ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume 63 10 Number 1, 2015
http://dx.doi.org/10.11118/actaun201563010077

LABORATORY TEST OF THE SOIL COMPACTION

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Abstract

MALÝ VLASTIMIL, TÓTH FRANTIŠEK, MAREČEK JAN, KRČÁLOVÁ EVA. 2015. Laboratory Test of the Soil Compaction. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,* 63(1): 77–85.

This paper presents the mechanical properties of soil. In order to determine the properties of soil under laboratory conditions, we made use of a special measuring device, viz. a bevameter. Two types of soil with different levels of moisture were examined and their mechanical properties determined. Measurements were taken of non pressed and compressed soil. A measuring network was set up, consisting of measuring and recording devices. In the course of measuring, the force and penetration depth of the pressing plate were recorded simultaneously. Four different diameters of pressing plate were used, resp. 25, 38, 50 and 70 mm. The pressure on the contact area was calculated after completion of the measurements, and the relationships between pressure and penetration depth were presented graphically.

Keywords: pressure, penetration depth, bevameter, soil moisture

INTRODUCTION

The use of mobile machines in agriculture causes undesirable soil compaction, resulting in changes in the physico-mechanical properties of the soil. The degree of soil compaction can be determined by measuring the physico-mechanical properties of the soil. Once this has been achieved, adequate steps may be implemented to improve soil conditions, e.g. by applying protective technologies of soil cultivation. There is a real need for the determination of soil properties, under laboratory conditions as well as under real-life operating conditions.

Under laboratory conditions more exact and objectively comparable results can be obtained. The scientific importance of the study of these results lies in the field of terramechanics. At present, several methods are known for determining the physico-mechanical properties of soil, and a number of appropriate measuring devices and measuring tools is used. From an historical and factual point of view, the valuable theoretical and practical work carried out by Bekker (1961, 1969) and his disciple Wong (1980, 1989) should be noted. Based on extensive experiments and theoretical analyses, Bekker (1961) in mathematical terms described the physical reactions taking place in the contact zone between wheel and soil. From this he derived the basic relationships for the vertical and horizontal force effects (penetration and rolling-resistance) resulting from the movement of the wheel over the soil. All his mathematical derivations are based on experimental data obtained through the use of measuring devices and measuring equipment. The measurements were carried out in laboratory conditions, each penetration test being performed at least twice. Round plates of various diameters were used, whereby the penetration depth of the plates was recorded together with the pressure exerted. Bekker made use of a measuring device called a "bevameter", which serves experimentally to determine:

- penetration depth in relation to pressure exerted,
- shear stress related to soil movement.

In Slovakia, Bajla (1998) has spent considerable time studying the mechanical properties of soil. He has performed extensive experimental measurements using a vertical and horizontal penetrometer of his own construction. Also, Varga (2010) has performed extensive measurements of the mechanical properties of soil, with a view to determine the effect of soil resistance in the case of a uniform plowing depth through the use of a three-point hitch tool pulled by a tractor. The deformation characteristics of soil at compressive load under laboratory conditions were reported by Abraham (2005).

MATERIALS AND METHODS

For the determination of the mechanical properties of soil at simple load by pressure and under laboratory conditions we made use of a measuring device specially designed at the Department of Machine Design, Faculty of Engineering, Slovak University of Agriculture in Nitra, Slovakia. This measurement device with accessories (Fig. 1) consists of a single-phase asynchronous motor (9) Klimac KT1 type. The motor is equipped with limit switches and an overload protection, which is adjustable with a spring preload of the torque clutch. The shaft of the motor is connected to the gear box by input-shaft (8). This gear box drives the spindle nut (5), which is attached to the double-wing propeller (6) of the optoelectronic revolution sensor (7). The optoelectronic force sensor (3) is mounted between the sliding bar of the spindle (4) and the pressing plate (2). A soil sample is placed in a metal container (1). Based on the number of spindle nut (5) revolutions and the thread pitch s = 6 mm, the penetration depth of the pressing plate (2) can be set. The pressure value depends on the force and surface area of the pressing plate. The data measured are continuously processed by computer (10), displayed on a monitor (11) and recorded on a recording device (15).

The laboratory measurements of the mechanical soil properties at simple pressure load were performed under these conditions. The soil was moistened to the desired moisture before the experiment and then placed in a container with dimensions 640 × 440 × 400 mm up to a height of 370 mm. Compression of the tested soil was carried out using a pressure of 100 kPa (1 bar) for 3 seconds, corresponding approximately to the compression occurring from the front and rear wheels of tractor on a single pass and with a driving speed 1 ms^{-1}.

