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INFLUENCE OF THE NUMBER OF PASSES OF AGRICULTURAL MACHINERY ON PENETRATION RESISTANCE AND THE DEGREE OF SOIL COMPACTION

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ABSTRACT

In the context of the ongoing development of mechanized agriculture, which implies the use of heavy agricultural machinery, often on soils with high moisture content, it increased significantly the risk of soil compaction. Compaction has become a problem of major proportions especially to farmers, because this phenomenon causes environmental damage, and affects soil quality and crop production. Penetration resistance is a valuable and easy to determine indicator of the degree of compaction of agricultural soil. In this paper are presented the results of some experimental research conducted to determine the penetration resistance of a plot of clover, under the influence of the number of passes of a tractor, in order to assess, from an qualitative point of view, the degree of soil compaction.

INTRODUCTION

Worldwide, soil compaction became a concern, as it is recognized as one of the major problems facing modern agriculture. Compaction is one of the most dangerous forms of degradation of agricultural soil, that has numerous negative effects.

In terms of environmental impact, compaction alters soil structure, reduces water and air infiltration, increases the risk of surface runoff and flood, reduces pesticide decomposition and increases pesticide leaching into groundwater, increases erosion and sediment transport, accelerates the potential pollution of surface water by organic waste and applied agrochemicals. In terms of agronomic impact, compaction increases soil strenght and limits root penetration into the soil, leading to poor development and yield reduction of most agricultural crops.

There are numerous factors influencing soil compaction, such as: soil properties (bulk density, structure, texture) [7], soil type, soil moisture content, number of passes of agricultural machinery, speed of agricultural machinery, contact pressure, wheel load, size and shape of footprint area between tire and soil [7, 23, 25]. Usually, the use of light tractors involves an increased number of passes on the soil, thus enhancing compaction of topsoil [11]. By using heavy agricultural machinery, is reduced the number of passes / soil area / agricultural work, due to large working width, which means that compacted layers of soil will form at lower depth, and the degree of subsoil compaction will be reduced [2].

The most common indicators of soil compaction are penetration resistance and bulk density [8, 13, 14, 16, 21]. Soil strenght, or penetrometry, measures the resistance opposed by the surface of soil to a vertical force produced by pushing a penetrometer or rod into the soil [13]. Surfaces of soil with high mechanical resistance may occur naturally, by artificial compaction produced by agricultural vehicles, or by the formation of thick layers of soil under the ploughpan. In compacted soils, high mechanical resistance reduces the development of roots and limits the absorbtion of water and nutrients by the plants. Thus, crop productivity is affected and agricultural works are required to reduce soil compaction [1]. Penetration resistance has a dynamic nature, and varies spatially and temporally with soil properties: moisture, bulk density, compressibility, texture, content of organic matter, total porosity [9, 22, 26], soil shear strenght and soil – metal friction [3]. Soil resistance is highly influenced by soil moisture and varies significantly during a year, with each wetting-drying cycle [21]. Usually, soil resistance increases with the increase of bulk density and the decrease of soil moisture [9, 21], with the exception of low compacted soils, whose resistance decreases as the soil dries [9]. The increase of clay content of soil leads to the decrease of soil resistance as the soil dries to the point of wilting. By increasing the content of organic matter, soil penetration resistance increases, especially if soil bulk density has high values [9].

After [16], the degree of soil compaction is influenced by the following factors: soil mechanical strenght, structure of the tilled layer at wheeling, soil water status and loading. Measurement of the mechanical resistance of soil by penetrometer tests is the conventional method to estimate the degree of soil compaction.

Two types of penetrometers can be used to characterize quantitatively the penetration strenght of soils: static and dynamic. In case of static penetrometers, the load required for the device to penetrate the soil is applied by pressing a spring fitted with an indicator which allows knowing the size of load. The cone is placed into the soil with constant speed and the load is measured by a load cell [5, 10, 17, 18]. Static penetrometers should be used on moist and soft soils [5]. Dynamic penetrometers have a metal rod with determined tip shape and size, on which slides a hammer piece that falls and hits a hard piece, and the penetrating tip gradually penetrates the soil with variable speed [5, 10, 17, 18]. The compact design of dynamic penetrometers makes them practical to be used in the field, especially in rugged soils [12].

