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PH.D. THESIS

TESTS OF THE EFFECTS OF AGRICULTURAL TYRES FROM ASPECT OF SOIL-PHYSICS

by

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1. INTRODUCTION

A considerable part of the output of tractors is utilized through the tyres. The transmission of the traction power is an interaction between the tyres and the soil. Besides transferring that traction output, the tyres have a harmful effect on the soil by compacting and destroying the soil structure.

Depending on the applied cultivation technology, power machines cultivate the soil and tread on it, when it has not a proper humidity level. What is more, soil cultivation is unnecessary in many cases, destroying the soil structure. The above mentioned effects are accumulated in the deeper layers of the soil for years. As a result, both Hungary’s and the world’s soils (in their physical state) are deteriorating.

Changes in the physical feature of the soil (first of all) such as a harmful compactness of the soil, which causes a bad water retention ability and airless in the soil, affect the environment and plant production.

No wonders, that intensive research work is conducted so as to reduce and prevent soil compactness caused be the tyres if power machines.

The counteraction of tyres and soil raise a number of question to be resolved immediately such as:

- to study various effects of soil compactness
- to develop agricultural tyres which takes the changes of the physical properties of the soil into consideration
- to study the main parameters of tyres in their complexity and to determine their effects on the soil.

The parameters values can be calculated be modelling, although these models do not take into account the changes in the physical state of the soil and its mechanical system.

Changes both in the state of the soils and various soil types result deviations in the extent of effects of the tyres on the soil.

Studies of the counteraction of the soil and the tyres at the Nyíregyháza Taurus Agrotyre Company date back to decades of years. Studying the tyres and soil counteraction. I intended to determine the effect of the shape of the tyres on soil layers to be in contact with the tyres.

This aim involves (to elaborate a research method to examine) an elaboration of a laboratory and field method for developing agricultural tyres. To fulfil my purpose I have to combine a special method and subjects and the measuring equipment.

My objections were to study the changes in the soil compactness caused by agricultural tyres in all their complexity on various cultivated soil. To determine changes in the trend and compare various soil tyres. To determine other changes within the trends. I carried out comparative studies of the changes in soil compactness and soil humidity caused by the statically loaded selected tyres.
The tests were conducted by a measuring system on location of the Nyíregyháza College.

To determine the mechanical parameters of the soil more exactly test objects were pushed into the soil modelling various tyres prints. As a results of these examinations a finite element software was developed for modelling the effects of the tyres on the soil.

2. MATERIAL AND METHOD

2.1. Location and equipment of the tests

The tests were carried out by the measuring system (**Fig. 1**.) of the Nyíregyháza College on 3 various soil types. The first soil sample came from the study farm of the Nyíregyháza College which is genetically a sandy soil with humus, and physically it is sandy soil. The second sample, according to genetic classification was a so called meadow chernozjom type, physically loamy type soil. It was characterised by the farm Megyaszó, Újvilág. The third soil sample came from Taktaharkány, Rómahát, genetically it is a meadow clay soil, physically a clay soil.

Fig. 1.
The open air measuring system,
the measuring vehicle and the instrument

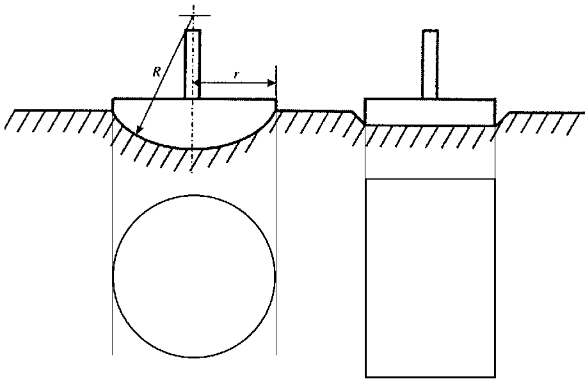
The soil samples were taken from 3 undisturbed soil sections at the beginning of the tests. The samples were investigated in the soil laboratory of the Nyíregyháza College. The mass volume of the soil samples, their humidity content and determined. To determine the connection between the soil resistance and mass volume, and to examine the initial compactness of the soil, the position of the compacted soil layers, the soil penetration resistance and the field water capacity on the selected soil sections were measured be a 3T System field penetrometer. To test the tyres cultivating the spaces between two rows a Lamborghini Formula 135 tractor of the Agricultural and Technical Faculties of the Nyíregyháza College was used.