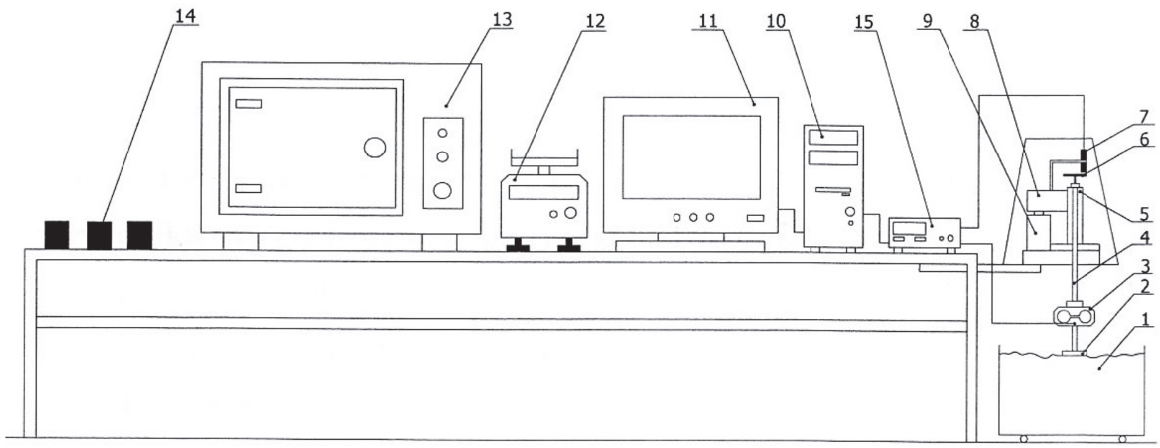
For the laboratory measurements following soil samples was used:

- soil moisture 4.81% and 16.03%, granularity Z1, non pressed soil,
- soil moisture 5.7% and 17.03% granularity Z2, non pressed soil,
- soil moisture 4.81% and 16.03%, granularity Z1, compressed soil,
- soil moisture 5.7% and 17.03% granularity Z2, compressed soil.

The soil moisture mentioned above is expressed in weight percentage. The granularity of the soil samples is presented in Tab. I.

RESULTS AND DISCUSSION

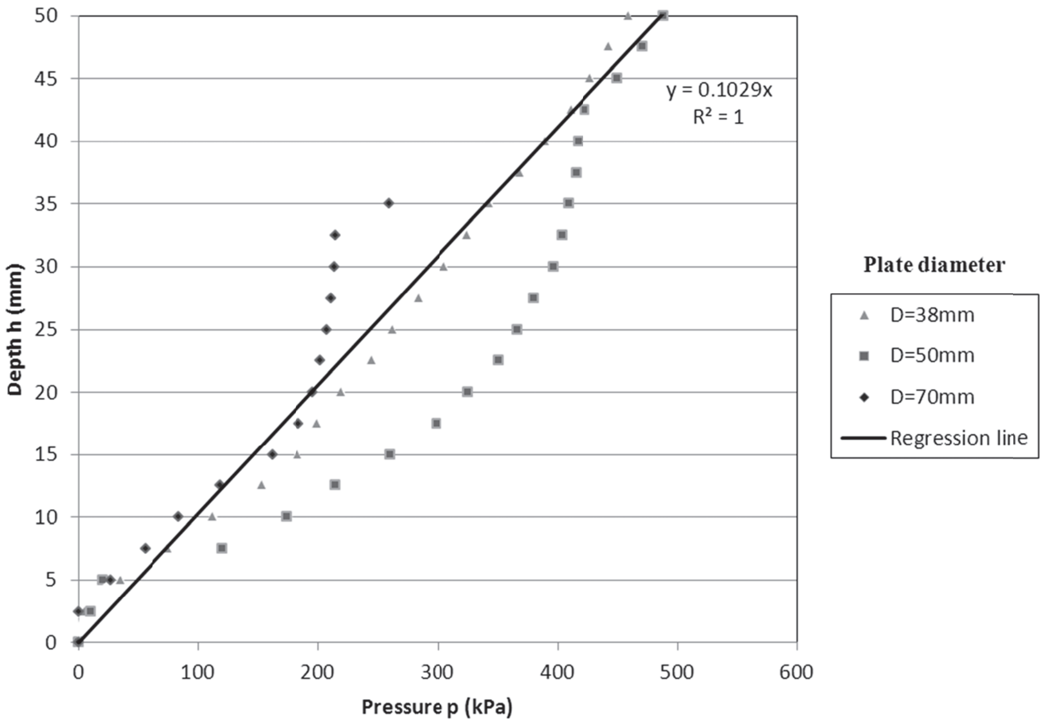
The results obtained from the experimental measurements of soil compaction using a bevameter, with soil moisture w = 4.81% and granularity Z1 confirm that penetration depth **h** increases linearly in relation to pressure **p** (Fig. 2). It can be further observed that plate diameter has



