Further Development and Improvement of Spade Diagnosis as Field Method for the Evaluation of Ecological Significant Structure Parameters of Soils under Agricultural Management

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Abstract

Further Development and Improvement of Spadediagnosis as a simple field-method for the scientific evaluation of some ecologically significant function-parameters of soils under agricultural management

Some conclusions made by the Conference of the International Soil Conservation Organisation (ISCO) in Bonn, Germany 1996 emphasised that to document the effects of soil and land management systems on ecological soil functions, sensitive indicators and simple suitable scientific methods have to be defined respectively developed, which are able to show the influence of management systems on soil vitality.

In this research paper the proposal is made to use soil structure as indicator for sound soil functions because of its close connections to water circulation, soil life activity and transformation capacity. With the Extended Spade Diagnosis (ESD) - a combination of soil investigation-methods - a methodology is presented, which combines structure evaluation schemes developed on current knowledge about sound soil structure conditions (qualitative data, but countable) and measurement of common soil structure parameters (quantitative data). ESD contains a new developed structure evaluation, a new developed simple test of aggregate stability, the count of root density in the subsoil with a stencil, measurement of soil moisture and bulk density with short core samplers and the measurement of shearing resistance.

Experimentation and improvement of ESD has been implemented 1996-2003 by BESTE as Ph.D.-thesis in agro sciences (Institute of Crop-Management, Department of Organic Agriculture, University of Gießen, Germany) within the Research- and Demonstration-Project Ecological Soil Management (PÖB), carried out by the Foundation Ecology & Farming (SÖL), *Bad Dürkheim*, together with the Federal Institute for Crop Tillage and Protection (LPP), *Mainz*, Germany and promoted by the Ministry of Agriculture, Viticulture and Forestry *Rheinland Pfalz, Germany*.

The research was based on investigations with different crops and different tillage systems. With results of ESD and a differentiated analysis of the morphology and stability of aggregates of 3 – 5 mm the experience could be emphasised that green fallow used in crop rotations contributes heavily to soil regeneration. There has been documented a raising up of aggregate stability and an improvement of soil structure conditions under green fallow continuing under the following crop.

Beside the improvement of aggregate stability test and structure evaluation scheme, adapted evaluation schemes for different soils (silty and sandy soils) and a knew rooting evaluation scheme have been developed.

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The **appendix** mentioned in the text is not presented with the translated version.

Illustrations

Tables

Abbreviations

ESD	Extended Spade Diagnosis
ISCO	Internationally Soil Conservation Organisation
UBA	Federal Environmental Agency
P	Plough
PÖB	Project Ecological Soil Management
RSU	Federal Council of Experts for Environmental Questions
SG	Cultivator
SP	Two layer plough
WBGU	Scientific advisory group of the Federal Government-Global Environmental Changes
ANOVA	Analysis of Variance
AGGRUPP3	Variable of meso structure, scale 1-3

1 Introduction

1.1 Problem definition

Soils fulfill five substantial functions in a balanced landscape ecosystem.

These according to WBGU (1994, P. 44), GLOESS (1997, P. 82 ff.) and UBA (1998, P. 12), are defined as follows:

Habitat and living space:	**Habitat diversity for biota (plants, animals, fungi)**
Production and utilisation:	**Production of nutrients and biomass**
Ecological regulation:	**Filtration-, buffering-, restoring-, transformation-capacity for water and organic and inorganic material**
Spatial function:	**Space for settlements, traffic and disposal**
Cultural function:	**Basis of human history and culture**

Different forms of the soil use must be able to ensure a maintenance of these soil functions on a long-term basis, in order to be lasting. Agriculture has according to surface the largest area part of the soil use. Current management practices lead world-wide with a third of the cultivated soils to soil degradation (UNEP/ISRIC 1991, RSU 1994, WBGU 1994, HURNI et al. 1996). According to De KIMPE and WARKENTIN (1998) soil degradation develops, if the balance between the natural soil functions is disturbed. The scientific advisory group of the Federal Government Global Environmental Changes (WBGU 1994, P. 49) and HURNI et al. (1996, P. 11) state above all soil erosion as well as the chemical, physical and biological degradation. They call the extent of the world-wide soil destruction a serious threat to our resources for food production (WBGU 1994, P. 108 ff; HURNI et al. 1996, P. 8). In the industrialized countries the soil compaction and in its consequence the increase of inundations, the decline of the ground-water formation and a decreased filter effect of the soils are symptoms for disturbed soil functions and beginning soil degradation (WBGU 1994, HAMPL 1995 a). Beside the load of the drinking water with nitrate and biocides (RSU 1985) this impact causes macroeconomic costs, which show that a pure profit orientation of agriculture in the entire balance is uneconomic (UBA 1997, WAIBEL/butchers 1998).

For an ecologically and economically long-term balanced productivity soil use systems beside the production function must take also the living space and the regulation function of the soil into account increasingly. They must therefore ensure a long-term maintenance of these three soil functions – in short: the *ecological workability* [1]of soils.

In order to be able to examine soil use systems regarding this requirement, suitable indicators and methods are to be selected and developed (UBA 1998). The International Soil Conservation Organization (ISCO) formulated this requirement as follows (P. 325):

"To progress in combating soil degradation there is a need of comparing soil management practices and land use systems due to their sustainability. Therefore we have to elaborate indicators with great evidence about the change of organic matter in soils, natural soil fertility, buffer capacity as well as indicators of quality for sustainable soil management. 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".

These indicators and/or the methods, which serve the examination, must react being sufficient sensitively to changes of management practice, in order to point changes out as early as possible.

1.2 Aim of research and hypotheses

Soils can be examined regarding their chemical, physical and biological characteristics with the help of diverse measuring and analysis methods. The complexity of soil system brings about it that often only partial cutouts can be regarded (e.g. plant-available nutrients in soil-chemical investigation) and on the other hand despite substantial investigation expenditure only detailed views into a small sector of soil functions are possible (e.g. soil micro biology), which already from reasons of cost make an overview of soil dynamics in annual course more difficult (see fig. 1). Simple soil-physical research methods are often aligned too one-sided to soil-mechanical approaches and do not take biological and ecological parameters into account sufficiently (UBA 1998) (Fig. 1). Aggregate stability tests for example permit statements about stability but however give no on information about good or bad spatial structural characteristics of the soil.

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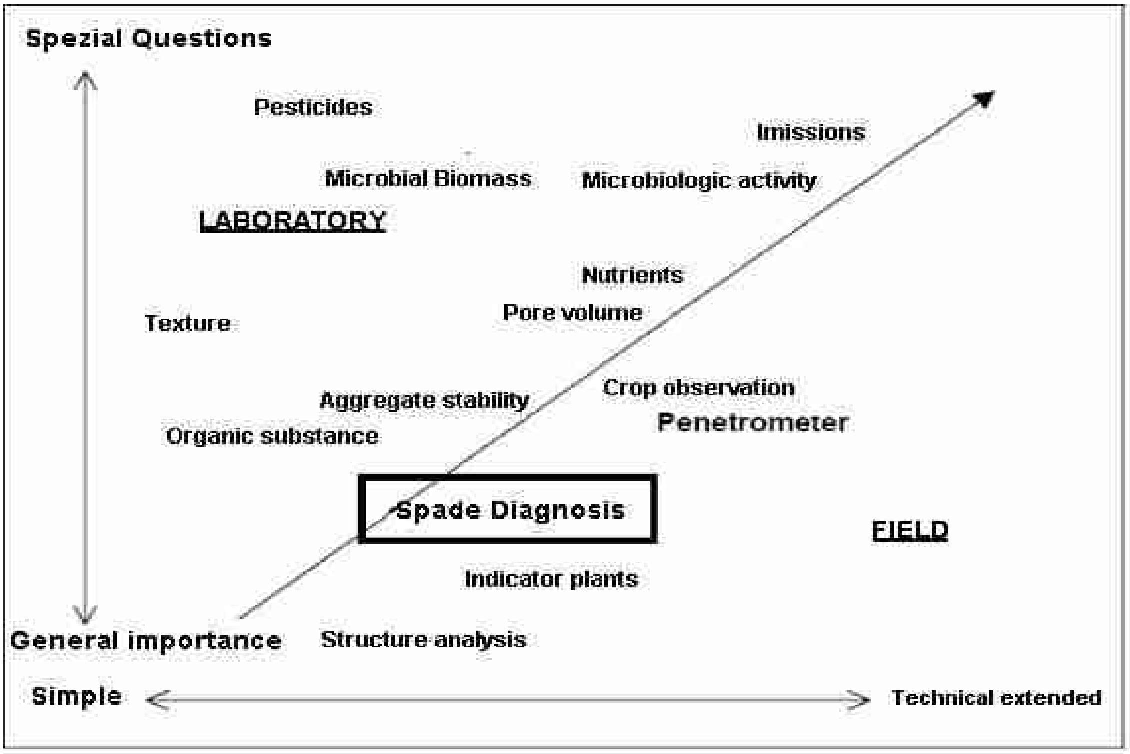
[1] By ecological workability of soils here and in-follow is to be understood:
The ability of soil to maintain important functions a high yield and sound crop production as well as an ecological balanced landscape ecosystem even under cultivation.

From the remarks of ISCO mentioned above the following research needs result:

I. Ascertainment of suitable indicators for the judgment of the consequences of agricultural use for the ecological workability of soils.
II. Development and/or combination of meaningful methods to recording the consequences of the soil use for these indicators.

The methods should be internationally applicable and of facile understanding. Rural knowledge and experiences are to be included in research designs.



Source: HAMPL/KUSSEL 1994

Fig. 1: Expenditure of different soil analysis methods

The closest interface between quickly and simply recordable morphological analysis and the functions of the soil represents the structure. It is suitable therefore as a sensitive indicator for the judgment of management measures. This is repetitive documented in the literature (GOERBING/SEKERA 1947, MUECKENHAUSEN 1947, BENECKE 1966, DIEZ 1982, BEYER 1991, KUNTZE/ROESCHMANN/SCHWERDTFEGER 1994, HAMPL 1995 b, HARRACH 1998). Important parameters, which have a large influence on the ecological workability, are aggregate stability, compaction, water and air conductivity, capacity of exchange of nutrients, biological activity and rooting intensity. They stand in close interrelation with the condition of the structure (AG BODEN 1994).

"*Each change in structure conditions has also changes in its functions as a consequence.*" (ALTEMUELLER /HARTGE 1991, P. 9)

"*A comprehensive structure evaluation stands at the beginning of all considerations for the land use and improvement of the soil.*" (KUNTZE/ROESCHMANN/ SCHWERDTFEGER 1994, P. 144)

The German term "*Bodengare*" stood long time for the optimal structure condition of a productive soil and was agricultural judgment scale in Germany (SEKERA/BRUNNER 1943, FRESE 1958). According to SEKERA (1984, P. 15) with the term "*Bodengare*" one understands the life building of the crumb structure by the native micro-organisms (see also FRESE 1958, P. 117). One first step to find a describing methodology for this term was done by J. GOERBING around 1947 with the development of the Spade Diagnosis. A soil brick is digged out with a diagnostic spade and is examined immediately for the condition of the structure (loose, means, firmly, possibly existing compaction layers, form of the aggregates) and other parameters (soil moisture, rooting) (see fig. 2).

Date:			**Remarks**:			
Plot:	**Crop:**					
			(Organic matter, earth worms, worm dropping)			
	Soil structure		**Roots**		**Soil moisture**	
Topsoil	loose crumble-structure	☐	many and fine roots	☐	wet	☐
	crumbles and clods	☐	few roots	☐	medium	☐
0-15 cm	sharp-edged compacted clods	☐	scarcely roots	☐	dry	☐
Subsoil	crumble-structure	☐	many and fine roots	☐	wet	☐
	crumbles and clods	☐	few roots	☐	medium	☐
15-30 cm	sharp-edged compacted clods	☐	scarcely roots	☐	dry	☐

(Changed according HAMPL 1995 c)

Fig. 2: GOERBING Spade Diagnosis, field record

The advantages of this method of soil examination are today still valid for practice:

The general impression of the soil condition provides information about ecologically relevant parameters, which go beyond a pure structure description. By the subdivision of the general impression into individual parameters the soil condition can be systematically examined and causes for changes in soil structure quality can be understood more exactly with regular repetition of the analysis. The organization in parameters facilitates the comparability. The direct contact to the soil remains and the condition becomes "understandable". Any sample treatment stands between the observer and the evaluation object soil. The "measuring instruments" is at any time available: Hands, eyes, nose (see for this fig. 3 and 4). Existing farmer experience in handling with soil is given structured use in this evaluation scheme. The method is very simply, easy to learn and the results are facile communicable. With GOERBING Spade Diagnosis the requirements summarized by the ISCO approximates therefore strongly. Their evidence of the evaluation of soil conditions was stressed again and again (GOERBING/SEKERA 1947, MUECKENHAUSEN 1947, EBERT 1952, TEIPEL 1952 a and b, VON CAPPELN 1959, DIEZ, 1982, DIEZ 1991, HARRACH/ VORDERBRÜGGE 1991, HAMPL 1995 b).

(Photo: HAMPL)

Fig. 3: Spade profile of a compacted soil

(Photo: HAMPL)

Fig. 4: Spade profile of a loose soil stabilized by roots

The comprehensive impression has been proved as very helpful for the judgement of foregoing management practices (crop-rotations, tillage-systems ...) and appropriate decisions about modifications of future soil management by agricultural consulters and farmers. „*With no other method a farmer can provide as much information about the condition of soil crumb as quickly, as simply and as cheaply*“ (HAMPL 1995). The immediate and almost holistic view on the actual state of health of a soil crumb, which is of great importance in account of the complexity of this ecosystem, has to be emphasised as a great advantage and cannot be delivered by data from laboratory studies with isolated samples. JUNG (1988) discovered high correlations with soil-physical measurements. A sufficient documentation and comparability of the results for scientific purposes are however not given with the estimated values to be investigated in GOERBING Spade Diagnosis. The rough verbal describing of parameter characteristics facilitates the final conclusion and decision for the practical man. It is however not differentiated and clearly enough for the scientific documentation.

On the basis of the disadvantages mentioned the GOERBING-Spate Diagnosis was extended 1994 by HAMPL and KUSSEL for the scientific recording of soil condition data (HAMPL/KUSSEL 1994, BESTE 1996). In this "Extended Spade Diagnosis" (ESD) the current condition of the structure in the field is combined with a systematic structure evaluation with physical field surveys and results from laboratory tests. Both quantitative measurements (e.g. shearing resistance), and qualitative evaluation methods (structure evaluation, silting test of aggregates) are applied. The parameters of the combination method ESD according to HAMPL/KUSSEL 1994 are structure evaluation, aggregate stability test, measurement of soil moisture, pore volume/bulk density and shearing resistance as well as the counting out of the root density. The systematic evaluation methods provide thereby the actual, complex information. The measurements of the current soil science values shearing resistance and bulk density/pore volume hold the connection to usual physical soil analysis and facilitate therefore the classification of the new evaluation methods.

Practical experiences with the extended method within a research work to the impact of different tillage had shown that ESD offers the potential to acquire data at low expenditure which provides meaningful information about ecologically important soil structure parameters (BESTE 1996). Above all structure evaluation and aggregate stability test appeared to be of great value for soil analysis. As a further result of these investigations it appears however necessary to improve the method in the fields of structure evaluation and aggregate stability test (BESTE 1996).

A priority request of this work is therefore to develop the ESD to a method for scientific purposes, which can
a) evaluate manage-caused changes of the soil structure quickly, reproducibly and at small expenditure
and which
b) makes possible to give recommendations for action.

According to this the partial methods of the ESD - evaluation of structure and aggregate stability - are to be improved in such a way that the performance of the structure can be taken into account for the maintenance of the ecological workability of the soil still better (see chapter 2).

The aims of research of the presented dissertation are defined therefore as follows:

1. All single methods which are applied within the framework of the ESD are to be examined for their sensitivity for already known manage-caused structure differences. It is essential to evaluate in this connection whether these methods provide suitable indicators of the structure condition of soils for the judgment about agricultural soil use.

2. In particular the partial methods structure evaluation and aggregate stability test are to be developed further and finally improved so far that manage-caused differences in the structure condition of the soil can be included methodically better.

3. Finally it is essential to judge the ESD as whole one in such a way whether this as a simple field method which can be recommended for use through third make an effective contribution to the evaluation of important parameters of the ecological workability over the evaluation of the structure condition.

For a comprehensive evaluation of the structure condition as an important indicator for the guarantee of the ecological workability of the soil is of highest scientific and practical interest whether the stability of soil aggregates, which are jointly responsible for the structure condition is due to colloid-chemical and physical or to biological causes. Taking as a basis the experience that polyedric aggregates with scarcely pore volume show a low part of biogenous stabilization compared with sponge-like, crumbly and porous aggregate forms (SUNKEL 1961), the morphology of the aggregates can give references to a higher or lower degree of biological stabilization factors. SCHINNER/SONNLEITNER (1996 b) and HAMPL-MATHY (1991 a) pointed out first indications that different forms of agricultural soil use can have influence on the biological part of aggregate stability (rotation and type of the crops, density and duration of the vegetation cover, tillage-depth, inverting-intensity, date of tillage) These facts are to follow further in the presented work.

The project ecological soil management (PÖB) described in chapter 3, within whose framework this work has been conducted, offers the possibility in accordance with the above mentioned goal of clearing up manage-caused differences in the structure condition and aggregate stability - here within the system "ecological agricultures". In the presented work the different tillage measures such as rotation of crops, crop types and different tillage systems could be examined.

The following hypotheses form the basis for the experimental design and methodical execution in dependence of the here present investigation possibilities:

- **Hypothesis I** Within the rotation of the crops sequence cereals, green fallow, cereals green fallow on the basis of its soil-regenerate effect causes a temporary rise in aggregate stability with increased amount of crumbles (see chapter 2.2) as well as a better structure.

- **Hypothesis II** Tillage plays an important role regarding the preservation of soil life. The plough loosens the structure more strongly, disturbs however soil life by the deep invertation. Not inverting tillage or flat inverting tillage causes a higher aggregate stability and an increased amount of crumbles with higher structure density compared with deep inverting tillage.

- **Hypothesis III** With the combination of morphological soil evaluation (structure evaluation, evaluation of the aggregate meso-morphology) and dynamic test (aggregate stability test) biological factors of the aggregate stabilization can be differentiated better from colloid-chemical and above all compaction-caused factors.

The hypotheses set up here - except hypothesis III - describe effects, which correspond to the current level of knowledge and have often been described in the literature. To reconstruct these effects with the partial methods ESD comprehensible, or - as formulated in hypothesis III - more differentiated is the basis for a positive evaluation of the expressiveness and applicability of the ESD.

1.3 Structure of the work

In chapter 2 the method ESD is introduced in detail. On the basis of the scientific context and own research work the fundamental aptitude of the used parameters in the ESD according to HAMPL/KUSSEL and of the new developed methods for the differentiated structure evaluation shall be worked out. In chapter 3 a description of the experimental design and methodology is made. In chapter 4 the results of the survey are presented and discussed. Chapter 5 contains the summarizing discussion, the comparison of the results with the hypotheses, method criticism, recommendations for the application of the method as well as the concept of an optimized form of the ESD and the formulation of further research needs. Chapter 6 provides completing short summary of the work.

2 Soil examination with Extended Spade Diagnosis (ESD) - state of research

HAMPL and KUSSEL (1994) produced the Extended Spade Diagnosis (ESD) with the goal to retain the substantial advantages of the GOERBING method - simplicity in the application and result transmission, complexity of the information, simple understanding as well as low intensity of sample treatment - and to ensure beyond that a greatest possible clarity and quantifiability of the information. They placed the following measuring and evaluation methods together to deliver data according to the parameters of the GOERBING-Spade Diagnosis (soil structure, rooting and soil moisture) (see tab. 1):

Tab. 1: Methodology and quantifiability of GOERBING Spade Diagnosis and ESD

Parameter	*GÖRBING-Spade Diagnosis*	*Result*	*ESD*	*Result*
Soil structure	Assessment of average of fragment size Description of fragment form	figure verbally	**Structure evaluation** For each tillage horizon and subsoil 5 scales with structure marks	figure
	Assessment of compaction	verbally	Pore volume and bulk density by analysis of gravimetric water content Measurement of shearing resistance	figure figure
			Test of aggregate stability 3 scales, calculation in percentages	figure
Rooting	Assessment of rooting	verbally	Counting of root density/cm^2	figure
Soil moisture	Assessment of soil moisture	verbally	Measurement of **soil moisture** with analysis of gravimetric water content	figure

In the following an embedding of the methods used in ESD according to HAMPL/KUSSEL (1994) into the scientific context regarding their expressiveness for the soil condition evaluation is given. Changes of individual partial methods and of introduction of the whole methodology are justified as preliminary work of the present research work.

2.1 Structure evaluation

Soil structure in soil science is defined as the way of spacey arrangement of solid soil matter. Micro structure and macro structure are divided. Micro structure has been described as the arrangement of soil particles, pores and precipitation substances which are visible under the microscope (SCHINNER/SONNLEITNER 1996 a). Referring MÜCKENHAUSEN (1993) macro structure is divided in 3 main groups: Single grain structure, coherent structure, and aggregated structure. In most cases soils under agricultural management show a mixed structure whereas a biogen aggregate structure is to strive for. Referring KUNTZE/ROESCHMANN/ SCHWERDTFEGER (1994), an ecologic optimum of soil structure is often termed as „swamp structure”. A structure of this quality is characterized by good buffer-, filter-, regulation-, habitat- and production- functions and referring KUBIENA (1938) for the maintenance of soil fertility there is no better structure quality than the “swamp structure”. Nutrition availability and supply for a sound crop growth are closely interconnected with the activity of soil organisms and the intensity of root growth. For this state of structure quality is of critical importance.

Older and newer scientific works, which come to the conclusion, that there is no secure connection between the structure condition of the crumb and the productivity (RID 1961, REX 1984, DUMBECK 1986, VORDERBRÜGGE 1989, KREUZER 1993, GROSS 1996) are based on surveys in conventional management system. The influence of the slightly soluble nitrogen fertilizer on the productivity which is used in conventional management, remained unestimated in the final conclusions up to now. In the management system of the ecological agriculture close connection of soil structure and productivity as it has been stated by DIEZ (1991) is distinctly measurable, since the influence of synthetic, slightly soluble nitrogen fertilizers is to be avoiding here and therefore an overlay of the structural effect is not given by the fertilizer effect. The system of ecological agriculture avoids quickly soluble nitrogen fertilizer for reasons of care of resources and protection of the aquatic environment (UBA 1997, GEIER et. al. 1997, HAAS 1997), the food quality (AHRENS et al. 1983, VOGTMANN/FRAGSTEIN 1984, BACKES et al. 1997), plant protection (CHABOUSSOU 1987, KAUER 1993, HÖFLICH 1996, ODÖRFER/POMMER 1997, WILDENHAYN in DIERKS/HEITEFUSS 1994) as well as energy conservation (HAMPL 1991 b, HAAS/KOEPKE 1994, HAAS et al. 1995) and was therefore designated by the UBA (1997) as an environment-conservation management system. In case of this management system using organic manure nutrient support and availability for a healthy plant growth depend particularly on the porosity of the soil structure, on the activity of the micro-organisms and the intensity of root growth. Since the water regime and all life processes in the soil, above all the effective nutrient supplies for the crop and therefore the harvest depends directly on the soil structure, a crucial importance is attached to its qualitative condition (SOBOTIK 1989, HELAL 1991, SCHELLER ONE 1993). The soil structure should be biologically stabilized crumbly. It should permit "*an intimate, homogeneous, vertical and horizontal penetrating of the soil with roots* " (LEITHOLD 2000).

In the memorandum "*For an environmentally sound soil use in agriculture*" of the Schwaebisch-Haller Agrarian Colloquium (ROBERT BOSCH STIFTUNG 1994, P. 19) is generally taken position as follows with the fertilizer question:

"*Thus with the nutrient availiability for the plant soil structure and rooting plays a significant role. The more intensively the rooting is and the more favourable the soil structure, all the better the utilisation of soil and fertilizer nutrients is. When which nutrients for the plants are available, strongly is determined by the activity of the soil animals and micro-organisms. These almost steer all dismantling and conversion processes in the soil and affect by it beside the humus budget also the nutrient subsequent delivery to the roots. Soil animals and micro-organisms differ in number and composition depending on the type of fertilising. Thus organic fertilising promotes soil life substantially more strongly than exclusive mineral fertilising*."

For the building up of an optimal structure humus, organic colloids as well as soil organisms and roots are indispensable (SCHINNER/SONNLEITNER 1996 a, P. 71).

Structure investigations therefore must take as far as possible the biological activity as a coining factor of the structure condition and structure stability into account, if they are to go beyond soil-mechanical evaluation approaches. Beside the biological stabilization of the aggregates (see chapter 2.2) between the biological activity and the morphology of soils exists a close connection. At the aggregation form or roughness of the soil the intensity of the biological activity can be judged. The optimal condition of the "sponge structure" cannot be quantified up to now in its single structure characteristics. Simple physical methods for structure evaluation (bulk density, pore volumes, penetration resistance, shearing resistance) concentrate primarily on the description of the soil density or the quantification of pores. These parameters give good indications for the analysis of harming compaction. About the presence of a agricultural valuable, sponge like, biogenous aggregate structure they can give however only reduced information. More complex methods for the structure evaluation from distribution of sizes of pores by RICHARD up to digital picture analysis (WILKENS 1992), X-ray-morphological investigations (WERNER 1993) and computer tomographic investigations (ROGASIK et al. 1995) are very expensive in execution and likewise give no approximate values for "a sponge structure".

Structure evaluations represent a relatively quick, simple and at the same time comprehensive methods for description of qualitative soil condition. They all represent a simplification of the structure description Referring the German soil science mapping instruction (AG BODEN 1994) and/or a description of structure referring MUECKENHAUSEN (WERNER/THÄMERT 1988, DIEZ 1991, HASINGER 1993). The Structure evaluation according to HAMPL/KUSSEL (1994, BESTE 1996, see tab. 2) follows the structure evaluation by DIEZ (1991), in which substantial aspects of positive and negative structure definitions, are easily described with "favourably" and "unfavorably". The amount of highly porose crumbles is thereby central evaluation factor.

Tab. 2: Evaluation scheme for the structure evaluation according to HAMPL/KUSSEL 1994

Horizon	Appearance	structure note
	Rough, round, crumbly, highly porose, no silting, no crusts, worm dropping	2
	- Intermediate mark -	1.5
Surface	Edges, fragments with smooth surfaces, beginning crusts	1
	- Intermediate mark -	0.5
	Crusts, silting, sealing	0
	Over 80% crumb structures	2
	- Intermediate mark -	1.5
Upper Crumb	Mixture structure from smooth, sharp edged fragments and crumbles	1
	- Intermediate mark -	0.5
	Mixture structures from crumbles and clotts	0
	Mixture structures from crumbles and small smooth, sharp edged fragments	2
	- Intermediate mark -	1.5
Lower Crumb	Mixture structures from crumbling and clotting	1
	- Intermediate mark -	0.5
	Sharp edged structure	0
	Well porose structure with irregular-round surfaces (unimpaired Loess structure with needle pass pores)	2
	- Intermediate mark -	1.5
Subsoil	Rough-prism-table, scarcely porose structure with clearly smooth surfaces	1
	- Intermediate mark -	0.5
	Plate structures, scarcely pores	0

HAMPL/KUSSEL (1994) make again clear simplifications compared with DIEZ. They subdivide their evaluation beyond that into practice-treatment horizons. The subsoil represents in this connection not the c-horizon, but the horizon not influenced by the tillage treatment. For each horizon they provide verbal briefly described comparison pictures and assign clearly rating notes to them. The value scales withdraw themselves to the Subsoil from the demand of an optimal sponge structure. The scale of vertical graduation is grounded on natural soil stratigraphy and typical habitat layering of soil biota as it has been described by GISI (1997).

