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A DOCTORAL SCHOD OF MULTIDISCIPLINARY AGRICULTURAL

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PH.D. THESIS

EXAMINATION OF SOIL PENETRATION WITH PENETROMETER

by

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1. THE ANTECEDENTS OF MY RESEARCH WORK, OBJECTIVES.

One of the basic elements of the sustainable development is the utilization of our natural resources including soil protection to provide the defence of its many functions. (VÁRALLYAY, 1993)

The physical degradation of the soil is one of degradation processes, endangering the soil state, and it is very difficult to prevent it. The deterioration of soil structure and soil compactness belong to these processes. (KUIPERS, 1987, STEFANOVITS, 1935, TAYLOR, 1987, UNEP-FAO, 1983). Initiated by the UNEP, an international project was started at the end of the 80's to survey the soil degradation processes. The results of the examinations proved, that the physical degradation of the raw soil and soil compactness have become a problem of world importance.

There is a complicated interaction between the formation of soil compactness and changes caused by soil compactness.

Soil compactness is a change in the physical state of the soil, therefore its examinations can be carried out by well-chosen parameters of the mechanical systems of soil physics. The examination of the mechanical soil resistance and humidity content in the same space and at the same time should be emphasised. SINÓROS (1992).

During the examinations of soil compactness one of the most frequent methods is, the measurement of soil resistance.

Without knowing soil humidity figures, penetration resistance itself is not enough to describe soil compactness. KOCSIS (1992) calls our attention to the fact, that soil resistance values at various humidity figures can't be compared. A lot of authors, to prevent the effect of humidity difference on soil resistance, compared the soil compacting effect of cultivation methods at humidity content filled to arable land water capacity. (DOUGLAS et al., 1980) (HILL at all, 1985) To compare various cultivation methods requires to establish the same humidity content of the soil layers, which is expensive and time consuming.

The latest Hungarian examinations show that there is a tendency to compare mechanical soil resistance at the same humidity content. (BIRKÁS, 2000, GYURICZA, 2000, RÁTONYI, 1999, SCHMIDT, 1998, SINÓROS, 1992)

The research team of Environmental Research Group at the Nyíregyháza College studies the interaction of the physical-menchanical system of the soil and the soil cultivation factors. My work within this group is the basis of my Ph.D. thesis. I aimed at applying new methods to determine the compactness of the soil, and to study the main interaction processes, using measuring methods and procedures and new measuring equipment, developed and applied by the research method. (SINÓROS, KAZÓ, SZŐLLŐSI, 1992)

To carry out my objectives a measuring system was developed by the research team led by Professor Sinóros-Szabó-Botond, which was an indispensible and unique equipment. The measuring system was placed into the tested soils in 1 meter depth, where I have been able to carry out my studies for 6 years.

Considering the above mentioned facts, 1 determined the following objectives of my examinations:

1. To examine the connection between the soil resistance and soil humidity in a measuring system on location, furthermore, to determine the functions of the two factors for various mass volume and for three soil types (sandy, loamy, clay soils).
2. To determine the (soil resistance values at different humidity content) calculation methods of converting the soil resistance values at different humidity contents to the same values, in case of 3 different soil types.
3. To examine the changes during the vegetational period in cultivated and non-cultivated rails (sandy, loamy, clay) regarding the position and advance of the compacted soils.
4. To examine the 5 varieties of sandy soils improving crop rotations by Westsik concerning their effect on soil compactness.

2. RESEARCH METHODS, PROCEDURES, THE COMPLETED EXAMINATIONS.

2.1. The determination of the connection of the soil mechanical resistance and soil humidity at given mass volume values.

To determine the connection of soil resistance and humidity values, I carried out measurements in the measuring system on location.

The measuring system on location consists of a long concrete place which is 2x1 m in diameter, 90 m long, drained in order to carry off and measure the amount of water coming through the soil section. In its first section according to genetical classification sandy humus, physically classified as sandy soil from Nyírtelek-Ferenctanya was filled. In the second section according to genetical classification, meadow chernozem, physically classified as loamy soils from Megyanó-Újvilágtanya was placed. In the third section according to genetical classification meadow clay soil, physically classified as clay soil from Taktaharkány-Rónahát was placed.