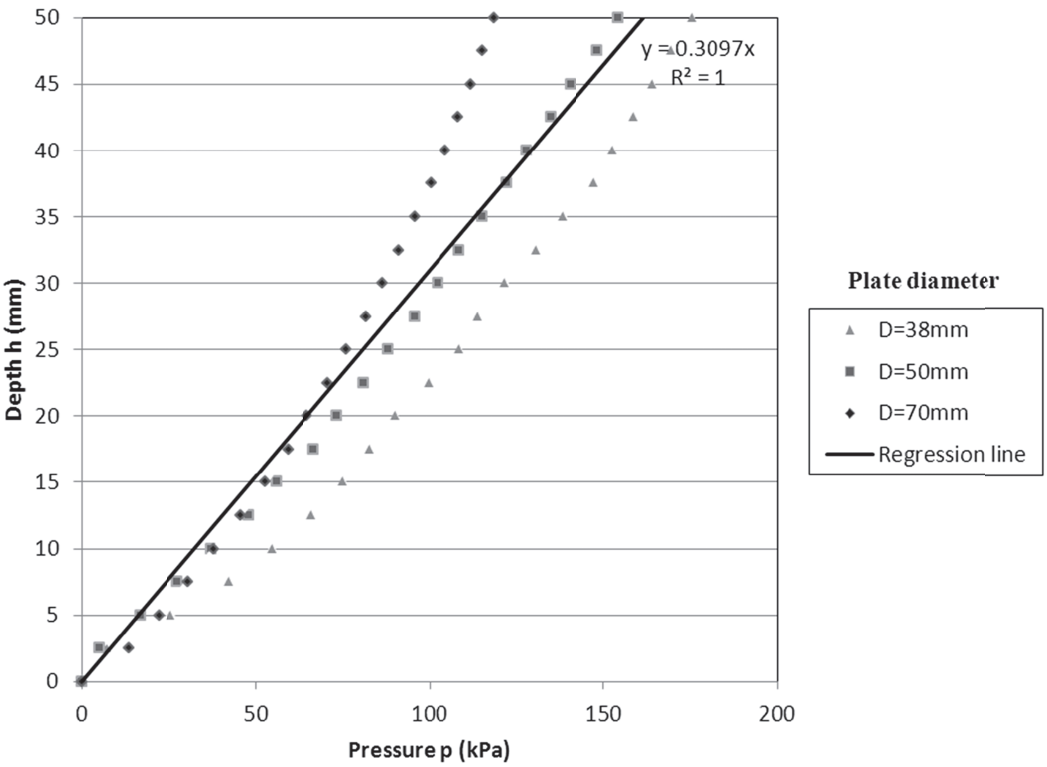
1: *Measuring network for measurement and evaluation of bevametric test*
1 – metal bin with soil, 2 – pressure plate, 3 – force sensor, 4 – displacement rod of servomotor, 5 – arbor nut, 6 – twowing propeller, 7 – rpm sensor, 8 – gearbox, 9 – single phase asynchronous electric motor, 10 – computer, 11 – monitor, 12 – weight, 13 – drier, 14 – sample, 15 – recorder.

I: *Granularity of soil samples*

Symbol of soil sample	Content of soil particules according to size in percentage				
	> 0.25 mm	0.25–0.05 mm	0.05–0.01 mm	0.01–0.001 mm	< 0.001 mm
Z1	6.16	5.57	53.8	17.92	16.55
Z2	40.49	13.52	25.67	10.61	9.71

