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Results of express-diagnostics evaluation of soil basing on penetration resistance measuring

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Abstract: *Results of express-diagnostics evaluation of soil basing on penetration resistance measuring.* The express-diagnostics method has the roots in medicine. It was needed for evaluation of influence of machines (negative or positive) on soil. At the same time the penetration resistance (*PR*) is one of attractive index for evaluation of soil physical properties. Under the same procedure we have observed the soil bulk density (by Litvinov's cylinders), moisture content (by soil moisture meter with soil moisture sensor Thetaprobe), penetration resistance (by Eijkelkamp penetrologger) and soil structure (by set of U.S.A. standard testing sieves). The field experiments at Haage Agro Ltd., near Tartu were carried out. Authors have found that in the spring of 2012 year the influence on soil by tractor and soil tillage machines depending of depth of soil layers was quite changeable. Also the same situation was in 2013 year. However, the diagram of penetration resistance that in deep of soil shows as typical three characteristics zones. If translate the character of diagram from Estonian to English language it can be so-called as pouches (or maximum amplitude): It is result of compaction of the shallow layer, II – compaction under the cultivation layer, III – cumulative compaction at subsoil layer which is result of long-term period influences of machines on soil. In results of laboratory simulation compaction test we have received the analogical diagram for penetration resistance. Including uniaxial compression device (patent application) the soil compactability in conditions of soil compression stress were as following: at bottom of cylinder 25, 100, 120 kPa. The results of soil compression stress showed that in cylinders the indices of soil structure is mostly worsen and at the same time it has been shown the same decreased level of soil bulk density ($Mg \cdot m^{-3}$) and penetration resistance (MPa). By corresponding index (τ_p) of excess of the optimum soil compression level, i.e. excess of the soil penetration or cone resistance is quite easy to provide an evaluation results and finally to assess the soil physical properties level, and thereby only on the assumption of soil moisture content 0.7–0.9 (70–90%) level of soil field capacity.

Key words: express-diagnostic evaluation, penetration resistance, field experiments, laboratory soil tests, index excess soil optimal level penetration resistance

INTRODUCTION

Estonia is currently well supplied with modern tractors and corresponding farm machinery [Lüüs et al. 2013]. However, if we have an ideal technical level of the tractors and farm machinery, but always it does not possibilities to get the same ideal quality of the work because the soil is vulnerable to compaction [Jones et al. 2003, Lüüs et al. 2013]. The soil vulnerability could be assessed by express-diagnostic evaluation method. This method we have took over from medicine. By this method mostly it is possible to estimate the soil physical properties. The main characteristics for the soil physical properties are: penetration resistance, bulk density, moisture content and soil structure. Penetration resistance may also call as soil cone resistance through which is possible quickly to show is the soil compacted or not after usage of corresponding farm machinery. The moisture content decides about soil compaction especially, when running of agricultural vehicles is observed [Buliński and Niemczyk 2007]. Changes in soil density constitute also result of such details like tractor wheel pressures [Powałka and Buliński 2014] and the others.

Between scientists have been discussed about this topic how is possible to characterize by penetrologger the soil physical properties because the soil cone resistance depending generally of soil moisture content. This is incontrovertible fact that if the soil humidity is equal to the level of soil physical maturity, that is of soil moisture content 0.7–0.9 (70––90%) level of soil field capacity, then by cone resistance could be described a significantly the soil physical properties. Many authors [Cubrinovski et al. 2001, Reintam et al. 2009, Botta et al. 2010, Kuht et al. 2012] indicated about this opportunity.

The next important characteristic of the soil physical properties is the soil structure. Mostly the soil structure observes for assessment of seedbed quality preparation [Hakansson 1983, Kitz 1983, Nugis 2010]. If the soil is too much compacted then the value of soil structure is not a very good. This topic has been studied mostly Scandinavian authors [SLU 1983].

Concerning choice of proper characteristics for assessment of soil physical properties many authors [Raczkowski 2010] have noted that "the soil bulk density is playing a main and important role for providing the favorable conditions for subsequent plant growth" [Lüüs et al. 2013].

Authors have found that it is very important if we can use suitable index (ι_p), which is possible to characterize an excess of level penetration resistance. For penetration or cone resistance (*CR*) the optimum level for Estonian soils it is not more than 0.5 MPa.