The soil from the arable land was placed in the original quality and in the adequate depth separately.

Prior to my examinations the soil settled in a natural way, free of any cultivation and mechanical impact. The settling lasted for 2 years.

The soil was placed this way, having different layers, but all of them were homogenious that was proved by control measurements of the 3T SYSTEM equipment.

Obtaining the data, 36 measurements were made during the vegetation period (March to October) in equal distributions within an area of 1 m^2. The values of soil resistance and humidity were measured by the 3T System soil tester. The instrument makes the measurements of soil resistance to 60 cm depth at every 1 cm. (KPa) and soil humidity (arable land water campacity, pF 2.5 volume percent.)

The measured values are stored by RAM, the data can be transferred into computers by interface.

Besides measuring soil resistance and humidity, the mass volume values of the soil layers from 0 to 60 cm at every 10 cm were determined. The mass volume of the soil were determined in the soil samples with original structure.

The samples were taken in 100 cm^3 containers repeated in 3 successions.

I calculated the mass volume by the quotient of the volume of dried soil and the volume of the container. The point set of the matching resistence values from every 10 cm layers were demonstrated in a coordinate system.

The functions were fitted by the Excel table operating program.

2.2. The impact of cultivation methods on soil compactness.

The soil compactness was measured in its original arable land site.

Cultivated land covered or not covered with flora, while meadow chernozem ploughed and tilled and loosened was tested. Besides studying cultivated lands I chose uncultivated ones where there were no cultivation and tilling.

During the vegetation period measurements were made three times (at the begining, in the middle, at the end), within a 20 m^2 area designated in advance. At a time 3x3 and 5x3 measurements for different soil types took place. (Three repetitions for each location. The penetration resistance values showed the state of soil compactness.)

The 3T SYSTEM soil tester was applied to measure soil resistance and humidity.

Analysing the state of soil compactness I used my computer program, which converts the resistance values at various soil humidity levels to identical values.

To prove the comparrisons I applied a one factor random variety analysis. SVÁB (1981)

2.3. The impact of sandy soil improving crop rotation on the compactness of the soil.

I examined the impact of sandy soil improving crop rotation on the compactness of the soil in the Nyíregyháza branch of the Research Centre of the Debrecen University. The experimental plot is covered by shifting sand, forming sand hills. Due to the varied terrain, the plot is not homogenous.

Westsik Vilmos started his crop rotation trials in order to improve sandy soils.

They are unique in the world, modelling the impact of uncultivation, straw, green, dung, root manuring on the soil productivity and structure. I made the measurements for 5 typical crop rotations. The crop rotations are divided into 3 parts. When the trials started, the statistical methods of experiments have not been spread, therefore the plots were treated without repetitions, every crop was sown in the crop rotation each year.

The description of the experimental crop rotations:

I. Crop rotation. Uncultivated land

The first crop rotation models the traditional cultivation. The crop rotation is divided into sections. Apart from growing potatoes and rye, the arable land is uncultivated.

The sections of crop rotation:

1. Uncultivated land. Weed is ploughed under, before blooming.
2. Rye, without chemical fertilisers.
3. Potatoes without chemical fertilisers.

II. Crop rotation. Soil improvement with green manuring (lupin)

Besides growing potatoes and rye, lupin is grown so that the biggest amount of green mass could be obtained, utilising the possible longest time of the vegetation period.

The section of the crop rotation:

1 Lupin is the main crop with P and K chemical fertilisers.
2 Rye with P.K. chemical fertilisers.
3 Potatoes with N chemical fertilisers.

III. Crop rotation. Sandy soil improving with lupin root green manuring.

Soil improvement with lupin green manuring. Growing papilionaceae crops, during the nitrification process, the bonded Nitrogen is harvested but the major part of it is retained in the soil. A favourable C/N proportion of the stalk and root remnants causes a fast decomposition, producing good quality humus soil, wich is a good plant nutritive.

Crop rotation sections:

1. Lupin grown for seeds with P, K chemical fertilisers.
2. Rye with P, K chemical fertilisers.
3. Potatoes with N chemical fertilisers.