In case of the evaluation of complex systems definitions of optimal conditions (task value) can take over "guiding value"-character (see KÄMPF 1953). Beyond that clearly defined comparison pictures also are well adapted for intermediate stages and negative conditions. The evaluation is made thereby not Referring a detailed description of the individual case, but via the decision for the fitting of a given substantial characteristic description to an actual appearance. The exact current appearance of individual details is not the center of attention, but the relative deviation from the optimal condition. This comparison evaluation facilitates and accelerates decision making and also leads when technical training is poor to smooth results. The Structure evaluation according to HAMPL/KUSSEL (1994) appears therefore suitable for the following reasons for a function-oriented structure evaluation:

- *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. It 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 regulation function;*
- *The vertical graduation in structure marks takes the soil stratigraphy and typical habitat layering of soil biota as well as the influence of agricultural soil treatment (especially tillage) into account.*

As a result of the 1995 carried out investigations with the structure evaluation according HAMPL/KUSSEL (BESTE 1996) a differentiation of the verbal characteristic describing referring HASINGER (1993) and own observations was made as well as an improvement of the mark graduation regarding statistical aspects at the preliminary stage of this work (see tab. 5, chapter 3.3.1).

2.2 Aggregate stability

Referring SEKERA/BRUNNER (1942) and KULLMANN (1956) the evaluation of the "Bodengare" beside the static examination of the structure condition contains also the examination of the "crumb stability", which describes the dynamic aspect of the soil condition. Also BAEUMER (1991) recommends beside the comparison between actual and desired values of the soil condition the examination of soil-fertility-determine processes for the clarification of relations between cause and effect. As indicator of natural processes in the soil above all the stability of aggregates against water is important. It is of distinct importance for the susceptibility of a soil to of exteriors and internal erosion as well as compaction.

MUECKENHAUSEN (1993) defines aggregates as separate soil bodies, which emerge by segregation or aggregation from the coherent or single grain structure. Under segregation predominantly physical processes can be summarized, whose common characteristic is the formation of segregates by the allocation of coherent structures, for example contraction by drying or disruption by frost effect. With such procedure mainly aggregates of sharp edged, smoothly and polyedric or prismatic form are arising. In case of strongly carbonatic or clay-dominated soils these aggregates can be quite stable, whereby this is not an indicator of high biological activity (see also LIEBEROTH 1969 and KUNTZE/ROESCHMANN/ SCHWERDTFEGER 1994).

By aggregation one understands on the one hand the physical-chemical composing of soil particles. By coagulation, i.e. by precipitating of soil colloids, micro aggregates develop (SCHACHTSCHABEL/HARTGE 1958). In this composing the clay humus complexes take part, furthermore the cementing tendency depends on the colloid condition, on the calcium and magnesium supply and - particularly with soils of the tropical climatic area - the presence of iron and aluminium (CHESTERS et al. 1957, MUELLER-SAEMANN 1986, MUECKENHAUSEN 1993). On the other hand one understands by aggregation the biological building of the micro aggregates and soil particles by roots, (TISDALL/OADES 1982) organic substances, excrements of soil animals, fungi hyphae and bacterial and plant exudates (e.g. polysaccharides) (ANDERSON 1991, KANDELER/MURER 1993). Intensity and maintenance of biological stabilisation depends on texture, soil biota activity and humus supply. It has to be taken into account, that the compound of organic matter is of equal importance as the absolute amount (CHESTERS et al. 1957, LYNCH 1983 SCHINNER/SONNLEITNER 1996 a).

Shortly summarized the relation of feeding humus to continuous humus is crucial for the persistence of the stabilization. CHESTERS et al. (1957) and LYNCH (1983) beyond that could find aggregate building and -stabilization only with simultaneous presence of sources of carbon and micro-organisms.

The term crumble is named the aggregation forms of the biological building up to meso- and macro aggregates, if referring KULLMANN (1958, P. 9) the aggregates show "rounded off edging as well as rough, porous surfaces and not brake open alongside existing columns but into micro aggregates, which show a condition similarly the meso aggregates". Referring SCHINNER/SONNLEITNER (1996 a, P. 87) crumbles can show diameters of < 1 - 10 mm. This order of magnitude designates also TEIWES (1988, P. 45) as the "part of cultivatedly valuable aggregates". There are not exact data concerning the aggregate sizes to be preferred for the analysis of aggregate stability in the literature. In most of the research work aggregate stability against water is measured in the area < 10 mm (CHESTERS 1957, CZERATZKI 1957, SUNKEL 1961 b, ASPIRAS et al. 1971, KEMPER et al. 1985, HOEVELMANN/FRANKEN 1993, KANDELER/MURER 1993, MURER et al. 1993, TIPPKOETTER 1993, DEBOSZ et al. 1998).

SEKERA/BRUNNER (1943, P. 170) mark a predominating of 1-3 mm large crumbles as a positive characteristic of the structural condition and consult the aggregate sizes 1-2 mm and 2-3 mm for the analysis of aggregate stability in their "bowl-method as a qualitative high-speed method". The bowl method according to HAMPL/KUSSEL (1994 and BESTE 1996) represents a standardized advancement of the SEKERA/BRUNNER method of the aggregate silting test. In state of current soil moisture aggregates between 2 and 3 mm size are moistened carefully. Each aggregate is marked now Referring the characteristic silting image (see also chapter 3, fig. 15):

- Aggregate does not disintegrate or only into few large fragments, water clearly:
- mark 2
- Aggregate disintegrates into several small fragments, water still clearly:
- mark 1
- Aggregate disintegrates very, water clouded:
- mark 0

With the help of the marks calculation of percentage is done.

Whereas in case of other common methods, the aggregates are dried before silting test, actual soil moisture is remained until silting procedure with this method. It has to be stated that the levelling out of soil moisture conditions through drying implicates distortion and an influence, which does not correspond with natural field conditions.

Drying of Aggregates before testing could cause distinct variation in stability reaction because of air slacking (WICHTMANN 1955, HENK 1989, AUERSWALD 1992, POTRATZ 1993, GÄTH 1995, ROTH 1996), reduction of fungi hyphae, amount of bacteria (WEST et al. 1987) or loss of biological activity (DUTZLER-FRANZ 1977). In case of re-moistened aggregates Referring drying WICHTMANN (1955) found, that stability reaction depend on the type of drying process before. So natural status of aggregate stability seems to be very susceptible for manipulation of moisture. Because of this the samples of this research have not undergone drying or re-moistening treatment. They have been introduced into the analysis keeping their actual soil moisture. Because of the great influence of Calcium-, Natrium- or Chloride-Ions on stability reaction the silting test has been implemented with distilled water, which has the highest chemical similarity to rain water (KULLMANN 1956).

Compared with today mostly carried out methods of the aggregate stability measurement (wet sieving DE LEENHEEER/DE BOODT 1954, KEMPER/ROSENAU 1986, SCHLICHTING ING/BLUME 1995; percolation method SEKERA/BRUNNER 1943, BECHER/KAINZ 1983), which presuppose expensive attempt-equipments and an intensive sample pretreatment, the "bowl method" offers the following advantages referring HAMPL/KUSSEL (1994):

- Speed,
- Need of few training time as well as low sample treatment,
- Simplicity in the application and result presentation.

As a result of own investigations with the bowl method the problem of all methods of aggregate stability measurement became clear. The exclusive examination of stability against water can lead to wrong final conclusions regarding soil functions, since also an internal compaction or a high clay content can be cause of stability (CZERATZKI 1957, MULLA et al. 1992, BERNARD/LEPKE 1996, BESTE 1996, ROTH 1996). According KULLMANN (1956) aggregates in such a way stabilized are of "lower agricultural value, because porosity is missing" and according UBA (1998) compact aggregates reduce "the supply potential for the plants because of the decreased nutrient exchange ability". To all well-known methods of the aggregate stability measurement therefore it applies that they make possible statements about stability but permit, however no conclusions on good or bad structural characteristics of soils.

As part of ESD the structure evaluation provides indications for it, to which cause a high aggregate stability is due. The estimates with the help of the verbally defined comparison pictures are however possibly not differentiate enough. For a comprehensive evaluation of the structure regarding its ecological workability with emphasis on the biological activity it is of great importance, if the stability of the aggregates is due to colloid-chemical, compaction-cause physical, or biological factors. Taking as a basis the acceptance that polyedric, scarcely porose aggregate forms show a smaller part of biogenous stabilization compared with sponge-like, crumbly porous aggregate forms (SUNKEL 1961, BLUME/BEYER 1996), the morphology of the aggregates can give some references to the building up type (see tab. 6, chapter 3.3.2). The assumption is based on the description of the pore areas in macro aggregates > 1 mm which are preferred from micro-organisms, roots and fungal hyphaes (SCHINNER/SONNLEITNER 1996 a, P. 98 ff). Early CZERATZKI (1957), but also many others describe a larger dependence of aggregate stability on the annual course of microbien activity within aggregates of the fraction of 2-5 and 5-8 mm as in the fraction 0,2-1 mm (a detailed literature overview is found at ANDERSON 1991). Therefore larger aggregates indicate the biological stabilization dynamics probably better. According TISDALL/OADES (1982), OADES (1984) and ANDERSON (1991) with the size of the aggregates the part of biogenous stabilization factors rises, while in the case of aggregates < 2 mm colloid-chemical, chemical and physical factors predominate (see also CHESTERS et al. 1957). A test row with aggregates of the size of 2-3 mm and 3-5 mm, therefore was carried out as a preliminary test of this research work, resulted in clearer differences between fallow and crop land with the group 3-5 mm (see appendix, tab. 1).

The tests of aggregate stability are therefore carried out for the crumb horizons with the fraction 3-5 mm. For the surface for reasons of the practice proximity 2-3 mm large aggregates are used, since larger fractions hardly exist at the surface and biological stabilization mechanisms are rare because of the extreme temperature and humidity fluctuations.

2.3 Root density

The rooting intensity in the soil stands with the structure in dynamic interrelation. Roots need the pore system of an uncompacted structure for a balanced, vertical and horizontal growth, whereby the tolerances against compaction varies depending on the plant species (HAUG/SCHUHMANN/FISCHBECK 1990, P. 138 ff). If the nutrient supply of the crop is to be achieved without chemical-synthetic fertilizers, a good rooting intensity is of essential importance for a high yield. The transient area of the crumb to the subsoil is of special importance for the nutrient and water development (HAUG/SCHUHMANN/FISCHBECK 1990, HARRACH/VORDERBRÜGGE 1991, MEUSER 1991). The counting out of the root density in the subsoil (40 cm depth), integrated by HAMPL/KUSSEL (1994) into the ESD, takes this transition into account in particular. It represents a modification of the drill core method Referring HELLRIEGEL (in BOEHM 1979 and in KOEPKE 1979), with which the withdrawing roots of both parts of a broken drill core are counted. Referring KOEPKE (1979) relatively close correlations between the number of the roots at the surface of fracture and the root mass and/or root length exist in the drill core. The diameter of the drill core, given by HELLRIEGEL, is replaced in the method according to HAMPL/KUSSEL by a counting stencil. The expressiveness of root counting with the drill core method depends on the basis of the natural heterogeneity of the rooting intensity strongly on the sample quantity (KOEPKE 1979). The ESD as a combination method with emphasis qualitative analysis can be accomplished however not with a high amount of samples. Referring first investigations (BESTE 1996) an estimate of the expressiveness of the root counting with small sample quantity could not be made yet.

2.4 Soil moisture and bulk density

To combine the results won by the structure evaluation with the standard parameters soil moisture and bulk density these standard parameters are determined with the method.

The soil moisture affects structure development, aggregate stability and the shearing resistance. These parameters can be judged only in connection with the soil moisture. Beyond that the soil moisture can give references to the water absorption and restore ability of a soil. Beside texture, precipitation and/or condensation and the distance to the groundwater vegetation cover and soil structures are manage-dependent affecting factors. Soils compacted by not adapted management have a smaller water reservoir capacity as carefully loosened and biologically stabilized soils of the same type of soil with equal climatic conditions and equal vegetation cover. Biologically produced middle pores "of an optimal sponge structure" (KUNTZE/ROESCHMANN/SCHWERDTFEGER 1994, (not to confuse with technically extreme loosened structure after tillage) permit an optimal utilization of the restore ability with sufficient ventilation and provision of living spaces for micro-organisms and their metabolic processes at the same time (LIEBEROTH 1969, MUECKENHAUSEN 1993, SCHINNER/SONNLEITNER1996 b).

Bulk density gives reference to compaction or non adapted loosening. By the combination with these standard parameters the results of the ESD can be set better into the context of other soil examinations, since the bulk density is an often used base factor.

2.5 Shearing resistance

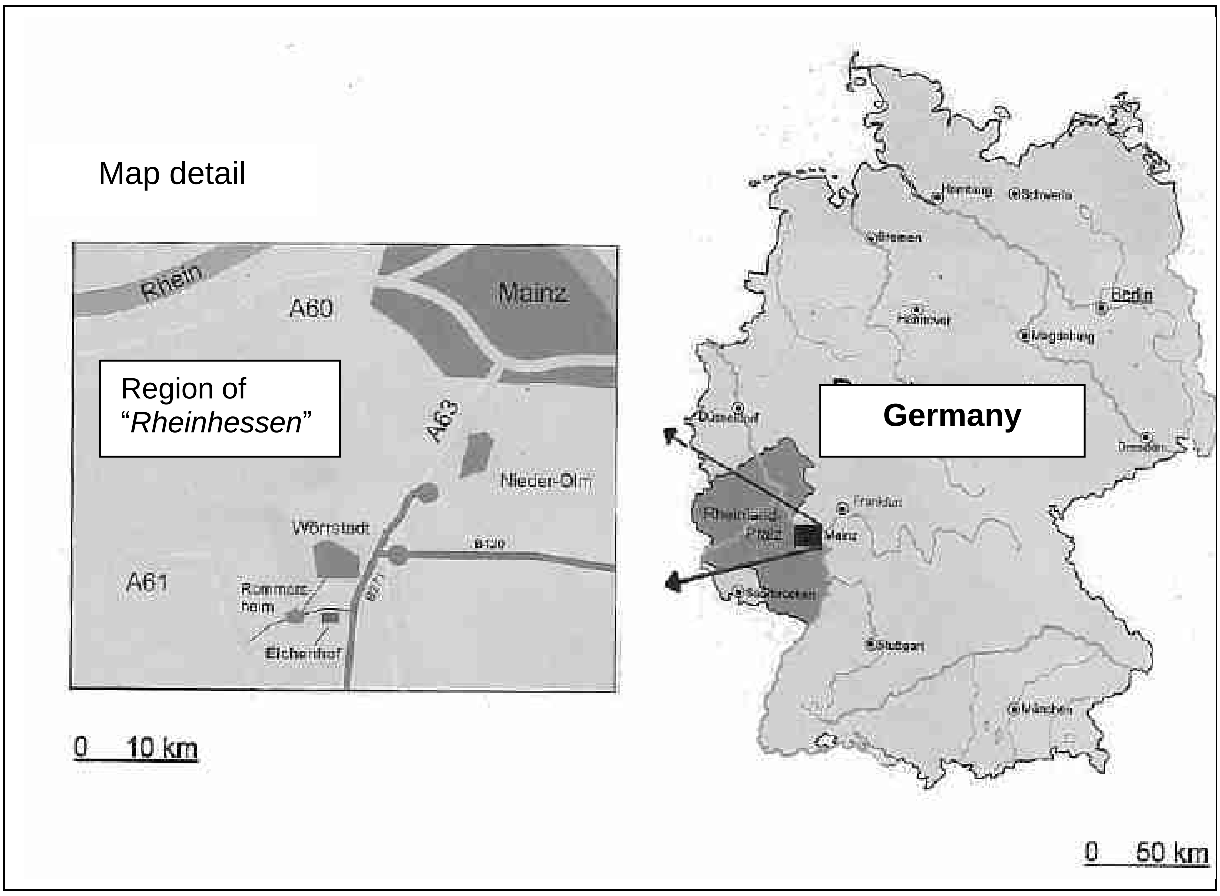
The shearing resistance is considered as a measure to the firmness of the soil structure (SCHAFFER ONE 1960). Clay part and soil moisture are most affecting factors for the evaluation of the shearing resistance and have to be determined with it. Abrupt changes in the structure layering at the transition in the Subsoil, as they are frequently observed with the plough tillage, can in case of equal soil moisture be measured well with the shearing resistance method (UBA 1998). Referring own experiences they are detected more sensitively in comparison with the analysis of the pore volume - equal soil moisture presupposed (BESTE 1996). The concentration on individual physical measured variables appears to be of less expressiveness compared with a combination of parameters and methods (UBA 1998).

3 Materials and methods

3.1 Location

3.1.1 Geo-spatial bases

The survey plot is located in central *Rheinhessen* on a hill (230 m ue. NN), 1 km south of Woerrstadt (see fig. 5).

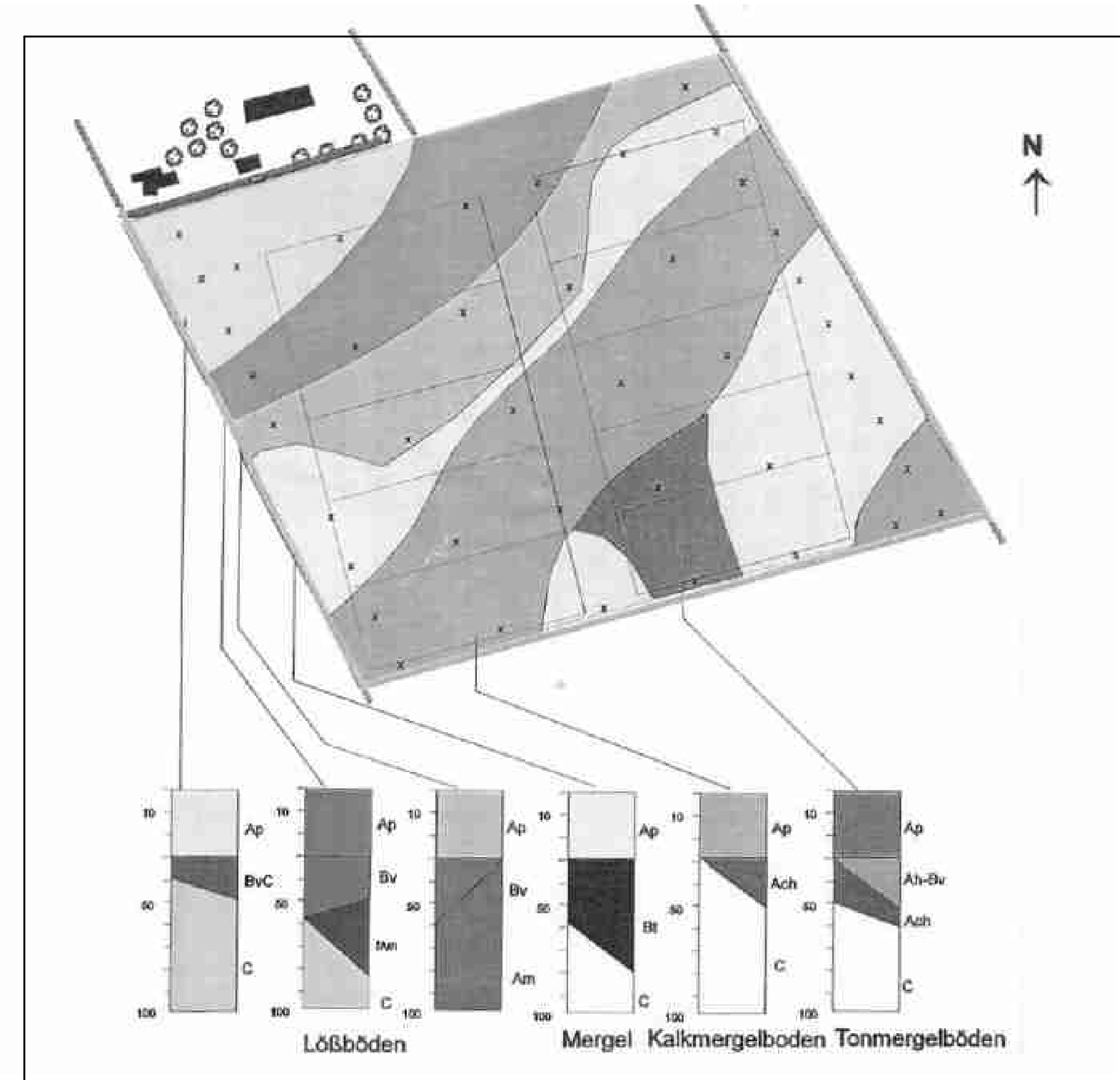


(Draft: GREIS in BESTE/HAMPL 1999)

Fig. 5: The survey plot located in central *Rheinhessen*

Limes and marl of the Miozaen form the geo-gene underground of the survey fields. Loess layers of Pleistozaen cover the northwest part. In the southeast part of the survey fields lime marl layers are found in the area of the soil genesis. Rendzina form the hill area (southeast), while to the downslope (northwest) colluvium is present (BUCHMANN 1994, see fig. 6 and appendix, text 1). The soil can be designated altogether to 60 cm depth as clay-silty to clay-loam (see appendix, tab. 29 and 46).

Out of the Loess deposited during the last ice age as aeolic sediment on far surfaces of *Rheinhessen* developed a Chernosem (under the influence of the post glacial steppe climate and due to the reheating of the climate in the Holozaen). For the Chernosem of the *Mainz* basin the high carbonate content in the A-horizon is characteristic (LUDWIG 1977, MUECKENHAUSEN 1993). The Loess loamy soils of *Rheinhessen* are very fertile. On the basis of their good base supply and the high silt part they reach soil value marks of 80-90 (highest soil value mark in Germany: 100).



Profiles to the proven soil units

Legend:
x measuring points
- plot borders (only PÖB)

0 100 m

(Draft: VOIGT 1998 according to BUCHMANN 1996)

Fig. 6: Soil map of the survey fields

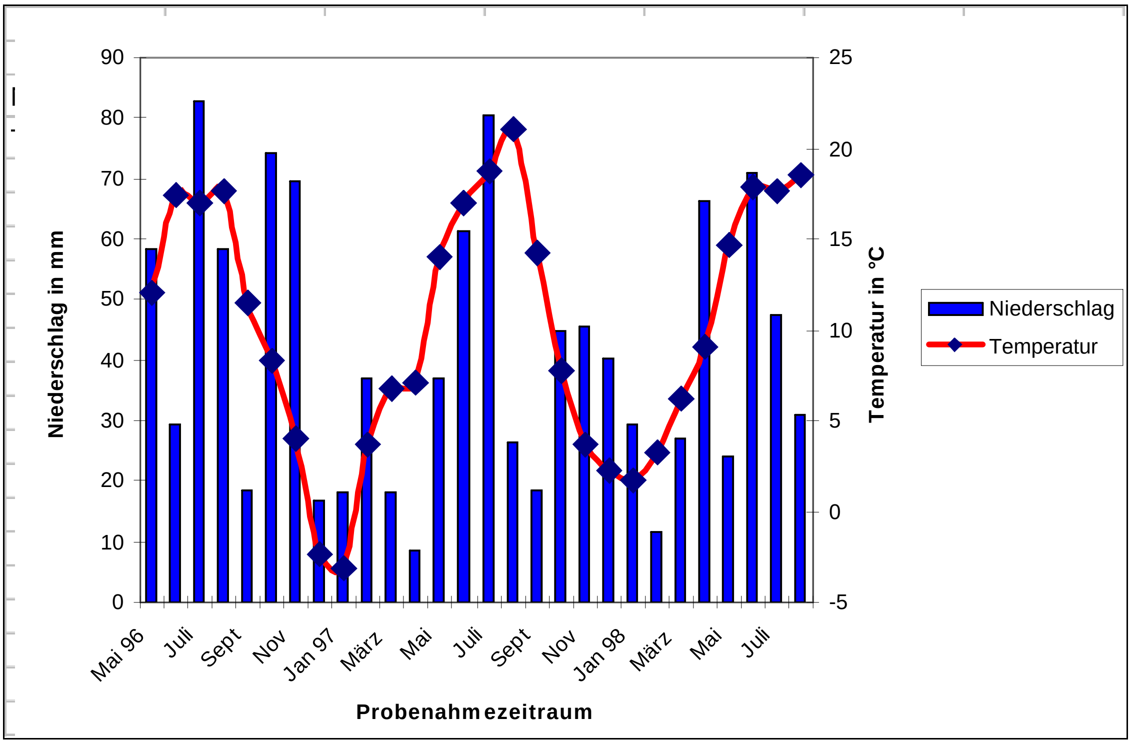
The chemical soil examination resulted in the following average values for the survey fields (see tab. 3, according to EMMERLING 1995 and appendix, tab. 47):

Tab. 3: Average soil-chemical characteristics of the survey fields of PÖB

$CaCl_2$-pH	% N_t	% C_{org}	C/N	CAL-P_2O_5 mg/100g	CAL-K_2O mg/100g	CAL-MgO mg/100g	$CaCO_3$ %
7.55	0.18	1.93	10.7	17.6	54.9	135.9	16.0

The high potassium values are attributed to the fact that clay minerals can fix high quantities of potassium with pH values of 7.5, the high Mg values arise as a result of marl admixtures in the soil (EMMERLING 1995).

Climatically *Rheinhessen* is protected against direct maritime climatic influences by the downwind position to the *Hunsrück* mountains, what brings about a quick heating up in the spring and a strong heating in the summer. The annual average temperature of the very mild climate amounts to 10°C. The orographic characteristics lead to precipitation poverty (500 - 600 mm in the year) due to the foehn wind effect (KANDLER 1977). Figure 7 shows the month averages of temperature and precipitation during the investigation period.



Niederschlag = Precipitation, Temperatur = Temperature, Probenahmezeitraum = Investigation period

Fig. 7: Month averages for precipitation and temperature during the investigation period

3.1.2 Project Ecological Soil Management (PÖB)

The "Project Ecological Soil Management" is carried out by the Foundation Ecology & Farming (SÖL), *Bad Dürkheim*, together with the Federal Institute for Crop Tillage and Protection (LPP), *Mainz* and it is promoted by the Ministry of Agriculture, Viticulture and Forestry *Rheinland Pfalz.*

Its aim is the demonstration of soil management techniques, which have maintenance and promotion of the ecological balance of agrarian ecosystems as a goal, as well as the placement of appropriate discussion contents and methods to the Federal Agricultural Consultance in *Rheinland Pfalz.* The start of the project was 1994, the planned running time amounts to ten years (HAMPL 1996B). The emphasis of the project lies on the investigation of different tillage variants in ecological rotation of crops regarding their consequences for the ecosystem soil and their applicability in the ecological agriculture. For the demonstration and research of different tillage systems the survey plots were put on in an expansion of 12 x 100 m. The five crop rotation consist of (green fallow, winter wheat with following intercrop, peas, winter rye with following intercrop and summer barley). The rotations are put on in double repetition with in each case three tillage variants, so that the survey extends altogether 30 plots. Green fallow and intercrops are leguminous based green manure mixtures with high root performance for soil regeneration. Tillage takes place in the summer in each case after cereals and for the stabilization of the loosened crumb is combined with the following seed of green manure mixtures. During the rotation of crops in three of five years after winter wheat and winter rye before intercrop as well as after summer barley before green fallow the differentiated tillage is carried out (HAMPL 1996b).

