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# SOIL STRENGTH, STABILITY AND STRUCTURAL STATE OF ORTHIC LUVISOLS UNDER DIFFERENT LAND USE

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A b s t r a c t. An attempt has been undertaken to evaluate the state of soil structure of Orthic Luvisol, being under different land use, on the basis of classical aggregate stability measurements as well as on the analyses of other physical parameters and properties of the soil. It was found that more real data are provided by the later approach, the first one being too much dependent on uncontrolled and subjective factors.

K e y w o r d s: soil structure, soil physical parameters, Orthic Luvisol, land use

## INTRODUCTION

It is well known that soil structure can be described either directly by analysing soil aggregation and its water stability (expressed by percentage contribution of various aggregate fractions in dry or wet state, respectively) or indirectly by measuring other physical parameters/ properties (e.g., soil strength, bulk density, water transmission properties, aeration status, etc.), which allow us to characterize the actual physical state of of the soil [2,3,10,11].

The first approach involves very laborious and subjective, to some extent, methodology. Too many factors affect the output data, beginning with the right time, place and way of sampling, sample handling, sieving technique, moisture state, etc. The second approach, being based on physical methods gives more real data, although sometimes they cannot be used for direct assessment and description of soil structure according to its classical definition.

The aim of the present work was to compare the assessment of the structural state of Orthic Luvisol being under different land use, on the basis of the two above discussed approaches, i.e., on the basis of a classical soil structure studies and by analysing some other physical parameters or properties of the soil.

## MATERIALS AND METHODS

### Research area, soil and land use

Three sites, located not far from each other at Czesławice near Nałęczów, on Orthic Luvisol developed from eolian deposits (loess) but being under different land use were selected for the study. The land use was: forest, extensive agricultural farming (private farm) and intensive agricultural farming (Agricultural Experimental Station, called here 'State farm'). Detailed description of the study area, sites and soil profiles has been already presented in the paper by Gliński [6]. It should be mentioned, however, that arable fields of the private and of the state farm were different as far as crop rotation, fertilization and tillage systems are concerned.

The textural class of these soils is silt uniformly distributed in soil profiles. The differences in coarser and finer size fractions results from the soil-forming processes of the lessive type. These differences are more visible in forest soil (natural conditions) than in arable soils. They are also confirmed by the values of a specific surface area which are higher in B horizons as compared to those in upper or lower horizons. The soils also differ in other soil properties, e.g. chemical properties. The organic matter content ranged from 1.32 to 1.88 %, the highest in forest soil and the lowest in soil under extensive farming. All soils are decalcified down to 1 m and acid, except the soil under intensive farming, because of a more intensive and regular liming. This is also confirmed by higher amount of $Ca^{2+}$ and $Mg^{2+}$. Higher contents of plant available P, K and Mg, and of trace elements are due to higher mineral fertilization. That is why a specific electrical conductivity was the highest in the soil of state farm (0.45 mS), in comparison with the soil of private farm (about 0.2 mS) and that of the forest (0.12 mS).

**Soil sampling and measurements**

Undisturbed and disturbed soil samples are used depending on the tested parameter or property. The following tests were performed.

*Soil aggregate stability*

Disturbed soil samples of 1 kg weight were collected from each soil horizon, air-dried and then sieved through a set of sieves having the following meshes: 10, 7, 5, 3, 1, 0.5 and 0.25 mm in diameter. Wet sieving was performed according to the modified Baksheiev's method, as described by Dobrzański *et al.* [4]. The final data are given as percentage contribution of water stable aggregates of each individual aggregate fraction and their total (summed up) content.

*Degree of compactness*

Parameters such as dry bulk density, air-filled porosity and soil strength have frequently been used to characterize the physical state of soil, mainly the state of compactness. However, these parameters have a limited value for comparison of the state of compaction between soil types. Particularly, bulk density may indicate an extremely compact state in one soil, but a very loose state in another. To facilitate the comparison of the state of soil compactness between sites, the concept 'degree of compactness' was suggested by Håkanson [8].

The degree of compactness, $D$, is calculated according to the equation:

$$D = 100\,\rho\,d/\rho\,dr \qquad (1)$$

where $\rho d$ is the dry bulk density of the soil and $\rho\,dr$ is the dry bulk density of the same soil in a reference state.

This state is the densest state that can be obtained by a static pressure of 200 kPa. The reference bulk densities, e.g., for silty loam and loamy sand are 1.612 and 1.788 Mg $m^{-3}$, respectively. For mineral soil the optimum $D$ value for most cultivated plants is about 87 %, independent of the textural compaction of the soil [9]. The exact description of the method and apparatus to measure the degree of compactness has been presented by Hakanson [8].