IV. Crop rotation. Sandy soil impovement with straw.

Sandy soil improvement with raw straw manuring is a common procedure of the West European farmers. Right after the harvest the chopped straw is ploughed under. Quite naturally N chemical fertiliser is added to decompose organic material.

Crop rotation sections

1. Rye with straw and N, P, K chemical fertilisers.
2. Potatoes, with N, P, K chemical fertilisers.
3. Rye without chemical fertilisers.

V. Sandy soil improvement with manuring.

Sandy soil is manured to improve it.

Crop rotation section:

1. Oats and vitch with manuring and with P, K chemical fertilisers.
2. Seed rye with P, K chemical fertilisers.
3. Potatoes with N chemical fertilisers.

The potatoes plots were tested. The penetation resistence values show the state of soil compactness. I used the 3T SYSTEM soil tester on location to measure the soil resistance and humidity content. I made the measurements on 5 plots (western bottom of the hill, western hillride, the top of the hill, eastern hillride, eastern bottom of the hill). On each location 3 measurements were made between the rows of crops. The impact of crop rotations on soil compactness was calculated by the original mean soil humidity content values. The differences between crop rotation effects were described by the method of the above mentioned statistical analysis.
The area stretches along sandy hills eastwards and westwards, due to varied terrain the soil is not homogenous. Accordingly, the comparisons were made at five locations, those effects are regarded typical, which were common for the five locations.

3. RESULTS.

3.1. Connection between the soil resistance and humidity values at a given mass volume values.

I examined and determined the connection between the penetration resistence and humidity for 3 soil types (sandy, loamy and clay soils). These connections are influenced by the mass volumes of the soil, therefore I separated the data base according to the mass volume values, measured at every 10 centimeter. By the separated data I decided the functions, describing the connections of soil resistance and humidity values at the given mass volume values.

During data processing the soil surface effect made its appearance, which presence was described by a number of authors. This effect does not exceed a 5 cm depth. Therefore function fittings were made in those soil layers, which were deeper than 5 cm. The best fittings offered the functions of negative exponents among those function fittings offered by the Excel computer program. The fitted functions are demonstrated in Table 1-3.

Table 1.

Equations of functions fitted to the soil resistance and humidity values measured in sandy soil layers every 10 cm.

Depth (cm)	Mass volume values (g/cm^3)	Equation	R	P (F)	P (t)
5-10	1,19	$y=8,0144x^{-1,0172}$	0,9448	< 0,0001	< 0,0001
10-20	1,30	$y=23,38x^{-1,2391}$	0,9740	< 0,0001	< 0,0001
20-30	1,32	$y=21,939x^{-1,1969}$	0,9692	< 0,0001	< 0,0001
30-40	1,33	$y=201,06x^{-1,1586}$	0,9595	< 0,0001	< 0,0001
40-50	1,43	$y=245,97x^{-1,1431}$	0,9406	< 0,0001	< 0,0001
50-60	1,38	$y=169,94x^{-1,0825}$	0,9455	< 0,0001	< 0,0001

y= soil resistance [MPa]; x= soil humidity [pF 2,5 tf%-ban]; p (F)= the significance of regression; p (t)= significance of parameters;

Table 2.

Equations of functions fitted to the soil resistance and humidity values measured in loamy soil layers at every 10 cm.

Depth (cm)	Mass volume values (g/cm^3)	Equation	R	P (F)	P (t)
5-10	1,15	$y=80,173x^{-0,9174}$	0,8942	< 0,0001	< 0,0001
10-20	1,17	$y=111,63x^{-0,9813}$	0,9380	< 0,0001	< 0,0001
20-30	1,20	$y=216,13x^{-1,1142}$	0,9403	< 0,0001	< 0,0001
30-40	1,22	$y=136,54x^{-0,9695}$	0,9573	< 0,0001	< 0,0001
40-50	1,32	$y=306,34x^{-1,1151}$	0,9611	< 0,0001	< 0,0001
50-60	1,27	$y=139,58x^{-0,9400}$	0,9700	< 0,0001	< 0,0001

y= soil resistance [MPa]; x= soil humidity [pF 2,5 tf%-ban]; p (F)= the significance of regression; p (t) = significance of parameters;

Table 3.

