TALAJTÖMÖRÖDÉS MÉRTÉKÉNEK MEGHATÁROZÁSA ’PACKUNGSDICHTE’ MÓDSZERREL ÉS TALAJ-MIKROMORFOLÓGIAI ELEMZÉSEKKEL

BARCZI A.[1] – NAGY V.[2]

[1]Szent István Egyetem Mezőgazdaság- és Környezettudományi Kar
2100 Gödöllő, Páter K. u. 1.
[2]Szegedi Tudományegyetem Mérnöki Kar
6724 Szeged, Mars tér 7.

Summary

The Thematic Strategy for Soil Protection focuses on the importance and conditions of soils, being that the soil is a renewable natural resource, which makes it also one of the most important means of agricultural production and forestry. Stress effects caused by different agricultural practices are becoming more and more threatening for soils, such as the utilization of complex machinery lines and the usage of chemical fertilizers and pesticides. Soil compaction as physical degradation is one of the most important degradation processes. In order to be capable of controlling soil compaction, the process itself needs to be realized and measured. The aim of our research is to evaluate and authenticate the ‘Packungsdichte’ compaction-measuring method through soil-micromorphological analysis.

ESTIMATE THE RATE OF SOIL COMPACTION USING 'PACKUNGSDICHTE' METHOD AND SOIL MICROMORPHOLOGY

Introduction

Soils are essential components of the global ecosystem and soil is one of the necessary requirements for human existence and an essential component of human civilization furthermore it is a fundamental prerequisite for agricultural production (Stefanovits 1977; Garrigues et al. 2013; Badalíková 2014). Moreover, soils keep the history of our environment and the heritage of humankind (Pető 2013; Pető et al. 2015). Special attention should be paid to the degradation processes of soils during environmental friendly landuse and during agricultural systems, which aims at sustaining the ecological conditions of the soil cover. Compaction is a mechanical stress that negatively affects the water, heat and air interoperability of soil, and causes significant damages in its structure. Different forms of soil compaction occur when trampling on wet soil surfaces, cultivating wet soil surfaces, and pressure of agricultural machinery. It has come up with the problem of soil degradation (Manninger 1957). It should be noted that Billege conducted research on the usage of different tillage tools (plow, wheels). In the latter case the compacted soil layer develops under the continuously disturbed soil, the rate of compaction (moderate, medium, serious and significant) and the depth of the deformed layer both depends on the compressive force exposed to the soil, the repetition of the compacting process, as well as the soil moisture (Billege 1938). Besides the reduced number of operations the optimally chosen agricultural tools are important to sustain the best soil conditions for crop production (Harrach 2011; Birkás 2011). This is the most important common task for our environmental protection and agriculture that requires differentiated attention by the state, the landowner, the land user and by the entire society; moreover it also demands deliberate and coordinated steps (Stefanovits 1977; Várallyay 1994; Harrach 2011; Birkás 2011; Badalíková 2014; Nagy 2015). The stress effects caused by different agricultural practices were becoming more and more threatening and serious for our soils. In order to fight against soil compaction it is essential to realize and measure the process of compaction itself.

The European Union has developed the Thematic Strategy for Soil Protection (COM(2006)231) to prevent and rein the most harmful effects caused to the soil. Emphasizing the importance of the role and sustainable usage of soil, the United Nations assigned the 5th of December as World Soil Day in its 68th General Assembly (September 2013).

The conservation of soil quality is fundamental to agricultural sustainability. Better soil quality is generally associated with greater concentrations of soil organic matter and a plentiful supply of essential mineral elements (White et al. 2014).

The micromorphology was actively developed in the last several decades as an instrument of genetic investigation of soils, regoliths, and soil-like formations (Bronnikova 2011). The aim of our examinations is to demonstrate, authenticate and evaluate the so-called ‘Packungsdichte’ compaction-measuring method through soil-micromorphological analysis.

The effect of different methods of tillage on basic physical and chemical properties of soil has to test in field experiment (Garrigues et al. 2013; Badalíková 2014; Farooq 2015).

