Qualitative Analysis of Soil Condition to Maintain Ecological Soil Functions under Agricultural Management

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Introduction
Besides the contamination of soil, ground water and drinking water with foreign substances, the rapid decrease of soil biota and organic matter content and due to that, the high susceptibility of soils for compaction and erosion, represent syndromes of soil degradation which have been termed frequently as a serious threat for the global resources of food production (UNEP 1990, WBGU 1994, HURNI 1996, KEU 2002). Many statements in science and policy summarise the urgent necessity of research to step further in combating soil degradation. To document the effects of soil and land management systems on ecological soil functions, sensitive indicators and economic suitable scientific methods have to be defined respectively developed, which are able to show the influence of management systems on soil vitality:

„Not only sophisticated methods but also quick methods that can be applied by non-researchers should be developed. [...] Although there is a dominant interest in quantitative data, qualitative data often is more relevant and revealing. [...]. There is an urgent need to involve farmers in technology development and adjustment so that their local experiences and knowledge can be focused into the research." (ISCO 1996).

Some years ago the field method „Spadediagnosis" has rediscovered and further developed for scientific use in a recent study (BESTE 2003 a). The immediate and non distort view on the actual state of health of a soil profile can not be delivered by isolated samples or data from laboratory tests. This comprehensive impression has been proved to be very helpful for the judgement of previous management practice (crop-rotations, tillage-systems etc.) by agricultural consulters and farmers as well as for scientific analysis.

1. Reference and target values

The specification of limiting-, task-, or reference-values for soil conservation presupposes that these also can be checked by a corresponding measuring. Just at the problem of soil compaction and structure degradation, till now, usable measuring techniques aren't applied. The costs of the administration and control effort are a general problem at the fixing of limiting values (WETTERICH 2004).

Soil indicators shall serve primarily to analyse and to judge the sustainability of soil management. In the course of the discussion it turns out again and again that the definitions and opinions of specialists are various and different with regard to the soil indicators. Depending on the question of examination different indicators are also necessary and useful.

With regard to the on-site and off-site symptoms of soil degradation as there are

- erosion,
- floods,
- compaction,
- endangerment of soil water recharge and quality,
- decreasing soil fertility,
- decreasing plant health and
- increasing fertilizer and plant protective substance effort

chief attention has to be lied on the condition of soil structure because of its close connections to water circulation, soil life activity, transformation capacity and aggregate stability. If the structure of our soils is in good condition, the symptoms described above - which threaten production and life-quality - are reduced decidedly and high costs can be saved. The good suitability of a structure examination for the judgement of management measures has been repeatedly documented and confirmed by farmers and soil specialists (BESTE 2005, RAJALA 2002, BESTE 2003 a, 2001, 2000 a, b, 1999 a, b, 1998 b, HARRACH 1998, HAMPL 1995 a, b, 1996, KUNTZE/ROESCHMANN/SCHWERDTFEGER 1994, HASINGER 1993, AID 1992, ALTEMÜLLER 1991, DIETZ 1991, GÖRBING/SEKERA 1947, MÜCKENHAUSEN 1947).

"Every change in soil structure condition consequently also has changes in his functions." (ALTEMÜLLER 1991).

"A comprehensive structure assessment stands at the beginning of all considerations for the suitable use and improvement of soil."
(KUNTZE/ROESCHMANN/SCHWERDTFEGER 1994)

The difficulty till now is that there are no uniformly standardized task values for the assessment of soil structure condition due to the variety of the soil types and structure expressions. It cannot be defined generally how many pores or earthworms a soil must have in 1 m^3, which Kf-value has to be measured, how high soil respiration has to be etc.. There are scientific based positive and negative areas in tendency for all these indicators for the different soil types but this makes assessment and decision for policy and action complicate and expensive.

For a uniform assessment of the soil condition and an orientation for future measures, task values are decisive. They on the one hand give clear specifications for the condition which is aimed at and with that for the action level. On the other hand a *judging* assessment of the actual state isn't possible without the definition of a task or reference value (fig. 1). TURIAN (1993) demands both target and load/overuse values to be able to carry out a safe assessment.