*Cone resistance*

The penetrometer tests were performed in the surface (40 cm) layer of the three soils studied. The penetrometer was a portable manual spring penetrometer manufactured by the Institute of Agrophysics, with a steel driving rod ended with a cone tip ($30^{o}$) of 1 $cm^2$ cross-area.

*Shearing resistance*

The shearing tests were performed basing on the principle described by Black [1] and Gliński and Konstankiewicz [7].

According to Coulomb-Mohr's law of internal friction:

$$F_s = \mu F_n + c \qquad (2)$$

where $F_s$ is the stress tangent to the shearing surface in a typical shearing apparatus, $F_n$ is normal stress on this surface, $c$ stands for cohesion and $\mu$ - coefficient of internal friction.

*Soil compaction curve*

Compaction testes were performed in 100 $cm^3$ Kopecky steel cylinders. Undisturbed soil samples are sealed with rubber covers after careful filling with a soil in the field. In a laboratory, soil samples were axially loaded with a pressure of 202.3 kPa. After removing the covers, an axial displacement height versus time was recorded. The initial height of the sample was 55 mm.

*Total porosity and pore size distribution*

Total porosity was calculated according to the formulae:

$$\text{Total porosity} = \frac{\text{Bulk density}}{\text{Particle density}} 100 \quad (3)$$

Pore size distribution was estimated by means of mercury porosimeter that uses the idea of the behaviour of repellent liquids in capillaries, as described by Gliński and Konstankiewicz [7]. The apparatus uses two ranges of pressures, i.e., from $10^2$ to 15 x $10^3$ kPa, and from $10^2$ to 15 x $10^4$kPa. The volume of mercury introduced at a given pressure is equal to the total volume of pores. The radius that may be estimated in this way does not exceed 50 Å. Because of a high repeatability of the results the test may be limited to one measurement only which makes the whole analysis considerably shorter.

*Infiltration rate*

This parameter was measured in the field with the use of a double ring infiltrometer, as described by Boersma (cited by Black [1]).

RESULTS AND DISCUSSION

When analysing the data on water stability of soil aggregates, presented graphically in Fig. 1, one can easily recognize the effect of natural soil-forming processes on aggregate stability in forest soil, especially in upper horizons (Ah, E and E-Bt1), where the content of organic matter is higher than in Ap and E horizons of arable soils, despite higher acidity of the forest soil. There is also lower contribution of the smallest fractions. On the other hand, there is a very clear effect of human activity on soil structure in arable fields. The evidence is given by a relatively good aggregate stability in soil well fertilized and manured, i.e., in soil being under intensive farming, showing high CEC, higher organic matter content and lower acidity. Due to faster translocation of elements down the soil profile the aggregation of deeper horizons can be recognized (e.g., in the Bt2 horizon in the state farm as compared to the forest or private farm) and a very poor aggregate stability in soils under extensive farming. On the basis of this structure characteristics one can assume that the soil structure on the field under many-year intensive agricultural farming undergoes positive changes, while that under extensive farming shows certain symptoms of degradation (also proved by some chemical parameters) [2,5].

However, when we analyse other physical parameters or properties of those soils, the assessment of soil structure is not so simple and conclusions are somewhat different.

For example, the data on soil compactness, characterized by the degree of compactness were 84.6, 75.9, and 85.5 % in the upper horizons of the forest, private farm (potato field) and state farm (maize for silage), respectively. The corresponding reference bulk densities were respectively 1.601, 1.621, and 1.626 Mg $m^{-3}$. Thus, on the basis of what has been expressed in the former chapter, these results suggest that the best physical status shows forest soil, followed by the soil under extensive farming and finally by the soil under intensive farming. For comparison, let us present the reference bulk densities in the plough layer of other soils: e.g., in alluvial soil (Abádszalók) - 1.457 Mg $m^{-3}$, meadow soil (Kisújszállás) - 1.584 Mg $m^{-3}$, meadow-solonetz (Karcagpuszta) - 1.676 Mg $m^{-3}$, calcarohaplic phaeozem (Macov-1) - 1.857 Mg $m^{-3}$, and fluvicalcaric phaeozem (Macov-2) - 1.715 Mg $m^{-3}$. Generally, the reference bulk densities were greater in soils having coarser texture and lower organic matter content (see Tables 1 and 2 in [6]). But it is also sensitive

