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Opinion

Edaphosphere: A Perspective of Soil Inside the Biosphere

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Abstract: The integration of soil into ecology in the current climate crisis is essential for correct environmental management. Soil is a part of ecosystems; above all, it is a component of the biosphere. It is necessary to establish a definition of soil that integrates biota and biodiversity without losing sight of the historical development of edaphology, the science that studies soil. In this opinion article, we proposes a definition for all soils grouped together in the edaphosphere, which is, in fact, a subsystem of the biosphere. In addition, we highlight the importance of the definition of soil provided by Vasily Dokuchaev, the founder of edaphology, with respect to the integration of soil into the biosphere and the differences between the concepts of pedosphere and edaphosphere.

Keywords: edaphology; biodiversity; dokuchaev; ecology; environment; earth systems

1. Introduction

Edaphosphere is a scientific term used to globally address soil, analogous to the use of 'atmosphere' in reference to the air. Because soils are remarkably diverse due to their formation process, known as edaphogenesis, it is impossible to identify a single type of soil in the natural environment. Therefore, the edaphosphere encompasses the entirety of all soils. Additionally, the edaphosphere constitutes the most superficial layer of the geosphere. This layer is the zone in which the geosphere, the biosphere, the hydrosphere, and the atmosphere interact [1]. Furthermore, the essential characteristics that define a soil have already been formulated and described by Hans Jenny [2].

$$(s = f(cl,\ o,\ r,\ p,\ t,\ ...) \quad (1)$$

In the above Formula (1), s represents the soil, cl refers to the climate, o represents the organisms or biota, r stands for relief, p denotes the parent material, t represents time, and '...' indicates other possible factors. The central idea underlying this formula is based on the five factors described by Dokuchaev, which serve as the key to integrating the soil or edaphosphere within the biosphere [3].

In turn, the biosphere was described by Verndasky in his work THE BIOSPHERE [4] as the surface envelope of the Earth in which living things transform chemical elements thanks to the energy of the sun. On the subject of soil, Vernadsky recalls how his teacher Dokuchaev taught him that soil is a special natural body (bio-inert), unlike from rocks [5].

As a result, the study of the biosphere is historically linked to the Dokuchaev school, where the soil is regarded as a natural entity defined within the biosphere. Soil is considered a natural body characterised by the chemical transformations of the Earth's crust driven by living organisms that harness energy from the sun.

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It should be noted that the use of the term 'natural body' is due to historical usage and that, due to the impact of human species on soils, the term is no longer adequate to describe the full diversity of soils today. In any case, what we are defending here is the idea that soils are bio-inert bodies because they are composed of a living part (biota) and an inert part (parent material).

2. Edaphosphere: A Matter of Definition

Another collective term for all the soils is the pedosphere. However, these two terms are not equivalent, and cannot be used interchangeably.

In 1924, at 'IV Conférence Internationale de Pédologie', there was a debate about the most appropriate name for the science of soil. One proposal was pedology, derived from the root 'pedios', meaning 'foot', and the other was edaphology, derived from the root 'edaphos', associated with the location of the roots. In the case of Spain, the science that studies the soil was called edaphology thanks to Huguet del Villar. He was deeply concerned about the separation of the study of biology and geology into distinct fields, which created challenges for the integrated biological and geological study of the soil as a bio-inert body [6]. At this juncture, it could be said that an interdisciplinary approach is necessary. However, this approach is not novel in soil science; on the contrary, a primary idea is to revive generalist research as means of mediation between specialised disciplines.

In 2002, Huggett defined the pedosphere, similar to the edaphosphere, as the most superficial layer of the geosphere. However, the former has been divided into two spheres, the edaphosphere and the debrisphere. The debrisphere is characterised by its interaction with the ecosphere [7].

According to Huggett, the edaphosphere corresponds to the A and B horizons of a soil profile. While this definition aligns with the original definition, the significance of the rhizosphere in relation to soil biodiversity makes it more suitable to use this term to define the A horizon [8].