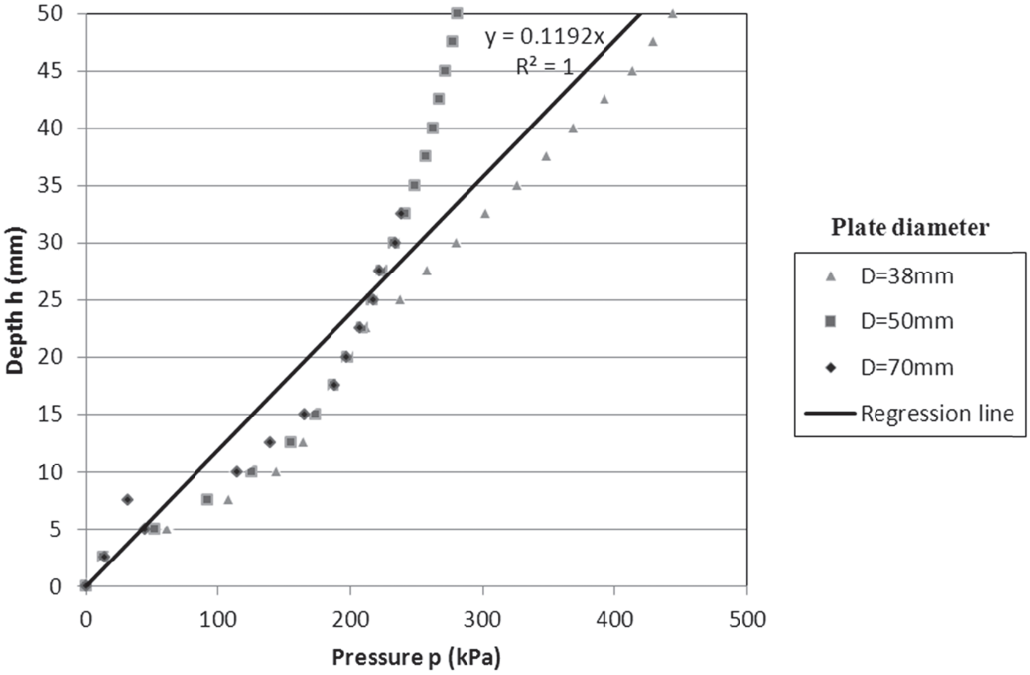


2: *Relationship between pressure and depth for soil moisture w = 4.8% and granularity Z1*

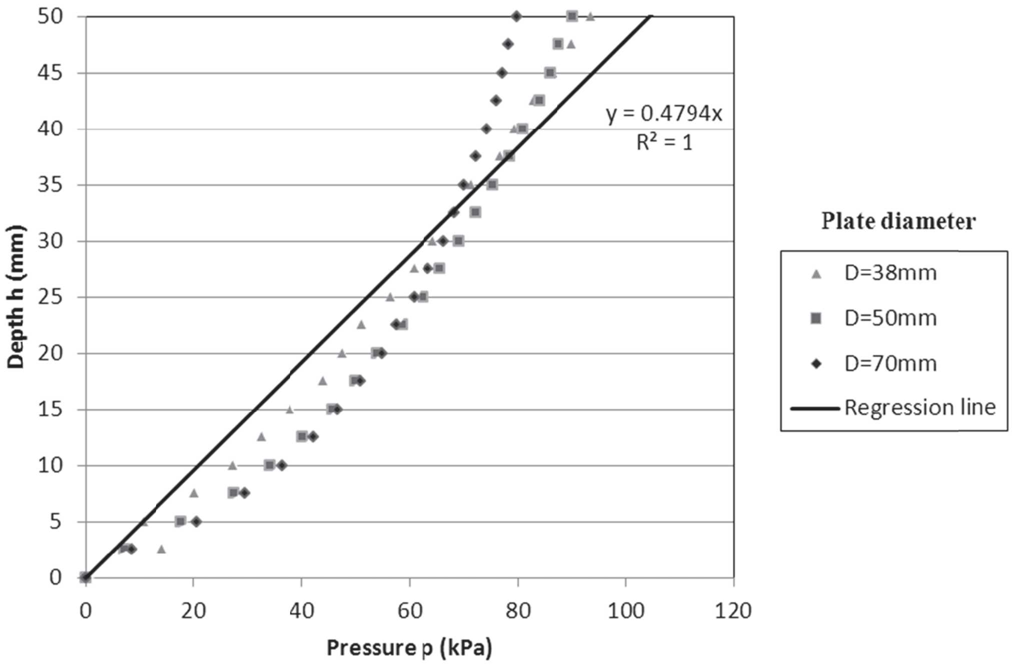


3: *Relationship between pressure and depth for soil moisture w = 16.03% and granularity Z1*

a effect on the penetration depth for the same value of pressure. In this case the relationship between pressure and penetration depth may be expressed by regression line **y** = 0.1029 **x** with correlation coefficient $\mathbf{R^2 = 1}$, as shown Fig. 2. For example for a pressure p = 400 kPa and plate diameter D = 50 mm the penetration depth is 40 mm.



4: *Relationship between pressure and depth for soil moisture w = 5.7% and granularity Z2*