Because the soil tillage machines are not only soil loosening but they are automatically compacted by wheels, therefore, the physical property of soil layer which is located a deeper than of work of the digging booms will become worse. According that our new viewpoint is consisted such idea when we should be to estimate the endurance of soil then for typical Estonian soils and to carried out the main suitable indicator by which is possible to assess not only the quality of soil tillage but also the results of influence on soil together of the tractor's wheels and digging booms. How it is possible to assessment immediately of soil physical properties through measuring of soil penetration or cone resistance in laboratory and field conditions such are our main objectives.

MATERIAL AND METHODS

The field experiments were carried out at field "Peedimäe" (Fragi-Stagnic Albeluvisol (sandy loam), Haage Agro Ltd., N58°22′ and E26°37′). Measurements were done in spring of 2012 after the soil shallow tillage and deep cultivation in autumn of 2011 years. At this field was used a standard machinery: compact disc harrow and medium deep cultivator. The soil physical properties (bulk density, soil moisture content and cone or penetration resistance; replications: n = 3) were observed. Actually these field tests consisted of express-diagnostics evaluations using the simplest and cheap method. Specific measurements included evaluations of gravimetric soil bulk density and moisture content (in Eerika laboratory of Institute of Agricultural and Environmental Sciences of the Estonian University of Life Sciences – EULS) by Litvinov’s cylinders (50 cm^3). The soil structure is evaluated by U.S.A. standard testing sieves (in Institute of Technology of EULS), with emphasis on soil structure aggregates from 2–4.75 mm across. Also these analyzes during soil compression tests in laboratory of the Institute of Technology of EULS were performed. For this the soil samples were collected from above mentioned field. Also we have measured the soil penetration or cone resistance by Eijkelkamp penetrologger to depth up to 50 cm in field conditions. In laboratory the bulk density were simulated. For this the soil in three separate cylinders (height 139 mm, diameter 134 mm) were compressed up to level of bulk density: 1.47, 1.72 and 1.85 $Mg \cdot m^{-3}$. After that three cylinders were placed on each other and after that the penetration resistance (MPa) were measured. Cylinders have been marked by the numbers in the order in accordance with the degrees of soil compaction. Before and after soil compression the effect of various structure aggregates of the soil (from agrotechnically unsuitable – soil aggregates with a diameter < 2 and > 4.75 mm up to suitable – between < 2 and > 4.75 mm) were observed. Also by uniaxial compression device we have studied the soil compactobility in conditions of soil normal compression stress: 25, 100, 120 kPa. For measuring of normal soil compression stress under the bottom of cylinder we have used the special equipment with strain gauge sensor [Kuznetsova 1984]. For maximum amplitude of penetration or cone resistance diagram (Fig. 1) we have called it “bug” (translation from Estonian language). The device for soil compression tests is protected by appropriate patent application (Method and apparatus for compaction of the soil at test cylinder, Patent application No P200100069 (EE), date of priority 28.11.2011, applicator: ECRI, authors: E. Nugis and R. Põldoja). The results of field experiments and laboratory tests statistically were analysed.

RESULTS AND DISCUSSION

The results of measurements on the field “Peedimäe” are presented in Tables 1 and 2 and Figures 1 and 2. Table 1 shows the positive effect of soil shallow tillage and deep cultivation in previous autumn of 2011 years [Lüüs et al. 2013]. Probably the influence of winter conditions and growth of winter rape did not influence substantially to the soil physical properties at this field. It is interesting to note that soil moisture content is little bit higher in soil layer 0.11–0.20 m which indicates to relatively often precipitations in spring of 2012 years. Usually it is dangerous in terms of soils vulnerable to compaction [Al-Kaisi 2001]. But it does not reach to the more deep horizons like up to 0.30 m. The same picture we could found related results of penetration resistance (Fig. 1).

