries, 2009), the long-term impacts of prehistoric agriculture on soils (Briggs et al., 2006), and the influence of soil processes and properties on artifact preservation (Jans et al., 2002). There is also a need for predictive modeling that allows buried archaeological sites to be located using paleoenvironmental models that integrate a wide range of information, including soils, and for better quantification of soil properties that distinguish natural from anthropogenic features (Bullard et al., 2008).

Figure 3. Artifacts within buried soil horizons at an archaeological excavation. The relationship between the soil horizons and artifacts can provide archaeologists with important information. Picture taken near Los Angeles, California, USA, courtesy of Jeffrey Homburg.

Environmental conditions influence social, cultural, and economic development (Wagner, 1977), and soils are important in determining which socioeconomic activities are feasible at a given location. Rice (*Oryza* sp.) is an important crop in locations like the Central Valley of California, USA, and the Po River valley in Italy because the heavy clay soils are more suitable to rice than any other crop. In the tropics, farmers will seek out Nitisols because they are much more fertile than the neighboring Ferralsols or they will exploit strong fertility gradients by planting their staple crops on more fertile soils close to their houses, while grazing is practiced on less fertile soils farther away (Tittonell et al., 2005). For similar reasons, remnants of native grassland and forest are often found on marginal lands within highly productive regions, such as the Corn Belt in the USA; farmers choose the best soil to cultivate but preserve native systems on less suitable soils. Furthermore, they will restore grasslands or forests on more vulnerable soils that have been strongly degraded by cultivation (Baer et al., 2000).

When considering the introduction of novel, and possibly more profitable, cropping systems within an agricultural landscape, the availability and distribution of different soils needs to be considered (Yi et al., 2014). Similarly, when new policies are devised to address environmental impacts, soils must be considered (Mérel et al., 2014). In recent years, several studies have linked biophysical and economic modeling to determine C supply curves for mitigation of climate change through changes in agricultural management (e.g., Howitt et al., 2009). Many schemes proposed for ecosystem service payments should consider soils, but many do not. Hence, it can be argued that there is great future potential for soil scientists to work with socioeconomists to develop and evaluate ecosystem service payment programs and/or similar schemes to value non-commodified services and goods, such as soil.

Soils have played roles in the outcome of war. French noblemen lost the 1302 Battle of the Golden Spurs against poor farmers because the French horses and large artillery sank into the swampy soils the farmers had lured them onto (Devries, 1996). Similarly, certain major offenses of the American Civil War were stopped when soldiers and their artillery became bogged in mud (Brown, 1963), and soil considerations were important during the planning of operations such as the invasion of Normandy in World War II (Lark, 2008). In turn, war has caused long-term and even irreversible changes to soils, leaving them polluted with oil, organic chemicals, and heavy metals (Helmke and Losco, 2013).

Figure 4. (Left) The Mormon Trail through south-central Iowa, USA. This trail was used by wagon traffic from about 1846 to 1853, but the effects of that traffic are still detectible in the trail's soils. Here the trail appears as a zone of reduced vegetative productivity in this August photograph (Brevik and Fenton, 2012). (Right) A 2300-year-old cart trail at Castellar de Meca in eastern Spain. Traffic from the carts led to the complete removal of the soil at this location. Photo by Artemi Cerdà.

Western society has largely lost its connection with soils and agriculture, with many children unaware of the source of their food (Bell et al., 2013). Soil and terms associated with soil (e.g., "soiled", "muddy", "dirty") have come to refer to a state of being unclean. This loss of connection is, in part, responsible for the degradation of soils and agriculture in general. Nevertheless, interest in soils and agriculture is rising again (Hartemink, 2008). Communities are forming around urban gardens, schools are establishing student farms, and edible landscapes are considered within urban planning. For soil scientists it is essential to elucidate how we can foster this new trend and develop novel ways that soils and their functions can be integrated into urban life and planning to improve the connection between soils and the urban population. This improved connection would allow for a more pleasant urban environment and improved well-being of its population.

7 Soil threats

The need for an interdisciplinary framework to understand the soil system is brought into sharp focus by the increasing pressures associated with land use and cover change, climate change, N fertilization, contamination with pollutants, and loss of biodiversity. Recent research has identified that (i) land use intensification reduces the abundance and diversity of soil biota, with direct consequences for ecosystem services provided by soils (de Vries et al., 2013); (ii) soils are being paved over at an increasing rate (Procop et al., 2011); (iii) soil C stores are dwindling (Bellamy et al., 2005); (iv) soil compaction, acidification, and salinization are widespread problems (e.g., Jones et al., 2003); and (v) rates of soil erosion, especially on agricultural land, are several orders of magnitude higher than rates of soil formation (Verheijen et al., 2009). At the same time, the global population is predicted to reach 9 billion by 2050; in combination with changes in dietary behavior, a large net increase in productivity and/or agricultural area is needed (Foley et al., 2011). Soils are thus under increasing environmental pressure, and this will have consequences for the capacity of the soil to continue to perform its variety of functions. However, the extent, severity, and consequences of soil degradation remain poorly documented (Bai et al., 2008; Wessels, 2009), and there is an urgent need for quantitative, repeatable measures of degradation.