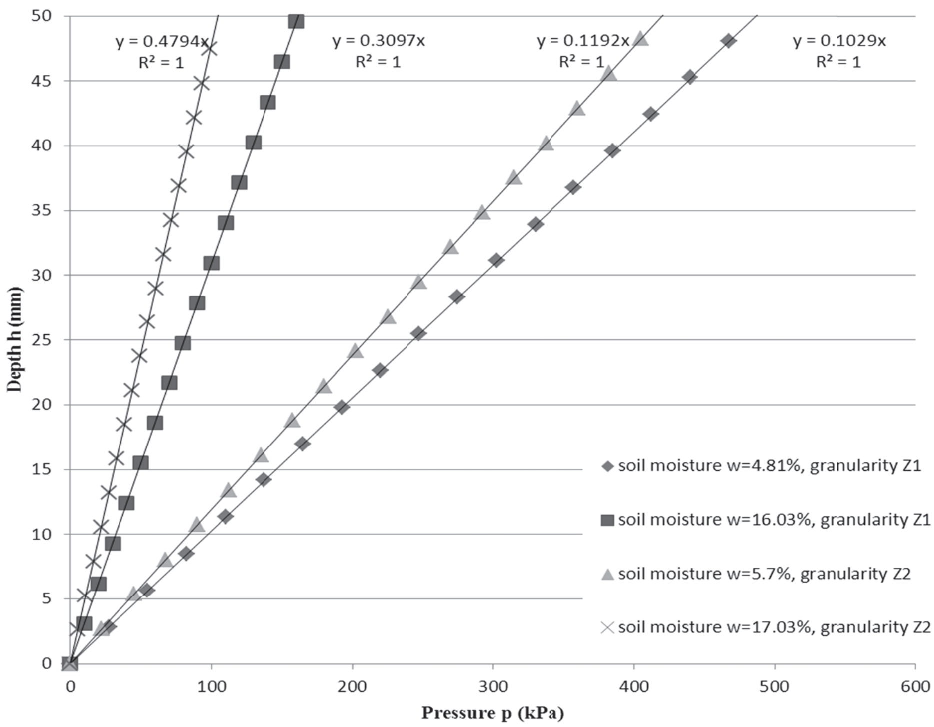


5: *Relationship between pressure and depth for soil moisture w = 17.03% and granularity Z2*

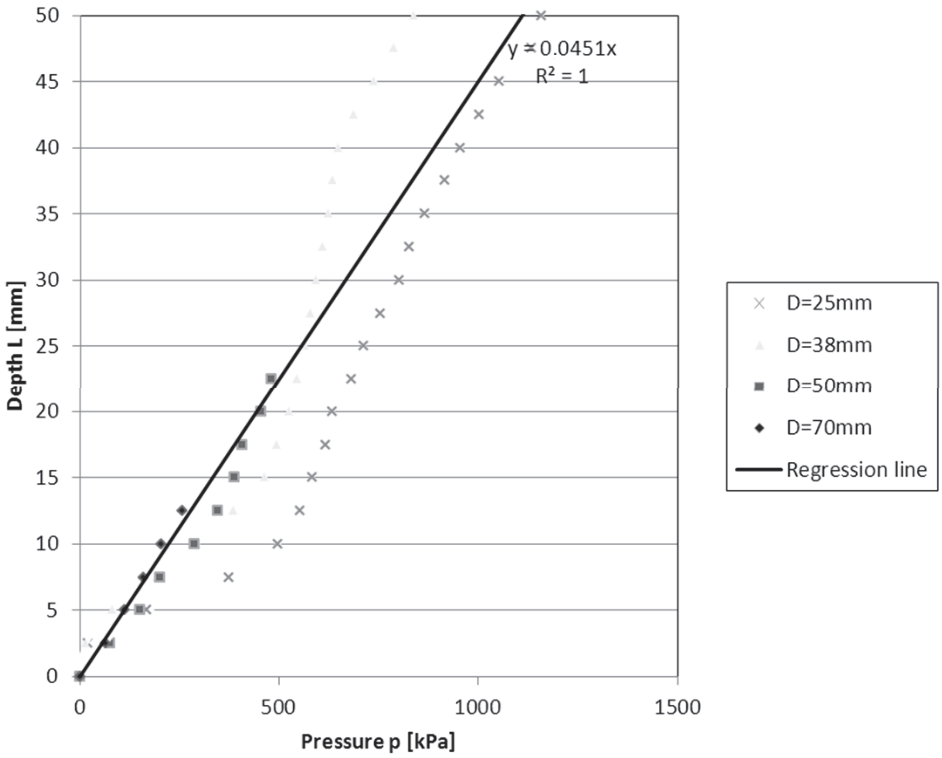
Different results were obtained for soil moisture w = 16.03% and the same granularity Z1 (Fig. 3). Fig. 3 shows that for pressure p = 100 kPa the penetration depth is approximately 30 mm. Similar results were obtained for granularity Z2 and analogous values of soil moisture, as compared Fig. 4 and Fig. 5. Ultimately, the summary diagram shown in Fig. 6 graphically illustrates results obtained from the experimental measurements of soil compaction for various soil moisture and granularity.

Based on of obtained results mentioned above we can stay that dry soil with a moisture level about 5% does not change expressively its mechanical properties, not even after compression and regadless of granularity. However, at a level of soil moisture of 16–17% the change in mechanical soil properties after compression is highest of all, up to 4 – fold.