Tillage variants:

- **P** plough (inverting to 30 cm depth)
- **SP** two-layer plough (reduced inverting to 15 cm, deeply loosening to 30 cm depth)
- **SG** Layer cultivator (not inverting, loosening in 30 cm depth)

3.2 Experimental design

On the basis of the hypotheses mentioned (see chapter 1.2) two attempt approaches with different variation conditions were created, in order to test the sensitivity and aptitude of the ESD on the basis of the different impact of the crop rotation and the tillage:

Attempt approach 1:
Comparative investigation of crops rotation dynamics within ecological management for the structure dynamics;

Attempt approach 2:
Comparative investigation of green fallow and rye as well as not inverting, reduced inverting and deep inverting tillage within ecological management on the structure dynamics

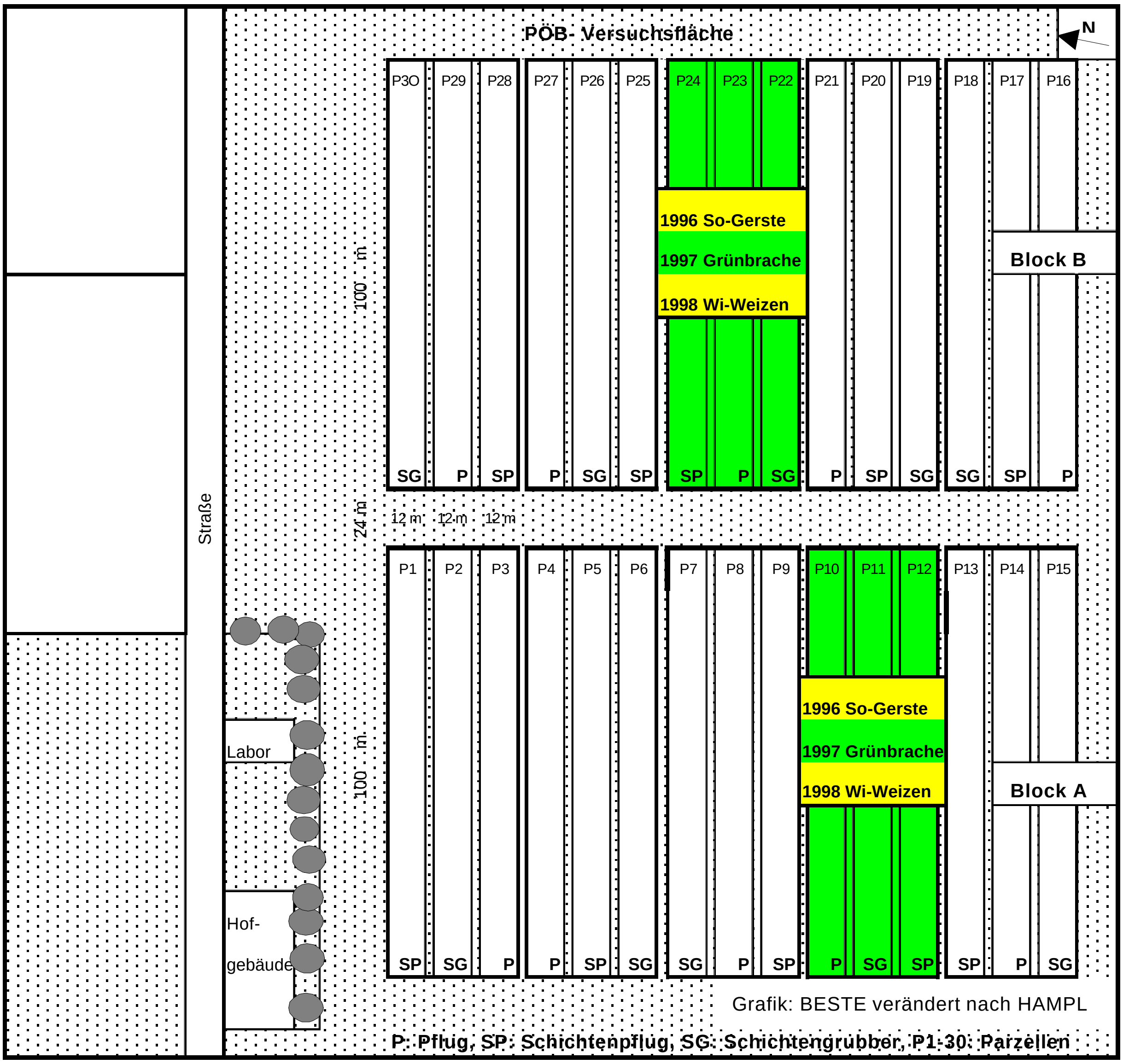
Within attempt approach 1 the comparison took place on the basis of the parameters structure, aggregate morphology, aggregate stability and soil moisture. The sampling taken place from May 1996 until July 1998, so in May and July 1996, in March, May, July and September 1997 and in March, May and July 1998, (the sampling in September 1996 and 1998 fell off for strong precipitation (partially snow), differentiated tillage was included.

Within attempt approach 2 in the years 1996, 1997 and 1998 in each case in May a complete Extended Spade Diagnosis was made.

The investigations and sampling took place within the Project Ecological Soil Management (PÖB).

Within the attempt approach 1 the rotation of crops sequence sampling was done in summer barley, green fallow and winter wheat in double repetition. The 3 tillage variants existing for each crop were included separately (see fig. 8). The differentiated tillage took place during this period in the late summer 1996 before the seed of the green fallow. The output substrate is Loess, Loess on marl and/or Loess on lime and clay marl (see fig. 6).

The survey fields of the PÖB are ecologically managed according to the directives of the AGÖL (AGÖL 1998). Up to the autumn of 1994 they were under integrated management (see tab. 4).



Versuchsfläche = Survey fields, So-Gerste = Summer barley, Grünbrache = Green fallow,

Wi-Weizen = Winter wheat, P = Plough, SP = Two-layer plough, SG = Layer cultivator

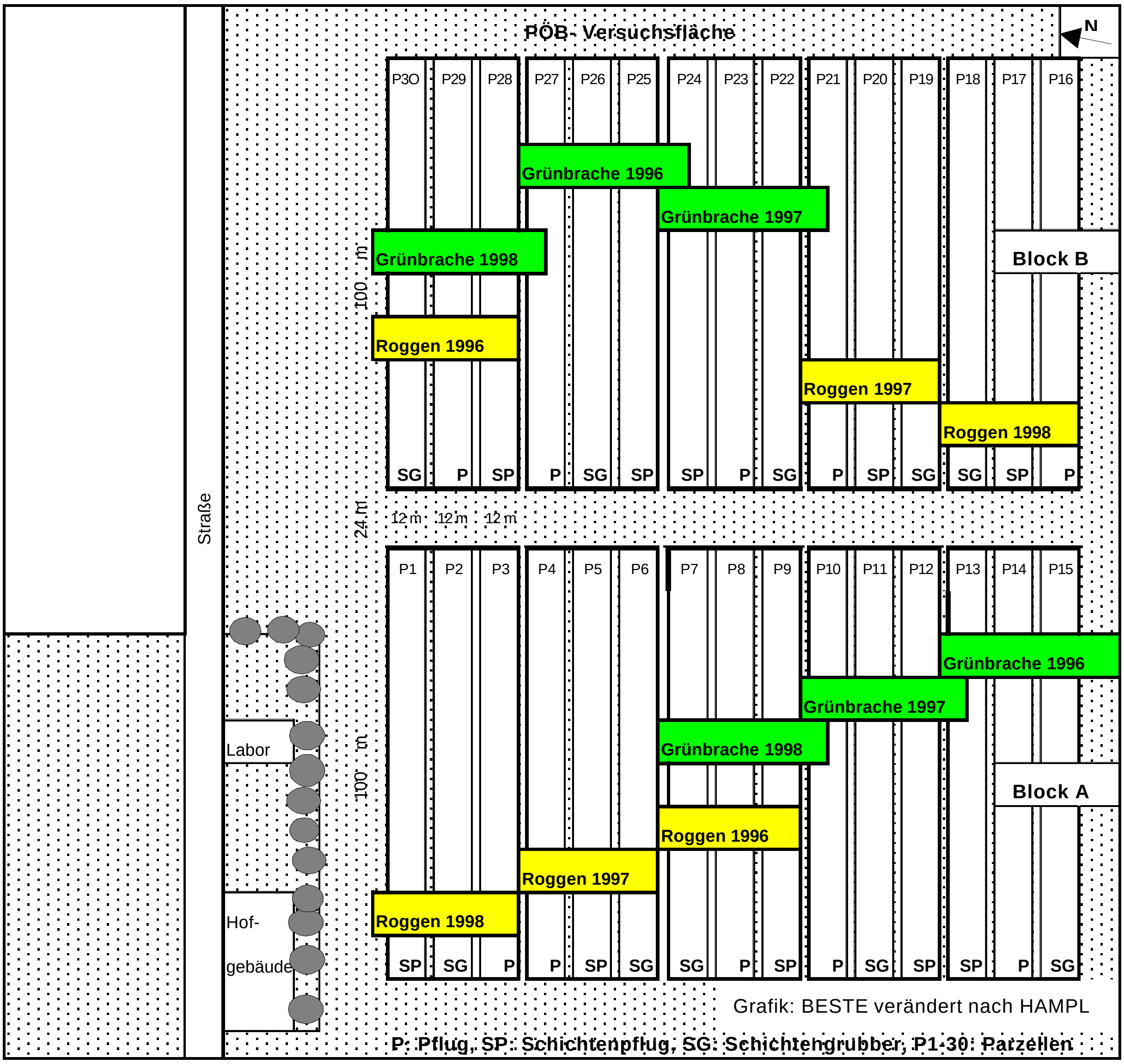
Fig. 8: Survey fields of the attempt approach 1

Tab. 4: Prehistory of the ecologically managed surfaces of the PÖB up to 1993

Measures	***Ecological management since 1994***	***Integrated management until 1993***
Fertilizing	Organic fertilizing (green fallow fertilizing, straw)	Mineral and organic fertilizing (NPK/pig liquid manure)
Tillage treatment	3 treatment variants, separately, in the summer in each case before green fallow or intercrop	Inverting and not inverting tillage according to the own decision, in the autumn
Rotation of crops	60% cereals, 40% leguminous (green fallow) and intercrops	80% cereals and 20% sugar beet, without intercrops (period: 1990-1993)
Weeds regulation	Mechanical, intercrops	Herbicides
Application of Biocides	no	
Fertilizing with animal excrements	no	(pig liquid manure)

(Source: HAMPL 1996 b and KUSSEL 1999)

Within the attempt approach 2 in each case in the years 1996, 1997 and 1998 the plots under green fallow and rye (two repetitions, for each three tillage variants) have been samples, whereby one rotated annually with the crops by plot to plot. The soil conditions were therefore changing according to the PÖB-Survey fields partly (particularly in the subsoil) (see fig. 9).



Versuchsfläche = Survey fields, Grünbrache = Green fallow, Roggen = Rye, P = Plough, SP = Two-layer plough, SG = Layer cultivator

Fig. 9: Survey fields of the attempt approach 2

3.3 Sampling

In chapter 2 on basis of the literature context and own scientific activities a fundamental estimate of the aptitude of the partial methods which are used within the ESD for a function-oriented soil evaluation was given. As a result of preliminary work (BESTE 1996) the reasons for changes in individual partial methods were described to the ESD. In the following a description of the version of the further developed partial methods which were used in the sampling of the presented work is given.

For the introduction of ESD the profile spade according to HAMPL/KUSSEL was used, which makes possible the bringing out of comparable soil bricks up to 40 cm depth. For the presented work each plot at four points were evaluated, measured and sampled in the horizons surface (0-1 cm), upper crumb (0-15 cm), lower crumb (15-30 cm) and subsoil (30-40 cm).

At a place, which is representative in relation to vegetation cover and surface for the condition of the plot to be examined, the profile spade is struck vertically into the soil. Before its open side one drives the flat spade into the soil (see fig. 10).

(Photo: HAMPL)

Fig. 10: Profile and flat spade in the soil

In front of the flat spade a small pit is dug and soil profile held by the profile and flat spades is taken out. With the flat spade as a table the profile can be placed on two diagnostic stands. The profile spade is carefully taken off (see fig. 11).

(Photo: HAMPL)

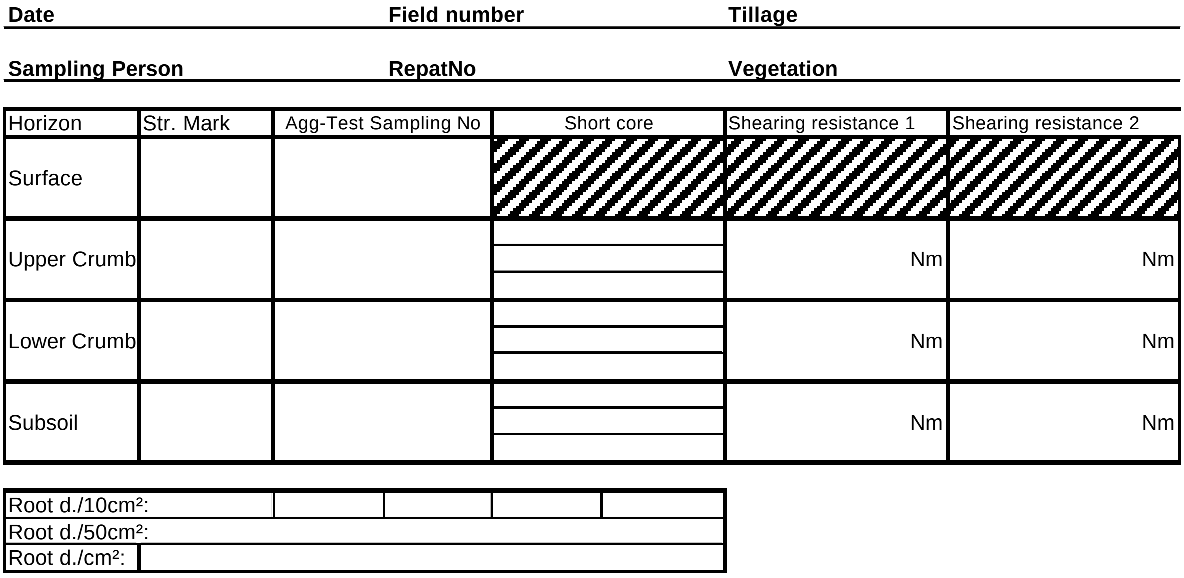
Fig. 11: Soil profile on the diagnostic stands, taking the profile spade off

The laterally disturbed areas are loosened with the help of a special, grobzinkigen "soil comb" carefully by the soil block, so that as natural a crumbling as possible is achieved. The centimeter marking appropriate at the "soil comb" facilitates the orientation with presenting on the block in the profile (see fig. 12).

(Photo: BESTE)

Fig. 12: Soil profile (to the left: upper crumb, middle: lower crumb, right: subsoil

At the soil profile now the rooting intensity in 40 cm depth is determined by means of root counting and a structure evaluation is made. After structure evaluation the aggregate samples for the silting test carefully are prepared out from the individual horizons. The short core samples for the analysis of soil moisture, pore volume and bulk density are taken from upper crumb, lower crumb and subsoil of the pit wall in the horizons. All evaluations, measurements and samplings are noted in the field record of the ESD (see fig. 13).



Date **Field number** **Tillage**

Sampling Person **RepatNo** **Vegetation**

Horizon	Str. Mark	Agg-Test Sampling No	Short core	Shearing resistance 1	Shearing resistance 2
Surface			▨	▨	▨
Upper Crumb				Nm	Nm
Lower Crumb				Nm	Nm
Subsoil				Nm	Nm

Root d./10cm²:				
Root d./50cm²:				
Root d./cm²:				

Fig. 13: Field record of the ESD

3.3.1 Structure evaluation

The structure evaluation was introduced with the version changed 1999 by BESTE:

Tab. 5: Structure evaluation for loamy soils (according BESTE 1996)

Layer	Appearance	Structure mark
	Rough, worm dropping, unite aggregates visible - not silted up, no crusts	**5**
	intermediate mark	4
Surface 0-1 cm	**Aggregates silted up, scarcely worm dropping, beginning crust-formation**	**3**
	intermediate mark	2
	Crusts, tears, aggregates silted up, surface sealed	**1**
	About 80 % crumbles, loose, in case of clayey soil: little polyeder, few middle sized fragments (4-5 cm)	**5**
	intermediate mark	4
Upper Crumb 0-15cm	**Mixed structure, containing crumbles (little polyeder) and fragments**	**3**
	intermediate mark	2
	Fragments and sharp-edged clods with smooth surface, scarcely crumbles	**1**
	Mixed structure, containing crumbles (little polyeder) and fragments	**5**
	intermediate mark	4
Lower Crumb 15-30cm	**Fragments and few sharp-edged clods with smooth surface**	**3**
	intermediate mark	2
	About 80 % sharp edged clods, higher part of distinct smooth surfaces, coherent structure	**1**
	Structure with high appearance of pores with middle sized fragments of rough surface or layering in coherent structure or typical undisturbed Loess structure in case of Loess-soil	**5**
	intermediate mark	4
Subsoil 30-40cm	**Structure with low appearance of pores, higher part of distinct smooth surfaces, big sharp-edged clods**	**3**
	intermediate mark	2
	Plat-like structure or coherent structure with low appearance of pores	**1**

The description of the soil fragments (crumb, crumbles, polyeder and fragments) is based on HASINGER (1993) (see tab. 6), whereby the term "fragment" was not assigned sharp-edged things "as such to", but was understood as a first neutral thing. And crumble the terms of fragments thereby for aggregates in the size area of centimeters are used.

In the case of the Structure evaluation it goes around the observation of the soil structure in the general context. The description of single aggregates is not the center of attention and is therefore less detailed than with the additionally accomplished particularly details Bonitur held of the morphology of the single aggregates (see chapter 3.3.2), which was made under the Binocular. The characteristic code used there was arranged only for this special investigation. The terms do not agree therefore partially with the Structure evaluation.

Tab. 6: Description of the soil fragments changed according to HASINGER (1993)

Term	**Diameter**	**Surface**	**Form**	**Factors of building up process**
Crumble	some millimeters	rough	irregular	biogeneous composed
Polyeder	some millimeters	smooth	edges	swelling and contraction
Fragments	generic term for aggregates in centimeter or decimeter size			
Crumbly fragments	< 5 centimeter	rough, rounded edges	irregular	composed from aggregates
Clods	decimeter	rough or smooth	with edges compact	swelling/contraction, mechanical treatment

3.3.2 Evaluation of the aggregate morphology of seaved aggregates

As one described in chapter 2.2, the biological activity of soils as a cause of aggregation can be taken into account better over a differentiated evaluation of the aggregating forms (restriction: sandy soils and skeleton soils). Therefore particularly an elevation of the aggregate morphology with eightfold enlargement by binocular was developed for this research work and was introduced before the aggregate stability test (see tab. 7). It should took part for clarification of the stabilization factors of aggregates and with good expressiveness simplified be incorporated into the methodology of the ESD.

Tab. 7: Evaluation scheme for the investigation of aggregate morphology with statistical codes

Form:	**Code F**	**Surface:**	**Code O**	**Pores:**	**Code P**
Polyeder	**1**	**smooth**	**1**	**none recognizably**	**0**
Plates	**2**	**roughly**	**2**	**scarcely**	**1**
Sub polyeder	**3**			**many**	**2**
Crumbles	**4**				
Internal structure:	**Code S**	**Signals of biogeneous building up:**	**Code B**		
coherently (regular matrix)	**1**	**no signals**	**0**		
aggregated (distinct built up)	**2**	**organic material, mucus or roots (visibly network)**	**1**		

3.3.3 Aggregate stability test on water stability

For the investigations of the aggregates samples are taken out of the horizons of the excavated profile block for the surface, upper crumb, lower crumb and subsoil. For the surface aggregates are sifted out from > 2 mm to < 3 mm and for the other horizons of aggregates from > 3 mm to < 5 mm. Per sample 40 aggregates were evaluated to their morphology and tested on water stability. This happens for the reasons specified in chapter 2.2 with current soil moisture. For the silting test aggregates were conveyed in two bowls with 20 cavities each with a tweezers and with the help of a pipette they were moistened carefully with rain water (optionally distilled water, see chapter 2.2). After a time of reaction of one minute the resulting aggregate fragments are distributed by short knocking at the bowl. The test on aggregate stability was standardized by the development of a silting evaluation with verbally defined silting images (BESTE 1997). The main silting stages 0, 1 and 2 keep thereby their importance (see fig. 14). With these calculation of percentage is done (see chapter 3.4).

stable, mark: 2
silting type 1: stable
st 2: big stable aggregate with some particles
st 3: shared into two aggregates

half silted, mark: 1
st 4: silted into middle sized aggregate particles
st 5: silted into little particles but stabilized with mucus

totally silted, mark: 0
st 6: totally silted into little particles
st 7: totally silted up, muddy water

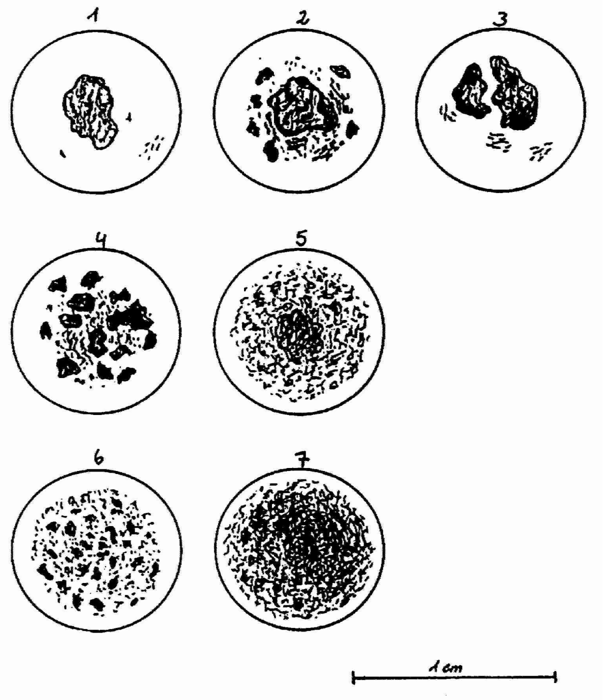


Fig. 14: Evaluation scheme of aggregate silting during water stability test (loamy soils)

3.3.4 *Root density*

At the lower surface of the freshly dug soil profile the root density is determined by means of root counting (see fig. 15).

Fig. 15: Root counting with stencil (Photo: HAMPL)

For the root counting on the lower edge of the soil brick in 40 cm depth (subsoil) a stencil with five windows à 10 cm^2 is used. Within the windows the number of withdrawing roots is counted with the magnifying glass and is then converted to the sum to a unit area of 1 cm^2.

3.3.5 Soil moisture, pore volume and bulk density

From the soil pits dug for the ESD per horizon, i.e. in 7 cm depth for the upper crumb, in 22 cm depth for the lower crumb and in 35 cm depth for the subsoil, three undisturbed soil samples are inferred. Short core samples with a volume of 20 cm^3 are pressed horizontally into the soil and then prepared out carefully. The fresh weight is still determined on the same day, in order to keep the evaporation losses small as possible. The soil moisture is determined with the gravimetric water content method. Over the decrease in weight, after drying the soil sample of defined volume at 105 °C, the driven out quantity of water and/or the water volume are determined. The pore volume is calculated from the firm ground material relative to the total volume depending on the density of compaction (here density of the soil db), with reference to (HARTGE and HORN 1992, P. 50 ff.):

Density of the soil (db) in $g \cdot cm^{-3}$ =

$$\frac{\text{Weight}_{\text{Entire sample}} - \text{Weight}_{\text{Water}}}{\text{Volume}_{\text{Short core}}}$$

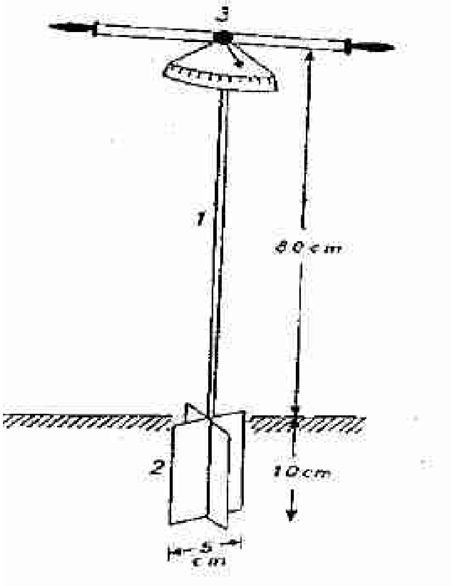
pore volume in % =

$$1 - \frac{\text{db}}{2.65} \times 100\%$$

In the ESD the undisturbed samples for the analysis of pore volume and bulk density from the soil moisture are taken by means of 20 cm^3 – short core samples, instead of as usual with 100 cm^3 –short core samples, in order to reduce the sampling expenditure. Comparative investigations with 100 cm^3 - short core samples did not show any differences in the results (BESTE 1996).

3.3.6 Shearing resistance

In direct proximity to the soil pit the ESD becomes with a wing drill, which is driven in each case into the soil up to the desired horizon depth, twice the shearing resistance is measured (see fig. 16).



1 = Steel shank
2 = Metal wings
3 = Torque wrenches with scale

(Source: SCHAFFER 1960)

Fig. 16: Shearing resistance measurer

By means of a put on torque wrench with measuring scale the maximum torque which is necessary for the overcoming of the shearing resistance of the soil is determined. It is indicated in Newton meters.

3.4 Statistics

The number of samples and number of individual values per examined plot for the different parameters are listed up in table 8. The number of repetition is two (block A and B).

Tab. 8: Measuring points and samples per plot

Parameters	*Measuring points per plot*	*Evaluatiosn/samples/measures per horizon*	*n per horizon per plot*
Structure mark	4	1	4
Aggregate stability and -morphologie	4	40 aggregates	160
Root density	4	1 (only subsoil)	4
Soil moisture, pore volume, bulk density	4	Attempt approach 1: 1 disturbed sample (only soil moisture)	4
		Attempt approach 2: 3 short core samples	12
Shearing resistance	8	1	8

The comparisons of the averages were computed with single factor based (soil depth, chapter 4.2.1) or multi- factorial analyses of variance (ANOVAS) made with the help of the statistics program SPSS for WINDOWS and a group assortment according to DUNCAN (with more than two factor stages). The comparison of the substrate (chapter 4.2.2) was made with simple t-Test. The exact number of cases entering into the statistical calculations in dependence of the factor combination and the factor stages as well as the statistical details of the analyses of variance and t-Tests are listed in the appendix for each analysis.