Equations of functions fitted into soil resistance and humidity values measured in clay soil layers at every 10 cm.

Depth (cm)	Mass volume values (g/cm^3)	Equation	R	P (F)	P (t)
5-10	1,16	$y=606,7x^{-1,3678}$	0,9179	< 0,0001	< 0,0001
10-20	1,19	$y=874,09x^{-1,4286}$	0,9030	< 0,0001	< 0,0001
20-30	1,22	$y=1602,2x^{-1,5351}$	0,9247	< 0,0001	< 0,0001
30-40	1,26	$y=1633,0x^{-1,4813}$	0,9188	< 0,0001	< 0,0001
40-50	1,30	$y=1517,4x^{-1,4209}$	0,9197	< 0,0001	< 0,0001
50-60	1,29	$y=1277,2x^{-1,3836}$	0,9548	< 0,0001	< 0,0001

y= soil resistance [MPa]; x= soil humidity [pF 2,5 tf%-ban]; p (F)= the significance of regression; p (t)= significance of parameters;

Analysing the function connections, I came to the conclusion, that a unit of types resulted in an ever increasing change in soil resistance at a given mass volume value. Reducing soil humidity by a unit of mass volume difference, caused an ever increasing change in soil resistance, though the extent of changes was lesser, than the effect of humidity differences. Comparing the effect of humidity difference with the changes in resistance under the effect of volume differences, I conduded, that the changes in soil resistance caused by humidity differences were greater, than those, caused by mass volumes.

The above mentioned conclusions are valid for all the 3 soil types, although the extent of the change in resistance caused by a unit of humidity and mass volume for clay soil, was becoming greater.

3.2. Algorithm to the values of soil resistance

To determine the connection of soil resistance and humidity values and to evaluate different soils, I elaborated a method in the form of algorithm. This algorithm takes into consideration the values of soil resistance, humidity and mass volumes and their connections.

The soil resistance values, measured at different humidity values can be transformed to identical humidity values by the algorithm.

Conversion of soil resistance values is based on function connection between soil resistance and humidity content in the case of three soil types (sand, humus, clay). The graphic figures show the process of procedures, the operations by the computer programs. The process of conversion is the same for all the three soil types, that's why I describe it only for humus soil. We can measure greater mass volume values, in arable land circumstances than those mass volume values, we measured during the process of the settling of the soils. Therefore I had to determine functions belonging to further mass volumes. The same problem exist for lower values as well because the soils become looser when cultivated therefore we receive lesser mass volume values. So, I determined functions belonging to four further mass volume values. For sandy soil 0,98; 1.04; 1,1; 1,55 g/cm^3, for humus 1,05; 1,1; 1,4; 1,5 g/cm^3 for clay 1,07; 1,1; 1,3; 1,4 g/cm3.

I intersected the functions from the calculated data base by lines at 40, 50, 60, 70, 80, 90, 99 mass volume %. The lines were parallel with the y axis. (Figure 1.) There were 6 points of intersection.

