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Interdisciplinarity of hydropedology

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Abstract

A new interdisciplinary subject hydropedology is developing owing to the necessity of sustaining optimal environments. Hydropedology provides the bridge between the disciplines of pedology, including soil macro- and micromorphology and vadose zone hydrology together with other disciplines dealing with land, air and water interfaces. Soil taxons and soil-forming processes are defined phenomenologically. Soil-forming processes which are usually linked have rates that differ by orders of magnitude. And, if soil polygenesis is considered, too, the equilibrium concept between the properties of soil taxons and soil forming factors is not applicable. The coupling of such processes on various tensorial orders leads to the conclusion that anisotropy is a general characteristic of soils. In order to ascertain the links between pedology and hydropedology, the formulation of physically meaningful transport parameters from a quantified knowledge of soil micromorphology is required. This linkage is achieved when the pore size distribution is reflected by the soil hydraulic functions, i.e. by the soil water retention equation and by the unsaturated hydraulic conductivity function. In future research, parameters of such functions must be related to quantified soil micromorphologic characteristics. The first attempt evaluating both functions is presented for soils manifesting a distinct bi-modal pore size distribution. A close cooperation of hydropedology with soil chemistry and microbiology will produce an insight into the role of organic substances upon the change of soil hydraulic parameters. The substances appear either as a consequence of soil pollution, or due to soil organic matter transformation. An example is presented on the change of saturated hydraulic conductivity caused by the adsorption of organic cations. Similar linkages are expected from the cooperation of hydropedology with plant physiology when the role of plant exudates upon the change of soil hydraulic functions is studied.

Keywords: Pedology; Soil genesis; Soil micromorphology; Soil hydrology; Soil hydraulic functions

1. Introduction

One of the common denominators identified by a broad spectrum of politicians, scientists and ecologists dealing with principal problems of the 21st century is sustainability of the earth's critical zone. Because soil and water are two critical components of this critical zone (Lin et al., 2005), it appears logical that further development of soil hydrology and soil physics should be extended by considering authentic field soil properties in their convolution of soil genesis. Kutílek (1966) took soil genesis into consideration when he used the term hydropedology for a new subject where physical theories were applied to deal with soil water properties and transport processes. Lin (2003) and Lin et al. (2005) have discussed a broad range of problems linked to integration of classical pedology with soil physics, hydrology and other related bio- and geosciences into hydropedology. The aim of the present paper is to discuss the interdisciplinary character of hydropedology. The interdisciplinarity will be demonstrated with links between hydropedology and neighboring disciplines, i.e. pedology, soil micromorphology, soil hydrology, environmental protection and plant physiology.

Interdisciplinary work is that which synthesizes and integrates across different disciplines to form a new discipline (Wikipedia, 2005). In interdisciplinary studies if we use the terminology of structural linguistic, information is translated in both directions between two systems formed usually of metaphoric (similarity) and metonymic (contiguity) observation of natural processes. The classically developed disciplinary

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structures are constructed by scientists and the role of interdisciplinarity is forming bridges over the fences of those disciplinary structures. The goal of interdisciplinary studies is therefore not the accumulation of new knowledge but a way of looking at the existing accumulated knowledge from the basis of the neighboring disciplinary structure. Typically, we differentiate between big and small interdisciplinarity (Morillo et al., 2003). The big one is typified by links between distant categories, e.g. discussions on interdisciplinarity between structures of natural and humanitarian sciences. The small one deals with close categories, where e.g. in natural sciences the classical disciplines consist of more or less isolated sub-disciplines and the interdisciplinarity is realized by using tools of one sub-discipline to the knowledge of the neighboring sub-discipline. Our approach for hydropedology features the small interdisciplinarity when the methodology of soil physics is applied to the discipline of pedology, soil micromorphology, soil biochemistry and their mutual links.

2. Links between hydropedology and pedology

Mutual links and feedbacks are not only restricted to natural processes, but they actively influence a theoretical basis for describing natural processes in neighboring disciplines. Theory on transport processes is a part of the theoretical basis of hydropedology and it influences the approach of a hydropedologist wishing to describe pedological processes. This approach is realized by the extension of transport processes to a general concept of fluxes on the phenomenological level. In the first step, we attempt to formulate the soil taxon and its development on the same phenomenological basis as the description of transport processes. Subsequently, we observe all processes using the same phenomenological principle.