The results obtained from the experimental measurements of soil compaction with various soil

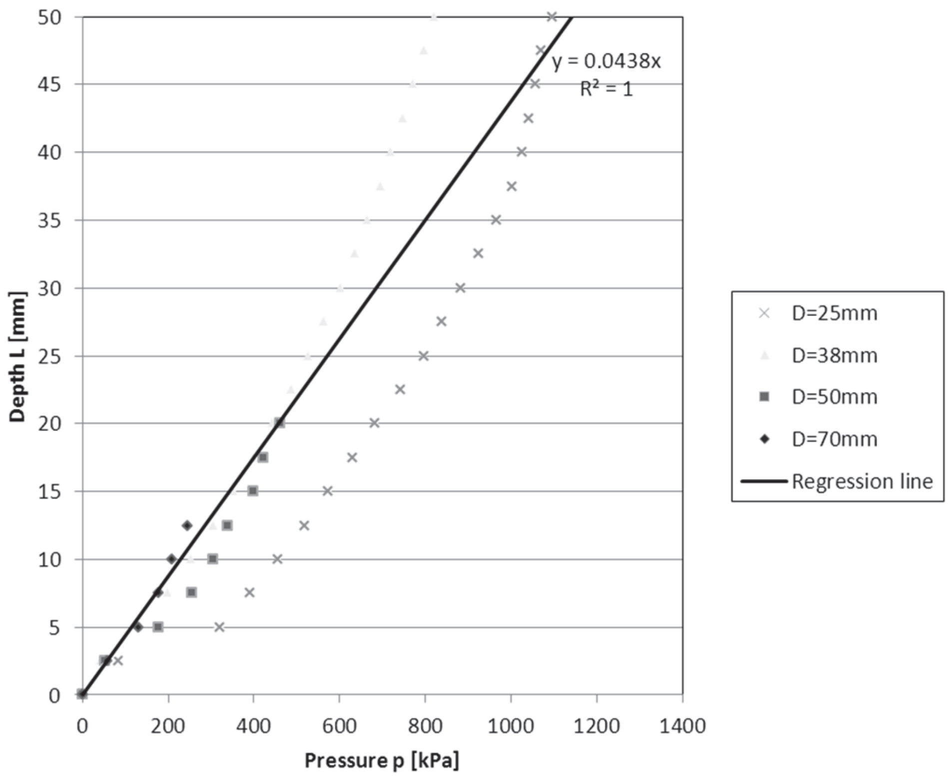


6: *Relationship between pressure and depth after regression analyze for various soil moisture and granularity*

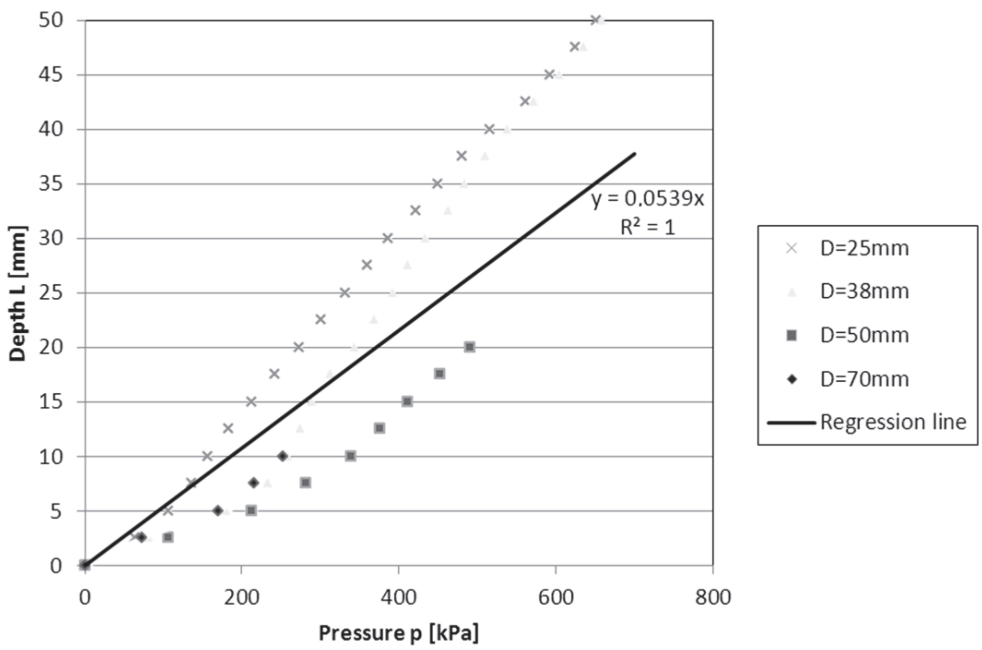


7: *Relationship between pressure and depth for soil moiture w = 4.8% and granularity Z1, compressed soil*

moisture and granularity of compressed soil are independently and graphically shown in Fig. 7, 8, 9 and Fig. 10. The summary diagram shown in Fig. 11 graphically illustrates relationship between pressure and depth after regression analyze for various soil moisture and granularity Z1 of the non pressed and the compressed soil. As shown in Fig. 11 there is high difference for the same soil moisture and granularity but for the non pressed and compressed soil. For example for the soil moisture w = 16.03%



