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Viewpoint

Policy relevance of Critical Zone Science

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ABSTRACT

Critical Zone Science extends the definition of soils beyond the traditional pedogenetic processes. The critical zone, as the interface linking the lithosphere, the hydrosphere, the atmosphere and the biosphere matches well the concepts that have recently emerged, especially in Europe, in relation to the development of a new soil protection policy for the European Union. The European Union (EU) Soil Thematic Strategy, as presented by the European Commission in 2006, intends to address the protection of soil functions that go far beyond the limited definition of soils as the first 2-m of the surface structured in pedogenetic horizons. The seven functions that the EU wants to protect (biomass production, buffering and filtering of water, biodiversity pool, source of raw materials, support for housing and infrastructure, carbon sink and archive of cultural heritage) require considering soils in a much broader context. The full unconsolidated material from the surface to bedrock has to be included if we want to fully understand and manage the seven soil functions considered of policy relevance by the EU. Soil science needs to go beyond traditional pedological studies and enlarge its scope by including a full understanding of the critical zone. In this sense Critical Zone Science can be considered the perfect match with the emerging concepts of the EU Soil Thematic Strategy. Indeed this reflects the recent evolution from the historical relevance of soils science in the framework of a single soil function, namely agricultural production, toward a shift of the attention of the importance of soils also in other policy areas beyond agriculture, including the water policy, the climate change policy, the biodiversity policy, the energy resources policy, the cultural policy, etc. At global level, Critical Zone Science community can contribute to the Sustainable Development Goals recent debates. A new scientific paradigm for soil science is needed if we want to respond to these emerging needs from new soil related policy areas. This new paradigm is Critical Zone Science and is adequately responding to these new needs going far beyond the traditional agricultural view on soils.

1. Introduction

The origins of soil science were mostly driven by the need to better understand soil functioning and distribution in relation to agricultural production. The increased knowledge of soils has been one of the cornerstones of modern agricultural development and has substantially contributed to the last green revolution.

But soils are not only performing the valuable function of supporting biomass production, they also are delivering a number of crucial services to all of us, including filtering, buffering and storing our groundwater and surface freshwater resources (Field et al., 2015; Banwart et al., 2013). Understanding the role of soils in the water cycle requires including not only the surface horizons of the traditional "agricultural" soils, but the full depth to the groundwater table, including the unsaturated (vadose) and the saturated zone (in hydrological terms). Indeed the new term of "hydropedology" was recently defined (Bouma, 2012; Lin et al., 2005) to enlarge the scope of traditional pedology beyond the soil profile at the surface (Table 1). Traditionally, pedology has been focusing on the first 2 m of soil on the earth surface, restricting its analysis and understanding of its functioning to the classical pedogenetic processes occurring in this rather limited volume of soil material. Indeed the current classification systems like the World Reference Base and the US Soil Taxonomy restrict themselves to an arbitrary limit of 2 m soil depth. In this "comfort" zone of soil classification, classical soil profile description can occur and is mostly responding to the traditional scope of soil science restricted to agricultural applications. Going beyond that traditional view is one of the great challenges of modern soil science. It requires transdisciplinary research, including agronomy, geology and hydrology, which are still rarely occurring in integrated research projects (Banwart et al., 2011). The critical zone is defined as the portion of the Earth's land surface that extends from the lower limit of

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Table 1
Nomenclature.

Critical zone (CZ)	Portion of the Earth's surface that includes the atmosphere, biosphere, pedosphere, and lithosphere interfaces
Hydropedology	A multidisciplinary research field combining soil science (pedology) with hydrology
World Reference Base	A framework for international classification, correlation and communication of soils

freely available circulating groundwater to the top of the vegetation canopy (Field et al., 2015).

In this direction, the EU funded project "Soil Transformations in European Catchments (SoilTrEC)" is a positive example (Banwart et al., 2012). This project has been one of the first attempts to develop trans-disciplinary research activities by focusing on four study sites belonging to the global network of Critical Zone Observatories (Lin et al., 2005). Multi-disciplinary teams have been working in those observatories for the full assessment of the critical zone, including the full hydrological cycle. A major future challenge will be the extension of this approach to the European Union and its translation into policy relevant data and information. This paper addresses major aspects of Critical Zone Science that could have future policy relevance at EU and global level.