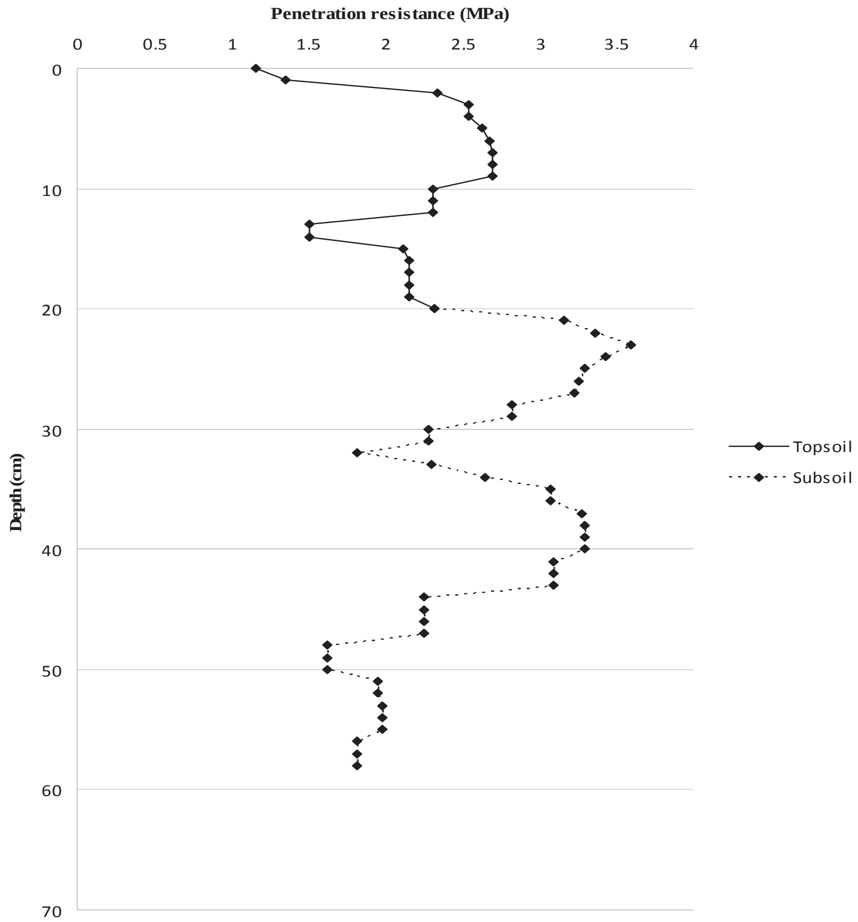

FIGURE 1. Example of penetration resistance for the topsoil and subsoil at field "Peedimäe" and the three specific ranges which could be called above as pouch (moisture content according Table 1. *W* = 15.6 – 28.2 %g/g)

As regard results of bulk density our opinion is that it is quite normal level and enough preferable for good growth of winter rape. If to compare the bulk density (Table 1) with cone resistance (Fig. 1) the correlation between theirs is not so much intense although maybe it achieve an enough adequately [Cubrinovski et al. 2001].

According to Figure 1, it is possible to identify in diagram the three specific ranges, i.e. so-called as pouch (translated from Estonian language), where I pouch shows the presence of shallow compaction which is the result of shallow tillage including influence of whether conditions. The II pouch is the result of influence of subsoiler works because the digging boom of subsoiler does not only loose of soil but at the same time some compacts it also. By III pouch is characterized such case when year to year the results of compaction are cumulated.

TABLE 1. Bulk density and moisture content of sandy loam soil (Fragi-Stagnic Albeluvisol) at winter rape field "Peedimäe" in spring after the soil shallow tillage and deep cultivation in previous autumn (n = 3)

Characteristics	Soil layer (m)			Maximum LSD_{05}
	0–0.10	0.11–0.20	0.21–0.30	
Dry soil bulk density ($Mg \cdot m^{-3}$) Standard deviation	1.32* 0.05	1.28* 0.08	1.40 0.07	0.07
Soil moisture content (%g/g) Standard deviation	23.2* 2.9	28.2* 4.6	15.6 3.9	4.3

Note: *No significant difference (P < 0.05, Student's test).

Actually we could be found the same picture a very often in the fields of Estonia if we will be tried to observe of soil physical properties as precisely as possible. Such a pattern is observed not only in Estonia, but also in other countries and soil conditions [Gyuricza et al. 1998, Rátonyi 1998, Schmidt et al. 1998, Iancu 2000] where authors have received analogous results.