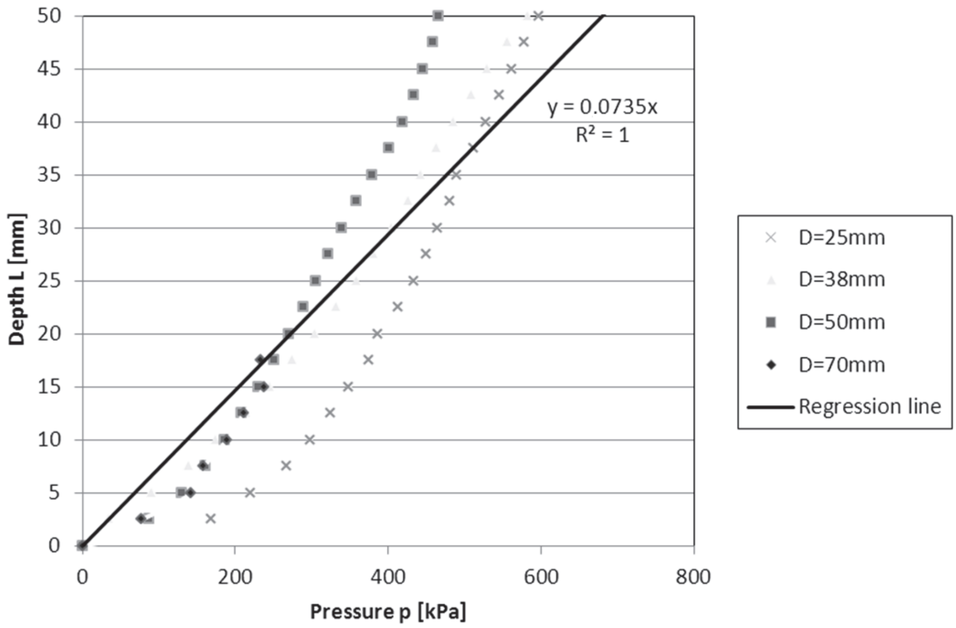
8: *Relationship between pressure and depth for soil moisture w = 16.03% and granularity Z1, compressed soil*



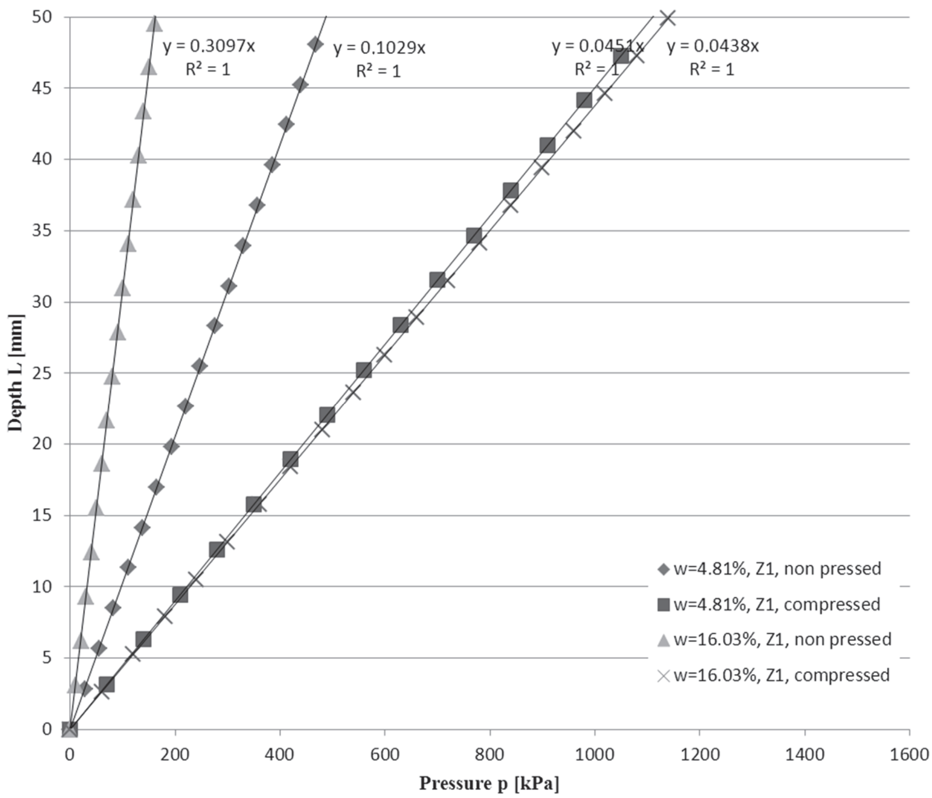
9: *Relationship between pressure and depth for soil moisture w = 5.7% and granularity Z2, compressed soil*

and non pressed soil the regression line is expressed by following formula y = 0.309x, $R^2 = 1$, whereas for the same soil moisture and compressed soil the formula is y = 0.0438x, $R^2 = 1$. Similar differences are shown in Fig. 12, however for the granularity Z2 and approximately the same soil moisture.