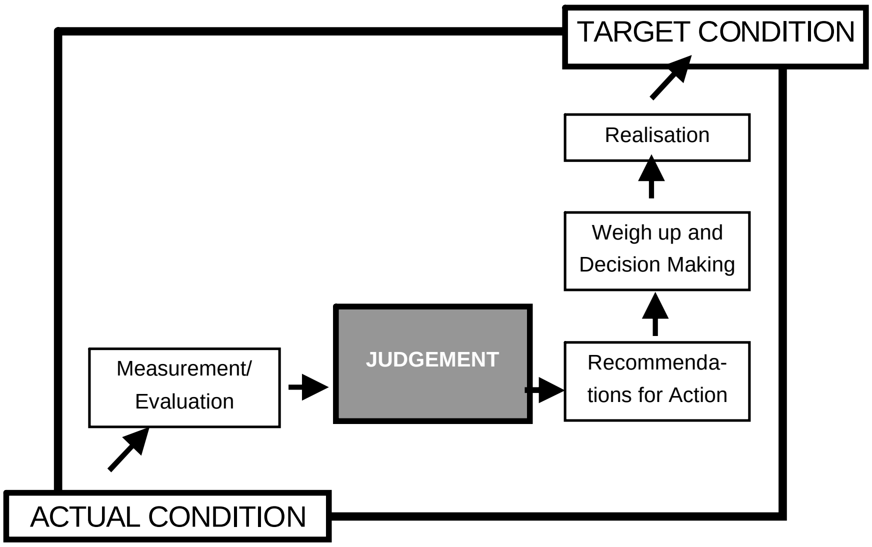

Fig. 1: Position of judgement in the process of planning and acting in soil conservation (BESTE changed ref. GLÖSS 1997)

At the enquiry after a suitable indicator or aim value for soil structure in literature one meets the term "soil tilth" which has been developed in the agricultural practice. This term stood for the optimal structure condition of a productive soil for a long time and was a agricultural judgement scale. SEKERA (1984, 1951) defines "soil tilth" as "*crumbly structure vitally built up by micro organisms*".
For the preservation of this structure condition much has been searched within the first 50 years of the last century aiming at an augmentation of fertility and productivity. Due to the impressive results of mineral fertilizer use and new technical developments after the II World War the exploration of the support and preservation of "soil tilth" fell of. The cognitions attained at that time are predominantly up-to-date today, however (BESTE 2005).

What corresponds to the term "soil tilth" after today's knowledge?
In the literature different definitions for soil structure are found. In general it is described as the distribution of firm soil substance in the space. Visible soil structure is distinguished in three main groups:
1. single grain structure (sand),
2. coherent structure (coherent structure, matrix example: Nougat) and
3. aggregate structure (put together, matrix example: Popcorn).

In general, cultivated soils show mixtures of these structure types.

A relatively fine crumbly expression of the mixing structure with high share in aggregated particles represents the so-called "sponge structure". It is most similar to "soil tilth" and is termed as to be the "*ecologically optimal*" structure condition which should be striven for by the majority of the soil scientists (KUNTZE et al. 1994, RBS 1994). The "sponge structure" is particularly beneficially for the balance of the ecological soil functions: habitat-, regulation- and production-function. In this structure condition soils achieve her highest fertility qualities. Research confirms that soil structure and productivity are in a close connection. At a good soil structure, any used fertilizer is processed better for plant nutrition than at a compacted one. Since the soil structure influences all ecological soil functions, not only the production function, her protection and her support - today primarily her regeneration - must be a central point of an socially and environmentally sustainable land use.

So how should the ideal soil structure look? – Some statements:

"A crumb structure which predominantly arises from the activity of micro organisms, plants and animals is favourable. Such a soil structure is the best precondition for an intensive rooting and causes therefore shortest routes in the process of the water and nutrient supply as well as at the gas exchange". (BAEUMER 1994)
"It should be crumbly, humic and aired well, but also sufficiently damp, nutritiously and easily grown through by roots." (ALSING 1995)
"It should be crumbly and stabilized biologically and permit a dense, homogeneous, vertical and horizontal penetration of the soil with roots." (LEITHOLD 2000)