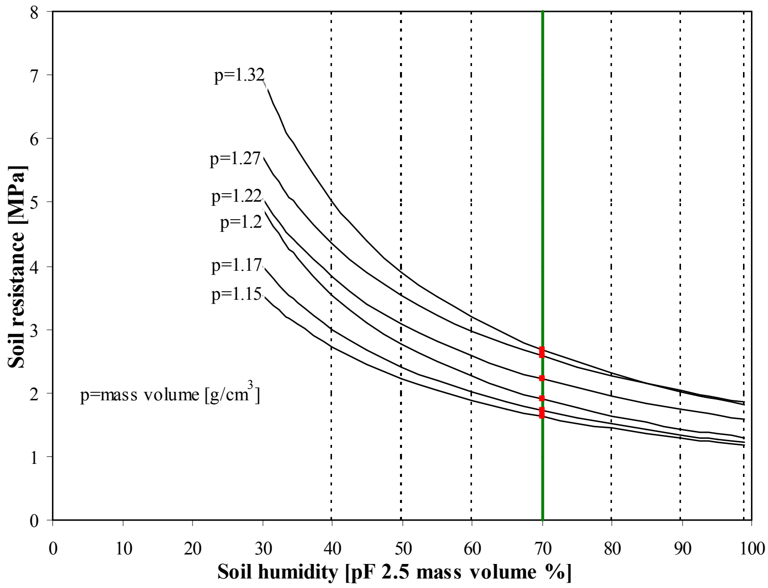

Figure 1. The points of intersection belonging to 70% humidity value of the functions of soil resistance and humidity at a measured mass volumed values.

According the functions of soil resistance and mass volumes, the 6 points of intersections, and fitted functions to them. The figure 2 shows it at 70 mass volume % values.

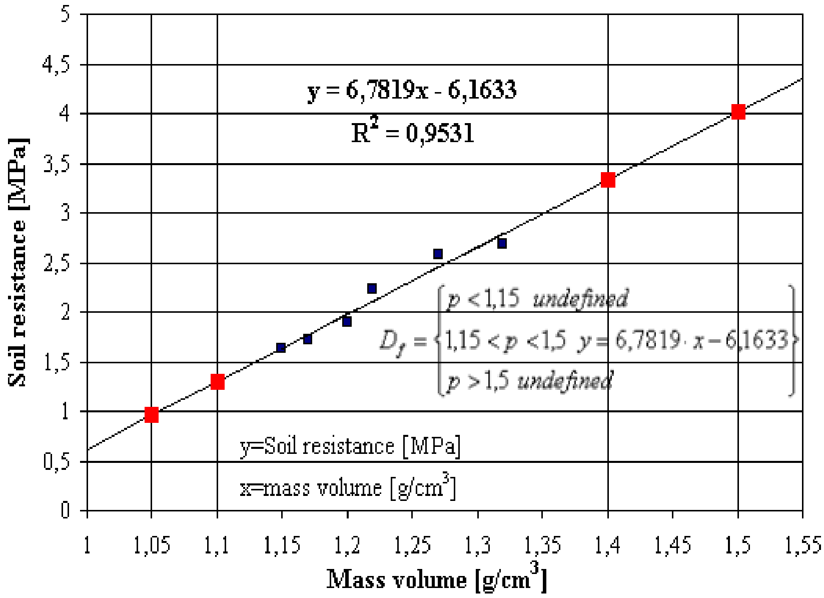

Figure 2. Changes in soil resistance in the function of mass volume at 70 mass volume % of the humidity content.

In the case of humus soils. The vertical lines belonging to 1,05; 1,1; 1,4; 1,4; 1,5 g/cm3 mass volumes values intersected the soil resistance values at 70% mass volume humidity values. These procedures were applied for 40, 50, 60, 80, 90 99t mass volume % humidity values, the points of intersection are in a coordinate system of soil resistance and humidity.

According to this, the least soil resistance occurs in the case of sandy soil, while it is the most in the case of clay soil.

For loamy soils the vertical lines belonging to 1,05; 1,1; 1,4;1,5 g/cm^3 mass volume values intersected the soil resistance values at 70 mass volume % humidity values.

The same procedures applied to the other humidity values at 40, 50, 60, 80, 90, 99 mass volume%. I placed the points of intersections in a coordinate system of soil resistance and humidity. (Figure 3.)