Examined factor variants for attempt approach 1 and 2:

1. Crop (attempt approach 1: 3 crop changes = year, equal plots; attempt approach 2: 2 crop types, each year, plot changes)
2. Tillage (3: plough, layer plough, cultivator)
3. Soil moisture classes (3: < 15%, 15-20%, > 20% soil moisture)
4. Block (2: blocks A and B)

The soil moisture provides factor stages in the classified form and can enter therefore likewise as an influence factor into the analysis (HOFFMANN 2000). The level of significance has been in each case $p < 0.05$. Significantly different averages of the examined groups are marked with different letters (a, b, c) in the tables (read line by line ones in each case).

From the structure marks simple averages are counted out for each group of comparison.

The value of aggregate stability in per cent for each sample refers in each case to the result of the 40 single aggregates tested per horizon and per sample. The maximally attainable stability value of a sample with the maximum mark "2" for each tested aggregate therefore amounts to 80. This value stands for 100% stability. The stability values achieved under it were set in per cent.

The aggregate morphology is compared by means of the meso-structure-variable "AGGRUPP3". This variable has a range of 1-3. The value 1 stands for polyedric, compact aggregates, the value 2 for aggregates of the type of sub polyeder and the value 3 for crumbly aggregates, according to the evaluation in table 6, chapter 3.3.2 and the classification of the aggregates in chapter 4.1. As more the average of the variable "AGGRUPP3" for an examined group is near to 3, the higher is the part of crumbly aggregates in the samples; the more close the value moves against 1, the higher is the part of polyedric, compact aggregates (see also fig. 18-21, chapter 4.1).

For the two most different of the three classified groups of aggregates types, the type of polyeder and the type of crumbles, (see chapter 4.1), was separately computed an analysis for the examined influence factor water stability. With the designation water stability is meant the evaluation of the silting tests marks (see fig. 14, chapter 3.3) for each individual aggregate (in each case "0" or "1" or "2"). The average for an examined group therefore lies between 0 and 2. The higher it is, the more aggregates were stable, the lower it is, the more the examined aggregates were unstable. Aggregation type of crumble and above all aggregation type of polyeder represent only relatively small part of the sample set (see fig. 21). Predominantly in the case of the survey of the stability of the type of polyeder it came therefore during the calculation of average values for the examined groups to partially lower *n*. This causes that the *n* for the calculations of the water stability of the crumbles and the water stability of the polyeder partly differ from the entire calculation population, (see table 14).

The bulk density is indicated with the counted average of g/cm $^{-3}$; also the shearing resistance in counted average of Newton meter (Nm).

For the root density the average is indicated in "number of roots per cm ^{2} ".

For the reason of the high amount of data one waived a presentation of the results for the surface. The structure characteristics of the surface are influenced usually strongly by the effect of precipitation and temperature, while the biological activity – which is emphasized on in this work - plays a smaller role. Under the green fallow cover the values of aggregate stability were usually higher than under rye (BESTE 1997 b, 1999) which SIEGRIST (1995) could discover similarly.

4 Results and discussion

4.1 Classification of the aggregates in type groups and test on stability

The evaluation of the aggregate morphology under the Binocular resulted in repetitive characteristic combinations. Based on the frequency of their appearing as well as on the basis of structural and ecological aspects the over 44000 single aggregates from the attempt approaches 1 and 2, examined for their morphology, were therefore summarized first into eight morphological distinguishable groups of type of aggregates, which surrendered from the observation. With the characteristics "FORM", "SURFACE" and "PORES" the samples could be ordered well into different types of characteristic (see fig. 17). As one can see from the correlation matrix (see tab. 9), the characteristic "INTERNAL STRUCTURE " could be sufficient described by means of the three abovementioned characteristics. The characteristic "SIGNALS OF BIOGENEOUS BUILDING UP" agreed again mostly with the type "MANY" of the characteristic "PORES" and the type "AGGREGATED" of the characteristic "INTERNAL STRUCTURE".

Tab. 9: Correlation matrix for the characteristics of the aggregate morphology

	FORM	***SURFACE***	***PORES***	***STRUCTURE***
FORM				
SURFACE	0.40 **			
PORES	**0.62 ****	0.31 **		
STRUCTURE	**0.62 ****	0.23 **	**0.80 ****	
SIGNALS OF BIOGENEOUS BUILDING UP	0.18 **	0.10 **	0.24 **	0.22 **

Aggregates of the horizons upper crumb, lower crumb and subsoil, n = 43348
** Level of significance of 0.01 (2-sides)

Main criterion of the ascending organization of the eight groups beside these overlapping characteristics were the morphological indications of biological activity. For example a rough surface permits a higher intensity at metabolic procedures on the basis of the extended surface. And the more pores an aggregate has (the more clearly it is built up, i.e. it is aggregated), the more micro habitats it shows for small organisms. Worm dropping as a clear product of biological activity represents an morphological exception. Worm dropping usually has an smooth surface and little to no pores, it is however a structure physiological positive indication of biological activity. It received therefore a special code and was assigned with the summary to the crumbles.

Description of characteristic of the eight groups of type:

1. Polyeder, smooth, no pores
2. Polyeder, smooth, few pores
3. Sub polyeder, smooth, no pores
4. Sub polyeder, smooth, few pores
5. Sub polyeder, roughly, few pores
6. Sub polyeder, roughly, many pores
7. Worm dropping
8. Crumbles, roughly, many pores

96 per cent of all cases is included by this group organization (see fig. 17).

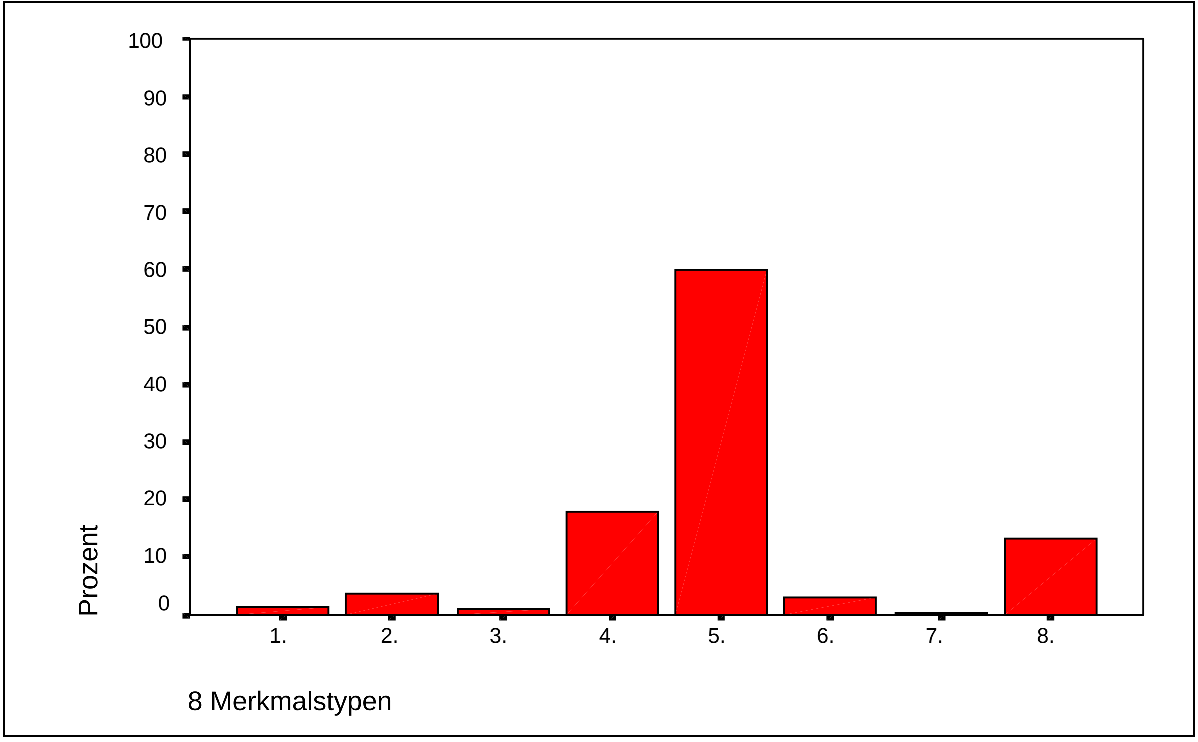


Fig. 17: Frequency of the eight types of aggregate groups

In order to be able to represent the functional important differences in the meso morphology more clearly, the eight types were summarized again in three groups of type, "type of polyeder", "type of sub polyeder" and "type of crumble". The following list contains the summary of the eight groups of type in three groups of type. The illustrations 18-20 show characteristic examples of aggregates to each group with Ø of 3 mm, magnified 8 times .

Type of polyeder

1. Polyeder, smooth, no pores
2. Polyeder, smooth, few pores

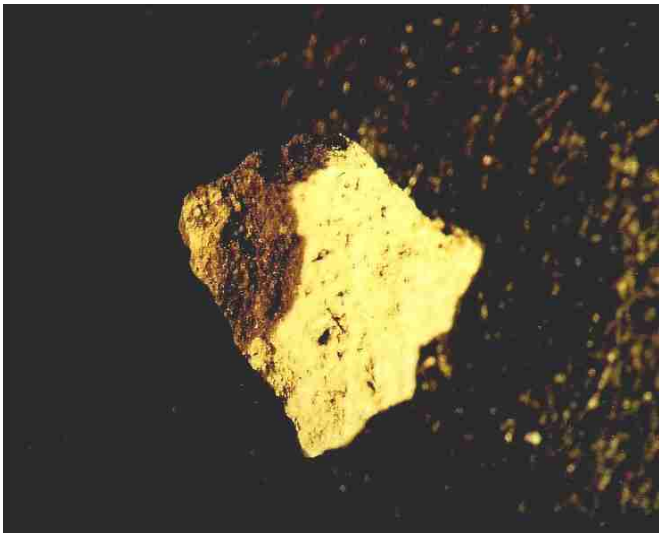


Fig. 18: Example: Polyeder, smooth, no pores , edges

Type of sub polyeder

3. Sub polyeder, smooth, no pores
4. Sub polyeder, smooth, few pores
5. Sub polyeder, roughly, few pores

Fig. 19: Example: Sub polyeder, smooth, few pores

Type of crumble

6. Sub polyeder, roughly, many pores
7. Worm dropping
8. Crumbles, roughly, many pores

Fig. 20: Example: Crumble, roughly, many pores

Illustration 21 shows the group sizes of the three groups of polyeder, sub polyeder and crumble.

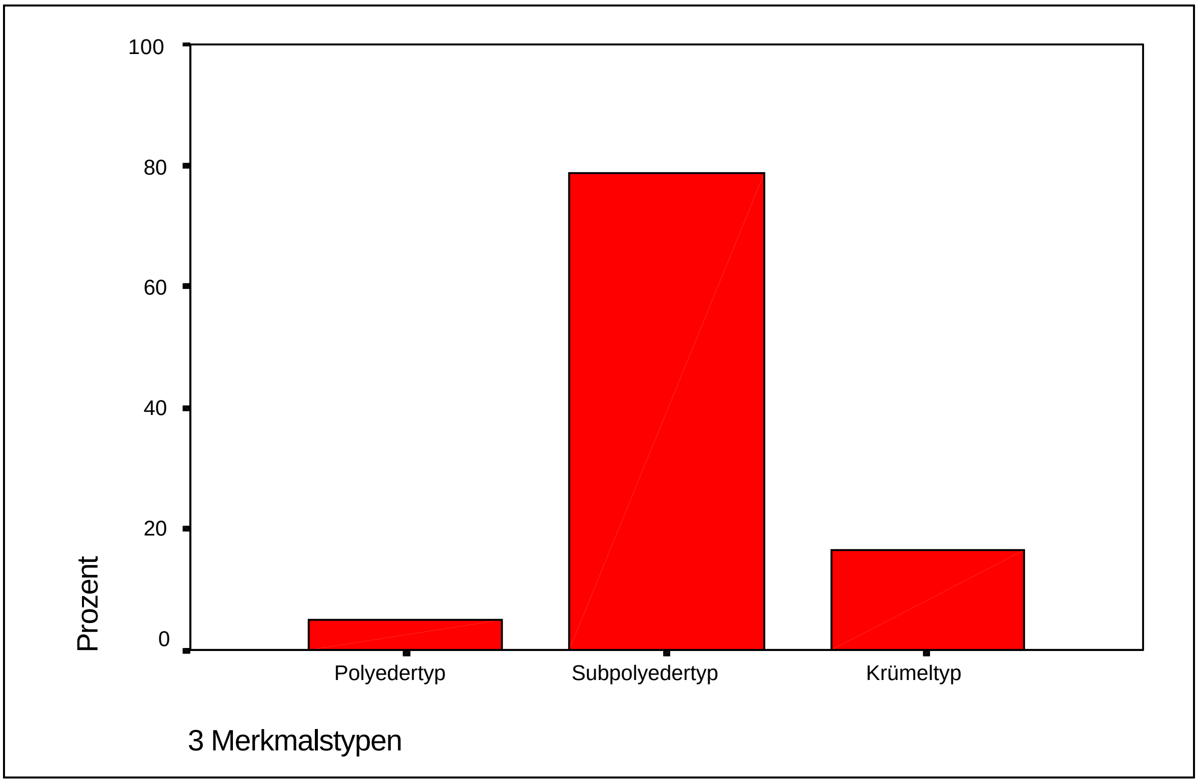


Fig. 21: Frequency distribution of the summarized three groups of type of aggregates

As in the classifying of the three groups (variable "AGGRUP 3") the quantitatively predominating part of aggregates is of the group of sub polyeder (characteristic code 2), crumbles (characteristic code 3) polyeder (characteristic code 1) show distinct smaller parts of the entire sample. This can be explained for the most part with the larger morphological description range of the characteristics for the type of sub polyeder. Whereas the type of polyeder with the definition "sharp edged" and "smooth" and the type of crumb with the definition "rough", “aggregated” and “”many pores” are very clearly specified under the term "FORM "of sub polyeder group there are several different classifications and combinations possible, beyond that several stages of the characteristics SURFACE ("smooth" and "roughly") and PORES ("none" to "little") are summarized on this type. This leads to the fact that this group represents a pool for relatively (compared with the two other groups) heterogeneous types of aggregates.

With the average of the variable "AGGRUP 3" as a structural indicator it is possible to gain a clear description of soil crumb, since a change of the average agrees well with the relation of the amount of type of crumbles to the amount of type of polyeder.

In order to clarify whether the morphological groups of type show in principle different stability, the aggregates (separately according to the attempt approaches 1 and 2) became tested according to groups of type on their stability. Attempt approach 1 with annual dynamics and crop change as well as attempt approach 2 without seasonal dynamics and crop change, but with soil changes (see fig. 8 and 9, chapter 3.2) show the same differences in the water stability of the groups of type among themselves. The stability characteristics behave from the type of polyeder over the type of sub polyeder to the type of crumb decreasing, whereby the differences between the groups are in each case significant (see tab. 10).

Tab. 10: Water stability (evaluation 0-2 *) of the groups of type, attempt approaches 1 and 2 [a]

	Type of polyeder	Type of sub polyeder	Type of crumble
Attempt approach 1, n = 24815	1.4 a	1.3 b	1.1 c
Attempt approach 2, n = 16118	1.4 a	1.2 b	0.9 c

* described as in chapter 3.3.3, tab. 6 and fig. 15

[a] calculation see appendix, tab. 2 and 3

4.2 Influence of differentiated observation- and local conditions on the parameters examined with the ESD

In order to be able to judge the influence of the management factors on the parameters of the ESD better, in-follow first the influence of the observation and local conditions soil depth, substrate and soil moisture on the parameters of the ESD is to be regarded more closely. The results - on the basis of the different plot situation, the soil units with attempt approach 2 (see fig. 8 and 9, chapter 3.2) and the different sampling dates represented with attempt approach 1 (soil moisture) - are presented separately according to attempt approaches. In chapter 4.4 the description of the results for the influence factors of the management follows (rotation of crops sequence, crop type comparison, differentiated tillage).

4.2.1 Soil depth

The comparison of the averages for the different soil horizons taken place with the help of a single-factorial analysis of variance. For this all factor variants and sampling dates of both attempt approaches entered into the calculations (see appendix, tables 4-7).

STRUCTURE MARK

Regarding the soil depth the subsoil achieves the upper area of the structure standard of valuation (average note 3,9). The averages for upper and lower crumb lie within the middle evaluation area (average note 3.4 - 3.6, see tab. 11) on the basis of the different evaluation scales of the horizons a test on significance is not appropriate. It remains to hold for both attempt approaches that the subsoil comes an optimal structure condition more closely than upper and lower crumb (tab. 11).

Tab. 11: Structure mark (1-5*) dependent on the soil depth, attempt approaches 1 and 2 [a]

	Upper crumb	*Lower crumb*	*Subsoil*
Attempt approach 1, n = 162	3.6	3.4	3.9
Attempt approach 2, n = 108	3.3	3.3	3.7

* as in chapter 3.3.1, tab. 5 described

[a] calculation see appendix, tab. 4 u.5

AGGREGATE STABILITY

Aggregate stability is on the average significantly higher in attempt approach 1 and 2 in the two upper horizons than in the subsoil (tab. 12).

Tab. 12: Aggregate stability (in% *) dependent on the soil depth, attempt approaches 1 and 2 [a]

	Upper crumb	*Lower crumb*	*Subsoil*
Attempt approach 1, n = 162	72.5 a	70.3 a	47.6 b
Attempt approach 2, n = 108	67.8 a	62.9 a	49.1 b

*% of max. attainable aggregate stability, as in chapter 3.3.3, fig. 15 ff and chapters 3.4 described

[a] calculation see appendix, tab. 4 and 5

AGGREGATE MORPHOLOGY

The averages of the variable of meso structure "AGGRUPP 3", in that the three groups of the aggregate morphology (polyeder - 1, sub polyeder - 2 and crumbles - 3), show a higher amount of crumbly aggregates significantly for attempt approach 1 in upper and lower crumb (the more closely the value lies to 1, the more polyeder; the more closely it lies to 3, the more crumbles became evaluated, see chapters 3.4 and 4.1) (tab. 13).

Tab. 13: Variable of meso structure "AGGRUPP 3" (1-3*) dependent on the soil depth, attempt approaches 1 and 2 [a]

	Upper crumb	*Lower crumb*	*Subsoil*
Attempt approach 1, n = 163	2.18 a	2.17 a	2.07 b
Attempt approach 2, n = 110	2.13	2.12	2.07

* described like in chapters 3.4 and 4.1

[a] calculation see appendix, tab. 6 and 7

WATER STABILITY OF POLYEDER AND CRUMBLE

The water stability (the more closely the value lies to 0, the aggregates silted more; the more closely it lies to 2, the more stable aggregates became evaluated) of the two groups of type is according to complete sample unit stability (see tab. 12) in the subsoil significantly lower. The group of the crumbles is altogether less stable thereby (tab. 14).

Tab. 14: Water stability (evaluation 0-2 *) of the groups of type dependent on the soil depth, attempt approaches 1 and 2 [a]

Attempt approach 1	*Upper crumb*	*Lower crumb*	*Subsoil*	***Attempt approach 2***	*Upper crumb*	*Lower crumb*	*Subsoil*
P, n = 140	1.71 a	1.59 a	1.25 b	P, n = 104	1.65 a	1.52 a	1.31 b
K, n = 162	1.24 a	1.16 a	0.81 b	K, n = 107	1.11 a	0.96 a	0.70 b

P = type of polyeder, k = type of crumb

* described as in chapter 3.3.3, tab. 6 and fig. 15

[a] calculation see appendix, tab. 6 and 7

BULK DENSITY, SHEARING RESISTANCEAND ROOT DENSITY

The only in attempt approach 2 raised parameter bulk density and shearing resistance show significantly rising values with increasing soil depth (tab. 15).

Tab. 15: Bulk density and shearing resistance dependent on the soil depth, attempt approach 2 [a]

n = 108	*Upper crumb*	*Lower crumb*	*Subsoil*
Bulk density in g cm^{-3}	1.28 a	1.32 b	1.39 c
Shearing resistance in Nm	32 a	67 b	118 c

[a] calculation see appendix, tab. 5

The root density was counted only in the subsoil and cannot be regarded therefore here differentiated.

4.2.2 Substrate

In order to be able to examine the influence of the substrate for the parameters, the samples were summarized in two groups of soil units. Group 1 unites samples of locations on Loess and Loess on Marl and group of 2 samples of locations on lime and clay marl. Regarding the comparison of the substrates all samples were charged to a group (all factor variants and sampling dates) as repetition. While in the case of attempt approach 1 both groups with the same amount of samples are represented (the in each year examined plots of the attempt approach 1 of the blocks A and B extend in each case to the half on both soil units, see fig. 6 and 8, chapter 3), the part of samples of the first and second soil unit with attempt approach 2 (the examined plots and thus the sampling locations rotated with the years over the attempt surface) varies, i.e. regarding the substrate (in attempt approach 2) the sample units are unequal largely (see fig. 6 and 9, chapter 3).

For attempt approach 2 the ESD (structure mark, aggregate stability, compaction and cutting off resistance) none of the parameters showed clear significant differences dependent on the substrate. The comparison of the detailed structural investigation (meso structure and stability of the groups of type polyeder and crumbles) provided weakly pronounced differences regarding the substrate with same tendencies as in attempt approach 1. The results for attempt approach 2 are to be found in the appendix in the tables 9 and 11.

STRUCTURE MARK

The group "Lime and Clay Marl" shows in attempt approach 1 in the lower crumb significantly and in the remaining horizons as tendency somewhat higher structure marks than the group of "Loess and Loess on Marl "(tab. 16).

Tab. 16: Structure mark (0-5*) as a function of the output substrate, attempt approach 1 [a]

n = 108	*Loess and Loess on Marl*	*Lime and Clay Marl*
Upper crumb	3.5	3.7
Lower crumb	3.2 a	3.5 b
Subsoil	3.8	3.9

* as in chapter 3.3.1, tab. 5 described

[a] calculation see appendix, tab. 8

AGGREGATE STABILITY

In the case of aggregate stability in per cent the difference between the two substrates is clearest. The group "Lime and Clay Marl" has significantly higher percentages of aggregate stability in attempt approach 1 than the group "Loess and Loess on Marl "(tab. 17).

Tab. 17: Aggregate stability (in %*) as a function of the output substrate, attempt approach 1 [a]

n = 108	*Loess and Loess on Marl*	*Lime and Clay Marl*
Upper crumb	69.2 a	75.9 b
Lower crumb	65.3 a	75.5 b
Subsoil	41.4 a	53.8 b

*% of max. attainable aggregate stability, as in chapter 3.3.3, fig. 14 ff and chapters 3.4 described

[a] calculation see appendix, tab. 8

AGGREGATE MORPHOLOGY

In the development of the meso structure there are no differences in attempt approach 1 and 2 dependent on the substrate (see appendix, tables 10 and 11). This means, none of the two substrates shows a meso structure with higher crumb content.

WATER STABILITY OF POLYEDER AND CRUMBLE

In the case of the Lime and Clay Marl samples polyeder and crumbles show as a tendency (significances are to be regarded with reservation because of the partially small differences) higher averages of water stability. This observation is more clearly developed (independently of significances with larger *n*) with the type of crumb as with the type of polyeder. The last shows a weaker influence of water stability by the substrates (tab. 18).

Tab. 18: Water stability (0-2*) of the groups of type as a function of the output substrate, attempt approach 1 [a]

		Loess and Loess over Marl	*Lime and Clay Marl*
Upper crumb	type of polyeder, $n = 432$	1.68	1.69
	type of crumb, $n = 1907$	1.10 a	1.23 b
Lower crumb	type of polyeder, $n = 277$	1.55	1.50
	type of crumb, $n = 1660$	0.94 a	1.26 b
Subsoil	type of polyeder, $n = 288$	0.77 a	1.05 b
	type of crumb, $n = 827$	0.75 a	0.91 b

* described as in chapter 3.3.3, tab. 6 and fig. 15

[a] calculation see appendix, tab. 10

4.2.3 Soil moisture

Despite comparable range and averages the soil humidity shows very different spectrum in attempt approach 1 depending on the sampling date, thus seasonally, (see appendix, tab. 12) (tab. 19).

Tab. 19: Ranges and averages of the soil moisture, attempt approaches 1 and 2

	Minimum	*Average*	*Maximum*
Attempt approach 1	7.8	17.2	29.9
Attempt approach 2	10.0	17.0	25.2

For attempt approach 2 all sampling dates and factor variants were included in the multi-factorial analysis of variance.

In order to be able to judge the influence of the entire soil moisture spectrum on the examined parameters in attempt approach 1, only the sampling of the years 1997 and 1998 were charged in a multi-factorial analysis of variance, because only in this years the three sampling dates March, May and July are represented (with the September date no annual repetition is present, therefore it remained outside forwards). In both years a comparable -distribution and amount of precipitation was present. The crops green fallow (1997) and winter wheat (1998) do not differ in the average of soil moisture in the upper crumb and lower crumb. The subsoil shows under winter wheat somewhat dryer values (see appendix, tab. 42). In the case of the investigation of the influence of soil moisture on the parameters of the ESD and the meso morphology in average of the two years 1997 and 1998 altogether, for attempt approach 1 seasonal effects (seasonally caused different soil moisture, plant growth, root growth, seasonal dynamics of the biological activity etc..) however could not be separated from the effect of different soil moisture. In order to clarify a possible connection between the different soil moisture of the individual samples and their evaluation and measurements in the parameters, for the attempt approach 1 additionally correlations of the soil moisture and the examined parameters of the ESD for the individual seasonally different sampling dates were calculated (on average of the two years).

For the variance-analytic calculation of the influence of the parameters of the ESD by the soil moisture, soil moisture classes were to be formed. For the description of the distribution of the soil humidity of attempt approach 1 and 2 an organization into three classes was proved to be meaningful: Class 1: < 15%, class 2: 15-20% and class 3: > 20%. For more differentiated grouping (for example five groups), the distribution of the values strewed too closely around the average This with five groups would have led to very unequal group sizes. So for the proving of the connection between soil moisture of the samples and parameter results for attempt approach 1 according to seasons could not be charged with these soil moisture classes in an analysis of variance, since for different sampling dates one or two classes do not show sufficient cases (in the upper crumb the values for the March sampling on average of the two years show a range of 19.6 up to 29.9% of soil moisture; for the July sampling on the other hand only a range of 12.4 up to 17.9% soil moisture).

Therefore correlations with the entire soil moisture spectrum for the respective sampling dates (for 1997-1998) were calculated for all samples. The results are found in the appendix under table 14 and 15.

STRUCTURE MARK

Attempt approach 1 shows in upper and lower crumb a clear rise in the structure marks in soil moisture class 3, over 20%. This means for upper and lower crumb better structure marks were assigned with high soil moisture. The subsoil does not show any different structure marks dependent on the soil moisture.

The average of structure marks of the attempt approach 2 are altogether lower and show a clearly smaller dependence on the soil moisture. The tendency to higher structure marks with soil moisture over 20% repeats however with the samples of the upper crumb. In lower crumb and subsoil no connection between soil moisture and structure mark exists in attempt approach 2 (tab. 20).