Methodology for determining penetration resistance is governed by standards. According to the Standardization Association of Romania, static penetration resistance is determined with the penetrograph, through the methodology described in STAS 12836-90, "*Tractors and Agricultural Machinery. Methods for determining the field test conditions*" respectively in the related standards STAS 7184/17-88, "*Soils. Determination of penetration resistance*" and the methodology for determining soil moisture is described in related standards STAS 7184/9-79 "*Soils. Determination of moisture*". According to the American Society of Agricultural Engineers, cone penetrometer is the standard equipment for the determination of soil resistance by penetration tests (ASAE Standards, 2002) [1]. Cone penetrometers are simple, easy to use and relatively inexpensive devices for assessing the penetration resistance or mechanical impedance of soils [26]. Standard cone penetrometer (ASAE S313.2, 1994) has cone base of 323 mm^2 (20.27 mm diameter) for soft soil, or 130 mm^2 (12.83 mm diameter) for hardened soil, both types being introduced into the soil with a uniform rate of 0.0305 m/s [19].

Experimental determination of soil penetration resistance by penetrometer tests is achieved under optimal conditions when the soil is not dry or very wet. Best results are obtained if such tests are carried out in winter. Studies conducted by Collins (1971) and Voorhees and Walker (1977) showed that soils with high moisture content have low penetration resistance [19]. If a 15 mm high layer of precipitation as rain is settled on the soil, one should wait two days for the redistribution of the water in the soil, before assessing soil resistance by penetrometer tests [15]. Experiments carried out by Ayers (1980) showed that clay soils require 24 hours to complete distribution of the water content, while coarse soils require less time [19]. A generally accepted method is to measure penetration resistance at or near field moisture capacity [9].

Due to soil stratification, soil compressibility, the variability of soil properties and soil-tool interaction, is often difficult to interpret soil information obtained by cone penetrometer [24]. Angle and diameter of the penetration cone, its mode of advance into the soil and the friction metal - soil can affect the correlation between values read by the penetrometer and normal resistance of the soil [6].

The depth at which is located the compacted layer of soil is indicated by the sudden increase of penetration resistance [15]. Penetration resistance larger than 2000 kPa will produce a significant reduction in root development and in growth of agricultural crops [19]. After [27], at penetration resistance larger than 2500 kPa, root elongation is severely limited. Also, penetration resistance measured with the penetrometer is usually 2 to 8 times higher than that actually undergone by root tips, due to the different way in which the roots and the penetrometer probes penetrate the soil [13].

MATERIAL AND METHOD

Experimental research to determine soil penetration resistance were carried out in November 2014, on a plot of clover (stubbled) at the National Research - Development Institute for Machines and Installations Designed to Agriculture and Food Industry – INMA Bucharest.

The tested soil has the following characteristics [25]:

- the layer at soil surface, between 0-20 cm deep, is loamy clay with glomerular rugged structure, medium and fine texture, is moderately plastic and adhesive, having a density of 2.49 g/cm^3, bulk density of 1.22 g/cm^3 and total porosity of 51 %;
- between 20-35 cm deep, the soil is clayey loam, with high angular glomerular structure and fine texture, moderately compact, plastic and adhesive, with total porosity of 46 %;
- the layer of soil between 35-80 cm is clayey loam, with medium prismatic structure and fine texture, is compact, plastic and adhesive, dry, with density of 2.69 g/cm^3, bulk density of 1.75 g/cm^3 and total porosity of 36 %.

In the experiments carried out in this study, penetration resistance was measured with the FieldScout SC 900 digital electronic cone penetrometer (Fig. 1), which operates in static regime and measures the force of resistance to cone penetration and the depth of cone penetration into the soil. Soil moisture was determined using the FieldScout TDR 300 capacitive portable moisture analyzer (Fig. 2), which can monitor and record soil moisture at four depths: 3.8; 7.5; 12 and 20 cm.

At the beginning of the tests, on the diagonal of the plot of clover were marked three points, found at 10 m distance from each other. Penetration resistance (P_r) was measured in each of the three points, from 2.5 to 2.5 cm, to a total depth of 45 cm, by means of FieldScout TDR 300 penetrometer. First, it was determined the penetration resistance (Pr_0) on the untrafficked plot („control”plot or „zero traffic” plot).