Surely this condition of soil structure described as optimal turns out differently for the different soil types. Sandy soils build up another soil structure as loam or clay soils. However, the interesting and decisive point is that in case of good humus supply and high biological activity the structure always moves in the direction of an increasing aggregate formation with a sponge like expression both for sandy soils and for the loam and clay soils. This means the "sponge structure" represents an optimal target value which is usable for the predominant number of soils being under agricultural management (restrictions must be stated for stony soils and peat soils).
For example: Single grains of sandy soils stick better together in case of good humus supply and high biological activity (aggregate formation) and the initially very high infiltration and airing moves in favour of a better water storing, filtering and cleaning capacity as well as a better humid habitat condition for soil organisms. For strong clay soils in case of high humus supply and biological activity the process of aggregate formation means a segregation, a splitting of the soil matrix in smaller units. This moves the high water storage capacity in favour of a higher infiltration and airing and due to that an increase of soil organisms habitat potential.
For all soils can be stated that the nutrient exchange capacity and aggregate stability increases at good humus supply and high biological activity.

2. Visual assessment of soil structure

For the visual assessment of soil and the judgement of structure condition the inner structure of the aggregates is particularly important. At the aggregate formation both physical processes (e.g. shrinking by drying or blowing-up by frost influence) and biological processes are involved. Soil particles which are sharp-edged, smooth, flat and of polyedric form arise primarily in loam and clay soils. Another form of aggregate formation is the physico-chemical "adhesion" of soil particles like e.g. at the soil colloids. The clay humus complexes are involved in it in loam and clay soils. But humus colloids and calcium ions do also stick together grains of sand. Furthermore by aggregate formation one understands the biological building up of soil particles. Organic substances (humus substances), soil animal secretion (carbohydrates and jelly-like substances), fungi hyphaes and bacterium colonies as well as plant roots - particularly fine roots - are involved. In general within this process soil particles arise, which are porous and sponge like looking (fig. 2). They are termed crumbles and show rounded edges, a rough, porous surface and do not break or disintegrate lengthways preformed tears, but into smaller rounded and irregular particles.


Fig. 2


Fig. 3

Aggregates formed in biologically inactive or humus underserved clay or loam soils which have a thick, sharp-edged appearance are of less value for the soil

functions since they lack the porosity. They reduce the filter and cleaning capacity as well as the nutrient supply potential for the crop due to their smaller surface and offer hardly habitat for fungi or bacteria. They can nevertheless be quite stable due to her density (fig. 3).
Although the single grain structure of sandy soils can seem very loose, it is extremely susceptible against compaction. Due to her texture sandy soils have a strong tendency to disintegrate into single grain structure at low humus supply and reduced biological activity. A sandy soil with an almost total single grain structure can be much more compacted than a loam or clay soil since the complete pore volume of a soil decreases with increasing grain size. Single grain structure also holds the danger of a strong nutrient washout.
So in inversion of arguments, positive conclusions can be drawn on the biological activity and the humus supply of the soil out of the appearance of many crumbly aggregated particles. Structure analysis therefore should take into account the biological activity and humus dynamic as a decisive factor of the visual structure condition and the structure stability as far as possible, if it shall go beyond purely soil mechanical judgement approaches and shall support decision findings for a sustainable soil management.

3. Reference value evidence of some selected soil structure analysis methods

Actual structure condition
Till now, the proximity or distance to the condition of the "sponge structure" could not be quantified in his individual expressions. Simple physical methods for the structure judgement as

- measuring of the bulk density or the pore volume and
- measuring of the penetrating resistance

have in common that they concentrate on quantifying aspects like the sum of cavities or a rough graphic of compaction data principally. These parameters give clues for the ascertainment of harming compaction or plough soles. However, they can not at all or only very restrictedly show the difference between the existence of a sponge like aggregate structure with many biogenic pores or a compacted structure with some secondary pores. Inner aggregate compaction is not discovered in any case.
More complex methods for the structure judgement as

- pore size distribution (RICHARDS cit. in SCHLICHTING et al. 1995),
- digital image analysis (WILKENS 1992),
- radiograph morphological examinations (WERNER 1993),
- computer-tomographic examinations (ROGASIK et al. 1995) or
- thin-cut analysis (ALTEMÜLLER 1991)

are very effortful in the execution, don't show the structure on-site in its actual condition and give no reference values for a judgement. Soil biological examinations (e.g. soil respiration or species composition) are also very effortful and don't deliver any assessment scales and reference values either for the structure.

