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Conceptual Remarks to the Project on ASSESSMENT OF THE STATUS OF SOIL STRUCTURE IN AGRICULTURAL SOILS

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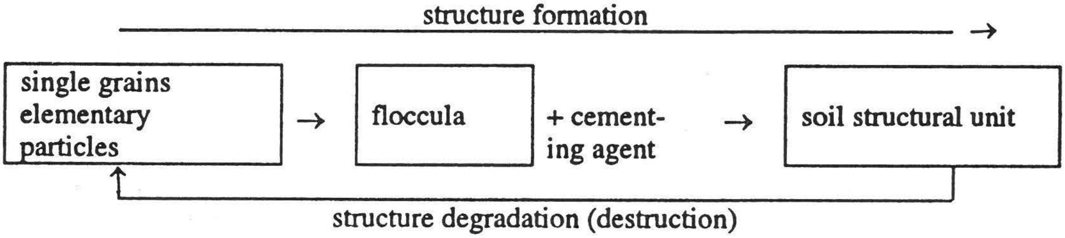
Soil structure is the spatial arrangement ('architecture') of primary, secondary and tertiary soil particles: single grains; floccules, micro- and macro aggregates; peds or structural elements and larger clods, respectively. Soil structure includes soil pores, voids, cracks and various biological channels: root- and worm holes, etc.

The **development of soil structure** is (one of) the first symptoms of the soil formation process which can be schematically illustrated by the following diagram:



The cementing agents can be organic matter, humus substances, carbonates, sesquioxides, clay, root residues, soil organisms and their excrements or exudates, or artificial soil conditioners. The mechanical action of plant roots plays an important additional role in the formation of soil structure. It is usually a slow process, taking years to decades. On the contrary, soil structure destruction (aggregate failure) can be very rapid, e.g., one single tillage operation in fully water-saturated, over-moistened (or in dry) soil may result in the complete de-stroyal of soil structure or - at least - in its serious deterioration within minutes. Consequently, the reversibility of the **degradation of soil structure** is - in many cases - only theoretical, because its re-development takes a much longer time than its destruction. This 'practically irreversible' character makes these phenomena particularly harmful and unfavourable among soil degradation processes.

Soil structure can be evaluated from two different points of view:

- from soil genetic aspect: as a visible and easily detectable indicator of soil genesis, as an integral 'product' of the specific mass and energy regimes of the formation processes of various particular soil types

(or other soil classification, soil taxonomy units);
- from practical aspects, as the distinguished 'key factor' of various soil functions.

The main characteristics of soil structure are as follows:
- size, shape and spatial arrangement ('architecture') of soil particles primary: single grains and elementar particles, secondary: micro- and macro aggregates and tertiary: peds, structural elements and clods;
- phases of development;
- rate of aggregation ('structure factor', 'dispersity index');
- stability against various influences (e.g., tillage and other agrotechnical operations; compaction effect of machines, animals or man; mechanical forces of rain (or irrigation water) drops or the surface runoff; 'explosion'-effect of entrapped air during the wetting of soil aggregates, etc.).

From genetical aspects the morphology of soil structure (size, shape, sharpness of edges, inner porosity) has more importance, while from functional aspects its compactness, 'architecture' and stability have particular significance.

In the present Project soil structure was studied from this functionality point of view. **The basic concept** of the Project was the thesis:

'Soil structure is a particularly important integral characteristic of the soil, determining the efficiency of its 'poly-functionalities'.

The **main steps in the research programme** of the Project were as follows:

1. Listing of the main soil functions (processes) important for sustainable biomass production and environment protection in which soil structure and related soil physical-hydrophysical properties have significant role:
   - **Most important media for biomass production**, ensuring (to a certain extent) the main soil ecological requirements of natural vegetation and/or cultivated crops: their air-, water- and nutrient-supply. Only the soil, this three-phase (or with the biota 4-phase) polydisperse system (containing elementary particles of various size and shape, micro- and macro aggregates, structural elements in a particular spatial arrangement) gives opportunity for the simultaneous occurrence of air, water and available plant nutrients in the system, which are the preconditions of soil-based biomass production.
   - **Storage and transport of heat, water, plant nutrients** and other substances, including **pollutants**, harmful and potentially toxic chemical compounds. In this respect size, shape and architecture of soil pores, including continuity are the main factors determining the storage capacity, energy relations and availability of water and plant nutrients, flow behaviour of water and solutes, aeration of the soil and conditions for plant root development. Pore distribution in soil is a function of soil structure.
   - **Filter function**, preventing surface and subsurface water resources from pollution.
   - **Transformation of various substances**, including abiotic and biotic processes.
   - **Buffer function**, preventing or moderating the unfavourable consequences of various natural (e.g., extreme weather conditions, etc.) or human-induced impacts (air, water or soil pollution by industrial and agricultural activities, transport, urban and rural development, tourism, etc.),
   - **Habitat for soil biota** and so, media for *bio-diversity*.

   These functions are strongly influenced, somtimes decisively determined by soil structure and its components. For instance, a considerable part of pollutants reaches the subsurface drinking water resources through preferential pathways: cracks, biological channels which are - in our concept - factors of soil structure.
2. Listing of the characteristics of soil structure, which are important from the viewpoint of the main soil functions (processes) mentioned above, including their spatial - both vertical and horizontal - and temporal variabilities (**parameter selection**).