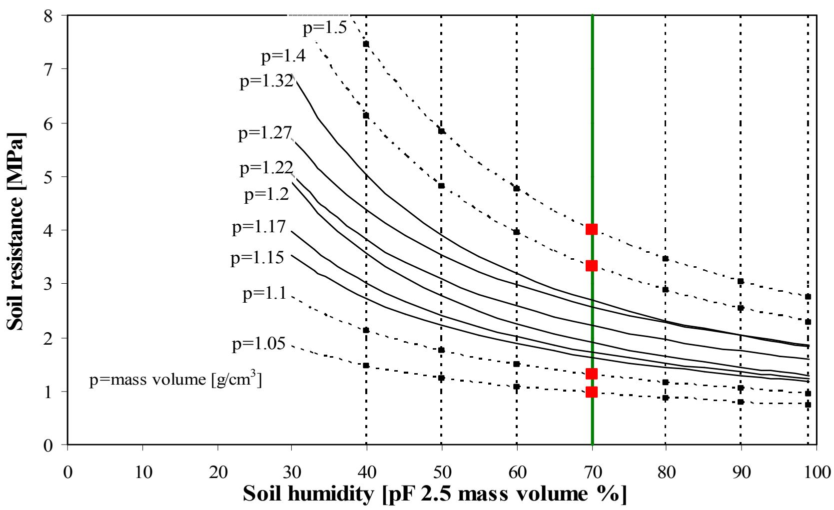

Figure 3. The determination of the connection between the soil resistance and humidity content at 1,1; 1,4; 1,5; g/cm^3 mass volume values.

Accordingly 7 points of intersection belong to each mass volume values (1,05;1,1;1,4;1,5 g/cm^3.) I fitted the seven points to the functions. So, I received the functions, describing the connection of soil resistance and humidity values at the above mentioned mass volume values.

The figure 4 shows the conversion of soil resistance values at the given soil humidity values into soil resistance values at other humidity values.

The figure demonstrated, that if we measure 4,3 Mpa at 50 mass volume %, we will receive 5,4 Mpa at 40 mass volume % in the same measuring point. We can follow the procedure of conversion. The starting point will be the soil humidity and soil resistance values, I find the next function (belonging to the p=1,32 g/cm^3) by a computer program, then I go as far as the point of intersection of the humidity value at 40 mass volume %.

Thus, we receive the expected amount of the increase in the soil resistance values, its original soil resistance values – this way we get the new soil resistance values.

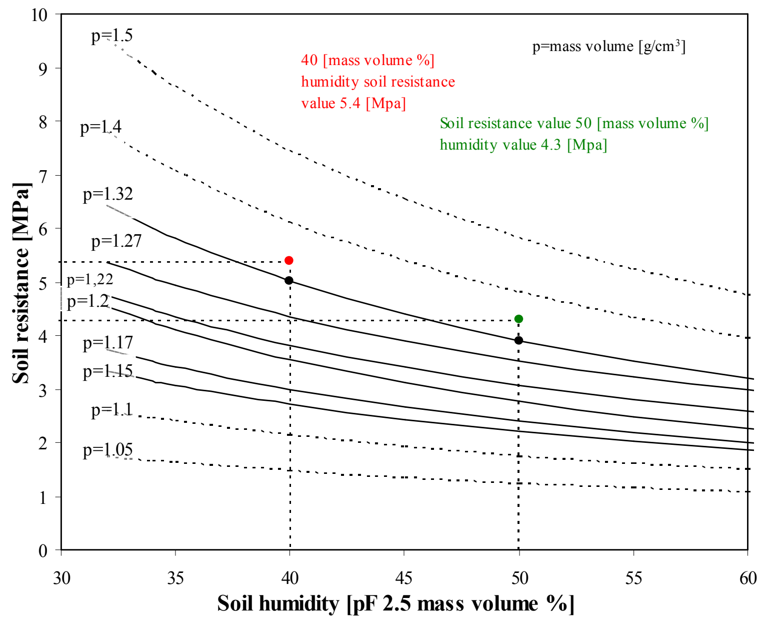

Figure 4. The method of converting the soil resistance values at various humidity values into identical humidity values.

Matching of the various soil resistance values at various humidity values with the trend of examination. According to the computer program I converted the soil resistance values along the function of the highest mass volume values, if the point determined by the humidity and soil resistance, lies above this function. The same is relevant to the points below the function, belonging to the lowest mass volume values.

As changes in mass volume values have a lesser impact on soil reistance, than changes in humidity values, I had to limit the system of conversion on the least humidity values. (Sand 20 mass volume % humus 25 mass volume % day 30 mass volume %.)
It is typical of the fitted functions, that they are steep at the least humidity values. Its quite natural, that the best way would be to measure at lesser humidity values. It was impossible to measure lesser values during the whole vegetation period (March to October). Therefore in the uncertain parts I took into consideration the soil resistance values from the latest part.