Material and method

In order to achieve research objective a German plot (Neurath) has been chosen near Cologne. Earlier it was an opencast mining area and in 1983 it was restored to plow land. This artificially created 'soil' reflects compaction in a easily measurable and examinable manner, therefore experiences and data gained during their analysis can probably be extended to agricultural fields and practice. In the visual examination of soil structure and compaction, the easily applicable ‘Spatendiagnose’ method is helpful. ‘Spatendiagnose’ means the examination of the plant’s accurate bearing place, during which the elements of soil structure, its colour, root distribution (Fig. 1), pores and extemporal layers are measured. The name and the description of the method come from Görbing (1947).

Figure 1: **Roots penetrating soil aggregates**

Field soil examination in fact can be called as the break-even point of academic soil science and agricultural researches. The interactive connection between soil and agricultural machinery should be examined in the field, taking into account the biological procedures of soil, because it can be restrictive in the aspect of plant production as much as the nutrition-content. Due to the decreased numbers of work procedures and not at last the well-chosen machinery, soil is suitable for plant production (Tebrügge et al. 1992; Birkás 2011).

‘Packungsdichte’ (henceforth PD) is complex but simple field method that primarily includes the evaluation of soil structure and estimate the rate of soil compaction. Each degree of PD includes several important soil state attributes: for example porosity, rooting ability of plants, capacity of receiving water and water permeability. Through the determination of PD values not only the soil functions and attributes but also information about soil aggregate structures and soil moisture can be gained. The determination of PD is carried out in fresh soil state from form the soil profile. The evaluation is done with the application of a scale reaching from PD value 1 (PD1) to PD value 5 (PD5). The category of PD1 stands for the least compacted soil condition, whilst PD5 refers to the highest compaction level. From the record of the elements of soil structure such as the size and direction of aggregates, biogenic macro-pores and root distribution the appropriate PD category can be concluded (Harrach et al. 2011).

The determination of PD values and the soil micromorphological sampling took place on the plough-lands and arable fields of Neurath. The examined soil of the area has no original parent material due to the intensive opencast mining activity. The territory, which was an opencast mining area earlier, was reclaimed with loess-like sediment. Table 1 gives an overview of the sampling protocol carried out on one of the anthropogenic soil profiles within the target area.

Table 1: **Details of the examined anthropogenic soil profiles**

Soil layer/Genetic soil horizon	**Depth**	**Sampling depth**	**Associated PD* category**	**Thin section code**
Ap	0-35 cm	10-18 cm	3	M95
C1	35-45 cm	35-43 cm	5	M99
C2	45-75 cm	55-63 cm	4-5	M93
C3	75-90 cm	80-88 cm	2-3	M90

*Detailed description of how these values were determined are included in the *Results* section.

During recultivation almost globular, so-called roll-aggregates were formed, which are often found embedded in the loess. These artificially formed aggregates were created during the transportation on the conveyor belt. If the roll-aggregates can be found in the examined soil profile then we might conclude that the soil was not loaded durably because these special, artificially formed structures should have been damaged due the compaction caused by heavy loads. Therefore roll-aggregates are fine indicators of the state of soil compaction (Rücknagel et al. 2013).

The sampling was carried out by modified Kubiëna-boxes (Kubiëna 1938). Stainless steel dishes were used to embed the samples. Soil samples need to be embedded by plastic resin that is able to polymerize. And first it was necessary to dry the soil samples in the boxes, it takes about 8 weeks to dry. After the total drying the embedded sample was cut in half and then glued to glass. After the agglutination the samples were grinded with a diamond edged polishing machine to a thickness of 10-15 μm. After the grinding the sample could have been analysed by a microscope.

The laboratory technique of thin section processing does not allow to make the same-sized soil thin section. However, the same size of area should be analysed and selected from every thin section, because this way each sample can be compared to each other. This way three main analytical areas (referred to hereinafter “big squares”) were delineated on each thin section. Each of these big squares had a size of $9 \cdot 10^6$ μm^2. In every case the sample had to represent correctly the PD category. The sampling area was divided by a grid to 24 sub-areas (“small squares”). Each of the “small squares” (Figure 2) were 500x500 μm.