Structure evaluations at the soil profile represent a relatively fast, simple and comprehensive method to describe and judge the condition of the soil functions. The structure evaluation referring BESTE (2003 a) differentiates and standardizes the simple approach of DIEZ (1991) in which the essential aspects of positive and negative structure conditions had been judged with the terms "favourably" and "unfavourably". The evaluation developed by BESTE is based on latest cognitions about the soil functions. It was tested on her meaningfulness in an extensive study and introduced for loamy, sandy and clay soils.

	Description of optimum Structure Condition	5
	Condition of transitional Quality	4
For e.g. Upper Crumb	Description of Condition of intermediate Quality	3
	Condition of transitional Quality	2
	Description of worst Structure Condition	1

Fig. 2: Principle of the structure evaluation ref. BESTE

The structure evaluation scheme consists of divisions depending on common tillage horizons. For each horizon there exist graduated verbal descriptions of visible soil conditions and corresponding structure marks according to the following judgement scale:

5 == > 4 == > 3 == > 2 == > 1
Optimal structure condition/target value Critical value/ecological function disturbed

The demand on soil structure characteristics differs with the horizons. In the subsoil a loose, porous and crumbly structure is not of such critical importance as in the crumb. So the given structure marks differ for each horizon accordingly. The scale of vertical graduation is based on natural soil stratigraphy and typical habitat layering of soil biota as it has been described by GISI (1997).
This newly developed structure evaluation offers the following advantages:

- The structure evaluation is soil type specific (clay-, loam-, and sandy soils)
- The evaluation of structure quality is not based on the measurement of physical and spatial parameters (e.g. amount and dimension of pores or lumbricid hollows) but on the difference between the existing visible state of structure arrangement and the given description of task value.
- The task value is given by a pictorially described optimum state of structure closely related to the requirement on soil functions. This facilitates the decision in marking different qualities of soil structure also for non professionals and it is less time consuming as well.
- The task value (structure mark 5) puts the main emphasis on a soil morphology, which stands for high biological activity and a sound production and regulation function.
- The vertical graduation in horizons takes the soil stratigraphy and typical habitat layering of soil biota as well as the influence of agricultural soil treatment (especially tillage) into account.

The method has been proved since 1996 in numerous analyses in Europe and Asia for research purposes and adviser demonstrations. Its greatest advantage is it that after a simple training the methodology also can be carried out by the farmer himself. The method is described in detail in BESTE 2003 (ordering possibility of English version under a.beste@t-online.de or www.gesunde-erde.net).

Penetrating resistance

The check of the penetrating resistance is one of the most frequently applied methods for the examination of soil structure due to the easy applicability and clear curve presentation. The measurement of penetration resistance is essentially dependent on three factors that is the pore volume, the shearing resistance of the texture and - particularly - the water content. The method is strongly depending on substrate and therefore comparably exclusively within the same soil texture. The measuring of the penetrating resistance is an adequate means for the localization of plough soles since layering, expansion and intensity of compaction can be shown relatively to the crumb simply and fast. Primarily for a pre-analysis for more extensive examinations this method can be recommended. However, it must be pointed out, that a vertical change of texture (clay layer, sand layer) in the profile can remain unnoticed without profile pit, drilling core or spade diagnosis so that the evidence for management caused differences decreases. A water content measured inaccurately also makes the evidence of data useless. In this cases it overcomes the danger of miss-interpretation.

For the check of the porosity of the soil structure in the crumb this methodology isn't suitable, reference or task values cannot be given. In case of high soil moisture - particularly for loam and clay soils - the low resistance conveys the impression of low compaction and can cover heavy compaction of the soil structure up through this.