3. **Identification** (with exact definition), **description, evaluation and quantification of these characteristics** (listed above) and their relationships with other soil properties (or land-site attributes), as well as with the main soil functions (processes). On the basis of a comprehensive analysis of the mechanisms of these processes and relationships models can be developed for their quantitative description and prediction, and the results can be interpreted for various cases to help the development and maintenance of optimum soil structure, as well as to prevent (or moderate) its degradation.

The main reasons of the physical degradation of soils are summarized in Table 1, including the possibilities of proper soil structure management.

4. Selection, elaboration, adoption and application of **'proper' (adequate) methods for the determination** of the above-mentioned characteristics. The *'proper'* in this case should fit the following criteria:
   - adequate for the given objective - including the objective determined scale;
   - adequate for the given conditions (specific and sensitive enough for the given soil- and other natural conditions);
   - adequate from scientific point of view: gives exact, precise, comparable, compatible and quantitative territorial information on well-defined soil parameters;
   - adequate from technical (application) point of view: applicable for routine serial analyses (gives opportunities of automation if it is theoretically possible) not too highly work- and time consumptive and not too expensive;
   - adequate for uniformization and standardization - if it is scientifically possible, meaningful and rational.

The **'determination'** includes, in this sense, methods for direct measurements, calculations or estimations, and they are extended to the determination of parameters, as well as to the elaboration of proper methods for the data base management (collection and arrangement of data); **data evaluation** (categorization with limit values) and **data interpretation** for various purposes.

Following this logical sequence of consecutive steps we draw two - maybe oversimplified - **general conclusions from our investigations:**

1. We do not have a good (properly adequate) and generally applicable method for the quantitative characterization of the status of soil structure in agricultural soils.

Table 1. Main reasons of soil structure destruction and possibilities of their control

Main reasons		Possibilites for control
Natural factors	Human activities	
- lack of structure-forming and stabilizing agents: ~inorganic and organic colloids ~cementing agents ~biological components (roots; microbial and earthworm activity) - natural structure destruction ~heavy raining ~surface runoff, flood, water-logging ~chemical properties (e.g. alkalinity, etc.)	- mechanization (heavy machinery; combined operations; over-tillage) - tillage in improper moisture conditions - poor moisture-control practice ~irrigation (intensity; method) ~drainage - unfavourable changes in organic matter regime (chemical soil properties; biological degradation; improper recycling; lack of organic fertilizers)	- proper agrotechnics ~ tillage (time; moisture content; accuracy, 'quality' and number of operations) ← technical background ~cropping pattern, crop rotation ~organic matter recycling ~ irrigation (moisture regime control) - chemical amelioration (improvement of acid and salt-affected soils, sands, etc.) - soil conditioning

2. We found that soil structure can be better characterized by using indirect methods, quantifying the various functions (particularly storage and transport (functions) of soil structure.

From the two potential options in this respect:

- to use soil structure characteristics (particle- or aggregate-size distribution, bulk density, total porosity and pore-size distribution, pore morphology, aggregate stability determined by conventional wet-sieving procedures, etc.) for the quantification of flow phenomena and transport processes in structure soils ? - or:
- to use the determined (preferably directly measured) water retention (pF) curves, flow- and transport parameters (e.g., saturated and unsaturated hydraulic conductivities, diffusion rate, etc.) for the quantitative evaluation of the status of soil structure ?

On the basis of our investigations we found the second option much more simple, applicable and interpretable. For example, it is easier to measure hydraulic conductivity *in situ* by tension infiltrometers than to calculate it from the pore morphology distribution pattern of the same soil, determined on undisturbed soil cores by expensive computer-aided scanning soil micromorphology technics or by computer tomography.

Or another example: how can we interpret the results of the 'questionable' conventional aggregate stability measurements by the traditional wet-sieving procedure for various practical purposes: e.g., for the characterization of the function of soil structure in the moisture regime of soil or in the water and nutrient supply of plants.

On the basis of our joint investigations the following *general proposals* can be formulated **for further studies:**

1. Studies on the role of soil structure in various soil functions (see earlier),
2. Studies to clarify, define, explain and quantify - as much as possible - the various 'anomalies' (according to our limited present knowledge) in the 'dirty' soil-water-plant system:

Phases	'Ideal' system	Soil
Solid	Inert quartz sand with uniform particle size	Polydisperse inorganic/organic system with polydisperse character and heterogeneous particle-size distribution
Liquid	H_2O	Soil solution with various concentrations and ion composition
Gaseous	Air	Soil air
Biological	∅	Roots, biota (microorganisms, earthworms, soil fauna)
Remarks	No phase interactions	Phase interactions (changes in minerology); cation exchange; sorption-desorption, etc.

3. Identification and quantification of the role (function) of soil structure in the transport processes of soils:
   - moisture regime,
   - transport of plant nutrients,
   - transport of other substances, including specified pollutants with particular attention to the flow through preferential pathways (bypass-flow).
4. Identification of the function of soil structure in the biological processes of soils and the influence of soil biota on the development and status of soil structure.
5. Special attention has to be paid within these investigations to the characterization of the 'resilience' of soil structure, as well as to the up-to-date interpretation of the status and the natural or human-induced degradation of soil structure and its functional consequences.
6. The further investigations in soil structure can be rationally and efficiently carried on in various case studies with well-defined (adequately specified) goals under well defined natural and management conditions. Any over-generalization in these fields may result in false mis-interpretations and misleading conclusions.