With respect to the debrisphere, this would be the sphere that puportedly exists beneath the edaphosphere. It corresponds to a region situated between the edaphosphere and the lithosphere. Formed by the disintegration of the weathered mantle, it can be found on various celestial bodies as well. The sole distinction between the terrestrial debrisphere and that of other celestial bodies is the presence of detritus [7]. This definition of the debrisphere would imply that it is possible to find soils or parts of soils without the presence of living organisms, contradicting Dokuchaev's definition of soil.

Furthermore, interaction between the spheres referred to as the ecosphere and the pedosphere has been proposed. However, an issue arises in that the term 'ecosphere' is frequently used interchangeably with 'biosphere' or 'Gaia' [9]. In reality, the soil is not merely interacting with the biosphere; it is an integral part of it.

However, if the set of all soils is defined as the edaphosphere, the A horizon can be defined as the rhizosphere, the B horizons as biogeochemical interaction horizons, and the C horizon as the pedosphere (the actual foot of soil according to pedon etymology), which structurally supports the upper horizons. In each of these horizons, both biota and parent material are present (Figure 1). As depth increases, the influence of biota on soil composition decreases, while that of the parent material increases. Nevertheless, in all horizons, both biodiversity and geodiversity are indispensable in defining the soil. The upper limit is marked by the O horizon or organic surface layer, while the lower limit is determined by the R horizon or bedrock.

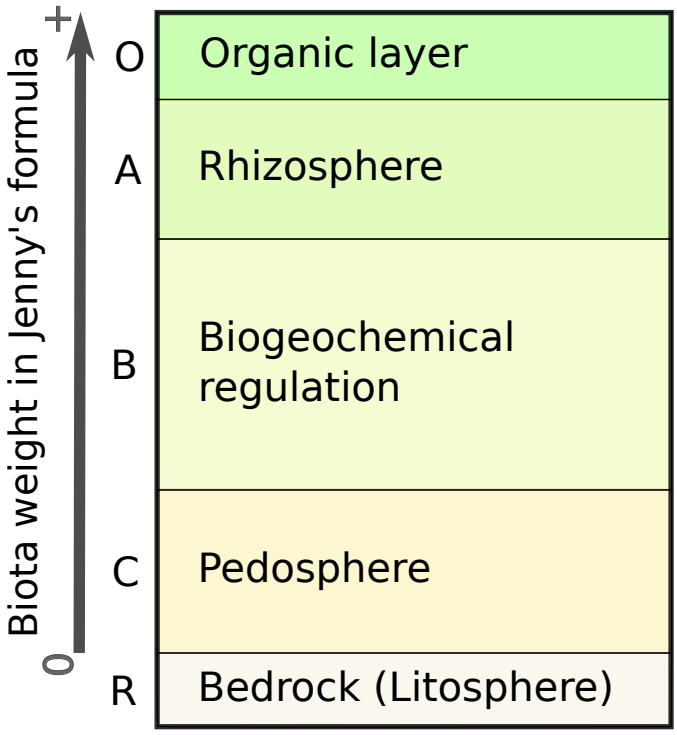

Figure 1. Soil horizons according to the edaphosphere concept.

The reason for choosing between edaphosphere or pedosphere is linked to the definition of soil itself. To choose the former, it is necessary to accept the definition of soil provided by Vasily Vasilyevich Dokuchaev. According to this definition, soil is simultaneously in the geosphere and in the biosphere, as both make up the soil, i.e., parent materials and biota, respectively, as defined by Dokuchaev [3] and cited as follows by Simonson [10]:

"The normal soils, are the result of the very complex interactions of the following soil-formers: ground, climate, vegetative and animal organisms, the age of the country, and the contour of the locality".

On the other hand, Merrill [11] provides a definition based solely on parent materials, which is more akin to the definition of the debrisphere:

"In brief, what is commonly known as soil is but disintegrated and more or less decomposed rock material, intermingled, perhaps, with organic matter from plant decay".

Thus, when working within the edaphosphere paradigm, it is assumed that the soil, and consequently the edaphosphere, emerges from the interaction between various systems, including the geosphere and the biosphere, which collectively constitute a broader system called the Earth System [12]. Moreover, the edaphosphere is subdivided into other subsystems, albeit ones that remain diverse and relatively understudied. Illustrative instances of these subsystems encompass the rhizosphere, which houses plant roots in association with fungi, prokaryotes, and fauna [13], and the biogeochemical cycles, which, while not exclusively confined to the soil, crucially rely on it for their continuity [14].