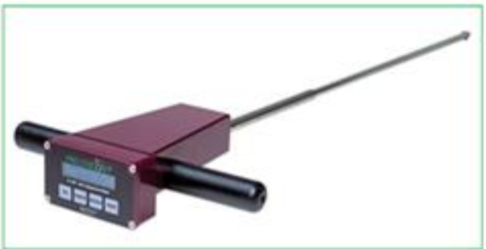

Fig. 1. FieldScout penetrometer

Fig. 2. FieldScout moisture analyzer

To determine the influence of number of passes of an agricultural machinery on the same wheel track on penetration resistance and the degree of compaction, it was used a New Holland TD80D tractor of 80 HP, equipped on the front wheels with 11.2R24 tires and on the rear wheels with 16.9R30 tires. The tractor passed over the soil, so that the marked points were found in the middle of wheel track. After the first pass of the tractor on the plot of clover, penetration resistance (Pr_1) was measured in the same points of testing. Next, measurements of penetration resistance (Pr_2) were repeated, in the same marked points, after the second pass of the tractor on the plot of clover.

To determine soil moisture (w), the FieldScout TDR 300 moisture analyzer was introduced at 3.8 cm depth into the soil, at 10 cm distance from the points in which penetration resistance was measured. The mean value of the three readings of soil moisture was w = 43.6%.

Fig. 3. Aspects during the experimental tests

In this paper, experimental data was interpreted based on literature which presents the limits within it can be estimated, in qualitative terms, the state of soil compaction, depending on the value range in which the penetration resistance is found (Table 1).

Table 1

Qualitative estimation of soil compaction depending on penetration resistance [4]

Soil compaction	Penetration resistance [kPa]
Weak	< 1000
Average	1000 - 2000
Severe	2000 - 3000

RESULTS AND DISCUSSIONS

First, it should be mentioned that the high value of soil moisture is due to weather conditions, given thet in the days before the experiments, poor rains fell and the water ponded in some areas. Also, given that the soil on which the tests were performed is clayey, the water infiltrates with a lower rate.

Tests carried out on the untrafficked plot were considered as reference (control), because to the data obtained from these tests are the data measured after the first and the second passes of the tractor. Penetration resistances obtained experimentally are presented in Table 2. Since the measurements were made in three different points along the length of wheel trace axis, we determined by calculus the mean values of penetration resistance, for each depth of the soil at which measurements have been made.

Table 2

Penetration resistance on the plot of clover

Soil depth [cm]	Pr_0 [kPa] (control)	Pr_1 [kPa] (after one pass)	Pr_2 [kPa] (after two passes)	Pr_{med} [kPa]
	Soil moisture w = 43.6 %			
0	280	298	675	417.7
2.5	371	386	895	550.7
5	747	930	1141	939.3
7.5	809.5	912.5	1176	966

10	912.5	895	1035.5	947.7
12.5	807	1123	1186	1038.7
15	1035	1246	1316	1199
17.5	1017.5	1385.5	1316.5	1239.8
20	1053	1460.5	1527	1346.8
22.5	1176.5	1685	1615	1492.2
25	1404	1787.5	1859	1683.5
27.5	1577	1629	2606.5	1937.5
30	1710.5	1835	2528.5	2024.7
32.5	1843.5	2190	2650.5	2228
35	1966	1848	2665.5	2159.8
37.5	2051.5	1893	2176.5	2040.3
40	2319.5	2229	2339.5	2296
42.5	2307	2224	2373.5	2301.5
45	2161.5	2089	2177	2142.5

Based on the recorded data it was drawn graphically the variation of penetration resistance with soil depth, for the measured soil moisture w = 43.6%.

In Fig. 4 is presented the variation of penetration resistance with soil depth on the plot of clover before the passing of the tractor (control plot). To establish a correlation between penetration resistance and soil depth it was used the regression analysis in MS Office Excel program, using linear variation laws. From the diagram in Fig. 4 it can be observed that the regression line of experimental data with the linear law $y = 44.8x + 337$ presents a high correlation coefficient ($R^2 = 0.966$).

By analyzing the values of penetration resistance on the control plot of clover, before tractor passing and considering the data presented in Table 1, the following were found:

- to 12.5 cm depth, the soil has a weak degree of compaction;
- to the depth of 15 - 35 cm, the soil has an average degree of compaction;
- to the depth of 37.5 - 45 cm, the soil is severely compacted.