Tab. 20: Structure mark (1-5*) of the horizons dependent on the soil moisture, attempt approaches 1 and 2

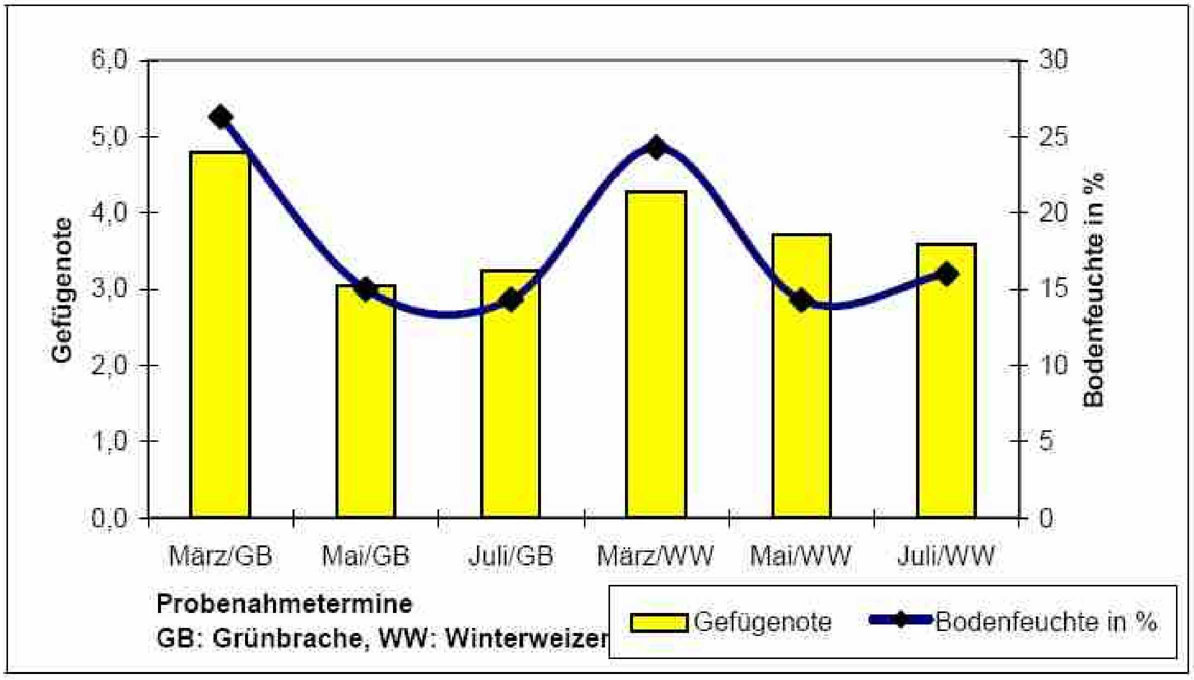
Attempt approach 1, n = 108	*< 15%*	*15-20%*	*> 20%*
Upper crumb	3.48 a	3.21 a	4.53 b
Lower crumb	3.20 a	3.32 a	3.65 b
Subsoil	3.92	3.80	3.85
Attempt approach 2, n = 108	*< 15%*	*15-20%*	*> 20%*
Upper crumb	3.30 a	3.03 a	3.95 b
Lower crumb	too few cases	3.29	3.15
Subsoil	3.33	3.67	too few cases

* as in chapter 3.3.1, tab. 5 described

[a] calculation see appendix, tab. 13 and 16

The calculation of the correlations for the individual samples resulted in a connection of soil moisture and structure mark in individual cases within the seasons, however no clear tendencies were brought out (see appendix, tables 14 and 15).

Figure 22 illustrates that in attempt approach 1 in the upper crumb the connection high soil moisture - high structure mark is clearly associated with the course of the annual dynamics. The entire soil moisture spectrum in average lies in March over 20%. The highest averages of soil humidity coincides in March 1997 and March 1998 with the highest averages structure marks.



GB = Green fallow, WW = Winter weat, Gefügenote = Structure mark, Bodenfeuchte = Soil moisture

Fig. 22: Soil moisture and structure mark in the upper crumb for the charged sampling dates 1997 and 1998, attempt approach 1

AGGREGATE STABILITY

In attempt approach 1 a significant decrease of aggregate stability becomes clear at values over 20% soil moisture in the upper and lower crumb. In attempt approach 2 the tendencies are equally, but not significantly (tab. 21).

Tab. 21: Aggregate stability (in% *) of the horizons dependent on the soil moisture, attempt approaches 1 and 2

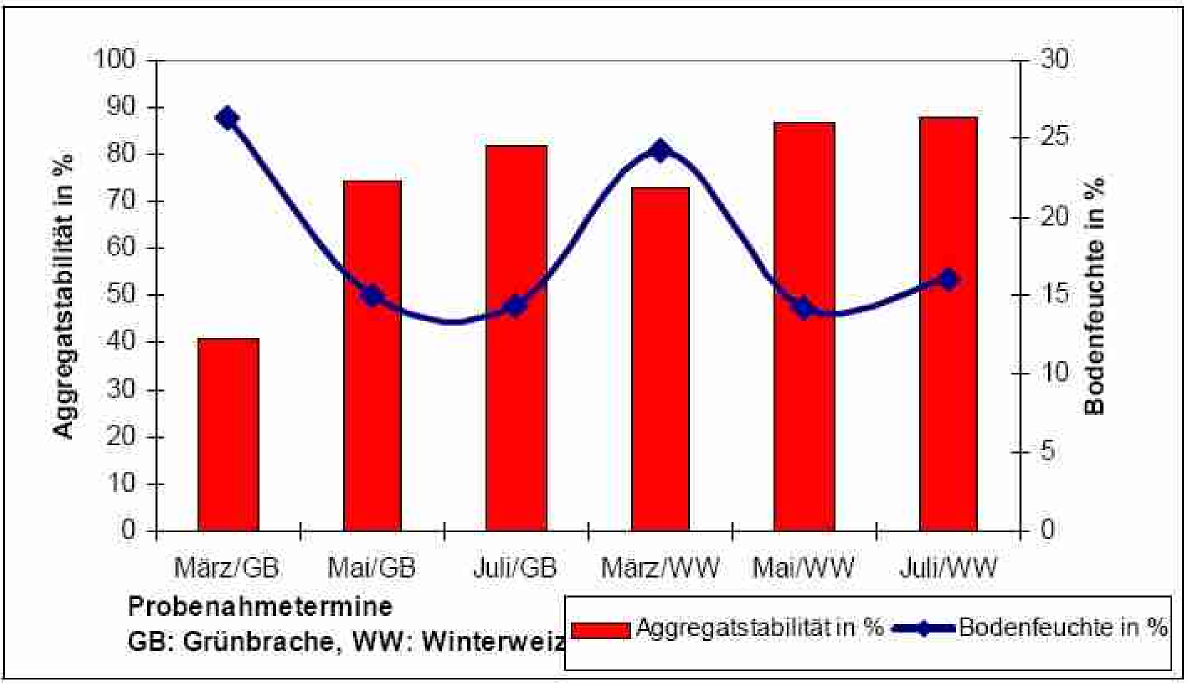
attempt approach 1, n = 108	*< 15%*	*15-20%*	*> 20%*
Upper crumb	82.4 a	83.7 a	57.0 b
Lower crumb	77.5 a	78.9 a	65.1 b
Subsoil	41.7	52.2	53.6
attempt approach 2, n = 108	*< 15%*	*15-20%*	*> 20%*
Upper crumb	70.7	69.8	66.5
Lower crumb	too few cases	65.0	55.6
Subsoil	46.0	49.4	too few cases

*% of max. attainable aggregate stability, as in chapter 3.3.3, fig. 15 ff and chapters 3.4 described

[a] calculation see appendix, tab. 17 and 18

The calculation of the correlations between the soil moisture spectrum within a season and the samples for aggregate stability resulted again only in individual cases a connection (see appendix, table 14).

When viewing the annual dynamics for the upper crumb it is remarkable that low values of aggregate stability in attempt approach 1 coincide again with the sampling dates with highest soil moisture in the spring (March) (fig. 23). This is likewise to be observed for the lower crumb (more weakly), but not for the subsoil (both not illustrated).



GB = Green fallow, WW = Winter weat, Aggregatstabilität = Aggregate stability, Bodenfeuchte = Soil moisture

Fig. 23: Soil moisture and aggregate stability (in %) in the upper crumb for the charged sampling dates 1997 and 1998, attempt approach 1

This means, in the biologically active horizons exists a stronger connection between seasonal micro-climatic situation in the soil (entire moisture condition - i.e. the averages of the soil moisture changing in the annual course) and aggregate stability (lower with very moist condition) as between samples of higher moisture or dryer samples of a certain seasonal sampling date and their aggregate stability.

AGGREGATE MORPHOLOGY

In both attempt approaches a tendency (significances with reservation) to an increased part of crumble aggregates is to be observed with soil humidity over 20% in the two upper horizons (tab. 22).

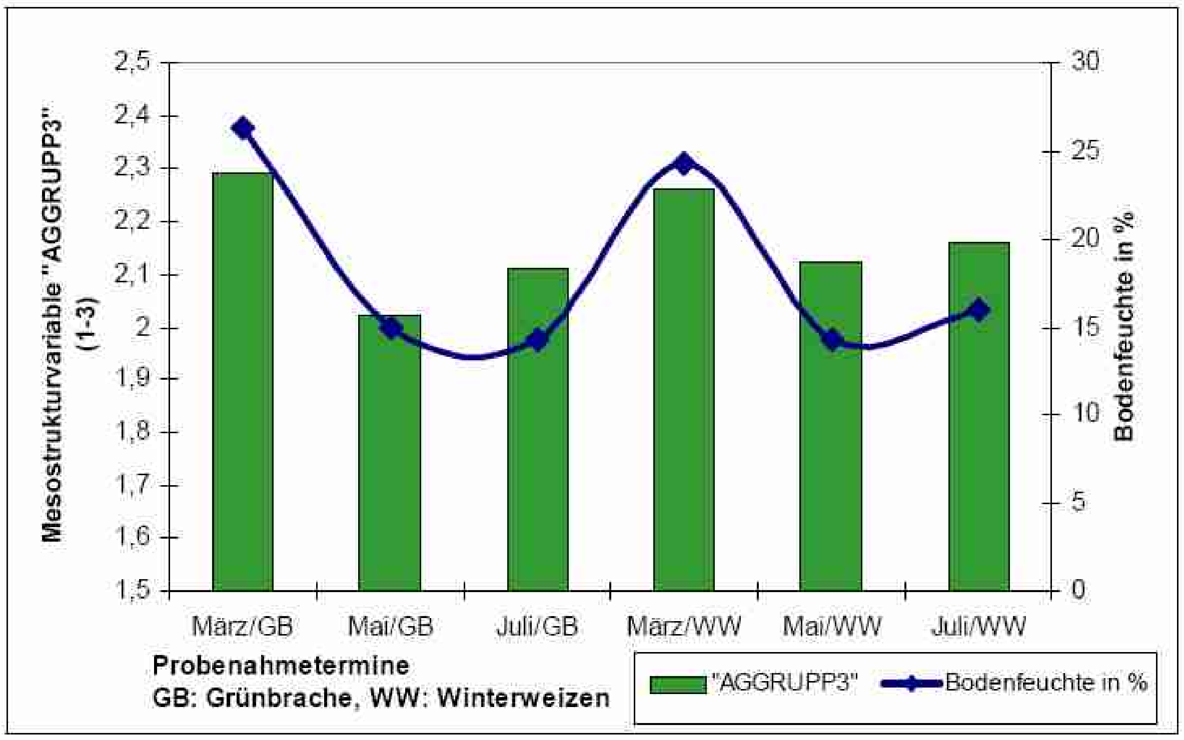
Tab. 22: Variable of meso structure "AGGRUPP 3" (1-3*) in the horizons dependent on the soil moisture, attempt approaches 1 and 2

attempt approach 1, n = 108	*< 15%*	*15-20%*	*> 20%*
Upper crumb	2.11 a	2.09 a	2.30 b
Lower crumb	2,1à	2.10 off	2.20 b
Subsoil	2.05	2.06	2.11
attempt approach 2, n = 110	*< 15%*	*15-20%*	*> 20%*
Upper crumb	2.02 a	2.08 a	2.31 b
Lower crumb	too few cases	2.06 a	2.52 b
Subsoil	2.0	2.0	too few cases

* described like in chapters 3.4 and 4.1

[a] calculation see appendix, tab. 19 and 20

In the case of calculation of the correlations an isolated connection (coefficient of correlation Referring Pearson: 0.16, for n = 1863, see table 15, appendix) between Variable of meso structure and soil moisture results for March in the upper crumb. The connection in the upper crumb strongly dependent on the season in figure 24 becomes again clear with the annual course of soil moisture and variable of meso structure (see fig. 24).



GB = Green fallow, WW = Winter weat, “AGGRUPP3” = Variable of meso structure, Bodenfeuchte = Soil moisture

Fig. 24: Soil moisture and variable of meso structure "AGGRUPP3" in the upper crumb for the charged sampling dates 1997 and 1998, attempt approach 1

WATER STABILITY OF POLYEDER AND CRUMBLE

Type of crumble and of polyeder reacts to soil humidity over 20% in the upper crumb with significantly decreasing water stability. In the case of type of crumble this tendency is also clear in the lower crumb. The type of polyeder does not show any connection in the lower crumb. In the subsoil a reversal of the weak tendency is to be observed (see tab. 23).

Tab. 23: Water stability (0-2*) of the groups of type in the horizons dependent on the soil moisture, attempt approach 1a

		< 15%	*15-20%*	*> 20%*
Upper crumb	type of polyeder $n = 34$	1.91 a	1.86 a	1.40 b
	type of crumb $n = 36$	1.39 a	1.45 a	0.96 b
Lower crumb	type of polyeder $n = 30$	1.74	1.74	1.73
	type of crumb $n = 36$	1.35	1.31	1.04
Subsoil	type of polyeder $n = 22$	1.40	1.42	1.65
	type of crumb $n = 35$	0.83	0.86	0.94

* described as in chapter 3.3.3, tab. 6 and fig. 15

[a] calculation see appendix, tab. 21 u.23

The stronger dependence of water stability on the soil moisture for the type of crumble also becomes clear in the correlation values (appendix, tab. 23), while the water stability of the type of polyeder does not show any connection with the soil moisture of the samples separated according to seasons (see appendix, tab. 21 and 23). In March the spectrum of the soil moisture lies predominately over 20%, which leads to negative coefficients of correlation for upper and lower crumb (the more highly the soil moisture the lower crumble stability). In the subsoil, as it has been observed with the analysis of variance already, a moving in opposite directions tendency becomes clear (here crumbles are more stable with soil humidity > 20%). The positive correlation in the lower crumb in July refers to a spectrum of soil humidity under 18%. In upper and lower crumb thus the tendency to lower water stability exists, if the soil moisture is over 20% and increasing water stability with increasing soil moisture, at values under 20%. In the subsoil a increase in water stability is to be examined with soil moisture over 20% as a tendency. The tendencies of the connection of crumble stability and soil moisture depend therefore strongly on the season (see tab. 24 and fig. 25).

Tab. 24: Correlation between soil moisture and crumble stability in the horizons separated according to seasons, attempt approach 1

n = 1920	*March*	*May*	*July*
Upper crumb	-0,11	/	/
Lower crumb	-0,30	/	+ 0.23
Subsoil	+ 0.25	/	/

For attempt approach 2 - without seasonal effects - no connection between soil moisture and the water stability of both groups of aggregate type is to be observed (tab. 25).

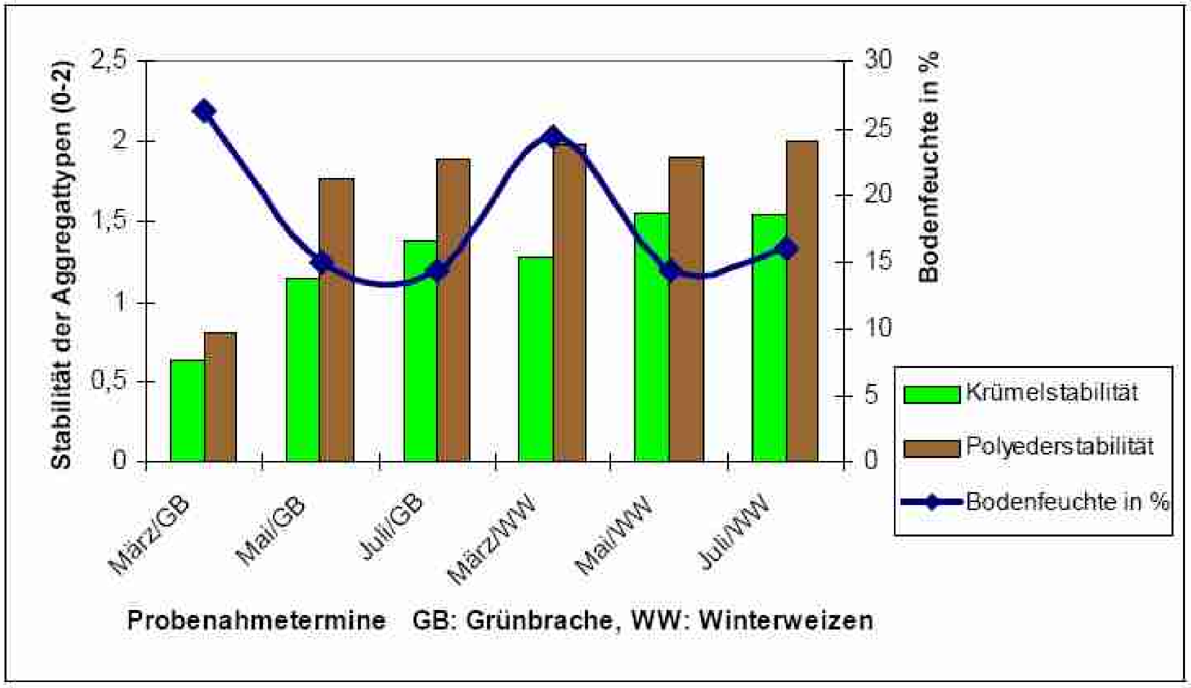
Tab. 25: Water stability (0-2*) of the groups of type in the horizons dependent on the soil moisture, attempt approach à

		< 15%	*15-20%*	*> 20%*
Upper crumb	type of polyeder *n* = 37	1.83	1.64	1.63
	type of crumb *n* = 38	1.10	1.10	1.18
Lower crumb	type of polyeder *n* = 35	too few cases	1.5	1.7
	type of crumb *n* = 35	too few cases	0.99	0.85
Subsoil	type of polyeder *n* = 32	1.23	1.33	too few cases
	type of crumb *n* = 34	0.57	0.71	too few cases

* described as in chapter 3.3.3, tab. 6 and fig. 15

[a] calculation see appendix, tab. 22 and 24

The water stability of the type of polyeder shows lower stability in attempt approach 1 in the upper crumb only in March 1997 with high soil moisture, then increases in stability stronger under green fallow and is to be registered during the investigation period (see chapter 4.4.1). The type of crumble shows depressions of stability to both appointments of high soil moisture (March 1997 and March 1998) (see fig. 25).



GB = Green fallow, WW = Winter weat, Krümelstabilität = Water stability of crumble, Polyederstabilität = Water stability of polyeder, Bodenfeuchte = Soil moisture

Fig. 25: Soil moisture and water stability of the groups of type in the upper crumb for the charged sampling dates 1997 and 1998, attempt approach 1

BULK DENSITY, SHEARING RESISTANCE AND ROOT DENSITY

Bulk density and shearing resistance (only measured in attempt approach 2) show no connection with the soil moisture (see appendix, tables 25 and 26).

The root density shows significantly different values for the soil moisture class lower 15% and the class 15-20%. In the class of higher soil moisture (15-20%) the average is lower (see tab. 26).

Tab. 26: Root density dependent on the soil moisture, attempt approach 2

n = 24	*< 15%*	*15-20%*	*> 20%*
root density per cm ^{2}	0.70 a	0.57 b	k.W.

k.W. = no values available

4.3 Discussion

4.3.1 Soil depth

With the soil depth light -, air and moisture- parameters and the nutrient offer in the soil change. Since the weight of soil column gets higher with soil depth the structure naturally is more compact. Soil flora and -fauna adapted on this natural differences in milieu (GISI 1997). In the upper horizons (depending on climate zone and vegetation in different depths) the biological activity is usually higher on the basis of nutrient -, water, and air offer (MUECKENHAUSEN 1993, KUNTZE/ROESCHMANN/SCHWERDTFEGER 1994, EMMERLING 1996, SCHINNER/SONNLEITNER1996 a). In the case of agriculturally used soils additionally a clear difference between tilled (in most cases up to 30 cm depth) and not tilled part of crumb exists (usually termed as subsoil). Beyond that different structure relationships in the crumb result from the employment of inverting, flat inverting or not inverting tillage techniques (FRANKEN/LOH 1986, TEBRÜGGE 1989, BÖHM et al. 1990, KANDELER et al. 1995, STOCKFISCH et al. 1995, SCHINNER/SONNLEITNER1996 b). The soil depth is therefore one of the largest influence factors for the spatial structural relationships and aggregate stability.

Regarding the soil depth the parameters structure mark, aggregate stability and aggregate morphology as well as the stability of the two morphological groups of type predominantly show clear differences for the individual soil horizons in attempt approach 1 and 2:

The structure marks are higher in the subsoil, aggregate stability and variable of meso structure show in the two upper horizons (upper and lower crumb) higher values, type of polyeder and type of crumble both show a higher stability in the upper horizons, the values of bulk density and shearing resistance rise with increasing soil depth (see tab. 11-15).

For the subsoil higher averages of **structure mark** were assigned than for the two upper horizons (see tab. 11). This is amazing first, since particularly in the upper horizons a good structure is aimed at. On the basis of the different value scales for the mark assignment of each horizon (see tab. 5, chapter 3.3.1) this meant that the upper horizons are more distant from their optimum of structure condition than the subsoil; it does not mean that the structure in upper and lower crumb is worse than in the subsoil. The subsoil on the survey fields altogether is in a good structure condition and shows any compaction tendencies (see BESTE 1996). The quality of soil structure of the subsoil as the horizon, which lies below the treatment border of tillage, is influenced particularly by the substrate and less or more indirectly by the biological activity or the crop management. The substrates Loess as Lime and Clay Marl which are present in the investigation area, developed in the present into a Grey Soil, which as type of soil is known for favourable structure characteristics (good porosity, good water restoring capacity, good crumble building). That applies also to the survey fields which are present here. The high marks for the subsoil show this. Beyond that in the last years under integrated management careful tillage can be stated (changes of inverting and not inverting treatment), which did not lead to plough soles (KUSSEL 1999). Upper and lower crumb as the horizons influenced more strongly by the management show after several years of ecological management still improvement prospects in the quality of soil structure. The optimal condition given for Loess in the structure evaluation (task condition for the note 5, see tab. 5, chapter 3.3.1) is not reached on average yet. Higher density of crumb areas in the tilled crumb are observed frequently in case of conversion to not inverting tillage (SUMMERS/ZACH 1992, KOELLER 1993). Two thirds of the samples of the survey fields 1 and 2 come from plots, which have been in conversion to not inverting tillage since 1994 (see fig. 8 and 9). This can explain, why in upper and lower crumb on average only structure marks in the middle area are reached.

Both higher **aggregate stability** and the higher values **of the variable of meso structure "AGGRUPP3"** (i.e. the higher amount of crumbly aggregates) in the upper horizons (see tab. 12 and 13) can be attributed predominately to the biological activity decreasing downward (MUECKENHAUSEN 1993, KUNTZE/ROESCHMANN/SCHWERDTFEGER 1994, EMMERLING 1996, GISI 1997).

The reversal conclusion - a larger number of crumbles causes a higher aggregate stability - is not permissible, because of the altogether smaller **stability of the type of crumble** in comparison with the other morphological types of aggregates (see tab. 10 and 14). Higher aggregate stability in the biologically more active horizons concerns all types of aggregates equally (see tab. 14) and is over the factor biological activity only to be brought in connection with a higher amount of crumbles. This factor can cause two different charakteristics: high aggregate stability by biological building of all groups of type of aggregates (see CHESTERS et al. 1957, LYNCH 1983, SCHINNER/SONNLEITNER1996 a) and high amount of crumble through biologically conditioned crumble building up (see TISDALL/OADES 1982, ANDERSON 1991, KANDELER/MURER 1993). From agricultural point of view the aim is a high aggregate stability with an as high a amount of aggregates of the type of crumble as possible.

The water stability of types of aggregates follows the row polyeder > sub polyeder > crumbles (see tab. 10). Referring KATSCHINSKI (1958) the water stability of mechanical compacted aggregates is the higher - by the large contact area of mechanical elements - the stronger the compaction is. This explains the higher water stability of sub polyeder and polyeder. On the basis of their granulated structure, crumbles are more susceptible to the disruption of the aggregate particles and the dissolving of water menisci by the water penetrating into the pores in comparison to polyeder and sub polyeder. These do not make possible a comparable quick entrance for the water cause of their closer, coherent structure. Referring KULLMANN/KOITSCH (1956) the lower stability of the type of crumble can additionally be explained with the following: In case of high soil moisture a frequent occurring of pseudo crumbles in the upper both horizons can be stated. KULLMANN (1958, S.10 ff) describes pseudo crumbles as "seeming crumbles" to be built up from smaller aggregates which are held together by capillary forces of menisci. Referring HAINES (1930) this is mostly the case, if the water content of the soil lies by 25%. This soil moisture is reached in the two upper horizons - particularly in the upper crumb - frequently (see appendix, tab. 27). Referring KULLMANN (1958), KATSCHINSKI (1958) and SEKERA (1984) there is a permanently effective dynamic between stabilization and destabilization of crumbles, which is influenced by several factors (moisture, temperature, biological activity, vegetation cover, manure, tillage). Thus crumbles can also quite be stable with given conditions (see chapter 4.4).

The bulk densities and shearing resistances show typical for arable land a rise to the subsoil not loosened by the tillage (see tab. 15). Altogether the here measured values of bulk density and shearing resistance are to be classified as to be low (see BESTE 1996). The tendency to less optimal structure conditions in the lower crumb, which is expressed in the averages of the structure mark, is not illustrated by these two measured parameters.

The appropriate indication of the differentiation of biological activity in the crumb horizons which is repeatedly measurable in PÖB and described in the literature (see MUECKENHAUSEN 1993, KUNTZE/ROESCHMANN/SCHWERDTFEGER 1994, EMMERLING 1996-1998, GISI 1997) could be confirmed with the parameters structure mark, aggregate stability and aggregate morphology by the results of the attempt approaches 1 and 2. The rise in bulk density and shearing resistance to the subsoil which has been additionally documented with the measuring of penetration resistance in PÖB (see HAMPL 1997) corresponds to the well-known and typical conditions in an arable crumb also (see GRUBER 1992, HARRACH/RICHTER 1992, EHRNSBERGER 1993, MUECKENHAUSEN 1993, KUNTZE/ROESCHMANN/SCHWERDTFEGER 1994, MUNKHOLM 1998)

4.3.2 Substrate

On the survey fields inhomogenities are present regarding the substrate. The examined fields lie partly in the area of Loess, partly in the area of Lime and Clay Marl in the underground. Both substrates do not show any large differences in particle size distribution and soil chemical characteristics (see appendix, tab. 29). Nevertheless small differences in clay and lime particle can cause different conditions for example for the stabilization of aggregates (CHESTERS et al. 1957, MUECKENHAUSEN 1993).