Examining the specimens 2 standard PatSAW 10 C digital scales, which were leased from FVM MI, were applied to set the values of the vertical tyres load and measure its variations.

A variable vertical load on the specimens were measured by a dual-operated C-100 350 mm stroked hydraulic cylinder attached to the three point bridle of the tractor and linked to the hydraulics system (**Fig. 2.**). To regulate the cylinder, a KI-5473 hydraulic obdurate with a maximum 250 bar load capacity and a manometer were applied.

Fig. 2.
Penetration of the pushing tools into the soil

The soil was loaded with two specimens during the tests. One of them had a rotation symmetrical circle with an indented surface, the other on was a rectangular prism (**Fig. 3.**). The diameter of the rotation symmetrical circle specimen adjoining the soil, was 422,6 mm.



Fig, 3.
Schematic drawing of the pushing heads applied for the experiments

The measurements of the prism shaped rectangular specimen are ad follows: 509x275,6 mm. The surfaces of both specimens adjoining with the soil are identical with the previously measured area of the soil print of the Taurus WRC 320/80R48 tyres.

2.2. The determination of the parameters of the tyres profiles and prints

The tyre prints of 5 various tyres cultivating spaces between rows were determined in the tests. 4 of them have identical profiles (Taurus, Michelin, Kleber, Alliance) (270/95), while one is a considerably differing one (320/80). The profile prints of the tyres were determined in 3 different ways. To measure the prints on solid pavement a Waagner-Biró test-bench was used.
By applying a special equipment and procedure 1 managed to print a painted and a strapped tyre profile on a 1 sheet of paper at a certain load. There were two kinds of tests: firstly, the selected tyres were put on a sheet of paper and a the print of the tyre profile on a solid surface was received.

In the second case-with a new method the tyres were moved on sit width farther making a new print, after each move a new print was received. The outlines of the full tyres print resembled cones, and they could be measured more exactly and reveal much more from the process of forming the tyres than a single print.
The third print was taken from the experimental soils after statically loading it.

2.3. Tests of tyres working on spaces between rows

I started each tyre test with control measurements. It means measuring with the 3 T System measuring instrument the parameters of the soil physical changes (soil moisture, soil penetration, compactness) prior to tests. The control data were arranged in a matrix. There were 15 measurements in each of the 4 rows.

I continued the measurements to the depth of 60 cm in the soil. Each measurement point was 5 cm from each other, the rows were 10 cm from each other (**Fig. 4.**).

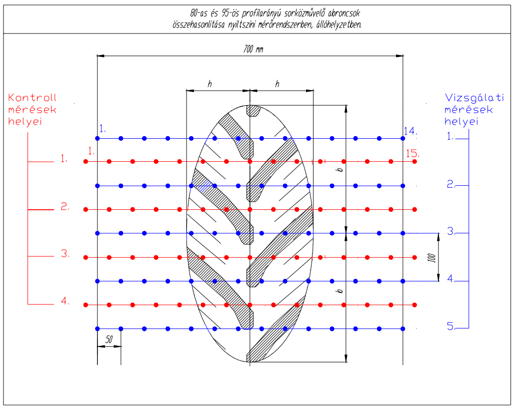


Fig. 4.
Layout of the measuring point

The measurement points were marked in a vertical direction to the movement of the tyres, after loading them. The points were

designated at a length of 5 cm from each other (14 pieces each) so that I could examine the lateral effect of the tyres on both sides of the profile prints in a further 25-25 cm with. A row had 14 measurement points, and they were tested 5 times in succession, located at a distance of 10 cm from each other. During the measurements some special points were marked. Among others I checked in the centre line of the tyre prints, on the tyre dents and their prints. I was going to find the season for the soil compactness under the tyre dents and between the dents.
3 various soils (sand, loam, clay) were tested in the field measuring system. The tests were repeated for each of soil types on 3 soil sections located side by side and the mean values of 3 measurement for each soil types were evaluated. At the marked measurement points the penetration resistance and soil moisture values were determined. In order to reveal the changes caused by loading I determined the pressure distribution map of the soil section below the tyres, and the changes in the soil humidity and the conical index of the 10 cm wide soil layers.