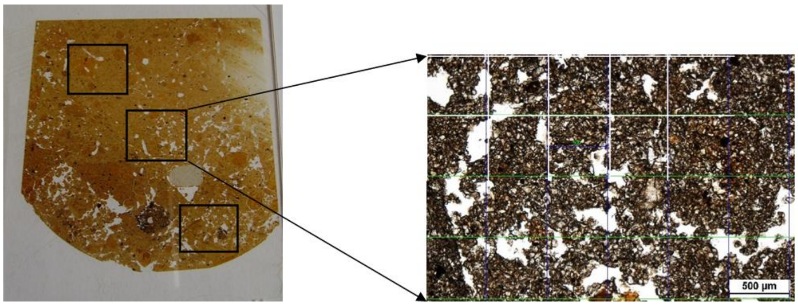

Figure 2: **Thin section 'M98' and 24 "small squares" situated inside the "big square"**

If the presence of the pores was not unequivocal (pores and some minerals show transparent images inside the thin section) then polarizer light was also applied during the analysis. Microscopic examinations were carried out by an image analyzer software called NIS Elements 3.0. Beside the general soil-micromorphological descriptions (Stoops 2003) of the thin sections the analysis of porosity conditions was emphasized. Regarding the fact that the areas of each "big square" are known, the dispersion and size of the pores inside the "big squares" have been measured, the total porosity conditions of the thin sections could have been determined. However, the size and form of each pore is different. The determination of pores is usually made based on the form and orientation of the pores. More authors (Lima et al. 2006; Aydemir et al. 2004) define differently the forms of the pores.

The diameters of the pores were measured and then perimeter, area were determined. Every analysis was carried out on a magnification of forty times. (Table 2 provides an overview of the attributes of each pore category and the number of pores within the analysed thin sections.)

Results

As shown in Table 1. the examined soil profile can be divided to four different parts due to its stratigraphic properties. The upper layer of the profile is a ploughed layer (Ap) with a thickness of 0-35 cm. The humus content of the ploughed layer was measured to be higher than in the lower layers. This soil cover is continuously ploughed the layer shows with favourable soil structure and porosity conditions in terms of compaction and PD. Furthermore favourable root distribution and macroscopically high pore ratio was noticed and the pore dispersion among aggregates was found to be prosperous. The aggregates looked like rounded crumbs or bigger nuts. After performing the drop test, the soil monolith fell to pieces at the sampling which refers to a loose soil structure. Considering the above ones this soil structure has appropriate water and air content. Regarding plant production the condition of the soil is adequate and it requires no agro-technical interventions. The PD value of the layer was determined to be 3: it means that it has an appropriate soil structure.

Going deeper in the soil profile the next layer (C1) can be found in the depth of 35–45 cm. The structure of this layer differs from the previous one. In this layer the artificial soil elements of 'rollaggregates' appear. In the case of favourable soil structure the 'rollaggregates' are rounded but in this layer the spherical shape is deformed and in most cases it is ellipsoid. Among the aggregates the bigger angular edged aggregates appear with a mildly polyhedral and columnar structure, too. During the macroscopical observations and profile description the pores among the aggregates have much closer spacing, root distribution and it is not as consistent as in the ploughed layer. There is a strong stability among the