Let us consider the following example:

'Researcher A' might define soil as the outcome of parent rock degradation, excluding the involved processes of edaphogenesis/pedogenesis, as well as the interactions occurring within the soil. This approach reduces soil to a solitary factor, akin to Merrill's perspective, who posited that soil is "secondary rocks in a state of incomplete consolidation" [10,11]. It is important to note that reductionist methodologies are frequently employed, fostering the notion of replicating soil under laboratory conditions.

In contrast, 'Researcher B' might prefer a soil definition aligned with Dokuchaev's, where biota constitute an integral part of the soil. In this view, the presence of climate shapes its composition not as a mere sum of components, but as a natural historical progression that defies replication in a laboratory unless Earth's history is painstakingly recreated.

These two conflicting viewpoints have pursued distinct trajectories and served varying objectives throughout the 20th century. However, with the onset of the new millennium, accompanied by climate change, diminishing biodiversity, and loss of soil fertility, alongside other ecosystem functions, the necessity of acknowledging that soil forms an integral part of the biosphere, not solely a constituent of the geosphere, is becoming apparent. As a constituent of the living beings' environment, the soil concurrently emerges from the activities of living organisms themselves [15].

Recently, Huggett has expanded his concept of the pedosphere to include the definitions of Dokuchaev and Vernadsky, though he continues to talk about the interactions between life and soil [16]. However, this does not account for the soil itself being a naturally bio-inert, which is to say living, body. This nuance is fundamental to concepts such as biocrust, a surface layer in which microorganisms are the main factor and which has important ecological functions such as redistributing water or ensuring the physical structure of the soil [17].

Lastly, an epistemological consideration arises. Latour has critiqued the contrived construction of hybrids as an effective approach to grappling with the intricacies of reality [18]. Disciplines such as biopedology, as proposed by Huggett, represent synthetic hybrids that encumber the study of soil. This is because Dokuchaev's definition of soil inherently encompasses living organisms, rendering any new specialization redundant. Huggett has introduces another hybrid, anthropedology; yet humans, as mammals, are inherently integrated within the biosphere ourselves. In any event, one could potentially discuss the concept of the noosphere as a novel phase of the biosphere [19].

3. Soil within the Biosphere: The Edaphosphere

Our crucial point lies in comprehending the following thesis: soil constitutes an integral element of ecosystems, meaning that without soil, life on Earth cannot thrive. While this thesis might encounter challenges when extended to marine ecosystems, advancements in the investigation of biogeochemical cycles have revealed that a significant portion of vital marine organisms depend on resources originating from terrestrial ecosystems as facilitated by water and hydrosphere cycles [20]. For example, diatoms, which produce oxygen and biomass in marine ecosystems, require silicon (Si) from aluminosilicates or clay from inland waters that discharge into marine ecosystems [4]. On the other hand, without the oxygen produced by diatoms, the existence of terrestrial aerobic biodiversity would not be possible, as the oxygen generated by diatoms is essential to maintain the atmosphere's composition [21].

It is not possible to apply environmental sciences when the Earth is seen as a set of isolated systems, nor will it be possible to develop ecology, the science that studies ecosystems, without studying the Earth as a unitary system. It is in this paradigm, the Earth understood as a system, that the edaphosphere acquires meaning. In this context, it is important to understand the concept of paradigm as defined by Kuhn [22].

Failure to appreciate the relevance of the biota as a soil-forming factor would mean completely ignoring the biological origin of the clay humic acid complex and its capacity to act with different biogenic ions such as calcium (Ca) [23]. It is debatable whether there are factors with different weightings in the edaphogenic process, as noted in Duchaufour's work [24]; however, it is undeniable that climate, biota, relief, natural history, and the interaction between these factors and parent materials have played a role in the formation of the soil. There is no soil where the biota does not transform matter by means of biochemical reactions. Even if the rhizosphere (horizon A) is eroded, there remains microbiological activity; in other words, without biota, there is no soil, no matter how scarce it may be.