2.4. Measurement methods of specimen tests

After the initial stage was established by a penetrometer, and the field measuring system was prepared, the power machine placed up the rails, rolled to the scene of the measurements. After assembling the measurement system two series of test were conducted by the cylinder providing the vertical load and the regulated hydraulic obturator.
In the first series the specimens sank into the soil at a certain period of time under a constant loading. Circular specimens were loaded by 1150, 1750 and 2100 kg, Rectangular specimens were loaded by 1750 and 2100 kg.
During the second tests the specimens were continuously being loaded by a fixed ’50 kg value, to 2100 kg, and the characteristic curve of the sinking was displayed on a scale paper.
After the measurements, the specimens were removed from the points, and the deformed soil state was established respectively by taking photos of them, and measuring.

The data are based on the size of the print, and other characteristic features.
Then the values of the penetration resistance and soil humidity were determined at the marked measuring points.

2.5. Finite element computer model tests

Tests with the specimens connect the real tyre tests with finite element numerical investigations. The finite element model simplifies considerably the soil loads, therefore instead of testing the complicated design of the tyre profiles and tyre prints, two specimens were measured. The tests results enabled us to set the parameters of the models and the software, in fact to compare the software results with the real ones.

The primary aim of the model was to estimate to what depth a certain tyre penetrates into a certain soil type (loamy sand) at a certain load. To do this, I needed the characteristics of the power and the penetration depth at various load of the specimens.

2.6. Methodology of the processing and evaluation of the experimental results

For the processing of the 3T System measurement results two different in-house programs have been developed. The first can be applied for data conversion by which the measured data are imported for an Excel tablet handling program. The second one is a so called Excel application by which the measured results can be monitored graphically in a more effective way then before and it is also applicable for finding the mathematical connections by using statistical procedures.

3. CONCLUSIONS

1. I developed a program to the 3 T-System to evaluate the penetration data the pressure distributional map (**Fig. 5.**) of the soil section. The program describes precisely the vertical distribution of the resistance and moisture data enabling to compare the various measurement date in a single diagram.

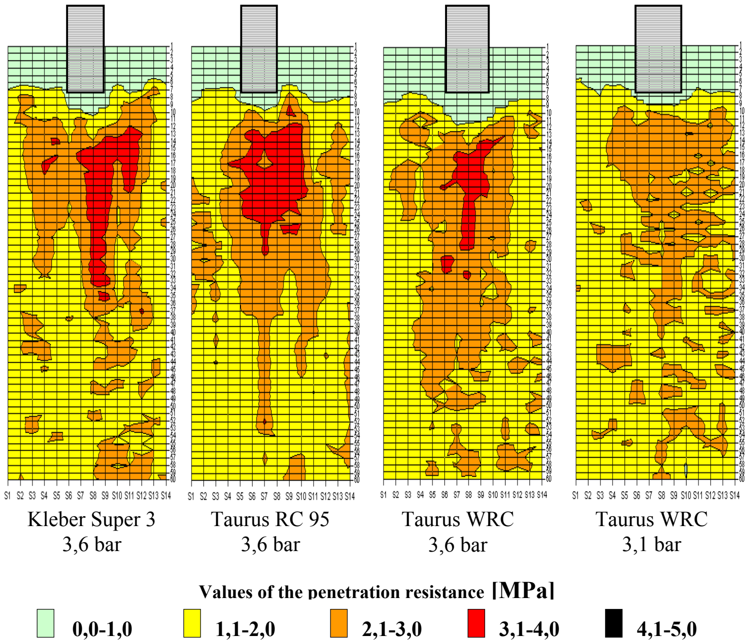


Fig. 5.
Distribution of the pressure values of the penetration resistance under different tyres in loamy soil