structural elements that refers to a possible strong compaction potential. As a conclusion there is a significant compaction in this layer so the value of PD was considered to be 5.
In the soil profile the next layer (C2) was determined at the depth of 45–75 cm. In this layer was the lack of 'rollaggregate' structures. The specific features were the angular edged columns with bigger structural elements again. The pores among the aggregates were fairly close to each other. Regarding pore distribution the macro pore ratio could not be determinable easily with the naked eye. The root distribution is not consistent and in most cases the roots were found on the surfaces of aggregates and they created a felty coating. Based on the field experience this layer was considered to be less compacted than the previous one so the value of the PD was determined to be between 4 and 5, this value can take the risk of plant production and it claims unconditional intervention, which means that the soil needs agricultural intervention in oder to develop its structure suitable for crop production.
The lowest soil layer (C3) was described at the depth of 75–90 cm. The structure of this layer was quite favourable, the structure was crumby and the shape of the aggregates was crumby, too. The spacing among the aggregates was bigger and the highest macro pore ratio could be detected in this layer. The relationship between structural elements was quite loose. The value of the PD was considered to be between 2 and 3.

From the Ap soil layer an 'M95' thin section was created from the depth of 10–18 cm. The specific features of the microscopic macrostructure were the half-worn, sharper columns. In the present thin section the skeleton grains are far from each other.
Within the thin section all in all $9{\cdot}10^6$ μm^2 area was analysed. Within the examined area the perimeter and the area were observed to analyse the quality and quantity of pores. According the pore shapes 251 pores fell into category of round-shaped pores and the shape of the remaining 48 pores were mostly drawn. During the analysis of the pores the diameter of the pores was also determined. Each pore diameter ultimately determines the groundwater management. Table 2 shows the number of pores in pore categories.
In the case of groundwater management the micropores are responsible for the bound water content of soil. The moisture in this pore space is not absorbable for plants. The mesopores group is also the pore space of the capillary water. The water content here is available for plants. The group of macropores is the gravity-capillary pore space of the soil, and the pore space of gravity water. In the first case plants can easily absorb moisture from these pores. The category of megapores is the pore space of the water between aggregates and the water content here is easily absorbable for plants.

The pore dispersion in the observed 'M95' thin section is quite prosperous. The pores of soil dispose of an advantageous size concerning water storage, the plants can easily pick up water.
From the analyzed $9{\cdot}10^6$ μm^2 area 23% showed pores and 77% of it forms the solid phase. The smallest pore has an area of 206 μm^2 and a diameter of 8 µm. The biggest pore is 387456 μm^2 big and its diameter is 351 µm.

From the soil layer encoded as C1 (35–45 cm) the thin section 'M99' was created. Sharper aggregates characterize the microstructure of the thin section. The structure can be defined to be porphyry regarding the relative dispersion of fine and rough structural elements. Within the thin section an area of $9{\cdot}10^6$ μm^2 was analysed: the perimeter, diameter and shape of 24 pores was determined. It displayed significantly fewer pores than it was experienced during the analysis of the previous layer. During the observation of the pore shapes 22 pores fell into the rounded pores, and the shape of the remaining 2 pores were mostly drawn. The Table 2 summarizes the number of pores within the thin sections. It can be determined that the pore dispersion is quite unfavourable within the observed sample. The pores in the soil are unfavourable size and dispersion concerning water storage. Within the $9{\cdot}10^6$ μm^2 analysed area of soil thin section 'M99' 192727 μm^2 area contained pores and it means that 2% of the sample consists of pores and the remaining 98% is solid soil material. The smallest pore is 356 μm^2 and its diameter is 3 μm. The biggest pore is 53493 μm^2 and its diameter is 11 μm. From the C2 soil layer (45–75 cm) thin section ’M93’ was created. The microstructure of the grinding showed a really compacted image. The specific feature of the structure is porphyry. Within the sample in some places there were iron flecks and manganese precipitations. The separation of manganese from the matrix is sharp. In the sample an area of $9 \cdot 10^6$ μm^2 was analysed. Within this area the perimeter, diameter and shape of 61 pores were determined. During the observation of pore shape all of the pores are rounded pores. This may be because the aggregates compressed strongly due to the compaction but the micropores between each soil grain were not compressed and their almost circular shape has remained. The Table 2 shows the pores dispersion. Within the observed thin section the pore dispersion is unfavourable similarly to the previous sample. The pores of soil dispose of unfavourable size and dispersion regarding water storage. From the analysed area of $9 \cdot 10^6$ μm^2 , 56212 μm^2 contained pores and it means that 1% of the sample consists of pores and the other 99% is solid soil. The smallest pore is 137 μm^2 and its diameter is 7 μm and the biggest pore is 5002 μm^2 with a diameter of 40 μm.