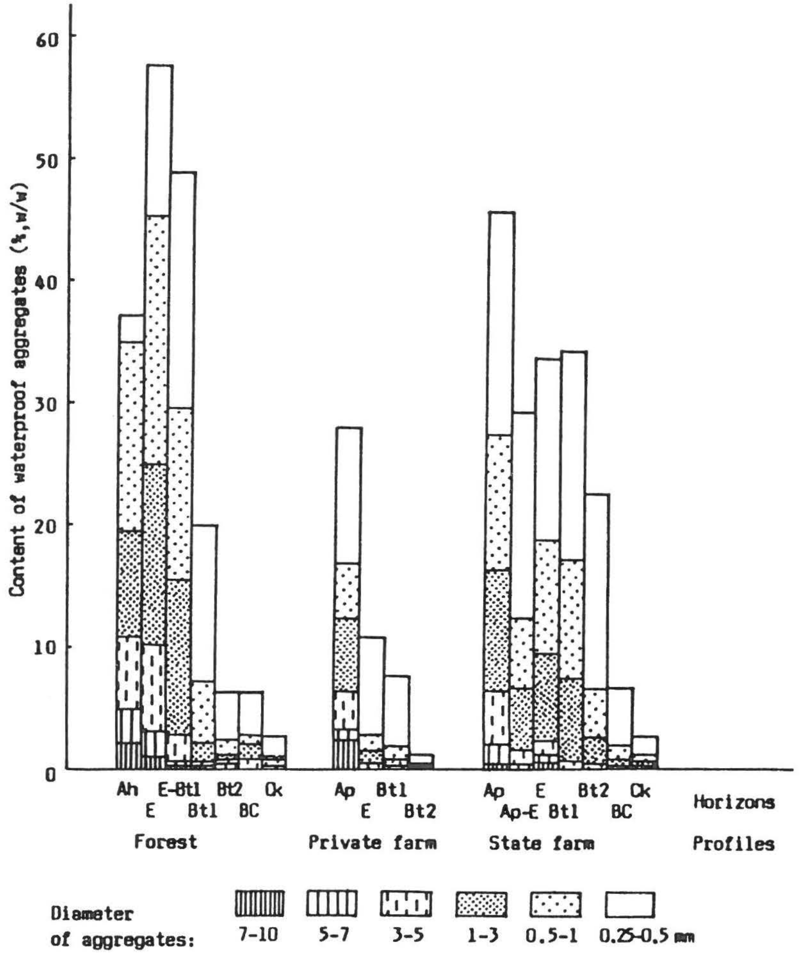


**Fig. 1.** Water stability of soil aggregates.

enough to be useful in comparative studies on the assessment of physical status of the same soil being under different land use.

The same concerns the next property, i.e., cone resistance, which was considerably influenced by the type of land use. The highest penetration resistance was measured in soil from the state farm, and the lowest in the forest soil. This can be attributed to the differences in bulk density, the highest being in the state farm or to the organic matter content, the highest was in the forest soil. But in all cases this property was strongly dependent on an actual soil moisture content, so it can not be interpreted irrespective of the later.

As can be seen in Fig. 2, the values of internal friction are the highest for the state farm soil (C), medium for the private farm soil (B) and the lowest for the forest soil (A). It can be explained that friction coefficient is in a way proportional to the soil compaction. One can find an opposite situation in the case of cohesion, which is increasing, that is being the highest in the forest soil and the lowest one for the state farm soil. This, in turn can be related to a considerable pulverization of the state farm soil during tillage operations with the use of tractors.

Soil compaction curves (Fig. 3), obtained in non-deformable steel tube (oedometer) for