Aggregate stability - susceptibility to erosion and compaction

Not only the visible expression of the structure quality is important but whether the soil is susceptible to erosion and compaction. According to SEKERA/BRUNNER (1943) and KULLMANN (1956) the judgement of the "soil tilth" also contains the check of the "crumb resistance", i.e. the aggregate stability which describes the dynamic aspect of the soil condition besides the check of the static condition. The stability of the structure or the aggregates cannot be checked visually. The measuring of the aggregate stability therefore is an important part of a comprehensive judgement of structure condition. As a simulation of natural events in the soil the stability against water is primarily important (rain, infiltration). It is decisively for the susceptibility of a soil to outer and inner erosion as well as compaction. The aggregate stability was therefore consulted in numerous old and new research for agricultural soil conservation as an indicator for erosion susceptibility, compaction susceptibility or biological activity. The test of the aggregate stability referring BESTE represents a standardized further development of the aggregate silting test according to SEKERA/BRUNNER (1943). The silting test was standardized by the development of a visual silting evaluation with verbally and graphically described silting images for loam, sand and clay soils. The silting process is introduced as closely to nature as possible with distilled water which one comes the rain water most nearly. In comparison with the methods of the aggregate stability measuring carried out today predominantly as

- wet sieving (De LEENHEEER/De BOODT 1954, KEMPER/ROSENAU 1986, SCHLICHTING/BLUME 1995),
- percolation (SEKERA/BRUNNER 1943, BECHER/KAINZ 1983),
- ultrasound diagnostic (TIPPKÖTTER 1993)

which need effortful test equipments and an intensive pre-treatment which contains a high danger of falsification, the "silting method" with silting image evaluation offers the following advantages:

- low sample treatment, low falsification danger,
- simplicity in the application,
- low time need,
- simply to learn and to communicate

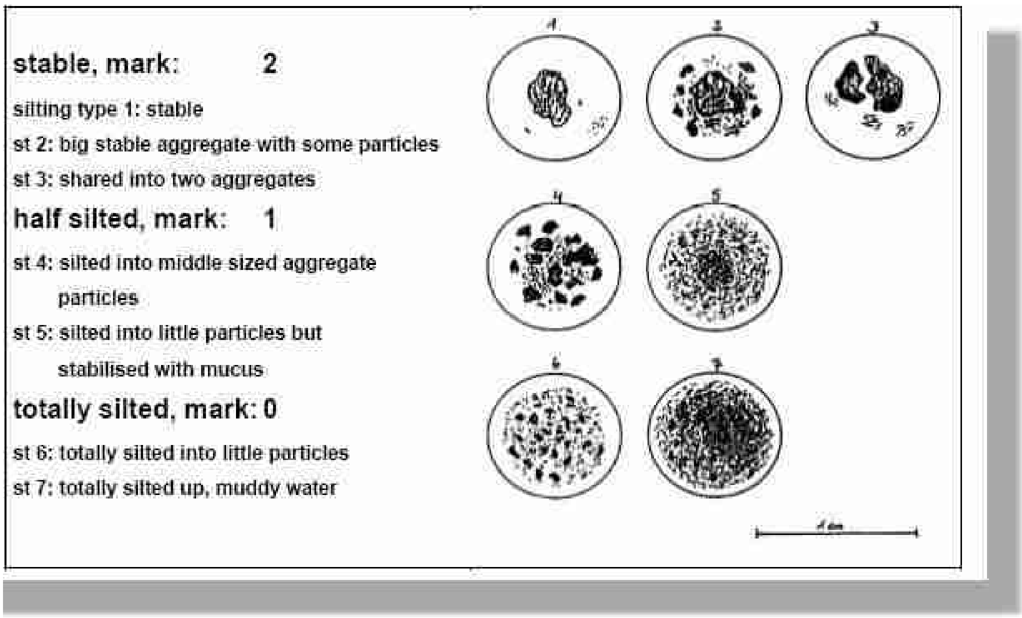

Fig. 3: Test of aggregate silting for loamy soils with evaluation images ref. BESTE

Specific target or reference values of the aggregate stability cannot be given for different soils. Due to the possibility of a compaction caused high aggregate stability a judgement of the functional ecological quality condition of the structure can be carried out only in combination with the structure evaluation. This applies to all methods of aggregate stability measuring. But on the other hand only with test of aggregate stability the dynamic aspect of the soil condition and its susceptibility for silting (and due to that compaction) can be checked.

The method has been proved since 1996 in numerous analyses in Europe and Asia for research purposes and adviser demonstrations. Its greatest advantage is it that after a simple training the methodology also can be carried out by the farmer himself. The method is described in detail in BESTE 2003 (ordering possibility of English version under a.beste@t-online.de or www.gesunde-erde.net).

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