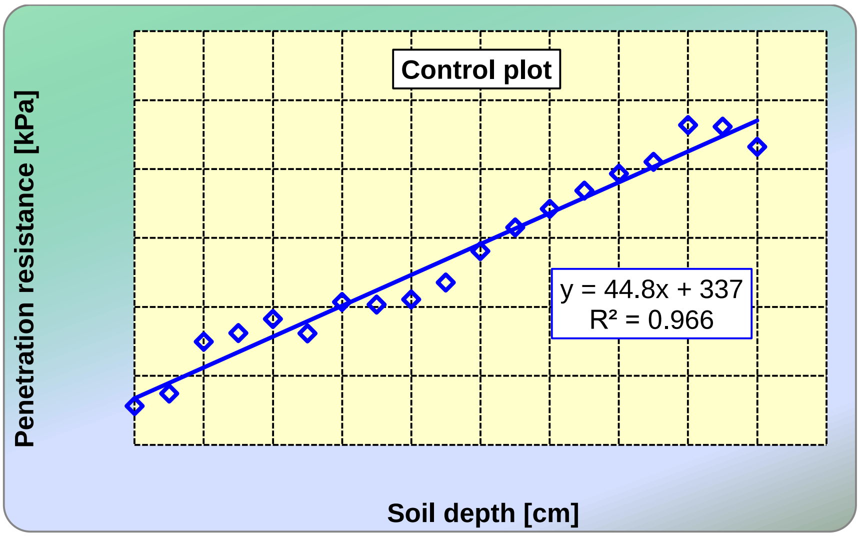

Fig. 4. Variation of penetration resistance with soil depth on the control plot

Fig. 5 shows the variation of penetration resistance with soil depth on the plot of clover, measured after the first pass of the New Holland TD80D tractor. Regression analysis revealed that the best correlation of the experimental data is obtained by a linear variation law, and in this case the correlation coefficient had a good value ($R^2 = 0.913$).

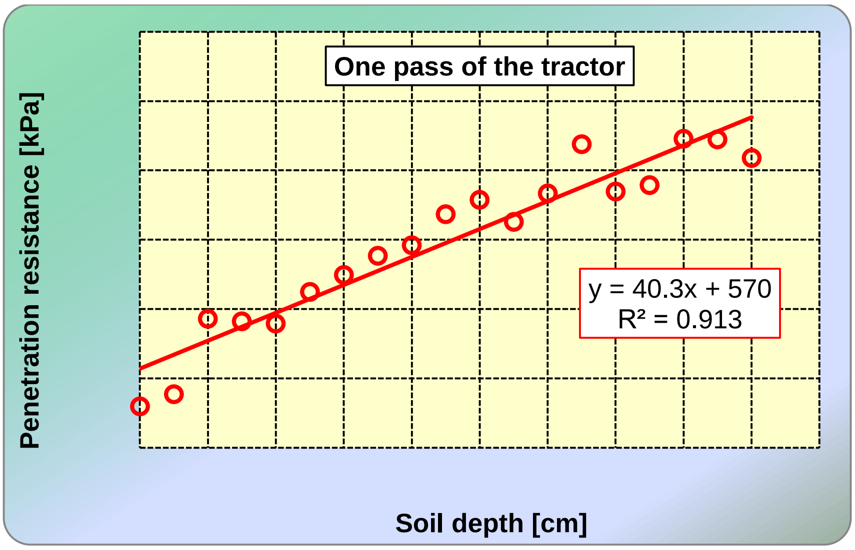

Fig. 5. Variation of penetration resistance with soil depth after the first pass of the tractor

From the analysis of the values of penetration resistance measured after the first passing of the tractor on the plot of clover and considering the data presented in Table 1, it was concluded that:

- to 10 cm depth, the soil is weak compacted;
- to the depth of 12.5 - 30 cm, the soil is average compacted;
- to the depth of 32.5 - 45 cm, the soil is severely compacted.

The diagram in Fig. 6 presents the variation of penetration resistance with soil depth on the plot of clover, measured after the second pass of the New Holland TD80D tractor. In this case, regression anaysis was also performed in MS Office Excel and the best correlation of experimental data was achieved for a linear law with a correlation coefficient of $R^2 = 0.801$.