If to set a goal for the soil compression in cylinder and to simulation of soil bulk density then we could be received of corresponding results (Fig. 2) which can be extended to the field results (Fig. 1).

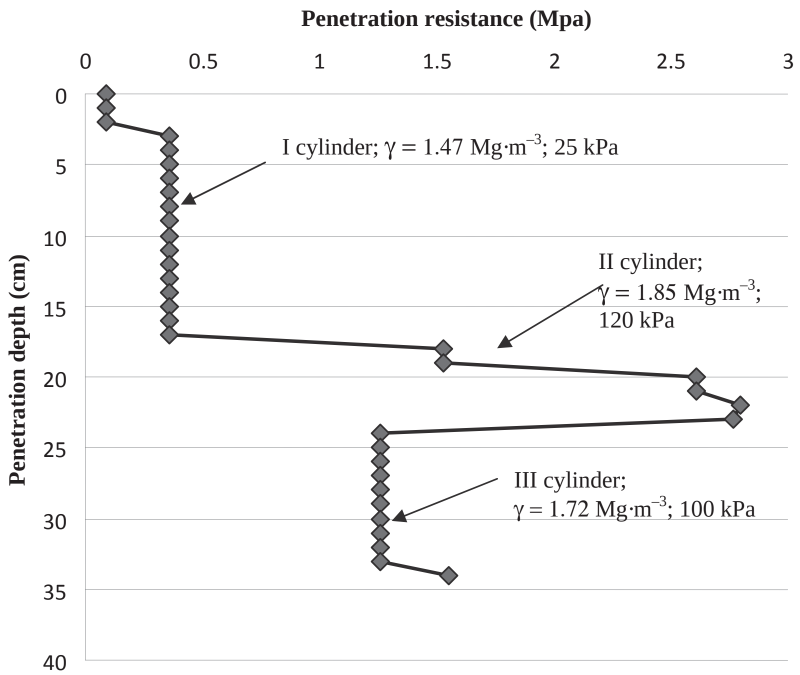

FIGURE 2. Results of penetration test with the same soil from the field "Peedimäe" in laboratory simulation stress (25, 100, 120 kPa) after soil compression by uniaxial apparatus (where γ – soil bulk density; humidity, W = 9.1 %g/g)

Thanks of simulation of soil bulk density and compression apparatus [Nugis and Põldoja 2013] we have gave a good opportunity to exchange in principle in laboratory conditions of any large scale of soil moisture content and bulk density. Having a different stage of soil compression it is possible eventually to get the corresponding diagram of penetration or cone resistance.

The next topic is related soil structure depending of soil compression (Table 2). It is well known that the index of soil structure – k_{str} (the corresponding equation can be seen at Note of this Table 2) is sensitive changes depending of soil compression, i.e. soil compaction, and in the results are shown in view soil vulnerability. Concerning that our opinion is that soil responsiveness depends of any negative mechanical influence from mobile technical means (modern tractors and corresponding farm machinery) during working at field, and soil structure is one of important characteristic of soil physical parameters.

Table 2 shows that if normal stress of topsoil is increased the index of soil structure is decreased conversely. For subsoil we have not the same trend as usual. Perhaps the same trend will occur in the transition to higher level of soil compression in cylinder. Be that as it may, but in addition the index of soil structure is decreased permanently after the soil compaction and soil tillage. Therefore, we should be choice a sparing field technologies which could be provided a good soil physical properties.

For characterizing of excess of the optimal level penetration or cone resistance it can be used the following equation:

$$\iota_p = \frac{p_i}{p_o} - 1 \qquad (1)$$

where:
p_i – penetration or cone resistance in the given soil layer (MPa);
p_o – optimal level of soil penetration or cone resistance (MPa).

According equation (1) the index of excess penetration resistance is calculated for each typical level of soil vulnerability which values are found for typical Estonian soils for three specific ranges of topsoil and subsoil layers (Table 3).