Similarly, the soil is affected by the climate, and in turn affects the climate as part of the biosphere [25,26].

The concept of a soil integrated with the biosphere allows critical issues such as as carbon sequestration, which has been proposed as a solution to the increase in CO_2, to be addressed, although this far from being a useful parameter for environmental management [27,28]. What is possible to affirm is the involvement of soil in the carbon (C) cycle, along with the rhizosphere and its contribution to biodiversity in the development of biogeochemistry [29,30].

Including soil as part of the biosphere is a fundamental pillar for understanding soil health. Soil health, although a concept that is currently under construction, has already allowed soil to be decoupled from agricultural productivity, leading to a rethinking of its importance to human wellbeing as a part of our environment [31,32]. Many other concepts related to a soil integrated into the biosphere require Dokuchaev's definition, as is the case for other biogeochemical cycles (phosphorus, oxygen, etc.) and for food sovereignty, among others [33,34].

In summary, it can be said that the edaphosphere is a notion that places the soil in its ecological context (Figure 2), defining it as the result of the interaction of various terrestrial systems: atmosphere (climate), biosphere (biota), geosphere (relief), and lithosphere (parent material), together with time (natural history) and other possible factors (Formula (2)).

$$edaphosphere = f(atmosphere,\ biosphere,\ geosphere,\ litosphere,\ time,\ ...) \quad (2)$$

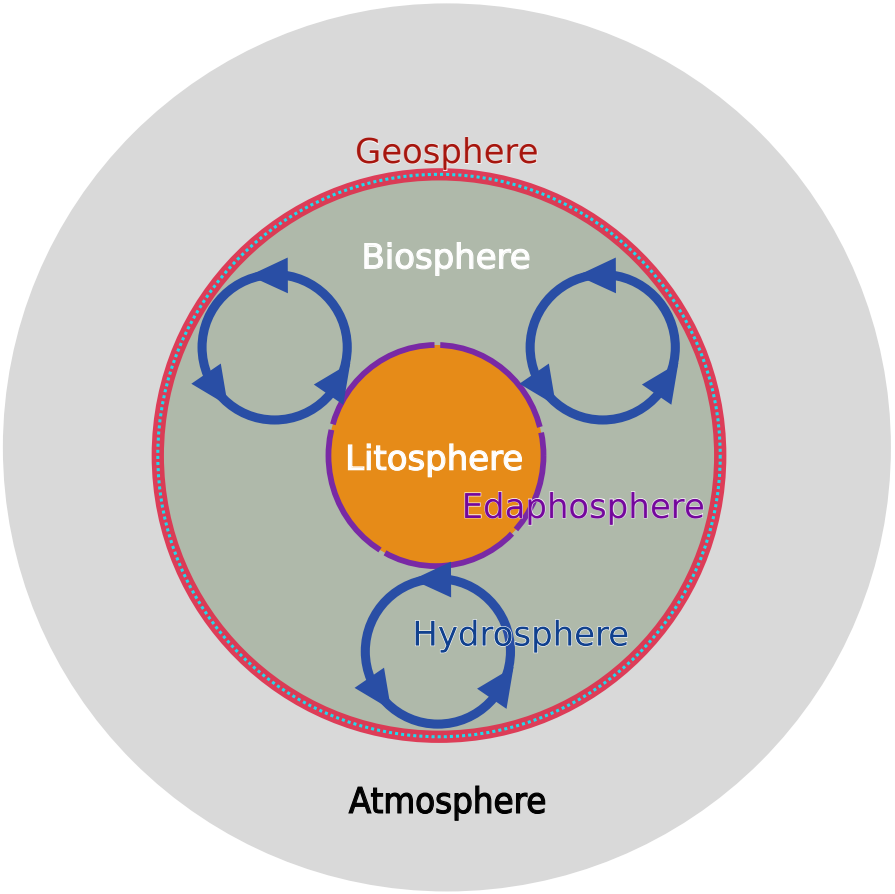

Figure 2. Earth systems in the terrestrial ecosystem.

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