From the results it follows that the different substrates "Loess and Loess on Marl" and "Lime and “Clay Marl" have only a considerable influence with the parameter aggregate stability while the other parameters are not significantly influenced (see tab. 16-18).

The higher **structure marks** of the group „Lime and Clay Marl“(only in the lower crumb significantly) are probably due to the higher skeleton part of the substrate Lime and Clay Marl, which contributes to a looser structure (see tab. 16).

The meso morphology does not show any differences depending on different substrates, i.e. none of the two substrates causes a higher crumb particle (see appendix, tab. 10 and 11).

The higher **aggregate stability** of the "Lime and Clay Marl"-samples is caused by the higher lime content, combined with a slightly higher clay content (see tab. 17 and appendix, tab. 8). A support of aggregate stability by higher lime or clay contents was documented repeatedly in the literature (CHESTERS et al. 1957, CZERATZKI 1957, SCHACHTSCHABEL/HARTGE 1958, DUTZLER-FRANZ 1977, MULLA et al. 1992, ROTH 1996).

The smaller influence **of the water stability of the type of polyeder** by the different substrates (see tab. 18) confirmed again the thesis of KATSCHINSKY (1959) that polyeder - on the basis of its morphological density - are already extremely stable and therefore less influenced by the substrate. However referring MUECKENHAUSEN (1993) and AG BODENKUNDE (1994) with higher clay content a more frequent building up of polyeder is known, which could not be observed here at the results of the Variable of meso structure. With a higher polyeder particle of the Lime Clay Marl samples the meso structure variable would have had to decrease (polyeder/crumbles relationship higher) in comparison to the Loess and Loess on Marl samples.

As it is described above generally the lower **water stability of the crumbles** in relation to the type of polyeder (see tab. 9) is more strongly influenceable by the differences in lime and clay content of the substrates. Which could bee observed with the higher water stability of the crumbles in the "Lime and Clay Marl"-group (see tab. 18).

In the case of the influence factor substrate the dynamic parameter aggregate stability reacts more sensitively to the (chemico-physical) differences as the soil-physical measurements of **Bulk density and shearing resistance**, whose averages in this survey show no differences depending on substrate (see appendix tab. 9).

4.3.3 Soil Moisture

Soil moisture is a substantially influencing factor for both physical and biological soil evaluation parameters. Physically it takes over swelling and contraction effects, formation of water menisci and reduction of friction resistance, and biologically over the change of the habitat conditions for soil life and its activity influence on the parameters structure mark, aggregate stability, aggregate morphology, stability of the groups of type, compaction and shearing resistance. The soil moisture itself depends again on precipitation and temperature and thus on the seasons - but also on the vegetation cover. The range of the measured soil moisture from attempt approach 1 (March, May and July) and attempt approach 2 (May) goes from just under 8% to just under 30% in attempt approach 1 and from 10% up to 25% in attempt approach 2. In the case of the three different sampling dates of attempt approach 1 however in each case very different spectra of soil moisture are present in the three-annual average (example three-annual average upper crumb March: 19,6-29,9%; July: 12,4-17,9%).

In case of soil moisture over 20% higher structure marks are present, combined with lower aggregate stability and a distinct more crumbles in meso structure (only in attempt approach 1 significantly). Shearing resistance and bulk density do not show any different values, dependent on the soil moisture. The root density is higher with lower soil moisture (see tab. 20-26).

The observations of the higher **structure marks** (see tab. 20), of lower **aggregate stability** (see tab. 21) and clearly higher m**eso structure values** (see tab. 22) in case of soil moisture over 20% can be explained with a precipitous increase of the part of pseudo crumbles in each case at the particularly damp spring date (March, spectrum of soil moisture > 20%, see appendix tab. 12 and 27) (see HAINES 1930, KULLMANN/KOITSCH 1956, KULLMANN 1958). On the basis of high soil moisture crumble-like aggregate are building up over menisci, which contribute to a porous, i.e. good spatial, structure as described under 4.2.4.1, (high structure mark, see tab. 20). The meniscus tension in case of high soil moisture is thereby however very weakly (HARTGE 1987) and the biological activity and thus stabilization of the aggregates in March is still on a low condition at the same time (SCHINNER/SONNLEITNER1996 a). The aggregates which can be addressed quite as crumbles, are however in a most unstable condition. That causes a high structure mark and a higher value for the meso structure variable because the structure is very loosely, well porose and crumbly and one find good conditions for biological processes. However these "pseudo crumbles" are extremely susceptible against silting, therefore they show low aggregate stability against water (and pressure load - the farmer knows that from spring-moisten soils). For comparison: in the case of pure frost influence (in biologically little active soils) larger particles of polyedric aggregates would be present (MUECKENHAUSEN 1993). The structure is then less porous, but relatively stable against water silting since polyeder with relatively high soil moisture still are stable against water silting (in tendency confirmed in tab. 24 and 25). In this case in March the reverse condition is present. The structure is to be evaluated as crumbly and therefore positive, however it is very susceptible to water silting and pressure load.

In case of the results of the attempt approach 1 the influence of the soil moisture on the parameters is not to be separated from the annual dynamics. There are above all seasonal effects of the moisture budget and the soil ecosystem altogether, which lead to different values of the parameters with different soil moisture. Correlations of samples and soil moisture within a season are to state nearly only in March with the stability of the group of the crumbles (since the soil moisture spectrum lies altogether over 20% soil moisture (see appendix tab. 23 and tab. 12) and the factor biological activity compared with the other two sampling dates (May and July) has still smaller effect (SCHINNER/SONNLEITNER1996 a).
Attempt approach 2 shows a very much smaller influence of the soil moisture on the parameters since the annual dynamics is excluded here. The observations from attempt approach 1 apply however equally to upper crumb:
Soil humidity over 20% goes here accordingly with better **structure marks** (see tab. 20), tendency of decreasing **aggregate stability** (see tab. 21) and a more crumbly m**eso structure** (see tab. 21 and 22).
In the case of **bulk density and shearing resistance**(only measured in attempt approach 2, see appendix, tab. 25 and 26) not any statistically secure influence by soil humidity over 20% is to be observed. By DUMBECK (1986) with field capacity (for loamy soil around 30%) a general reduction of the shearing resistance is described. This soil humidity is not present with the samples examined here.

In the case of the parameter **root density** a higher value of the root density parallel to smaller soil moisture contents (< 15%) was observed (see tab. 26). KÖNEKAMP and ZIMMER

(1954) could likewise observe this effect and attributed it to a somewhat "prospecting for water" –activity with dryer soil conditions.

It remains to hold that in the case of soil humidity over 20% a clear change of the structure condition both spatial-optical (impression of a crumbly loose aggregate structure) and regarding the stability characteristics against water (very susceptible to silting process) must be expected. From practice the bad over drive conditions of soils with high spring soil moisture is known. For the sampling for structure evaluation this condition as an extreme condition must be taken into account. In principle it is to be held that in the case of increasing soil moisture particularly in the upper crumb an increase of crumbly aggregates can be expected.

Reciprocal effects of the soil moisture with the crops green fallow and winter wheat and/or green fallow and rye which were examined in the analyses of variance (see appendix, tab. 13.,17 and 23) are however not allocatable with the existing values. Averages and spectrum of the soil moisture classes are almost unanimous under both crops (see appendix, tab. 42) and thus cannot be responsible for differences regarding the parameters. Both factors carry however to that a part of the explanation of the variance, in the way their significant or tendentious influence on these parameters has been discussed in 4.5.1 and 4.5.2.

4.4 Influence of different management measures on the parameters examined with ESD

4.4.1 Crop rotation summer barley, green fallow, winter wheat

The calculation of the crop rotation effects of summer barley 1996, green fallow 1997 and winter wheat 1998 was made with the data of the sampling dates May and July for the three years. Thereby on the one hand the sampling date March influenced strongly by the soil moisture is excluded. On the other hand only the sampling dates May and July are available for all three crops. The calculation taken place in a multi-factorial analysis of variance. Additionally to the factor crop the factors tillage (see chapter 4.4.3) and soil moisture have been put into the calculation.

STRUCTURE MARK

In the upper crumb the structure mark increases regularly from summer barley over the following green fallow to winter wheat. The lower crumb behaves accordingly in tendency but shows however no significant change. In the subsoil a lighter decrease from summer barley to green fallow and an increase to winter wheat again is to be state (see tab. 27).

Tab. 27: Structure marks (1-5*) of the horizons in the crop rotation

n = 108	*Summer barley 1996*	*Green fallow 1997*	*Winter wheat 1998*
Upper crumb	2.60 a	3.15 b	3.64 c
Lower crumb	3.09	3.25	3.33
Subsoil	3.90 a	3.70 off	4.00 b

* as in chapter 3.3.1, tab. 5 described

[a] calculation see appendix, tab. 30

AGGREGATE STABILITY

Aggregate stability increases in the horizons upper and lower crumb highly significantly over the rotation of crops. The increase is clearly higher from summer barley to green fallow than that from green fallow to winter wheat. In the subsoil only an increase under green fallow is to be observed, under winter wheat the value decreases again (see tab. 28).

Tab. 28: Aggregate stability (in %*) of the horizons in the crop rotation [a]

n = 108	*Summer barley 1996*	*Green fallow 1997*	*Winter wheat 1998*
Upper crumb	61.4 a	78.2 b	87.4 c
Lower crumb	55.1 a	73.5 b	83.8 c
Subsoil	34.3 a	54.8 b	43.5 off

*% of max. attainable aggregate stability, as in chapter 3.3.3, fig. 15 ff and chapters 3.4 described

[a] calculation see appendix, tab. 31

AGGREGATE MORPHOLOGY

The values of the variable of meso structure "AGGRUPP3" are high in the upper crumb under summer barley and lowest under green fallow in the year after. Then a significant increase under winter wheat is to be registered. In the lower crumb the value under green fallow is likewise lower than under summer barley, it does not change under winter wheat then any more significantly. In the subsoil only under green fallow a increase is to be observed, under winter wheat it is dropping again (tab. 29).

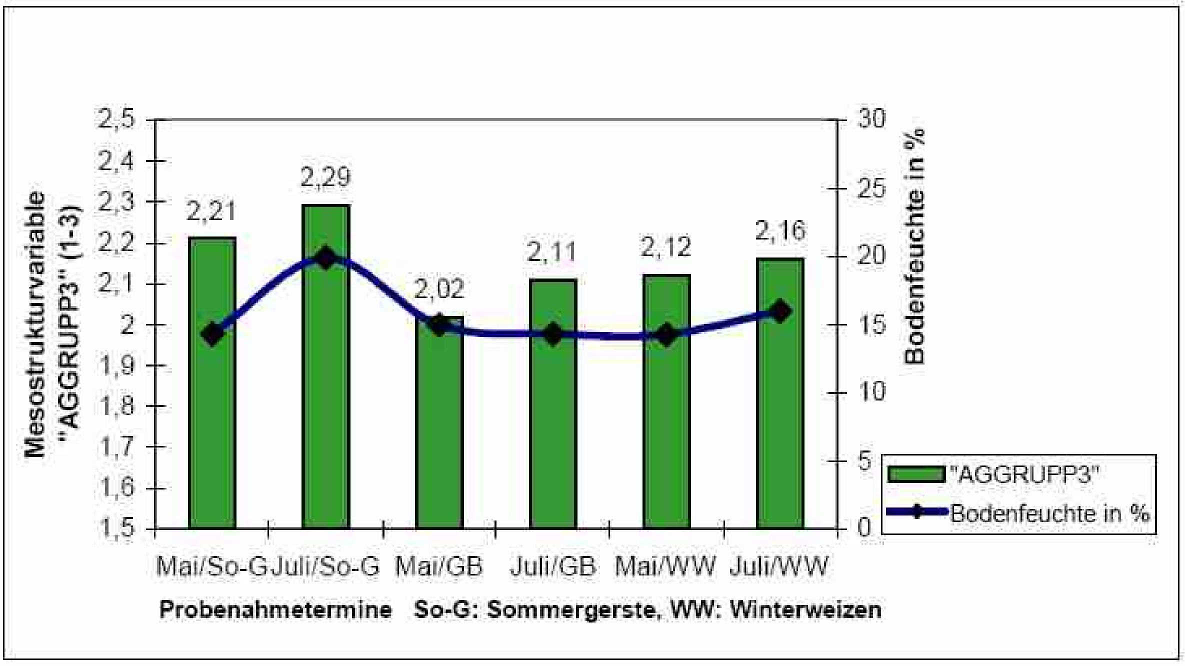
Tab. 29: Variable of meso structure "AGGRUPP3" (1-3*) of the horizons in the crop rotation [a]

n = 108	*Summer barley 1996*	*Green fallow 1997*	*Winter wheat 1998*
Upper crumb	2.25 a	2.07 b	2.14 c
Lower crumb	2.26 a	2.10 b	2.11 b
Subsoil	2.10 a	2.26 b	2.11 a

* described like in chapters 3.4 and 4.1

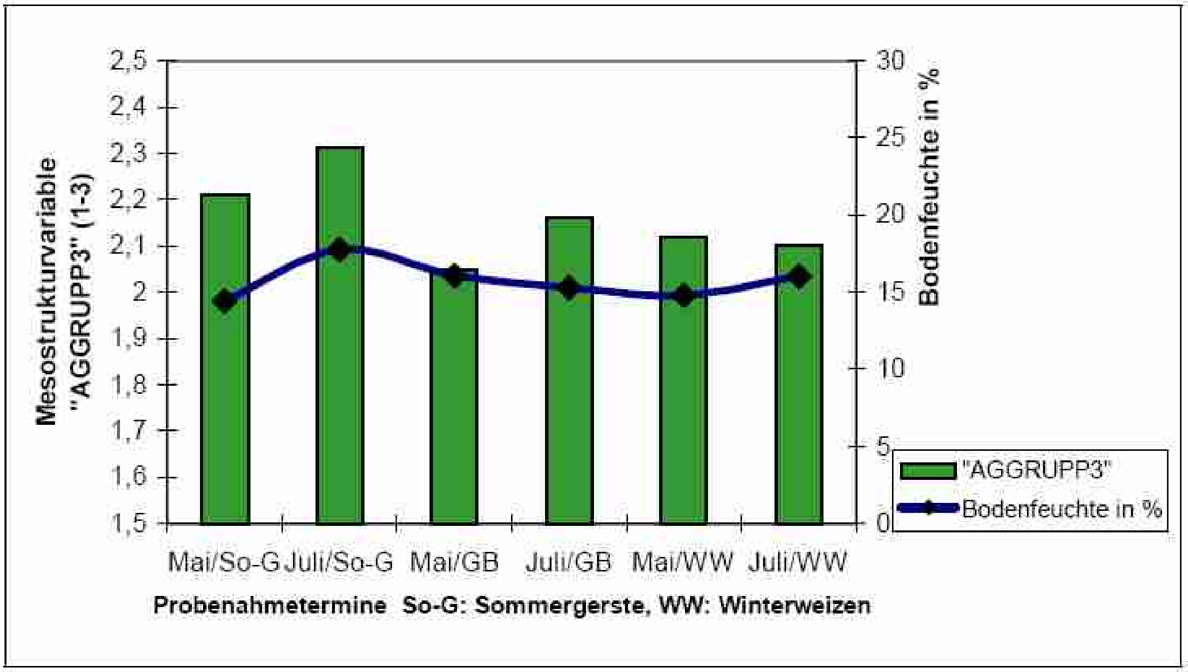
[a] calculation see appendix, tab. 32

The low value of the variable of meso structure in upper and lower crumb under green fallow does not correspond first to the expectations of a structure with higher part of crumble under the regeneration crop green fallow. With the differentiated observation of the values of the 6 sampling dates entered for the analysis of the crop rotation the dynamics of the meso structure becomes more interpretable. After high values in July 1996 under summer barley a strong depression of the average is to be observed in upper and lower crumb in May 1997 under green fallow. Then an increase in both horizons under green fallow is to be registered, in the which continues in the upper crumb to winter wheat and again reached the level of May 1996. In the lower crumb after the increase under green fallow and after a constant value under winter wheat in May then a decrease of the value until July is to be observed (see fig. 26 and 27).



So-G = Summer barley, GB = Green fallow, WW = Winter weat, “AGGRUPP3” = Variable of meso structure, Bodenfeuchte = Soil moisture

Fig. 26: Soil moisture and variable of meso structure "AGGRUPP3" at the 6 sampling dates of the crop rotation in the upper crumb



So-G = Summer barley, GB = Green fallow, WW = Winter weat, “AGGRUPP3” = Variable of meso structure, Bodenfeuchte = Soil moisture

Fig. 27: Soil moisture and variable of meso structure "AGGRUPP3" at the 6 sampling dates of the crop rotation in the lower crumb

In the comparison with the course of the soil moisture at the same sampling dates it is clearly to be seen that the peek of the average of the variable of meso structure in July 1996 under summer barley gets together with a peek in the soil moisture, which is not repeated at the other two July dates 1997 under green fallow and 1998 under winter wheat. The lowest point of the variable of meso structure in May 1997 under green fallow beside a smaller soil moisture is probably caused by the tillage preceded in August 1996, which was made within the investigation period on the plots of the attempt approach 1 only at this time.

WATER STABILITY OF THE GROUPS OF TYPE

The stability of the individual groups of type is in each case signficantly higher under green fallow than under summer barley. The type of crumble shows beyond that in upper and lower crumb also under winter wheat another significant increase in water stability. The group of the polyeder under winter wheat shows no more significantly higher value after the increase under green fallow (tab. 30).

Tab. 30: Water stability (0-2*) of the groups of type in the horizons for the crop rotation

		Summer barley 1996	*Green fallow 1997*	*Winter wheat 1998*
Upper crumb	type of polyeder *n* = 36	1.5 a	1.8 b	1.9 b
	type of crumb *n* = 36	1.1 a	1.3 a	1.6 b
Lower crumb	type of polyeder *n* = 34	1.1 a	1.6 b	1.9 b
	type of crumb *n* = 36	0.9 a	1.2 b	1.4 c
Subsoil	type of polyeder *n* = 29	0.7 a	1.6 b	1.2 b
	type of crumb *n* = 35	0.6 a	1.0 b	0.7 off

* described as in chapter 3.3.3, tab. 6 and fig. 15
[a] calculation see appendix, tab. 33 and 34

4.4.2 Crop type comparison green fallow and winter rye

For the comparison of the crop types green fallow and winter rye the data of the attempt approach 2 were computed with the factors tillage and soil moisture in a multi-factorial analysis of variance.

STRUCTURE MARK

The structure mark is significantly higher in the lower crumb under green fallow than under rye. In the remaining horizons the tendency is equally, but not statistically secure (see tab. 31).

Tab. 31: Structure mark (1-5*) of the horizons in the crop type comparison winter rye and green fallow

n = 108	*Green fallow*	*Rye*
Upper crumb	3.59	3.19
Lower crumb	3.29 a	3.08 b
Subsoil	3.63	3.59

* as in chapter 3.3.1, tab. 5 described

[a] calculation see appendix, tab. 16

AGGREGATE STABILITY

Aggregate stability in the lower crumb is significantly higher under green fallow than under rye. The tendency is again in the other two horizons equally, however not significantly secure (see tab. 32).

Tab. 32: Aggregate stability (in% *) of the horizons in the crop type comparison winter rye and green fallow

n = 108	*Green fallow*	*Rye*
Upper crumb	72.1	63.9
Lower crumb	69.8 a	55.2 b
Subsoil	52.4	45.6

*% of max. attainable aggregate stability, as in chapter 3.3.3, fig. 15 ff and chapters 3.4 described

[a] calculation see appendix, tab. 18

AGGREGATE MORPHOLOGY

The meso structure does not show any significantly higher part of crumbles for one of the two crops in all horizons (see tab. 33).

Tab. 33: Variable of meso structure "AGGRUPP 3" (1-3*) of the horizons in the crop type comparison winter rye and green fallow

n = 108	*Green fallow*	*Rye*
Upper crumb	2.13	2.12
Lower crumb	2.15	2.21
Subsoil	2.06	2.05

* described like in chapters 3.4 and 4.1

[a] calculation see appendix, tab. 20

WATER STABILITY OF THE GROUPS OF TYPE

The stability of both groups of type is in tendency, but not significantly higher under green fallow than under rye (tab. 34).

Tab. 34: Water stability (Evaluation 0-2 *) of the groups of type in the horizons in the crop type comparison winter rye and green fallow

n = 108		*Green fallow*	*Rye*
Upper crumb	type of polyeder, *n* = 35	1.71	1.63
	type of crumb, *n* = 36	1.15	1.06
Lower crumb	type of polyeder, *n* = 35	1.61	1.49
	type of crumb, *n* = 35	1.14	0.76
Subsoil	type of polyeder, *n* = 32	1.41	1.20
	type of crumb, *n* = 34	0.76	0.62

* described as in chapter 3.3.3, tab. 6 and fig. 15

[a] calculation see appendix, tab. 22 and 24

BULK DENSITY, SHEARING RESISTANCE AND ROOT DENSITY

Bulk density and shearing resistance are in tendency, but not significantly lower under green fallow in all horizons than under rye. The root density does not show any significant differences between green fallow and rye (tab. 35).

Tab. 35: Bulk density, shearing resistance and root density in the horizons in the crop type comparison winter rye and green fallow

n = 108	*Green fallow*	*Rye*
Bulk density in g ·cm $^{-3}$, Upper crumb	1.25	1.31
Bulk density in g ·cm $^{-3}$, Lower crumb	1.31	1.36
Bulk density in g ·cm $^{-3}$, Subsoil	1.38	1.41
Shearing resistance in Nm, Upper crumb	26.1	37.8
Shearing resistance in Nm, Lower crumb	61.7	74.8
Shearing resistance in Nm, Subsoil	116.5	119.7
root density per cm ^{2} in the Subsoil, n = 24	0.63	0.56

[a] calculation see appendix, tab. 25.,26 and 28

4.4.3 Effects of the differentiated intensity of tillage

For the comparison of the tillage variants all sampling dates of the three years 1996-1998 for both attempt approaches (attempt approach 1: altogether 9 and attempt approach 2: altogether 3) became computed in two multi-factorial analyses[2]. The description of the results is made again separately according to the attempt approaches 1 and 2.

STRUCTURE MARK

The structure marks do not show any statistically secure differences for the three tillage variants in attempt approach 1 and 2 in all horizons (tab. 36).

Tab. 36: Structure mark (1-5*) of the horizons dependent on the tillage variants, attempt approaches 1 and 2 [a]

Attempt approach 1, n = 162	*Cultivator*	*Layer plough*	*Plough*
Upper crumb	3.5	3.8	3.5
Lower crumb	3.3	3.4	3.4
Subsoil	3.9	3.9	3.8
Attempt approach 2, n = 108	*Cultivator*	*Layer plough*	*Plough*
Upper crumb	3.4	3.4	3.2
Lower crumb	3.3	3.2	3.3
Subsoil	3.7	3.7	3.6

* as in chapter 3.3.1, tab. 5 described

[a] calculation see appendix, tab. 16 and 36

AGGREGATE STABILITY

Aggregate stability shows clear differences between the tillage variants. The values in the upper and lower crumb of the not inverting (cultivator) and flat inverting (layer plough) variant are higher as those of the inverting variant (plough) (significantly for attempt approach 1). In the Subsoil this relationship in both attempt approaches turns. This observation is not however statistically secure (tab. 37).

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[2] The factor crop has been put into the analysis of variance but for reciprocal effects it is not interpretable however on the basis of the different sampling dates for each crop and therefore cause the different group sizes.

Tab. 37: Aggregate stability (in %*) of the horizons dependent on the tillage variants, attempt approaches 1 and 2 [a]

Attempt approach 1, n = 162	*Cultivator*	*Layer plough*	*Plough*
Upper crumb	78.2 a	73.1 b	66.2 c
Lower crumb	74.9 a	71.1 a	65.0 b
Subsoil	46.2	47.6	49.0
Attempt approach 2, n = 108	*Cultivator*	*Layer plough*	*Plough*
Upper crumb	72.6	68.8	62.1
Lower crumb	65.1	65.1	58.8
Subsoil	45.0	49.7	52.5

*% of max. attainable aggregate stability, as in chapter 3.3.3, fig. 15 ff and chapters 3.4 described

[a] calculation see appendix, tab. 18 and 37

AGGREGATE MORPHOLOGY

In the upper crumb the the meso structure does not show any differences in both attempt approaches for the tillage variants. It shows a significantly higher value for plough in the lower crumb in attempt approach 1 compared with the layer plough. In the subsoil and in attempt approach 2 totally no differences are to be discovered (tab. 38).

Tab. 38: Variable of meso structure "AGGRUPP 3" (1-3*) in the horizons dependent on the tillage variants, attempt approaches 1 and 2 [a]

Attempt approach 1, n = 162	*Cultivator*	*Layer plough*	*Plough*
Upper crumb	2.18	2.17	2.18
Lower crumb	2.17 off	2.12 a	2.22 b
Subsoil	2.04	2.08	2.09
Attempt approach 2, n = 108	*Cultivator*	*Layer plough*	*Plough*
Upper crumb	2.12	2.14	2.10
Lower crumb	2.14	2.10	2.13
Subsoil	2.07	2.08	2.06

* described like in chapters 3.4 and 4.1

[a] calculation see appendix, tab. 20 and 38

WATER STABILITY OF THE GROUPS OF TYPE

The water stability of both groups of type similar to complete unit stability points out (partially significant) the tendency to lower values with the inverting variant (plough) in both attempt approaches in the horizons compared with the inverting (cultivator) or flat inverting variant (layer plough) (see tab. 39).

Tab. 39: Water stability (0-2*) of the groups of type in the horizons dependent on the tillage variants, attempt approach 1 and 2

Attempt approach 1		*Cultivator*	*Layer plough*	*Plough*
Upper crumb	type of polyeder *n* = 52	1.68 a	1.82 b	1.61 a
	type of crumb *n* = 54	1.42	1.18	1.13
Lower crumb	type of polyeder *n* = 48	1.66	1.63	1.48
	type of crumb *n* = 54	1.26	1.16	1.07
Subsoil	type of polyeder *n* = 39	1.22	1.37	1.21
	type of crumb *n* = 53	0.86	0.79	0.84
Attempt approach 2		*Cultivator*	*Layer plough*	*Plough*
Upper crumb	type of polyeder *n* = 35	1.60	1.76	1.62
	type of crumb *n* = 36	1.22 a	1.11 off	0.93 b
Lower crumb	type of polyeder *n* = 35	1.63	1.48	1.45
	type of crumb *n* = 35	0.98	1.03	0.87
Subsoil	type of polyeder *n* = 32	1.18	1.48	1.28
	type of crumb *n* = 34	0.78	0.65	0.68

V1 = attempt approach 1, V2 = attempt approach 2

* described as in chapter 3.3.3, tab. 6 and fig. 15

[a] calculation see appendix, tab. 22.,24.,39 and 40

BULK DENSITY, SHEARING RESISTANCE AND ROOT DENSITY

The bulk density does not show any significant differences between the tillage variants in the horizons (see tab. 40).