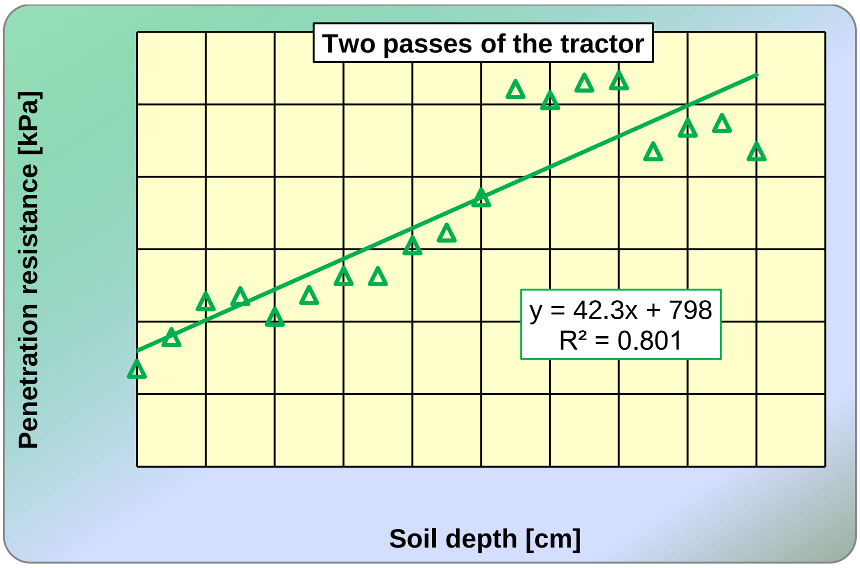

Fig. 6. Variation of penetration resistance with soil depth after the second pass of the tractor

By analyzing the values of penetration resistance depending on depth of the plot of clover, recorded after two passes of the tractor and in view of the data presented in Table 1, the following were found:

- to 5 cm, the soil is weak compacted;
- to the depth of 7.5 - 25 cm, the soil has an average degree of compaction;
- to the depth of 27.5 - 45 cm, the soil is severely compacted.

With the mean values of penetration resistance, corresponding to each depth at which the measurements were made, was plotted the diagram presented in Fig. 7.

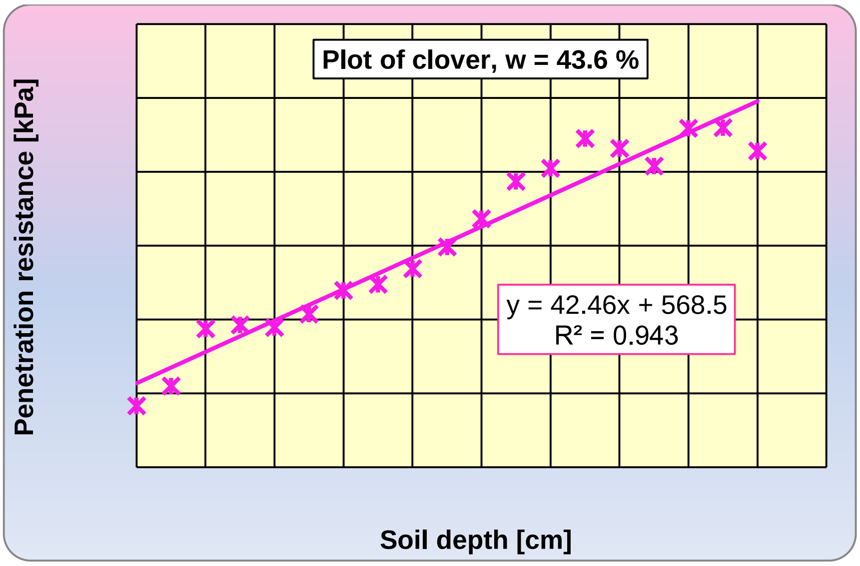

Fig. 7. Variation of mean penetration resistance with soil depth

By linear regression analysis was obtained the line of linear regression, whose equation $y = 42.46x + 568.5$ is useful to estimate the mean penetration resistance to a certain depth of soil under the same conditions. The correlation coefficient obtained in case of mean penetration resistance depending on the number of passes of the tractor on the plot of clover has a very good value ($R^2 = 0.943$).

CONCLUSIONS

Determination of penetration resistance is a simple and effective method for assessing the state of soil compaction.

Penetration resistance has linear variation on soil depth. Between 0-20 cm deep, penetration resistance has relatively small values, which however increase beyond this depth.

Penetration resistance is dependent on the agricultural works applied to the soil. The hardpan is found at depths of 20-25 cm, depending on the agricultural works carried out in previous years, being mandatory to perform deep plowing or deep loosening of soil every 2-3 years. Sometimes, this depth increases up to values of 30-35 cm, where is observed a severe compaction, so that we can say that plowing was performed under better conditions, but the weight of agricultural machinery has led to deep soil compaction.

Increasing the number of passes of the tractor on the soil resulted in increased penetration resistance, to the depth of 0-35 cm, compared to the case of untrafficked plot of clover. At depths greater than 37.5 cm, the influence of traffic intensity is less relevant, and the values of penetration resistance are similar to those measured on the untrafficked soil.

Values of penetration resistance indicate that a significant reduction in root development and in growth of agricultural crops would occur: on the control plot at depths over 35 cm; after the first pass of the tractor at depths over 32.5 cm; after the second pass of the tractor at depths over 27.5 cm.

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