The C3 soil layer is the lowest examined layer in the profile. The thin section was encoded as ’M90’. The sample was collected from the depth of 80–88 cm. The microstructure of the observed thin section is characterized by a very loose tissue. Its aggregates are total rounded and there are quite big pores among the aggregates. The tissue of the grinding is similar to the previous ones because it is porphyry. During the observation of pore shapes, 51 out of the 73 pores have been categorised to the rounded pores. The remaining 22 pores belonged to the drawn ones. Accordingly, the pore dispersion is consistent (Table 2). Within the examined area ($9 \cdot 10^6$ μm^2) 4054864 μm^2 area contained pores. So the examined thin section shows a really loose structure. The smallest pore is 246 μm^2 with a diameter of 9 μm, whilst the biggest pore is 238613 μm^2 with a diameter of 276 μm.

Table 2: **The classification of soil pores by their size**

The name of pore group (Diameter [μm])	**Features and water management function**	**The appearance of pores in the thin sections regarding pore category (number of pieces)**			
		M95 (PD3)	M99 (PD5)	M93 (PD4-5)	M90 (PD2-3)
Micropore (<0,2)	Fine pores. Pore space of bound water.	0	0	0	0
Mesopore (0,2-10)	Medium pores. Pore space of capillary.	15	22	14	3
Macropore (10-50)	Moderately rough pores. Capillary-gravity pore space.	235	2	47	31
Macropore (50-1000)	Rough pores. Gravity pore space.	49	0	0	39
Megapore and cracks (>1000)	Quite rough pores and cracks. Gravity pore space.	0	0	0	0
	Σ	**299**	**24**	**61**	**73**

Conclusions

The aim of the soil-micromorphological sampling and analysis was to validate the PD categories determined under field conditions. PD categories of each layer were demonstrated with the results gained during the microscopic analysis of the soil thin sections as summarised in the followings. One of the most important correlation test was between the PD categories and the porosity test of thin sections. It clearly shows that by comparing each categories there is a well-defined difference between porosity (1%) of ‘M93’ thin section that has strongly compacted (PD4-5) tissue and porosity (45%) of ‘M90’ thin section, which has the loosest ((PD2-3)) one. While in the case of the most compacted thin section the PD is 5 and porosity is 2% (‘M99’ thin section).

During the correlation test it was determinable that in the case of loose structured soil the dispersion of pores was more favourable. In the case of PD2 and PD3 categories the soil disposed of a mesopore and macropore categories and the number of pores was also outstanding. In the case of the strongly compacted PD4 and the most compacted PD5 the pores only are mesopores and macropores. Moisture stored in pores is hardly absorbable for plants but in the PD2 and PD3 categories have water content in the pores which was easily accessible for them.

According to the previous consequences the conclusion is that PD categories determined in field conditions correlate well with the microstructure determined in the thin sections, with each pore category and with pore conditions within the thin sections. However, strong correlation between PD categories and pore shapes could have not been evidenced.
Based on the analyses, the PD categories determined in field conditions are proved to be correct but with the help of the thin sections each category can be refined. Accordingly, in the case of thin section ‘M93’ where PD4-5 was determined in field but after the observation of the thin sections it is rather PD5 (the most compacted soil). The thin section ‘M90’ where in field conditions PD2-3 was determined it could be rather classified into the PD2 because this sample had the most favourable structure and the biggest porosity. The PD5 result of the sample ‘M99’ and the PD3 result of the sample ‘M95’ were proved to be correct.

Although artificially created soils were used in the baseline research, but it is anticipated that these results are to be applied in practice within the frames of Hungarian agricultural production and soil protection. The easy-to-use spade test will hopefully be useful tool in the hands of the Hungarian farmers.

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