Tab. 40: Bulk density, shearing resistance and root density in the horizons dependent on the tillage variants, attempt approach A2

n = 108	*Cultivator*	*Layer plough*	*Plough*
bulk density in g ·cm ^{3}, Upper crumb	1.27	1.25	1.30
bulk density in g ·cm ^{3}, Lower crumb	1.34	1.31	1.32
bulk density in g ·cm ^{3}, Subsoil	1.43	1.34	1.39
Shearing resistance in Nm, Upper crumb	31.1	33.5	32.1
Shearing resistance in Nm, Lower crumb	76.2	67.7	58.5
Shearing resistance in Nm, Subsoil	117.1	114.8	120.6
root density in cm ^{2} in the Subsoil, n = 24	0.61	0.60	0.59

With the shearing resistance no significant differences between the tillage variants are to be observed likewise. The inverting variant (plough) shows a lower value in the lower crumb than the not inverting (cultivator) and flat inverting variant (layer plough). In the case of the transition of lower crumb into the subsoil with the plough is to be noticed a more extreme increase in the shearing resistance, which is typical for plough treatment, while the transition into the subsoil with the other two tillage variants is less extremely.

The root density in the subsoil shows no significant differences between the variants likewise.

4.5 Discussion

4.5.1 Crop rotation summer barley, green fallow, winter wheat

The green fallow in an ecological crop rotation performs several tasks, which both directly and indirectly support the development of the soil structure (see HAMPL 1995 c, SCHNEIDER/EMMERLING/SCHROEDER 1995). It provides an increase of the biodiversity in the system and as green manure for the supply of nutrients (above all C and N). By the vital building up of the soil structure with roots the technically loosened structure condition is stabilized directly. Under green fallow therefore in attempt approach 1 in the case of equal substrate an improved structural condition of the topsoil was expected (see fig. 8, chapter 3.2)

The crop rotation effect of green fallow on structure mark, aggregate stability and water stability of the groups of type is clear and predominately highly significant:

After summer barley a higher structure mark and an increase of aggregate stability until winter wheat are to be observed under green fallow, while the variable of meso structure shows the lowest values - and thus a smaller part of crumbles - under green fallow. Tested on their stability aggregates of the type of crumble show a significant stability increase under green fallow, likewise until winter wheat. Aggregates of the type of polyeder only under green show fallow a increase in stability. This remains high right away then under winter wheat (see tab. 27-30).

With the increase **of the structure mark** under green fallow (see tab. 27) the vital building up of the preceded loosened (tillage) structure by the various rooting is understandable (see HAMPL 1995 c).

Aggregate stability likewise clearly increases under green fallow. This effect still is going on to under the subsequent crop winter wheat (see tab. 28). HOEVELMANN/FRANKEN (1993) could also observe an increase in aggregate stability until the subsequent crop sugar-beets after clover. Soil organisms are stimulated (see AICHINGER 1995 et al., HÖFLICH 1996) and the microbial activity is increased by root secretions and root decomposition of the leguminous based mixture (see KANDELER et al. 1995). This provides building up of the structure and the stabilization of aggregates (see VASILU 1958, KANDELER/MURER 1993, AICHINGER et al. 1995, SCHNEIDER/EMMERLING/SCHROEDER 1995).

The values **of the meso morphology** show at first unexpectedly lower values under green fallow (see tab. 29). As implemented in chapter 4.3.3 already, a pronounced seasonal dynamic of the up and dismantling of crumbly, porous aggregates results in connection with the soil moisture - particularly in the upper crumb. With pulling apart that seasonal sampling sequence becomes clear that that peek of the variable of meso structure "AGGRUPP3" in July 1996 under summer barley, before green fallow effect, in upper and lower crumb gets simultaneous with a strong peek of soil moisture. Therefore it can be lead back with large probability to already mentioned strong formation of pseudo crumbles with high soil moisture (over 20%) (see fig. 28 and 29). The in comparison low values of the variable of meso structure in July 1997 and July 1998 without high soil moisture underline that. This effect additionally increases the high average value of the variable of meso structure under summer barley. The strong character of the depression of the variable of meso structure in May 1997 under green fallow might, beside well-known biological aggregate building and destabilization processes during the winter (decrease of part of type of crumble, see SLATER/HOPP 1951, ZACHARTSCHENKO 1956, CZERATZKI 1957, SCHACHTSCHABEL/HARTGE 1958, HOEVELMANN/FRANKEN 1993) with simultaneous frost aggregate building (increase of part of type of polyeder, see MUECKENHAUSEN 1993) and the lower soil moisture under green fallow compared with the soil moisture in the same period under barley (see appendix to also attribute tab. 41) in this case be caused by the preceded tillage in August 1996and thus destruction of existing crumbles (see VASILIU 1958). The examination of the reciprocal effects between crop rotation and tillage resulted in a decline of the variable of meso structure after the tillage. This was particularly strong with treatment of plough (see appendix, tab. 35). In May 1998 - without disturbance by tillage - under winter wheat in the upper crumb an equal situation is to be observed to July 1997 (green fallow) instead of a depression and in the lower crumb the depression in May 1998 is likewise more weakly as in the year before (see fig. 28 and 29). From May until July 1997 under green fallow with the increase of the values of the variable of meso structure in upper and lower crumb a building up of crumbly aggregates is to be registered, which reaches the level of May 1996 in the lower crumb in July 1997 nearly again (at May 1996 however particularly high on the basis of high soil moisture).

The water stability of the groups of type shows, like structure mark and complete unit stability, clearly higher values under green fallow, whereby the increase in the water stability of the type of crumble still goes on to under the subsequent crop (see tab. 30). Here it can be assumed carefully that the green fallow effect contributes not only to an increased building up of crumble, but also to a relatively durable crumble stabilization.

The view of the stabilization of the aggregates and that after the tillage late beginning building up of crumbles under green fallow in the crop rotation to under the subsequent crop emphasizes the necessity to combine the intervention of the tillage with structure-regenerating intercrops or green fallow (see HAMPL 1995 c).

Reciprocal effects between tillage and soil moisture in the upper crumb for the parameter aggregate morphology, cannot be explained by an examination of the soil moisture for the tillage variants. The upper crumb with cultivator treatment shows is somewhat higher moisture compared with plough treatment (see tab. 44, appendix), this goes however neither with significantly higher nor lower values of the variable of meso structure with cultivator compared with plough in the DUNCAN-Test (tab. 45, appendix) in the analysis of variance (see appendix, tab. 32).

4.5.2 Crop type comparison green fallow and winter rye

While with the crop rotation barley, green fallow, winter wheat the effects of the green fallow cannot be compared under equal annual conditions, with the comparison green fallow and rye in attempt approach 2 (see fig. 9, chapter 3.2) equal annual conditions are given. However an influence by non-homogenous substrate and the annually taking place field change is present in attempt approach 2. In attempt approach 2 no dynamic development of the structure condition is evaluated but the structure condition under two different crops at equal sampling date.

the expected stimulation of the biological activity under green fallow Compared with rye could be analyzed with the used parameters.

Higher aggregate stability is accompanied by a clearly better structure condition (structure mark) in the lower crumb under green fallow. The remaining values show likewise particularly in the lower crumb according to this tendency a better and more stable structural condition under green fallow compared with rye: Tendency to higher variable of meso structure, higher stability of the groups of type as well as lower bulk density and shearing resistance(see tab. 31-35).

Comparable results described also VASILIU (1958), KANDELER/MURER (1993), AICHINGER et al. (1995) and SCHNEIDER/EMMERLING/SCHROEDER (1995) for aggregate stability and structure and beside this for shearing resistance and compaction BESTE (1996) and HAMPL (1995 b).

The differences turn out however less distinctly as expected. The results of chapter 4.2.3 show a frequent connection between increased average of the variable of meso structure and high soil moisture particularly in the seasonal soil moisture dynamic. This effect with the comparison of the crop types green fallow and rye (attempt approach 2, sampling in each case only in May 1996-1998) however not carries. A weather-related different soil moisture of the respective year affects both crops at the same time in attempt approach 2. A contribution to the explanation of the altogether lower than expected values of aggregate stability and the variable of meso structure under green fallow can again be supplied by the time lag to the in each case in August preceded tillage before green fallow. The distance for last tillage is shorter under green fallow (9 months) as under rye (21 months). Also VASILIU (1958) could observe that this technically intensive intervention affects first destroying of the naturally built and mechanically relatively loosely connected crumb aggregates. Additionally artificial aggregates of the type of polyeder (in the strict sense segregates) are formed by smashing of larger units during the tillage - like mentioned in 4.3.3.1 in case of plough treatment even more strongly.

The sampled green fallow plots in attempt approach 1 and 2 are 1997 in each case the same. The diagrams of the sampling dates of the variable of meso structure in chapter 4.4.1 (fig. 28 and 29) show a strong depression in May 1997 under green fallow after the tillage (what has been taken place in August 1996), which directly is followed by an increase of value still under green fallow up to July 1997.

Completing, a comparison of the soil condition under green fallow and rye regarded exclusively in May is too isolated in order to show the clear impacts of the green fallow on the soil regeneration particularly with unequal distance to preceded tillage and different sampling locations intensified by the field change. These clear impacts are better shown in the view of the crop rotation (attempt approach 1) with more uniform soil conditions and higher number of sampling dates in their temporal development (see chapter 4.4.1).

In the case of the direct, simultaneous comparison of the soil condition under green fallow and rye it must be stated that a better structural condition is in tendency given under green fallow, but it is not clearly developed.

4.5.3 Effects of the differentiated intensity of tillage

The tillage represents a strongly disturbing intervention into the soil ecosystem. With 30 cm depth of inverting a stronger disturbance of the soil biocenosis was repeatedly observed than with not inverting treatment (see FRIEBE 1995, HAMPL 1995 b).

The tillage variants show in second until fourth year of the survey time of the Project Ecological Soil Management little to hardly statistically secure differences:

Structure mark, aggregate morphology, stability of the groups of type as well as bulk density and shearing resistance hardly show significant differences dependent on the tillage variants. Exclusive the aggregate stability shows for the not inverting variant (cultivator) in upper and lower crumb a significantly higher value than for the inverting variant (plough) (see to tab. 36-40).

The different inverting intensity became clear by the different shifting of organic material and the differently strong disturbance of biological factors in **the aggregate stability**, which decreases with the intensity of the inverting in upper and lower crumb significantly (see tab. 37). This can be explained with the stronger disturbance of biological processes with increasing inverting intensity (see HOEVELMANN/FRANKEN 1993, KOELLER 1993). In the subsoil this relationship turns in tendency. This effect could be connected with the shifting of organic material into larger soil depths with inverting treatment. The values of EMMERLING (1997 and 1998) and SEITZ (1997) for C_{org} and microbiological parameters of the survey fields show that the mixture effect by treatment of plough leads to more adjusted (C_{org}) or partially reverse s (microbial biomass, biological activity) relationship of the upper and lower crumb data at in each case lower level for plough compared with cultivator. This was often documented for the comparison of intensive inverting with not inverting tillage (FRANCEN/LOH, TEBRUEGGE 1989, BOEHM et al. 1990, KANDELER et al. 1995, STOCKFISCH et al. 1995).

Possibly this mixture effect in the plough variant leads to stronger crumble shifting into the lower crumb, which could explain the higher value **of the variable of meso structure** there compared with the other two variants (see tab. 38).

On the basis of the disturbance of the biocenosis with the inverting this effect is however obviously not associated with an increase **of the stability of the crumbles** in the lower crumb with plough treatment. This and **the stability of the polyeder** are according to complete unit stability in upper and lower crumb in tendency smaller in the variant plough than in the variant cultivator - and less clear than layer plough (see tab. 39). In the subsoil not affected directly by the tillage treatment the shifting of organic material into larger depths (30 cm) by the plough can possibly affect aggregate and crumble stabilization (see EMMERLING 1997 and 1998), what could explain the reversal of the values in the subsoil. The tendencies are however too weak and too non-uniform, in order to support this thesis. As a reciprocal effect of the tillage variants with the crop types (appendix, tab. 34) can be held for polyeder stability in attempt approach 1 that it is in tendency higher under green fallow and with treatment of layer plough in the subsoil (tab. 30 and 39). The reasons for a high stability of all aggregates under green fallow are discussed under 4.3.3.1. The layer plough may shift organic material into deeper soil layers and disturb soil life less on the basis of its more careful loosening in the lower crumb, what also can lead in the subsoil to in tendency higher stability of the aggregates. In the case of the crumbles this is not be observed – but here the values of the groups of polyeder and crumbles are not comparable among themselves however on the basis of different group sizes. Both effects in the case of treatment of layer plough under green fallow cause in any case a sum effect for the stability of the polyeder.

The bulk density does not show any statistically secure differences between the tillage variants (see tab. 40). with **shearing resistance**(see tab. 40) is to be observed the frequently described abrupt change of loose crumb to compact subsoil with plough and regularly increase in the density with cultivator (see EITZINGER/KLAGHOFER 1995, BESTE 1996). Frequently this effect causes a worse rooting of the subsoils with inverting treatment (plough). This is not confirmed by the data which are present here. **The root density** does not show any differences dependent on the tillage variants (see tab. 40).

Reciprocal effects of the tillage with the factor soil moisture for the parameter aggregate morphology in the lower crumb in attempt approach 2 can be leaded back to a significantly higher value of the variable of meso structure with the highest moisture stage (> 20%, see tab. 21, chapter 4.2.3) and a in tendency higher value of the variable of meso structure with the smallest inverting intensity (see tab. 38, chapter 4.4.3). This connection does not go back however to a higher value of the soil moisture in the lower crumb with cultivator treatment and must be caused by here not representable factors therefore.

Reciprocal effects, which exist for the factors crop type and soil moisture with the main factor tillage computed here according to appendix, table 37 and 40 for attempt approach 1 for the parameters aggregate stability and stability of the polyeder, are caused by the used sampling date selection (all sampling dates). This causes different sampling dates for each crop, why in the case of the calculation of the main factor crop (see 4.4.3) another sampling date selection was used. Thus the reciprocal effect here is due to unequal spectra of moisture (for each crop not each season was sampled). In the calculation of the main factor crop (appendix, table 31 and 34) is this reciprocal effect also not to observe according to the sampling date selection adjusted for each crop.

5 Detailed discussion and final conclusions

In order to examine the Extended Spade Diagnosis (ESD) according to the aims of research formulated in chapter 1.2 with regard to its expressiveness or to be able to improve and develop it further, the hypotheses I-III in chapter 1.2 were set up. The assumptions formulated in the hypotheses correspond to today's level of knowledge about the influence of different management measures on the soil structure. The possibility to confirm or disprove in the attempt approaches 1 and 2 the expected results which were formulated in the hypotheses (see chapter 3.2) with the help of the ESD is criterion of assessment for the expressiveness of the ESD for the ability to give answers about important structure parameters regarding the ecological workability of used agriculturally soils. Following the hypotheses are examined in detail for their acceptance or refusal by the results of the data collected with the help of the ESD.

5.1 Hypothesis discussion

To the hypothesis I:

Within the rotation of the crops sequence cereals, green fallow, cereals green fallow on the basis of its soil-regenerate effect causes a temporary rise in aggregate stability with increased amount of crumbles (see chapter 2.2) as well as a better structure.

The data and results collected with the help of the ESD permit an acceptance of the hypothesis to. Within the crop rotation cereals (summer barley), green fallow, cereals (winter wheat) with ecological management under green fallow could be observed a strong increase of aggregate stability, which remained some months until the subsequent crop and partially decreased then. The stabilizing effect was longer durably with the group of type of crumbles as with the group of type of polyeder. If this effect was for longer durable after the green fallow and subsequent crop or if the stability level under the following "use crops" drops again strongly, could not be clarified in this work but would however be of great interest. With the help of structure mark and aggregate morphology an improvement of the structure conditions with increase of the part of crumbles could be documented also. This effect began because of the preceded tillage however delayed. Leguminous based mixtures stimulate soil organisms (AICHINGER et al. 1995, HÖFLICH 1996) and show increased microbial activity in the soil (KANDELER et al. 1995). This is by many authors unanimously brought into relation with the biologically conditioned structure and the stabilization of aggregates (VASILIU 1958, KANDELER/MURER 1993, AICHINGER et al. 1995, SCHNEIDER/

EMMERLING/SCHRÖDER 1995). The stimulation of the biological activity by leguminous based mixtures, in the literature also described for intercrops and fodder plants (see HOEVELMANN/FRANKEN 1993), could be demonstrated well on the basis of the results of the structure mark, the evaluation of the meso morphology and the aggregate stability test. Thereby The in the temporal dynamic of the crop rotation development was more clearly as in the temporally isolated comparison of green fallow and rye. The last attempt was however more difficult in interpretation because of the influence of soil moisture on the macro and meso structure. In the comparison of green fallow and rye at the same time this was avoided, but caused by the small number of repetition samples only tendencies for a better structural condition under green fallow could be discovered. These were clearer with the parameters structure mark and aggregate stability as with the parameters bulk density and shearing resistance.

To the hypothesis II:
Tillage plays an important role regarding the preservation of soil life. The plough loosens the structure more strongly, disturbs however soil life by the deep invertation. Not inverting tillage or flat inverting tillage causes a higher aggregate stability and an increased amount of crumbles with higher structure density compared with deep inverting tillage.

The data and results collected with the help of the ESD permit an acceptance to the hypothesis II. With not inverting tillage in accordance with HOEVELMANN/FRANKEN (1993) and KOELLER (1993) a higher aggregate stability in upper and lower crumb was documented compared with inverting tillage. This is led back by the authors mentioned to the disturbance of biological factors in upper and lower crumb during inverting tillage. Also for the mixture effect of the plough regarding C_{org} content and/or the microbial biomass which has been observed by FRANCS/LOH (1986), TEBRUEGGE (1989), BOEHM et al. (1990), KANDELER et the al. (1995) and STOCKFISCH et al. (1995) could be found tendencies on the basis of the crumb distribution. This mixture effect leads to more balanced and/or reverse relationships in upper and lower crumb in comparison with not inverting treatment (with inverting treatment in the lower crumb a higher value of the variable of meso structure, i.e. higher crumb particle was found). The parameters structure and meso structure as well as bulk density and shearing resistance show no clear differences for the tillage variants in the comparison of the horizons among themselves. The measurement of the soil resistance provides however important information about cultivation and ecological conditions. Thus horizon-refer the shearing resistance does not show any significant differences between the treatment variants, but the vertical increase in the shearing resistance from lower crumb to the subsoil is however with not inverting tillage regularly and with inverting tillage more abrupt, as it is described in the literature often (see TEIWES 1988, HARRACH/RICHTER 1992, EITZINGER/KLAGHOFER 1995, GROSS 1996). Usually this is connected with a larger pore continuity and potentially better rooting properties with not inverting treatment (ROGASIK et al. 1995, BESTE 1996). In this work no appropriate observation could be made over the analysis of the root density.

The results suppose on the basis of higher aggregate stability and the tendencies of the remaining results first a more positive evaluation of the not inverting tillage variant. Frequently a transition in not inverting tillage systems is associated however with closer structural conditions. But, a structure which is too close can partially also affect the biological activity and important ecological functions negatively on a long-term basis, while aggregate stability can remain increased because of the compaction effect. In the case of the renouncement of mineral fertilizing the exchange of nutrient is not optimal for the production function because of the smaller surface of the soil particles with close structure (KULLMANN 1956, SCHELLER ONE 1994, UBA 1998). Under these circumstances it is to be made sure that the structure mark of the not inverting variant does not drop under those of the inverting variant. Differently regarded a low aggregate stability of the inverting variant likewise can lead also to compaction on a long-term basis, while the structure mark is still being sufficient well classified on the basis of the clear optical loosening effect. The demand for combined evaluations of the static and dynamic soil condition is emphasized thereby.

To the hypothesis III:
With the combination of morphological soil evaluation (structure evaluation, evaluation of the aggregate meso-morphology) and dynamic test (aggregate stability test) biological factors of the aggregate stabilization can be differentiated better from colloid-chemical and above all compaction-caused factors.

The data and results collected with the help of the ESD do not provide the necessary data combination for the acceptance of the hypothesis IV (high aggregate stability with compacted soil condition). Mainly the combination of morphological soil evaluation and aggregate stability test should be able to differentiate between cases, with which a high aggregate stability against water is due either by a compacted structure or by the cultivatedly and ecologically desirable biological stabilization of porous structural conditions. In chapter 4 it could be shown that by the morphological description of the soil condition and the aggregate stability test management effects on the biological activity can be described and interpreted more differentiated, than this would be possible solely with the soil-physical methods bulk density and shearing resistance. Good structure conditions (high structure mark, high part of crumbles) with at the same time high aggregate stability can be reached only by means of stimulation of the biological activity. This the analysis of the crop rotation could show with the help of the used methods (structure evaluation, evaluation of the aggregate morphology and aggregate stability test with field-moisten aggregates between 3 and 5 millimeters). The methods can describe the influence of the soil functions by management measures well at morphological level over the description of differentiated structure characteristics. They permit many conclusions about the influence of the ecological soil functions on the basis of the close connection between morphology, biology and the regulation functions, however without being able to measure these directly.

The case of high values of aggregate stability with at the same time low structure mark is not present with the data collected in this work and therefore could not be placed into the direct comparison.

An example of an appropriate condition is found in the work of GROSS (1996, P. 99 ff). GROSS finds higher aggregate stability values of the direct seed (no tillage) variant. At the same time the soil structure of the direct seed variant is described as a "compact aggregate matrix" with "higher density of the soil" (P. 116). In this case a high aggregate stability can certainly be evaluated positively in relation to the drive over conditions of the field, while the maintenance of the ecological functions of the soil appears questionable with compact aggregate matrix and high soil density (see remarks chapter 1.1 and 2.1). With this background high aggregate stability values of dense layered soils, as they are frequently measured with direct seed systems, are to be seen critically. The as favourably mentioned large number of vertical macropores built by earthworms in otherwise relatively compact structure contains the danger of the quick and little filtered penetration of nitrogen and pesticides in the groundwater. Additionally it is supposed to not contain high water reservoir ability of the soil.

Current methodologies of isolated water stability tests cannot clear up, if the aggregate stability is caused by biological stabilization (which is important for the soil functions) or by physical compaction (which has stated to be a sign of functional degradation). This can lead to incorrect evaluations about functional structure conditions (CZERATZKI 1957, MULLA et al. 1992, BERNARD/LEPKE 1996, ROTH 1996). For all these methodologies it has to be emphasised that they deliver data about water stability but no evident results about good or bad status of soil structure quality. Structure evaluation gives some information about the

process, which causes high aggregate stability. High aggregate stability can only be evaluated as favourable, if structure marks of 3 and higher than 3 are given. In case of structure marks lower than 3, a high aggregate stability is frequently caused by compaction or liming.
The question remains open whether the particularly favorable structure condition, so-called "sponge structure", which has been described in literature and aimed at in practice for centuries with its high capacity of nutrient exchange, its high vertical and horizontal pore continuity, the good conditions for an regularly distributed root growth and the balanced water absorption not has altogether larger advantages as only a good drive over condition.

The combination of the aggregate stability test with the structure evaluation therefore represents an important examination possibility, if compaction-caused aggregate stability is to be differentiated from a high stability with good structural conditions (dependent on comparable substrate). This does not mean that a perfect crumb structure is an exclusive condition for a lasting form of agriculture. A high degree of "sponge soil structure" = high part of crumbles (dependent on the soil horizon) should be aimed at however (KUBIENA 1938, LIEBEROTH 1969, TEIWES 1988, DIEZ 1991, KUNTZE/ROESCHMANN /SCHWERDTFEGER 1994, SCHELLER 1994, SCHINNER/SONNLEITNER 1996 b, UBA 1998). This means, structure conditions of structure marks 3 and upward are to aim at.

While the case of high aggregate stability with bad, structure mark (under 3) indicating a compacted structure within the examined groups of the attempt approaches are not present here the observation of the reverse phenomenon could be documented: high structure marks and a meso morphology with high part of crumbles with at the same time low aggregate stability. This effect of strong crumbly structure observed together with high soil moisture could only be decoded by the combination of aggregate stability test and structure evaluation. This aggregate matrix termed as "pseudo crumbles" referring KULLMANN/KOITSCH (1956) can morphological first not be differentiated from "genuine" crumbles (biological built crumbles). Only with the help of the aggregate stability test they are exposed as extremely short term aggregation. The evaluation of the aggregate morphology describes the morphological current condition. It is marked with a very short term increase in aggregated soil particles with extremely low water stability. Classifications of this condition as "wrongly" or "genuinely" are not appropriate. The structure is here currently (and only at short time) closer to the structural optimal condition, as it could be recognized by the higher structure marks with high soil moisture in the spring. The soil is however at the same time most sensitive in this condition against water silting (and, as from practice it is known also against load by driving over), why "optimally" in this case is not set right away "loadable by driving over". The opinion, good structure conditions are at the same time connected with high stability and vice versa must be replaced through a dynamic comprehension of the soil condition. A compact structure with high aggregate stability is (independent of the season) just as possible and developable, as the reverse case. Only the combination of structure valuation and stability test can show this connection sufficiently differentiated and at the same time methodically limit the danger, which proceeds from (to positive) evaluation of the structure by soil conditions of high moisture. The large weak point of the structure evaluation, which cannot differentiate on the basis of the observing character purely optically between biologically built up and water-stick together crumbles, so only by the combination of the methods becomes measurable and for safe interpretations calculateable. The combination of the further developed methods in the ESD therefore despite certain weak points can bee seen as a progress for a qualitative soil evaluation and provides some new statements about functional relevant structure conditions of soils.

5.2 Expressiveness of the methods - method criticism and research needs

5.2.1 Expressiveness of the methods of the ESD

STRUCTURE MARK

The expressiveness of the compared with the evaluation according to HAMPL/KUSSEL (1994) improved structure evaluation has been confirmed by the submitted results in accordance with the literature. The structure mark shows, how strongly the structure condition of the soil differs from the condition represented in the description of structure as the optimal or as the negative condition. The description of the appearances thereby is based on current scientific knowledge about functional soil conditions (see chapter 2.1). Qualitatively different conditions, which often cannot be seized and evaluated sufficient with methods of the single parameter measurement, enter in their entire complexity directly into the evaluation. The result is a simple mark (code), which can be computed statistically easily. With the help of this mark (or the average) the complex condition is very clearly represented and can be compared quickly with other parameters.

The soil condition can be arranged quickly with the structure mark in "badly", "well" and "mean" and be evaluated qualitatively. Are there however fine differences of the structure present, which permit in short or in the medium term still no classification as "badly" or "well" or as "mean", then linear methods limited on one parameter provide important additional information (aggregate stability: silting, bulk density or pore volume: volume condition, shearing resistance: soil resistance). The combination of the methods makes a qualitatively rating evaluation possible on simultaneous delivery of soil-physical characteristic values, which deliver basical informations about the usually well-known parameters and can facilitate the comparison of investigations of different locations (with comparable substrate).