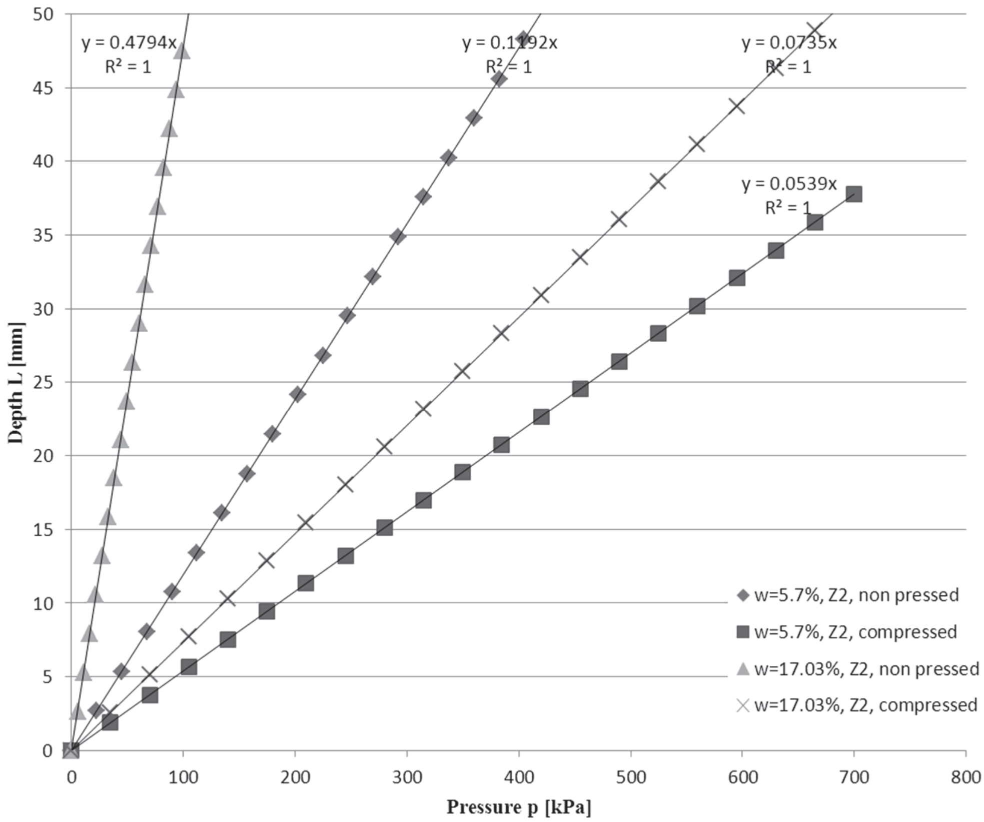
So, in view of the fact that the most favourable moisture level for standard types of soil for cultivation is within 15–17% range, it is recommended to use all available means (dual tyres, caterpillar tractors, soil protection technologies) to reduce soil compaction caused by mobile agricultural machines.



10: *Relationship between pressure and depth for soil moisture w = 17.03% and granularity Z2, compressed soil*



11: *Relationship between pressure and depth after regression analyze for various soil moisture and granularity Z1, non pressed and compressed soil*



12: *Relationship between presure and depth after regression analyte for various soil moisture and granularity Z2, non pressed and compressed soil*

CONCLUSION

Our laboratory experiments and measurements identified a number of new relationships, which were up to now never presented in this way, and which need to be further theoretically analyzed. In the first place, there is an interesting fact that reduction in plate diameter, and thus in the surface area of the pressing plate, will generally little decrease the pressure for the same value of penetration depth. This may be considered as anomaly or paradox. This paradox may be explained by the fact that by pressing the plate into the soil, the soil is compressed on area equal to the surface area of the plate, while at the same time soil being cut and pushed away at the circumference of the plate. However, in calculating the pressure values, the shear stress at the circumference of the plate is not taken into consideration. As a result, the pressure values are to some extent distorted.

Acknowledgement

OP VK – CZ.1.07/2.3.00/30.0031 Postdoktorské pozice v technických a ekonomických oborech na MENDELU" společně řešeného TF SPU Nitra a ÚZPET AF MENDELU.

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