3.3. The impact of the cultivation on soil humadity

It is true for the 3 soil types, that the state of compactness at the beginning of the vegetation period is less for cultivated land, than for uncultivated one. The differences are reduced at the end of the vegetation period. The measurements proved, that differences in the soil resistances for cultivated and uncultivated lands, for all soil types are declining by the end of the vegetation period.
This is due to the changes in the cultivation depth of the cultivated land, because the compactness of uncultivated land did not change during the vegetation period. The increase in soil resistance was the highest for meadow chernozem (120%). The soil resistance of tilled soils after 15 cm depth exceeded that of the uncultivated land. For loosened meadow chernozem soil it occured below 20 cm depth.

While I did not measure 3 Mpa critical limit for none of the soil types at the beginning of the vegetation period, by the end of it on humus below 15 cm meadow chernozem below 20 cm I got higher values than the ones I mentioned. On clay soils it did not occur, due to the higher humidity content. I gained the maximum values of soil resistance at 5-10 cm, below the cultivation depth. They increased during the vegetation period, but they did not exceed 30%. The compactness of the tested soils did not change statistically at 45-50 cm depth. Mostly they were higher significantly, than on uncultivated land.

Therefore it can be concluded, that the compactness became bigger, more than 3Mpa, in the higher soil layers. On meadow chernozem soils, the probability of plough bottom effect is less, due to soil loosening. Contrary to the 4,8 Mpa soil resistance of the tilled soil, on loosened land 3,5 Mpa was the maximum value, and in soil layers of more than 3 Mpa compactness was narrower. As the soil compactness below 45-50 cm soil depth did not change during the vegetation period, the effect of aggregates can be neglected.

The resistance values were higher for cultivated soils below 40-45 cm, than those for uncultivated ones, we can draw an important conclusion from this fact. The main role in the difference of soil resistance is played by the tyres of tractors and harvester combines.

3.4. Evaluation of the experiment on the sandy soils improving crop rotation regarding soil compactness

As the measurements proved, that the compactness of the uncultivated land in the control soil improving crop rotation experiments, was bigger than in the other crop rotations in all depth sections.

Plough bottom disease was prevelant in all crop rotations, as the soil resistance curves show. This relates mainly to uncultivated land. The compactness of the green and root manured crop rotation was lesser in the deeper layers (40-60 cm), than in straw and dung manured plots. It's due to the roots of the lupin in the deeper soil layers.

A marked difference between the green manure land and root manured land was only in the upper 25 cm soil layer. Due to the great amount of organic material ploughed into the upper soil layers, the compactness of the green manured plot was lesser. Green manuring and dung manuring had the same effect on soil compactness on the upper 20 cm layer of the soil. Dung manuring proved to be more effective between 20-30 cm, while below this layer the beneficial effect of lupin is inevitable.

Green manured crop rotation caused a more loosened soil compactness, than straw manuring in all soil depths. Straw manuring unlike root manuring had a beneficial effect on the upper 30 cm soil layer while below it, root manuring was better. There were no significant differences between dung and straw manuring, so the soil compactness of the two plots was almost the same.

4. NEW SCIENTIFIC ACHIEVEMENTS

4.1. Methodological achievements

1. To determine the interaction between the soil resistance, humidity and mass volume I introduced a new method by using an open-air measuring system concerning three different soil types. Almost new examination procedures and measuring systems were applied in my tests, based ont he soil resistance and soil humidity values, measured by the 3T SYSTEM equipment, developed one and a half decade ago.

2. I introduced a method based on soil resistance and humidity function connection to compare the effect of various cultivations and agricultural technology on various soil types (sandy, humus, clay) taking into account the soil resistance values and soil humidity.

4.2 Numerical correlations

1. The correlations were described by tight fitted functions for sandy humus and clay soils at mass volume values belonging to 10 cm soil layers. The function fittings gave the best results, when power functions of negative exponent were applied. (For sandy soil: R = 0,94 – 0,97; for humus: R = 0,89 – 0,97; for clay: R = 0,90 – 0,95 with correlation factors.)