The results altogether show as expected a parallelism between structure mark and meso structure (see fig. 22 and 24, chapters 4.2.3) the high structure marks therefore stand for a higher amount of aggregates of the crumble type on the level of the meso morphology. Thereby it is clarified that the expressive consideration of the "crumbles" in the structure evaluation (see tab. 5, chapter 3.3.1) reflects well changes of the meso structure. Unfavorably it is to be marked that both methods are clearly influenced by the soil moisture. Since the evaluation of the aggregate morphology is very time-consuming beyond that, an assumption into the Extended Spade Diagnosis can be waived. The influence of the soil moisture must be avoided by the sampling time or be restrictively taken into account with obviously high soil moisture in the interpretation and/or be differentiated in the statement with the aggregate stability test.

AGGREGATSTABILITAET STABILITY AGGREGATE

Excluding the compaction-caused stability both aggregates are influenced by the same factors. Both polyeder and crumbles are stabilized by increased clay or lime content (see tab. 18, chapter 4.2.2). likewise the biological activity has stabilizing consequences for all types of aggregates (see tab. 30, chapter 4.4.1; tab. 34, chapter 4.4.2). For the production function as well as for the filter - and buffer - function the building of aggregate of the crumble type with simultaneous stabilization is important. This is however above all dependent of the work of a unimpaired biological activity (chapter 2.2, and tab. 28, chapter 4.4.1). Therefore high values of the parameter aggregate stability can be evaluated as positive, if a certain lowest amount of aggregates of the type of crumble is present at the same time. This can be examined, without the evaluation of the aggregate morphology, with the help of the structure mark as stated above (structure marks 3 and higher). The aggregate stability test with field-moisten aggregates between 3 and 5 mm (for the crumb) and silting pictures, as it is used here, provided results which correspond to the knowledge about the aggregate stabilization influencing factors present in the literature. Beyond that it is little expensive and by means of the new development evaluation scheme for the silting test it is less depending on the subjective estimate of the observing person compared with the method according to HAMPL/KUSSEL (1994). The test led to clear differences of the examined variants, which correspond with the influence factors of aggregate stability described up to now in the literature and formulated in the hypotheses. Therefore one can recommend the application. As disadvantage remains the difficulty of the seaving process with the field moisten aggregates. Here "mini-dumplings" can develop easily by the movement. Additionally the selection of the aggregates for the silting test should be held as coincidentally as possible.

ROOT DENSITY

The expressiveness of the counting out of root density as a "bio indicator" for the structure condition remains vague with the given number of sample. In the case of small number of sample with execution of the complete ESD therefore the replace of the quantitative method of root counting by a qualitative rooting evaluation is more recommended (see tab. 43 chapter

5.3). In the case of partial investigations with the ESD (e.g. only structure evaluation and aggregate stability) with increased number of sample one can use the root counting with stencil.

BULK DENSITY AND SHEARING RESISTANCE

The expressiveness of the soil-physical characteristic values bulk density and shearing resistance was confirmed in accordance with the literature.

5.2.2 Influence on the parameters by substrate and soil moisture

The influence on the used parameters by different substrate shows that within surveys with comparisons of management the following must be considered:

1. The output substrate should be homogeneous

or

2. In each variant a sufficient quantity of samples should be separately recordable according to substrate with sufficient number of repetitions (more than two repetitions are recommended)

or

3. The comparison must be limited to the qualitative statement, how far the examined soil condition is distant from an optimal condition potential at the concerning location.

Present information about soil chemistry and soil type is both for sampling planning, as well as for the evaluation of the results of ESD is therefore to consult if possible.

The version of the ESD tested in the present work cannot be used on strongly clay soils, sandy soils or skeleton soils (e.g. slate soils).

Both structure evaluation and the evaluation of the aggregate stability test (silting stages) must be adapted to the conditions of the abovementioned soils. In this work for it only proposals can be made, whose aptitude is still to be examined (see tab. 41 and 42 as well as fig. 28 and 29, chapter 5.3).

For all parameters an influence by the soil moisture, well-known sufficiently from the literature, must be stated. The evaluation of the aggregate morphology and less strongly the structure evaluation show here the largest influence. Further research with different substrate and different soil moisture conditions would be desirable. Nevertheless particularly by the use of field-moist samples a more differentiated impression of the current structure condition and its susceptibility against silting and erosion can be given as with dried samples. It is to emphasize that the influence of the biological component by this pretreatment is not clarified sufficiently yet. Here research needs continuing. In the case of a comparison of management or tillage treatment variants with small number of sampling dates the influence by extreme conditions of the climatic annual dynamics (soil humidity content, biological activity) should be excluded however if possible. Therefore a sampling within the vegetation period with soil moisture contents under field capacity is urgently recommended - also on the basis of the better seaving conditions of the field-moisten aggregates. With the shearing resistance also a soil moisture below the field capacity is to be respected with the measurements. The analysis of bulk density is dependent smallest on the soil moisture, although it depends also on swelling and contraction mechanisms of the soil substrate. In principle the soil moisture should be recorded additionally as parameter to each measuring and sampling date or estimated with the help of the soil science mapping instruction.

5.3 Current version of the field method Extended Spade Diagnosis (ESD)

The final conclusions regarding the expressiveness of the partial methods of the ESD, made in chapters 5.1 and 5.2, find their expression in the in-follow represented version of the ESD.

5.3.1 Structure evaluation

The newly developed Structure evaluation on the present investigation location has been proved to be a sensitive indicator for manage-caused effects on the soil condition, which makes a quick rating evaluation possible.

Carrying out the Evaluation with field comparisons it is to be made sure that comparable soil moisture and comparable substrate are given. In the following beside the structure evaluation for loamy soils described in chapter 3.3.1, a proposal of a structure evaluation for sandy and clay soils is given based on MUELLER (1958), DIEZ/WEIGELT (1987), AG BODENKUNDE (1994), HARRACH (1998) and own observations (tab. 41 and 42).

Tab. 41: Structure evaluation scheme for sandy soils

Layer	Appearance	Structure mark
	Grain of sand sticking together in aggregates (about 2 mm) with visible organic material, no crusts	**5**
	intermediate mark	4
Surface 0-1 cm	**Grain of sand partly sticking together in aggregates (about 2 mm) with visible organic material, partly single-grain structure, humid: loose coherence, dry: beginning crust-formation or mainly single-grain structure**	**3**
	intermediate mark	2
	Mainly single-grain structure, scarcely aggregates with organic material, humid: loose coherence, dry: crusts or mainly single-grain structure	**1**
	Grain of sand sticking together in bigger aggregates (>2 mm) with visible organic material and/or roots. Careful deformation of aggregates is possible without decay, no compact clods	**5**
	intermediate mark	4
Upper Crumb 0-15cm	**Grain of sand partly sticking together in aggregates with visible organic material but mainly single-grain structure , humid: partly appearance of compact fragments (>4 cm) and clods, dry: compact fragments and clods. With lightly pressure crumpling into loose single-grain structure and aggregates**	**3**
	intermediate mark	2
	Mainly single-grain structure, scarcely organic material, humid: compact big clods and fragments (> 6 cm), dry: very compact big clods and fragments, crumpling into loose single-grain structure with more heavy pressure	**1**
	Grain of sand, partly sticking together in aggregates with visible organic material, partly single-grain structure. Deformation of some aggregates is possible without decay, humid: formation of bigger fragments, dry: fragments and clods, with lightly pressure crumpling into loose single-grain structure	**5**
	intermediate mark	4
Lower Crumb 15-30cm	**Mainly single-grain structure scarcely organic material, humid: compact big clods and fragments, dry: very compact big clods and fragments, crumpling into smaller fragments or loose single-grain structure with more heavy pressure**	**3**
	intermediate mark	2
	Single-grain structure, almost no organic material visible, humid: very compact, high density of big clods and fragments, dry: very compact big clods and fragments, crumpling into smaller fragments and clods only with heavy pressure	**1**
	Mainly single-grain structure, scarcely organic material visible, humid: compact big clods and fragments, dry: very compact big clods and fragments, with pressure crumpling into single-grain structure and smaller fragments	**5**
	intermediate mark	4
Subsoil 30-40cm	**Single-grain structure, no organic material visible, very compact big clods and fragments, with pressure crumpling into smaller fragments and clods**	**3**
	intermediate mark	2
	Single-grain structure, no organic material, very compact, high density of big clods and fragments (banks), crumpling into smaller fragments and clods only with heavy pressure	**1**

Tab. 42: Structure evaluation scheme for clay soils

Layer	Appearance	Structure mark
	Rough, unite aggregates visible-not silted up, worm dropping, no crusts	**5**
	intermediate mark	4
Surface 0-1 cm	**Aggregates silted up, scarcely worm dropping, beginning crust-formation**	**3**
	intermediate mark	2
	Crusts, tears, aggregates silted up, surface sealed	**1**
	Mixed structure, mainly crumbles and little polyeder (mainly not sharp-edged), loose few fragments	**5**
	intermediate mark	4
Upper Crumb 0-15cm	**Mixed structure of crumbles, little polyeder and fragments**	**3**
	intermediate mark	2
	Fragments and sharp-edged clods with smooth surface, compact, scarcely little polyeder. Humid: dump and slippery, dry: compact and very firm	**1**
	Mixed structure, containing crumbles, little polyeder and fragments	**5**
	intermediate mark	4
Lower Crumb 15-30cm	**Bigger fragments with smooth surface few crumbles and polyeder, some sharp-edged clods**	**3**
	intermediate mark	2
	About 80 % sharp edged clods, higher part of distinct smooth surfaces, coherent structure. Humid: firm, surface slippery, dry: compact and very firm	**1**
	Coherent structure with some bigger pores and many little pores, middle sized and bigger fragments. With pressure crumpling in little fragments and polyeder possible	**5**
	intermediate mark	4
Subsoil 30-40cm	**Coherent structure with low appearance of pores, big sharp-edged clods. Crumpling in fragments and polyeder only with heavy pressure. Humid: firm, slippery surface, dry: compact and very firm**	**3**
	intermediate mark	2
	Compact structure, no pores visible, no crumpling possible. Humid: firm, slippery surface, dry: compact and very firm	**1**

5.3.2 Counting out of root density and rooting evaluation

Provided that the number of sample for the survey variants is higher as 4, which is present in this work, or can be increased by time series investigations (KOEPKE 1979), the analysis of the root density in the subsoil with the help of the stencil counting, which is referring HELLRIEGEL comparable with the drill core method, is to recommend further, since it is little expensive. Regarding the qualitative recording of the rooting conditions in the crumb with small sample number and without temporal repetitions a root evaluation is recommended (BOECK 1997, NEUDECKER ONE 1997, HARRACH 1998, see tab. 43). A qualitative evaluation of the rooting, which is likewise consulted in the GOERBING spade diagnosis for a comprehensive evaluation of soil condition, can include functional ecological relations between structure and rooting in the direct comparison in connection with the structure evaluation. Beyond that a qualitative rooting evaluation has the advantage that it can be accomplished with relatively hard and dry soil or stony subsoil still well, while counting out roots with the stencil causes difficulties because of the possibly decay of the subsoil.

For this reason in-follow a proposal is given alternatively for a usable rooting evaluation to substitute root counting within the ESD. The development of the evaluation is based on the final conclusions and descriptive observations of KOEPKE (1979), HELAL (1991), BOECK (1997), NEUDECKER (1997), HARRACH (1998) and own observations.

Tab. 43: Rooting evaluation scheme

Horizon	Appearance	Rooting mark
	A lot of roots and fine roots, strongly branched, distributed very regularly and sticked together with small aggregates (large contact area of roots and soil)	**5**
	- intermediate mark -	4
Upper crumb 0-15 cm	**Moderately roots and fine roots, scarcely branched, partly irregularly distributed in "bushes", growing through larger fragments in macropores**	**3**
	- intermediate mark -	2
	Rooting is very irregularly ("bushes "and partly horizontal root felt) Growing particularly in macropores (or at the surface) of larger, sharp-edged fragments	**1**
	Many roots and fine roots, strongly branched, distributed very regularly and sticked together with small and larger aggregates (large contact area of roots and soil)	**5**
	- intermediate mark -	4
Lower crumb 15-30 cm	**Moderately roots and few fine roots, scarcely branched, partly several roots growing parallel in macropores of larger, sharp-edged fragments and crumble or to their surface**	**3**
	- intermediate mark -	2
	Very irregular rooting ("bushes"), several roots growing parallel in macropores of larger, sharp-edged fragments and crumble or to their surface, partially horizontally bent and flatly squeezed roots	**1**
	Roots strongly branched, some fine roots, distributed very regularly and partially sticked together with small and larger aggregates and fragments (large contact area of roots and soil)	**5**
	- intermediate mark -	4
Subsoil 30-40 cm	**Roots scarcely branched, hardly fine roots, partly several roots growing parallel in macropores of larger, sharp-edged fragments and crumble or to their surface**	**3**
	- intermediate mark -	2
	Very few roots, very irregular growing, frequently growing parallel in macropores of larger, sharp-edged fragments or to their surface, frequently bent horizontally and flatly squeezed	**1**

5.3.3 Test of aggregate stability

The silting of the aggregates differs easily in optical development with sand, loam and clay soils referring own observations to appropriate soils, whereby the decay pictures of the three levels “stable”, “half silted” and “totally silted” among themselves are quite comparable. An adaptation of the silting evaluation therefore above all facilitates the quick and safe classification for the three levels. Following a proposal for a silting evaluation for sandy and clay soils is given.

stable, mark: 2
silting type 1: stable
st 2: shared into two aggregates

half silted, mark: 1
st 3: silted into middle sized aggregate particles

totally silted, mark: 0
st 4: totally silted into little particles

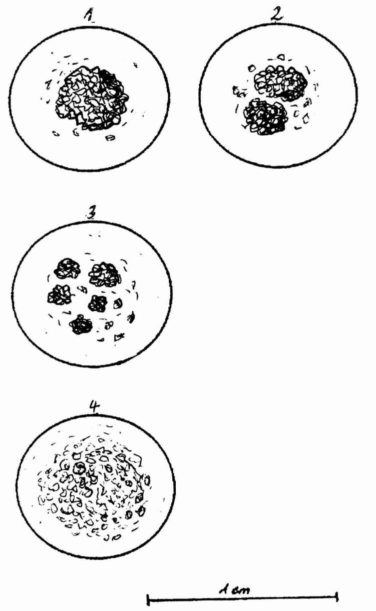

Fig. 28: Evaluation scheme of aggregate silting during water stability test for sandy soils

stable, mark: 2
silting type 1: stable
st 2: shared into two aggregates

half silted, mark: 1
st 3: silted into middle sized aggregate particles

totally silted, mark: 0
st 4: totally silted into little particles

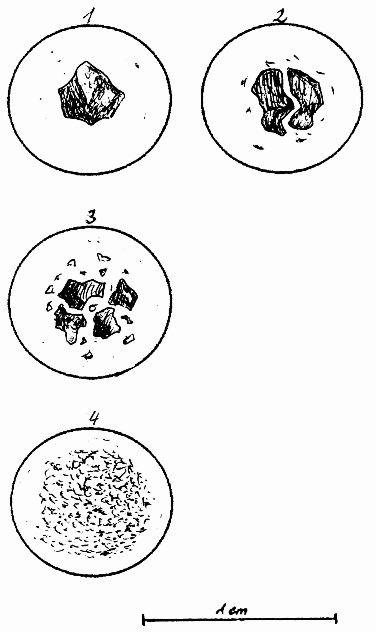

Fig. 29: Evaluation scheme of aggregate silting during water stability test for clay-soils

5.3.4 Soil moisture, bulk density and shearing resistance

The standard methods for the determination of the characteristic values soil moisture and bulk density can provide interesting additional measured values to water regime and soil physics within the ESD and remain in the form introduced in chapter 3.3.5 an integral part to the ESD. In comparison to the differentiated results of structure evaluation and aggregate stability test their expressiveness is to be seen rather additionally and its employment depending on the survey question.

The analysis of the shearing resistance (see chapter 3.3.6) in current research work has been substituted through the measurement of penetration resistance with the help of a penetration sonde. Both methods are comparable in result and expressiveness and reducedly applicable with high soil moisture (higher than field capacity) only. For a measurement of the soil resistance within the combination method ESD both are suitable equally, whereby on the basis of the desired comparability with other research results preference is to be given to the employment of the penetration sonde.

5.4 Final critical remarks on the experimental setup

In principle for the survey planning in the Project Ecological Soil Management is to be marked that the smallest possible number of repetition (two blocks) was selected. Thereby the expressiveness is statistical limited. In the case of a sufficient number of sampling dates and samples (attempt approach 1, crop rotation: 6 sampling dates) nevertheless clear differences of the factors could be computed. The less clear differences (tendencies) of the comparison of rye and green fallow are to be seen in this context . Here for each year only one sampling date was present, which must be estimated as too little for the evaluation of the dynamics of biological activity.

In the opinion of the author the small differences between the tillage variants are not mainly due to the small number of repetition or levelling effects of crop or substrate, although here multiple reciprocal effects may be present.

Already in preceded work the observation could be made that synergetically working system- and over all crop rotation- effects have a substantially stronger influence on the development of the soil structure than different tillage techniques and this particularly with ecological management (FRANCS/LOH 1986, HOEVELMANN/FRANKEN 1993, MAEDER 1993 PFIFFNER 1993, HAMPL 1995 b, SCHNEIDER/EMMERLING/SCHROEDER 1995, SIEGRIST 1995, BESTE 1996, BESTE 1997 b to 1999, NEUDECKER 1997). Soil protecting management is achieved therefore distinctly better by an adapted production system altogether - and above all a various crop rotation and intercrops, which means soil life promotion -, as by the isolated employment of a favourized tillage technique. Thus regarded on soil protection the effect of tillage treatment is of subordinated importance.

6 Summary

Key-words: Functional soil evaluation, structure evaluation, test of aggregate stability, analysis of aggregate morphology, aggregate building factors, crop rotation and tillage effects on soil conditions, Extended Spade Diagnosis

The soil, like water, air, and energy, is one of our most important resources. Our future living conditions will depend most fundamentally on how well we manage this nourishing resource. A serious endangerment of ecological soil vitality caused by the effects of pollution and high external input management systems in agriculture, can be confirmed at a global level. Besides the contamination of soil, groundwater and drinking water with foreign substances, the rapid decrease of soil biota - biological degradation - and, amplified by this, the high susceptibility of soils for compaction and erosion - physical degradation, represent two more syndromes which have been termed frequently as a serious threat for the global resources of food production (UNEP/ISRIC 1990, WBGU 1994, HURNI 1996, BESTE/HAMPL 1999). Some conclusions made by the Conference of the International Soil Conservation Organisation in Bonn 1996 summarised the urgent necessity of research to step further in combating soil degradation. There it has been emphasised that to document the effects of soil and land management systems on ecological soil functions, sensitive indicators and simple 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).

In this research paper the proposal is made to use soil structure as indicator for sound soil functions because of its close connections to water circulation, soil life activity and transformation capacity. With the ***Extended Spade Diagnosis*** (**ESD**) - a combination of soil investigation-methods initially developed by HAMPL/KUSSEL (1994) - a methodology is presented, which corresponds closely with the demands of ISCO especially in a low technical expenditure and a simple communicability. **ESD** contains a new developed structure evaluation, a new developed simple test of aggregate stability, the counting out of root density

in the subsoil with a stencil, measurement of soil moisture, pore volume or bulk density with short core samplers and the measurement of shearing resistance. Thus **ESD** combines structure evaluation schemes developed on current knowledge about sound soil structure conditions (qualitative data, but countable) and measurement of common soil structure parameters (quantitative data). At the beginning of the investigation the structure evaluation scheme and the test of aggregate stability were improved by BESTE (1997).

The objective of research in this paper is it to test the evidence of the soil investigation methods applicated in the **ESD** with regard to the effects of soil and land management systems on ecological soil functions.

Current tests of aggregate stability are not able to show if the aggregate stability is caused by biological stabilization (which is important for the soil functions) or by physical compaction (which has stated to be a sign of functional degradation). This can lead to incorrect evaluations about functional structure conditions. Therefore additionally to the **ESD** there has been also implemented an evaluation of aggregate morphology in this experimentation trial. With that a distinct investigation of the connections between aggregate stability caused by biological stabilization or by physical compaction, the building up of agricultural desirable crumbly and porous aggregates and the actual structure conditions has been intended.

The sensitivity of the parameters applicated in **ESD** to the influence of site factors and management systems or techniques and their evidence for the ecological affection of soil functions through management factors has been tested with two designs of investigation.

The first design was drawn to document the influence of a typical crop rotation in an organic management system (Summer-Barley, Green Manure, Winter-Wheat - with intercrops) on soil conditions. Investigation parameters were soil structure evaluation, evaluation of aggregate morphology, test of aggregate stability and soil moisture. Samples were taken in March, May, July and September.

The second design was drawn to compare the soil conditions under Winter-Rye and Green Manure in the organic management system. In this design a complete **ESD** was implemented, so the parameters were structure evaluation, test of aggregate stability, count of root density in the subsoil, measurement of soil moisture, bulk density with short core samplers and the measurement of shearing resistance as mentioned above. In addition to that the evaluation of aggregate morphology was implemented too.

Both designs of investigation contained the separate survey of three different tillage techniques:

Layer-Cultivator (conservation tillage, non inverting, loosening to 30 cm depth),

Two-Layer Plough (reduced tillage, inverting to 15 cm depth and loosening to 30 cm depth),

Plough (intensive tillage, inverting to 30 cm depth). The experimentation last three years (1996-1998).

The investigations of sensitivity of the parameters to the site factors soil profile, pedogenic properties and soil moisture show the following results:

Soil profile

1. Aggregate stability and aggregate morphology show the typical differentiation of soil layers in biological activity according to current state of the art: Aggregate stability and amount of crumbly, highly porous aggregates are diminuating with soil depth.
2. The structure mark which has been computed for the upper crumb shows developing potential to reach optimum conditions. For the lower crumb susceptibility for compaction has been stated as tendency. This already has been observed frequently when inverting tillage was changed to non inverting tillage as it is the fact in this case (change 1994) for thirty percent of the experimental patches. The subsoil has been marked as to have structure conditions near the optimum (the scale of demanded structure conditions for a sound soil in the structure evaluation scheme varies with soil depth because of the bioecologically variation of light, moisture and density with soil depth. The attached structure mark shows the distance between optimum condition and actual condition).
3. Results of bulk density and shearing resistance confirm corresponding experiences with agricultural soils: They are augmenting with the soil depth.

Pedogenic properties

4. The two separate observed groups of soils (I.: Loess/Loess over Marl, II:: Calcic and Siltic Marl, termed as Clay Marl) show their influence in higher structure marks in case of the more stony material (Calcic and Siltic Marl). This is comprehensible according to functional ecology because of the higher amount of macro pores in stony material.

5. The augmentation of aggregate stability with higher contents of Calcium and Silt (Calcic and Siltic Marl) which is already known could be confirmed too.
6. The amount of crumbly, highly porous aggregates could not be sated as to be influenced by one of the two soil groups.
7. Results of bulk density and shearing resistance show no difference dependent on different soil groups.

Soil moisture

8. Soil moisture shows the highest influence on the parameters in the results of the first investigation design (sampling four times yearly - seasonal periodicity of soil moisture). A corresponding tendency could be also stated for the second investigation design: With a soil moisture over 20% the samples gained higher structure marks, the aggregate stability was lower and the amount of crumbly, highly porous aggregates higher. This results are due to the occurrence of arising „pseudo-crumbles“ with high soil moisture in early springtime. There could be observed a high amount of crumbly, highly porous aggregates when soil moisture was high, which leads to a good spatial soil structure. But this structure condition is highly susceptible against water siltation because of the „pseudo-crumbles“ which already not have been stabilized by biological factors but only by meniscal water-tension in the early springtime. Apart from this some observations about the reaction of polyeders, subpolyeders and crumbly, highly porous aggregates in different conditions of soil moisture and also in their annual rhythm have been explored.
9. Bulk density and shearing resistance don’t show any influence depending on soil moisture. The influence of soil moisture on the shearing resistance around field capacity mentioned in the literature could not be documented in this case because of the dry moisture conditions which have not reached 30% (which is the field capacity of the soil type investigated here).
10. Root density is proportionally inverse to soil moisture which is explained with the higher growing intensity of roots searching for water in soil (KÖNEKAMP/ZIMMER 1954).

The investigations of sensitivity of the parameters to management techniques show the following results:

Influence of Green Manure in the crop rotation and in comparison to Winter-Rye:

1. Augmentation of structure mark.
2. Augmentation of aggregate stability up to the following crop.
3. Increasing formation and stabilization of crumbly, highly porous aggregates.
4. Tendency to less shearing resistance and lower bulk density under Green Manure vegetation.

Comparison of tillage techniques

1. No statistically safe differences in structure marks.
2. Distinct higher aggregate stability with non inverting tillage (Layer Cultivator).
3. No statistically safe differences in the amount of crumbly, highly porous aggregates.
4. Higher stability of crumbly, highly porous aggregates in the upper crumb with non inverting tillage (Layer Cultivator).
5. No differences in the results of bulk density. Regular increase of shearing resistance with soil depth when tillage has been non inverting (Layer Cultivator). Abrupt increase of shearing resistance from the lower crumb to the subsoil when tillage has been inverting (Plough), as it has been investigated frequently before.
6. No differences in root density.

Evidence of methodology

The evidence of the **improved structure evaluation** has been confirmed by the gained results which correspond with literature. The structure mark shows the distance of actual soil condition to optimum conditions or degraded conditions. The difference in quality of soil conditions is taken into account in a very comprehensive way of evaluation. This qualitative evaluation could not be achieved by methodologies which gain results with the measurement of single parameters only. Whatever the result is a simple evaluation mark which facilitates statistical calculation. Soil condition is represented clearly and comparison with other parameters can be done simple and fast.

The **new developed test of aggregate stability** which is implemented with aggregates of actual soil moisture between 3 and 5 mm of size delivers results which show sensitiveness to the factors which are causing aggregate stability according to current knowledge. Apart from this it is easy to do and with the improved evaluation scheme of aggregate silting it is less depending on subjective assessment of the implementing person. The test delivered clear differences between the surveyed management variations and can therefore be recommended for investigations about the influence of agricultural management on aggregate stability.

The evidence of the **counting out of root density** by means of a stencil in the subsoil seems to be indifferent when samples are few. Therefore in case of implementing the whole **ESD** and taking few samples only it is preferable to use a **qualitative root evaluation scheme** instead of the quantitative root counting. When **ESD** is implemented only partly (e.g. only structure evaluation and test of aggregate stability) and many samples are taken the root counting in the subsoil by means of the stencil can be kept.

The evidence of the **physical standard parameters bulk density and shearing resistance** has be confirmed with the results according to literature.

The parameters and methods used in combination as a part of **ESD** show - as the most soil investigation methods - dependence on pedogenic properties and soil moisture. This experience has been intended to be taken into account by giving some advises fore implementation of **ESD**. Apart from this suggestions for some **structure evaluation schemes and silting evaluation schemes which are adapted to sandy soils and clay soils** as well as a **rooting evaluation scheme** have been worked out and presented.

ESD in its improved version can achieve to document scientifically but without high technology expenditure effects of management systems or techniques on soil vitality. It combines the actual and comprehensive impression of soil condition in the field with exact quantitative data information of soil parameters. Advantages moreover that are facility and communicability because of its vividness and close connection to farmers knowledge about soil. Thus it can help to facilitate decisions about soil management planning and practice also in regions and projects where investigations with high-technology methods are to expensive or not well adapted for consultance presentation.

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