Soil degradation dates back to approximately 3500 BC, when farmers began to exploit highly erodible soils on steep slopes. Archeological studies have linked the degradation of soil to the rise and collapse of civilizations in the ancient world, the Pacific, and Mesoamerica (Montgomery, 2007). Considerable research has been directed towards the functioning and protection of soils from degradation. Early research on soil degradation was largely concerned with improving soil productivity (Tóth et al., 2008); now there are large bodies of work that consider the functioning of soils from a hydrological perspective (Ludwig et al., 2005). An increasing focus of research addresses the role of soils in C sequestration (Lal, 2004) as well as biodiversity and soil ecosystem services (de Vries et al., 2013). Although the global community's awareness of soil degradation has lagged in comparison with its awareness of climate change and biodiversity loss, soil degradation, protection, and restoration are now increasingly linked to food security, water security, energy security, biodiversity, and many ecosystem services. In the same sense that it is used for food, water, and energy, soil security has been proposed to represent an overarching concept for the maintenance and improvement of the world's soil resources to continue to perform their functions (McBratney et al., 2014). It is therefore no surprise that soil loss and degradation are now considered challenges of a global dimension and are included in environmental policy frameworks. A prime example is the United Nations Convention to Combat Desertification (UNCCD), which recognizes the central role of soils in sustainable development and has proposed the ambitious goal to achieve zero net land degradation by 2030 (UNCCD, 2012).

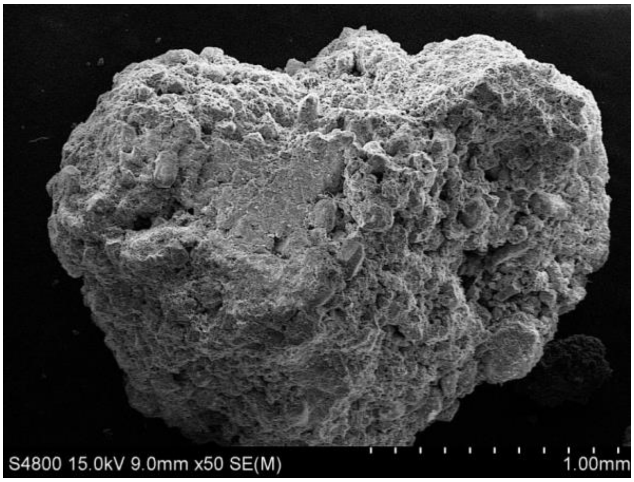

Figure 5. Scanning electron microscopy (SEM) photograph of a soil macroaggregate. Picture taken from a forest soil sample from Benitatxell, Alicante, Spain, 2013.

8 Interdisciplinary aspects of traditional soil topics

The soil systems topical category allows a place in the journal for authors to demonstrate the interdisciplinary aspects of topics that are traditionally soil science focused. This could include addressing soils problems that would benefit from an interdisciplinary approach. To provide an example of this, we will focus on one of oldest topics in soil science, the study of soil structure, and yet one in which we have struggled to make progress from an empirical to a predictive understanding. We argue that this progress will only be possible if researchers with different backgrounds work together, providing another illustration of the interdisciplinary nature of soil.

Understanding soil structural formation (Fig. 5) involves aspects of biology, chemistry, geology, and physics within the context of the soil environment. Soil structure results from the organization of mineral particles and organic particles through soil processes, requiring the active involvement of microorganisms and soil fauna (Bronick and Lal, 2004; Six et al., 2004). The degree of soil structure formation influences water and nutrient movement and their availability for plants, resistance to erosive agents, etc., all of which are important in the creation of an adequate medium to support life (Bronick and Lal, 2004). Many consider aggregate stability as a reflection of soil structure and soil health in general because it depends on an integrated balance of chemical, physical, and biological factors.

Soil aggregate and, in general, soil structure studies are closely connected with other research areas such as hydrology and erosion (Cerdà, 1996), soil microbial dynamics (Caravaca et al., 2002; Kong et al., 2011), biogeochemical cycles (Pronk et al., 2012), degradation studies and conservation measures (Dlapa et al., 2012; García-Orenes et al., 2012), and greenhouse gas emissions (Mangalassery et al., 2013), and therefore have intimate interdisciplinary relationships.

Future challenges in the study of soil structure include rates of soil structural formation in space and time, its temporal changes, properties such as microporosity, and its relationship with ecological niche differentiation that supports microbial diversity. Advances in new non-destructive techniques to study and characterize the architecture of soils, the detection and quantification of microorganisms, and the location of active organisms at the micro- and the nanoscale are needed. The relation of soil structural stability to water repellency and its role in soil ecological functions is also an important topic (Lozano et al., 2013). Hence, tying existing and new knowledge together into a framework that allows us to predict changes in soil structure, and its interactions with the wider soil system and beyond, will require extensive cross-disciplinary collaboration that draws together our existing knowledge and identifies where new work is required both within soil system science and beyond.

9 Concluding remarks

The holistic study of soils requires an interdisciplinary approach, as demonstrated by the examples provided here. As a new journal, it is the intention of *SOIL* to publish on all topics that fall within the science of soil, but with an emphasis on the interdisciplinary aspects of this scientific field. This could range from topics that combine subjects such as soil science and natural sciences (e.g., biology, chemistry, geology, physics) or soils and engineering with less traditional topics such as the link between soils and social sciences (e.g., anthropology, economics, political science, sociology) and even soils and art or literature. It is our hope that this editorial and the collection of review papers published in this first issue of *SOIL* will serve as examples of topics we would like to see published in *SOIL* and will stimulate excitement among our readers and authors to participate in this new venture.

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