2. The profile prints were determined regarding the tyres, cultivating the spaces between the rows at a constant tyre pressure and 2 different loads.
3. To specify the tyres profile prints a new dynamical method was introduced. On a Wagner-Biro test bench the tyres are printed at a fixed load. A single print is a traditional one of the tyre profile. Then revolving continuously the tyre by a rib

width, another print was made. During a whole revolution a come-like tyre point at a fixed load takes shape giving a more deer picture of the tyres surface and the rolling prints, than a single static print. The figure outlines exactly the whale tyre, and the proportion and the position of the tyre surfaces exposed to an intensive pressure (**Fig. 6.**).

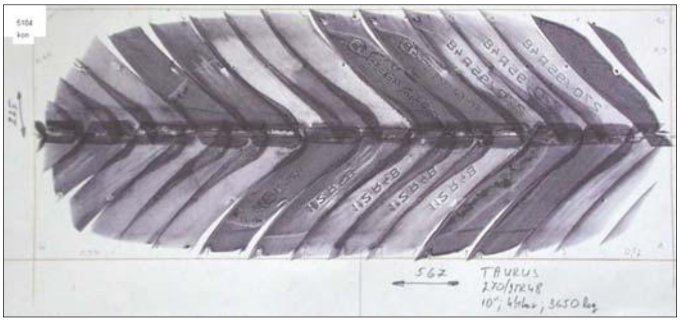


Fig. 6.
The new dynamical surface and the rolling prints of the tyres profile

4. Two specimens were designed whose surfaces are identical with the soil prints of the tested WRC 320/80 type tyres, and the rounding radius of the circle diameter specimens corresponded to the curvature of the tyre surface sunk into the soil.
5. A measuring system was assembled, which helped to regulate the penetration of the specimens into the soil. The tests of the measuring system was successful.
6. Comparing the tyres cultivating the spaces between rows, I come to the conclusion, that there are two kinds of tyre profiles. Kleber and Michelin belong to the first one, with a small rib surface compared to that of the whole tyres.
   Taurus and Alliance belong to the other type, where the ribs constitute a burger part of the print, than in the first case.
7. A has been concluded, that concerning the compacting effect of the tyres, the width of the tyre prints is much more decisive, than the length of the prints. The tyres with wider

tyre print compact the soils to a lesser extent, than in the case of the tyres with a narrower prints.

8. It has been concluded, that soil compactness diminishes extensively at 0,5 bar inner pressure. This advantageous effect seems to be significant in the upper 20 cm soil layer, where soils are cultivated.
9. Tyres with identical inner pressure, and loading compact soils differently, but the deviations are not significant.
10. Cone index values for different soils and before loading and after loading were measured. Changes in cone index value show, that wider-tyres with lower profiles compact the soil to a lesser extent.
11. Pressure distribution curves are different for different soils. In the case of identical tyres loading, the pressure distributional curve on dry and compacted soils is nearly circle shaped. Pressure distributional curves are extended on humid and light soils, so soil pressure compact the soils much deeper. It is proved, that pressure peaks are located at the central line of the tyres. It has been concluded, that pressure distribution depends on soil loading and the physical features of the soils.
12. We came to the conclusion, that a single static tyre load on soils changes considerably in the compactness of the upper layers of soils, damaging the roots growth of plants.
13. Due to loading of the tyres the soils got compacted and the humidity of the soils changes as well. From this aspect, those types of types profiles are considered advantageous, which affect the soil humidity content to a lesser extent (**Fig. 7.**).
14. The characteristic curve of the penetration of the specimens into the soil, at a fixed static loading was determined from specimens test. The shape of the specimens (circle or perpendicular diameters) does not sum to affect significantly the results. It was the tyres surface contacted with the soil that affects considerably the penetration of the tyres into the soil.