Dokuchaev (1883) defined soil as a result of processes acting due to soil-forming factors: parent material, climate, organisms, relief and time. Later on, man's activity was included. The factorial description of soil genesis is frequently misinterpreted and instead of a description of processes, the equilibrium state between factors and soil taxons is searched. Let us discuss this assumption of an equilibrium state on a theoretical basis.

We denote here the soil taxon at the lowest level of taxonomy by Π^* It is represented by a set of soil properties $\{\Pi_i\}$. With each i-th property Π_i depending upon the action of the j-th soil-forming factor F_j according to the functional factorial model, and assuming a smooth functional relationship $\Pi_t(F_j)$, the change of the i-th property is

$$d\Pi_i = \sum \left[\frac{\partial \Pi_i}{\partial F_j}\right]_{F_n \neq j} \mathrm{d}F_j \tag{1}$$

with index $F_{n \neq j}$ denoting that all other factors except F_j are kept constant. Inasmuch as the change in characteristics of the soil taxon Π^* is the consequence of the change of all properties Π_i we define

$$d\Pi^* = \sum_j \sum_i \left[\frac{\partial \Pi_i}{\partial F_j}\right]_{F_n \neq j} \mathrm{d}F_j \tag{2}$$

Definition (2) is valid if the time for reaching equilibrium (TRE) of mutually isolated processes is the same. In order to keep our approach as transparent as possible, we neglect now the coupled processes, see Eqs. (3) and (4) later on. This simplification is the meaning of the term "mutually isolated processes". Additionally, we may assume that for $0 < t < \mathrm{TRE}$, $\mathrm{d}F_j/\mathrm{d}t = 0$, i.e. the factors of soil formation do not change in time. As we shall read below, those conditions are usually not satisfied.

Since TRE is a hypothetical term, let us relate it either to the half-life process or to the turnover time of individual soil components as a robust indicator of TRE. Chemical weathering of minerals has a wide spectrum of half-lives which are dependent on the type of mineral and on the chemical composition of the medium surrounding the mineral. If weathering resistant minerals are not considered, the half-lives range from 10^{-1} year to 10^4 years. Estimating from the data of Tisdall and Oades (1982), easily oxidizable components of soil organic matter have half-lives less than 1 year, whereas forms associated with longer term accumulation have half-lives greater than 25 years. Turnover times of C in soil organic matter vary from hours to thousand of years, and mineral surfaces play a stabilization role (Trumbore, 1993; Torn et al., 1997). Mean residence time of humic substances bound by clay minerals differs by one order of magnitude from those not bound.

Moreover, any given decomposition process has a broadly variable rate dependent upon the soil-ecological conditions and nature of the process. For example, the decomposition time of organic matter in forests of a temperate zone has values up to 10^2 years, while that in a tropical region is only 10^0 years (Jenkinson, 1981). The age of organic C in soil horizons ranges from 10^2 to 10^3 years depending on the pedotaxon and on the humus fraction (Kögel-Knabner, 2002).

Owing to human activity, some soil formation factors change rather quickly ($<10^0$ years) while the phases of climatic alterations in Holocene change in a span of 10^2 to 10^3 years. If the scale of our observation is extended to the entire Pleistocene, the range of substantial climatic change is increased to 10^4 to 10^5 years. We speak about relict soils and polygenetic soils if the soils keep some features characteristic for the earlier climatic conditions. After a climatic change, new processes follow which are different from the earlier ones and contribute to new types of soil characteristics (Arnold et al., 1990). A specific feature of this process is that the earlier formed soil starts to be the parent material of the new, developing soil. Those sets of certain properties $\{\Pi_{iR}\}_\sigma$ not reflecting the recent processes occurring in the soil are described with a subscript R to accentuate the relict character of those properties. However, not all $\{\Pi_{iR}\}$ belonging to the earlier pedotaxon Π_R^* are kept in the recent Π^*. In such cases, the polygenetic pedotaxon is described by $\{\Pi_i\} \cup \{\Pi_{iR}\}_\sigma$ When the rate of eliminating a relict characteristic under the action of the changed factors is not known, we apply the approximation $\partial \Pi_{iR}/\partial F_j = 0$.

A simple example of polygenesis is demonstrated on Chernozems of Central Europe. Luvisols (Parabraunerde) were developed on loess under the vegetation cover of forests in early Holocene with wet climatic conditions. The soil profile was