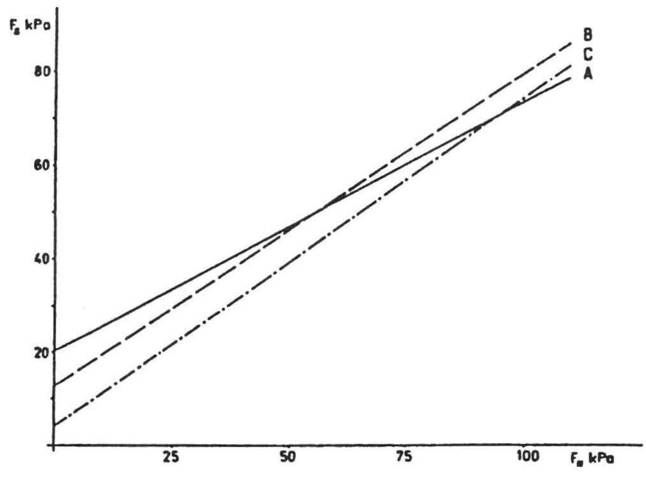


**Fig. 2.** Internal friction. A - forest; B - private farm; C - state farm.

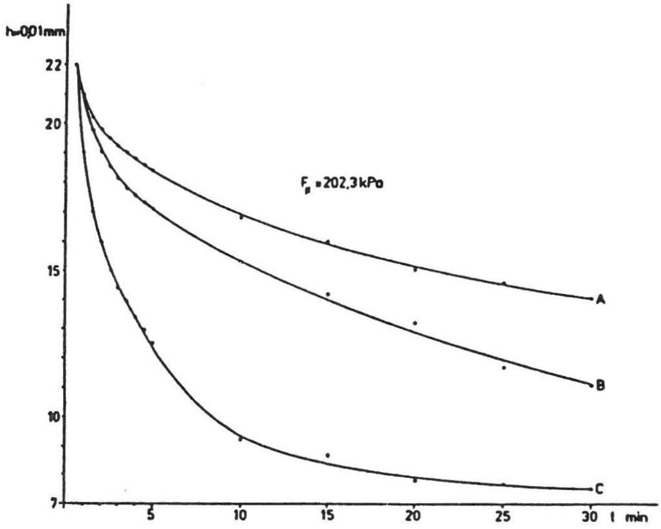


**Fig. 3.** Soil compaction curves. Explanation as in Fig. 2.

undisturbed soil samples show similar effects as shearing experiments. Forest soil appeared to be most sensitive for compaction, whereas that from the state farm, being the most compacted one (curve C) - is characterized by the lowest susceptibility for compaction.

Total porosity values were rather high, ranging from about 40 to 45 % v/v in deeper horizons of all the three soils studied, where no significant differences were found. This is obvious because of the uniform loessial parent material. The porosity of upper horizons varied from 59 to 48.8 % v/v in Ah and E horizon of the forest soil, from 53 to 44 % v/v in Ap and E horizon of the private farm, and from 46 to 44 % v/v in Ap and Ap-E horizon of the state farm soil. The values of total porosity for finer pores, determined with the mercury porosimetry ranged from 21 to 34 % w/w. However, the highest values were recorded in the private field, slightly lower in the forest, and the lowest in the state farm field.

Average pore radius was between 2.0 and 4.7 microns and was differentiated both within and between soil profiles. The most differentiated values were within the state and forest soil profiles, while the least differentiated values were within private farm soil.

The highest values of infiltration rate (4-11 mm $min^{-1}$) were under forest soil, the lowest (0.2-0.4 mm $min^{-1}$) in the soil intensively cultivated in the state farm, and intermediate (2-4 mm $min^{-1}$) in the soil extensively managed (private farm). Also the highest values were during the initial 40 min of the measurement, but they varied depending on the utilization. With the elapse of time these differences decreased. After 180 min, when the process reached nearly steady state rate (about 2.1 mm $min^{-1}$ in potato field in private farm), the infiltration in the forest soil was lower by 23 %, and in the state field under maize by 91 % as compared to that in the private field. Also data on porosity showed that in soils under potatoes and forest the contribution of large pores (2 mm) was greater than in the state farm soil sown with maize.

These results suggest that the configuration of the solid phase characterized by the pore distribution, infiltration rate and others is much better in the soil under extensive private

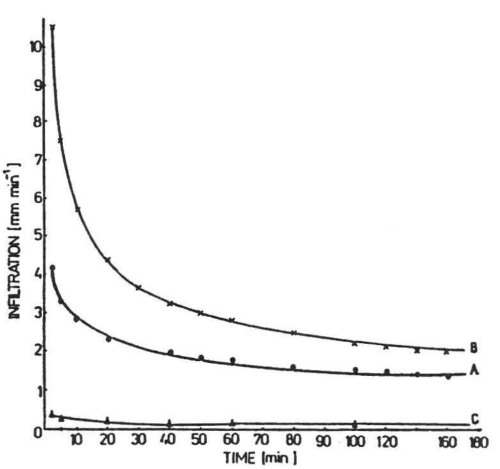


**Fig. 4.** Infiltration rate. Explanation as in Fig. 2.

farming. This has also been proved by the studies of Walczak *et al.* [12]. It can be assumed than that the differences in the examined physical parameters and properties have been caused by different tillage systems, crop rotation and other field works in the private and in the state farm.

## CONCLUSIONS

The investigations carried out in three soils undoubtedly pointed out to a significant differentiation in the soil structure state as a result of different land use of these soils, despite that they are derived from the same parent material (deep loess deposits).

Most of the tested methods and analysed parameters or properties appeared to be sensitive enough to recognize the changes in the structural state of silty soils under different land use. However, the conclusions based on the data obtained from different measurements are sometimes contradictory and may lead to misuse of the data. This was evidenced, for example, by the values of pore size distribution and porosity (higher values in private farm soil) and the infiltration rate (lower values of the above but better infiltration rate); better aggregate stability in the state farm soil than in forest soil versus higher compactness, etc.

Therefore, we should emphasized here that the assessment of structural state of agricultural soils should be done in respect to the clearly defined purpose of the study, either in view of its classical approach (mainly soil morphology, soil classification, etc.) or in view of the role that soil structure state plays in various soil functions. This was also stressed by Blum and Rampazzo [1] and Várallyay [12].

Finally, we should also stress that there is still an urgent need for further investigations in this field to introduce new elements for the quantification of soil structure functions in the sustainable production of biomass and environmental protection.

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