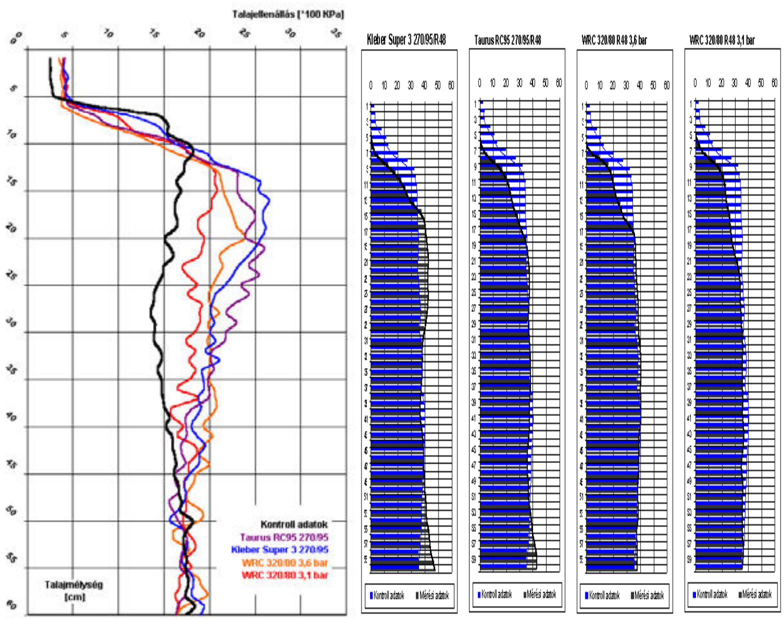


Fig. 7.
Changing of the soil compaction and moisture content after loading by different types of tyres

15. A the singing of the specimens into the soil bi-linear curve describes the most precisely. After a quick initial sinking, the further sinking is interpreted in a slightly inclined linear function of time. The incline of the lines depends on a static loading force.
16. There is a close connection between changes in soil moisture due to soil loading and changes in soil resistance. The increase in soil humidity diminishes the soil resistance.
17. Soil compactness determines the sensitivity to the factors, compacting the soils. A compacted upper soil layer prevents compacting factors from spreading into the deeper layers.
18. The tyres have the most unfavourable effect on the upper 12-20 cm layer of the soil, the loading of the tyres is accounted for forming an upper compacted soil layer, and below, a 40-

60 cm thick soil layer. The compactness of the lower layers (20-40 cm) can be caused by wrong cultivation technology. (e.g. plough foot).

19. According to the test results of the FEM program, the numerical models adequately reflect the considerable changes in volume due to shearing deformation of the soils.
The tests proved, that the Cambridge Cam Clay soil plasticity model can describe the volume changes which is highly dependent on the farmers cultivation activity. The model, as the tests have proven closely describes those processes, which occurs in the agricultural soils (**Fig. 8.**).

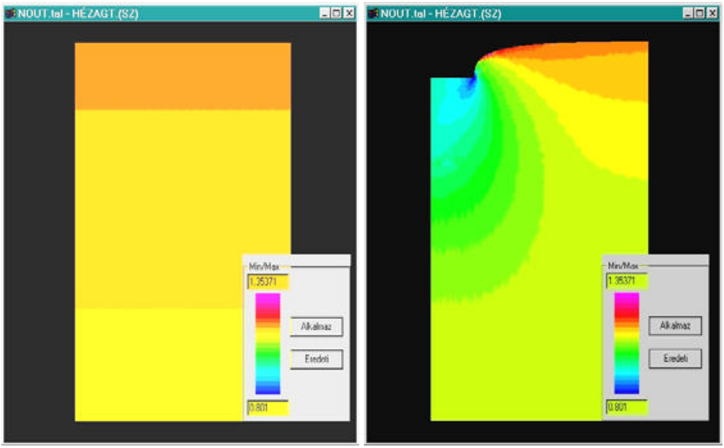


Fig. 8.
Changing of the voids ratio according to the finite element analysis

20. According to the measurements and calculations the power-sinking curve referring to sandy and adobe soils describes adequately those changes in specimens caused by a loading power. In the beginning the functions show a flexible, then a hardening tendency.
21. It was proven, that the initial (in-situ) tension state and the values of the initial mechanical parameters determine the measurement results of the model.