2. The cultivated soil layers (sandy humus, chernozem, clay) were getting compacted during the vegetation period. The increase

amounted to 50-120 %. By the end of the vegetation period I have got lesser resistance values in the upper 15-20 cm depth, than in uncultivated lands.

3. The soil compactness exceeding the critical 3 Mpa limit is widening upwards, as far as 15-20 cm cultivate layers.
I found a significant difference for loosened chernozem soil and tilled plots. Contrary to the 4,8 Mpa maximum resistance of the ploughed soil, I measured 3,8Mpa on loosened soil at 80 mass volume % humidity volume. The compacted layer exceeding 3 Mpa was significanthy narrower (27-42 cm, 20-60 cm).

4. According to my examinations the compatness of the cultivated soils changed in the soil layer ranging from 0 to 45 cm. The effect of cultivation on the soil resistance was greater under the depth of 45 cm for cultivated soils, than for uncultivated soils. It's due to the impact of the tyres of power machines and combines.

5. My experiments with Westsik sandy soil improving crop rotation proved, that orgonic manuring has a significant effect not only on soil fertility, but its structure and looseness as well.
Green manuring has a beneficial effect on all types of soils. Compared to other crop rotations, it looses soil in the upper and low soil layers The dung and straw manuring in the crop rotation has a beneficial effect on the upper soil layers, while root manuring on the lower layers. The dung and straw manured crop rotations have the same effect on soil compactness.

5. THE UTILISTION OF THE ACHIEVEMENTS

1. To describe soil compactness with penetration soil resistance values, humidity values had to be taken into consideration. A measuring equipment (3T SYSTEM) measures simultaneously soil resistance and humidity in the soil layers at every 1 cm distance. The 3T SYSTEM soil tester can examine soil, humus clay soils. I offer my comperative transformational method of examining soil resistance humidity content and soil compactness to those experts, who study soil. I put my method to practice in my thesis.

2. My tests proved the compacting effect of the soil cultavition aggregates, that’s why I insist on continuing the research of the Nyíregyháza Taurus Agrotyre Company in this field, regarding the tyre development with respect to changes in soil compactness.

3. Green manuring besides improving soils it loosens them.

6. THE LIST OF PUBLICATIONS REFFERING TO THE SUBJECT OF THE THESIS

6.1. Publications in scientific journals

1. **I. SZŐLLŐSI** – ZS. P. KISS (1999): Changes in the penetration values during the vegetation period. Assosiation of Agricultural Colleges. Scientific News. 3. 20. 1999. (Ed. Fenyvessy I. p. 118-127.)

2. **СЕВЛЫШU И.** – КUШШ Ж. П. – КОВАЧ З.: (2001). Справнение традициональной обработки почвы с минимальной обработкой с точки зрения уплотненности почвы. Проблеми економичного и социального розвитку региону и практика наукового експерименту, Науковый-техничный сборник, Выпуск 17. Үжгородський Державний Үниверситет, Киев-Үжгород. p. 50-55.

3. **I. SZŐLLŐSI** – ZS. P. KISS – Z. KOVÁCS– T. CZIRJÁK (2001): Changes is penetration resistance on different soils during the vegetation period. Agrochemistry and Soil Science. TOM 50, No 3-4 p. 185-206.

4. **I. SZŐLLŐSI** – L. TOLNER - ZS. P. KISS – Z. KOVÁCS - T. CZIRJÁK: (2002). The effect of uncultivation and green manuring on soil resistance and soil humidity. Bulletin of The Szent István University Gödöllő 2001-2002. (Ed. Füleky Gy. et al.) p.109-118.

5. **I. SZŐLLŐSI** (2002): The examination the effect of various cultivation forms on soil compactness by identical soil humidity level. (to be published, Agrochemistry and Soil Science)

6.2. Lectures held on conferences

1. **I. SZŐLLŐSI** (1996): Cultivation energy tests in various soils. XXVI. Óvár scientific days. Mosonmagyaróvár, 09.29.1996. (Ed.: M. Neményi) p. 1032-1035.

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