2. Policies relevant to critical zone

Critical Zone Science (CZS) goes far beyond the traditional pedological view on soils. Therefore a number of policies are relevant to CZS beyond strictly soil related policies: climate change, water management, biodiversity protection, air quality, water quality, waste management, agriculture and, of course, environmental policies, are all relevant areas for CZS.

2.1. European Union policies

In the European Union (EU) soil related policies have been coordinated within a common EU Soil Thematic Strategy (European Commission, 2006). Within that strategy soils are defined as the full extent of unconsolidated materials from the surface to bedrock, therefore very much matching the definition of critical zone (National Research Council, 2001). The strategy defines four main pillars of action: binding legislation for soil protection in the EU (Soil Framework Directive), integration of soil protection in other EU legislation, research, and awareness raising. Of these four pillars of action only the last three are in their full implementation phase while the first pillar (legislation) has been put on hold due to a blocking minority of EU member states opposing the proposed framework directive on soils.

CZS is particularly relevant the integration of soil related elements in other EU legislation and policies, like the Common Agricultural Policy, the Water Framework Directive, the Habitats Directive and the various EU policies related to climate change. All these policies require considering the multi-functionality of soils, as defined within the EU Soil Thematic Strategy.

Main soil functions relevant to the EU policy are:

(1) Biomass production, including agriculture and forestry;
(2) Storing, filtering and transforming nutrients, substances and water;
(3) Biodiversity, such as habitats, species and genes;
(4) Physical and cultural environment for humans and human activities;
(5) Source of raw materials;
(6) Acting as carbon pool; and
(7) Archive of geological and archeological heritage.

Addressing all these seven functions is a major challenge for soil science, since they require a new research paradigm for soil science going beyond traditional pedology. The critical zone provides all ecosystem services. As part of critical zone, soil and the above mentioned seven functions contribute to ecosystem services. The soil functions may co-exist which means that over exploitation of one function does not exclude the maximum exploitation of the others.

2.1.1. Biomass production

This is the traditional focus of soil science. The early origins of pedology addressed the various soil properties in relation to their influence on crop growth. Addressing this function requires in depth understanding and analysis of the soil properties in the rooting zone of the major crops. Most soil classification systems have therefore been restricting their focus on the first 2 m of depth, which is where the major pedogenetic processes take place and where the majority of the rooting system can be found.

2.1.2. Storing, filtering and transforming nutrients, substances and water

Soils are a recycling engine for organic and inorganic substances. A crucial function of soils is its ability to transform waste products and make them newly available to the ecosystem. The capacity of filtering and buffering water is at the origin of clean drinking water and is a crucial function to be protected. The quality of groundwater sources depends on well-functioning soils in the vadose zone. Protecting this function requires a catchment-based approach, and indeed the current EU water legislation (Water Framework Directive) is addressing good management practices for catchments in order to protect water resources. Obviously such an approach requires trans-boundary legislation, since many major catchments in Europe are shared between several bordering EU Member States.

Not only water, but many other substances are recycled within soils, organic matter among them. The capacity of soils to transform these organic materials strongly depends on the presence of an active soil food web; therefore a close link of this function exists with soil biodiversity.

2.1.3. Soil biodiversity

There is more biodiversity below ground then above ground, but only little is known about this large biodiversity pool. Existing EU policies addressing biodiversity are increasingly taking into account soil biodiversity. Nevertheless there is the need to gain a more complete understanding of this complex and largely unknown below ground ecosystem. CZS should in the future focus in further understanding this large biodiversity pool, starting with the full inventory of existing taxa in European soils.

2.1.4. Physical & cultural environment for humans and human activities

We live on our soils and we live off our soils. Soils support our houses and infrastructure and it is there that we develop our cultural environment. Protecting this social and economic function of soils is fundamental and should be understood in conjunction with the threat of soil sealing. Sealing soils by housing and infrastructure occurs if we want to have our physical and cultural environment, but we have to strike the right balance between sealing and protecting the other competing vital functions of soils. Understanding the social and cultural dimension of the Critical Zone is of crucial importance and requires integrating social sciences into Critical Zone Science as a trans-disciplinary scientific paradigm.

2.1.5. Source of raw materials

Soils are a major source of raw materials. Areas rich in peat, sand, gravel, clay and other surface deposits of mineral resources need to