4. NEW SCIENTIFIC CONCLUSIONS

1. *For the evaluation of tyres and for the analysis of their effects on the physical properties of the soil a new method and a system of facilities has been worked out.*
   - a.) An up to date has been not know oa procedure has been developed for determination of the rolling print on rigid surface in case of rotation of the profile by one lug width.
   - b.) The tyres soil compacting effects can be evaluated by the new measurement technique being supported by the given methodology and computer package. The tyre caused soil pressure distribution map has been determined by which the theoretical results can controlled experimentally.

2. *During the investigation of the effects of the tyres on soil:*
   - a.) It has been show, that the inner pressure of the tyre has significant importance of the soil state changes. It has been realized, that an 0,5 bar inner pressure reduction can reduce substantially the compaction.
   - b.) It has been shown, that only one static type tyre loading causes significant soil compaction.
   - c.) The small width tyres compact primarily the upper 20 cm layer.
   - d.) There is a close relationship between the moisture and the soil resistance changes caused by loading.
   - e.) It has been found, that the biggest pressure values are not close to the surface but at the depth of 8-10 cm.
   - f.) On base of the Cone index changes the connection according to which the wider tread and lower profile tyres load the soil surface weaker then others has been emphasized.
   - g.) The soil compaction is more strongly influenced by the footprint width as the length of it.

3. *On foundation of the experiments carried out by pushing heads:*
   - a.) It has been shown, that the shape of the applied pushing heads do not influence significantly the measured values. The measure of the penetration is influenced primarily by the contact area between the head and the soil.
   - b.) The process of the penetration of the tyre into the soil can be well described by the functions obtained by the experiments with the pushing head. The functions show an elastic then later, an elastic-plastic behaviour.
   - c.) It has been shown, that a substantial part of the penetration is proceeded in the first loading interval then later, the penetration process of the pushing head can be described by a bilinear function.

4. *On base of the finite element analysis:*
   - a.) It can be said, that the Cambridge Cam Clay material model, which has been applied for the numerical investigations reflects the substantial volume changes of to soil due to shearing in an adequate manner. The investigations proved, that the model can be applied for description of volume changes of the soil in the given soil cross section dependent on earlier stress state history. The general experience, that the model is applicable to describe the processes in the soil approximately between given limits.
   - b.) It has been emphasized, that the finite element results are highly dependent on the soil in situ stress state and the mechanical parameters.

5. PROPOSALS

1. By the new method of determination of the tyre footprint a more realistic picture can be obtained for the tyre surface in contact and rolling print then by the classical procedure. Studying the drawing of the footprint the total contour of the print and the mostly pressured tread sections and proportions dangered by wear can be determined. These information are absolutely necessary for the tyre constructors.

2. On base of the new method and evaluation program which has been developed for analysis of soil physical properties caused by different tyres from one side these soil physical properties due to the tyres can be evaluated and the preferable and non-preferable application fields of given tyres can be determined from the others.

3. The given research results to be concerned of the interaction of the tyres and the soil proposed both in field of the professional advisatory and soil protection and environmental activity.

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

6.1. Published in journals

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11. **ZS. P. KISS** - L. SÁRKÖZI (2002): Finite element analysis of agricultural soil compaction caused by ellipsoidal shape of rut. University of Miskolc, microCAD Inter. Sci. Conf. Geoinformatics and Spatial Inform. Section, 03.07.2002. p. 55-64.

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3. **ZS. P. KISS** - I. SZŐLLŐSI (1998): Evolution of the interaction of agricultural tyres and soils, University of Ungvar, Ungvar, Ukrajna, 1998. máj. 29-30. p. 113-115.

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8. **ZS. P. KISS** – I. SZŐLLŐSI (1999): Development of environmentally friendly tyres. Central Section of Environmental Protection at the Hungarian Agricultural Association. Conference on Environmental Protection. MTESZ, Budapest.

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