According equation (1), if $p_i = p_o$ then $\iota_p = 0$ which is an agrotechnically

TABLE 2. Results of laboratory tests related to soil structure a percents of corresponding soil fraction depending of soil normal stress (measured by U.S.A. standard testing sieves)

Soil normal stress at bottom of cylinder (kPa)	Diameter of soil fraction (mm)							
	for topsoil				for subsoil			
	>4.75	2–4.75	<2	k_{str}	>4.75	2–4.75	<2	k_{str}
25	63.0	30.8	6.2	0.4*	49.9	42.0	8.1	0.7*
100	67.3	25.9	6.8	0.3*	38.4	29.0	32.6	0.4*
120	81.6	34.7	6.8	0.3*	36.9	38.9	24.2	0.6*

Note: *If diameter of soil particles > 4.75 = a, 2 – 4.75 = b and < 2 = c then k_{str} = b / (a + c). $P < 0.05$, Student's test were carried out and as a result it was found for index of soil structure – k_{str} of topsoil LSD_{05} = 0.02 and for subsoil LSD_{05} = 0.05. It means that between changes k_{str} related normal stresses and soil layers is significant difference.

TABLE 3. Some results of index excess penetration resistance for each typical level of soil layer and evaluation of soil to vulnerability (for typical Estonian soils, i.e. loamy sand, sandy loam)

Range of soil vulnerability	Index excess (ι_p – upper numeral) and penetration resistance (p_i (MPa) – the numeral located below) depending of depth (m) of soil layer			Evaluation
	topsoil layer		subsoil layer 0.25–0.50	
	shallow layer 0–0.10	ploughing layer 0.11–0.24		
No vulnerability	0.2 0.6	2.0 1.5	3.8 2.4	good condition of soil
Little vulnerability	3.4 2.2	5.0 3.0	7.0 4.0	tolerable condition
Sustainable vulnerability	5.4 3.2	7.8 4.4	11.0 6.0	subcritical condition
Vulnerability	9.0 5.0	12.0 6.5	14.0 7.5	unacceptable limit

suitable level of soil physical properties is considered; it is like something that as our grandmothers headlands soil conditions. If in results of soil compaction the penetration or cone resistance will be increased then the index ι_p is increased correspondingly (Table 3). It means that the several kind excess of level penetration or cone resistance can be ranged.

The results of evaluation of penetration tests at field "Peedimäe" of Haage Agro Ltd. (Fig. 1) after using of modern farm machinery and if compare with results at Table 3 were shown that the soil physical properties according calculation of index ι_p at shallow layer (top of I pouch) of the soil corresponds to little bit more than a tolerable condition (ι_p = 4.4 and p_i = 2.7 MPa) but at the same time it is about two time less than subcritical condition. For ploughing layer we have (top of II pouch) 1.3 time less than subcritical condition (ι_p = 6.2 and p_i = 3.6 MPa), and for subsoil layer we have (top of III pouch) a more good situation (ι_p = 5.2 and p_i = 3.1 MPa) which corresponds about little bit less than tolerable conditions.

According evaluation of penetration tests at laboratory (Fig. 2), where we have been simulated by corresponding compression apparatus of soil compaction, it can be seen that in the first cylinder (soil bulk density – γ = 1.47 Mg· m^{-3}, normal compression stress of the soil – σ = 25 kPa and optimal level of soil penetration or cone resistance – p_o= 0.1 MPa which applies in the rest also for others two cylinder) index ι_p = 3.0 and cone resistance – p_i = 0.4 MPa, which indicates to a little bit less than tolerable conditions of soil vulnerability. For second cylinder where the soil was over compacted (γ = = 1.85 Mg·m^{-3}; σ = 120 kPa; p_i = 2.8 MPa) we have already ι_p = 27, which indicates to a very large extent unacceptable soil vulnerability limit, and in third cylinder where we also have had little bit less situation with compacted soil (γ = 1.72 Mg· m^{-3}, σ = 100 kPa, p_i = 1.3 MPa) where ι_p = 12.0, which is indicated as unacceptable soil vulnerability limit.

CONCLUSIONS

Our study clearly showed that modern tractors and corresponding farm machinery, like cultivators, drills despite their high technical level can be source of compacted soil and finally can be source of destroyed soil structure when the Estonian farmer are not careful and wise in theirs activities. Fortunately the situation with soil physical properties at field "Peedimäe" of Haage Agro Ltd. is not so very bad. To obtain such results we suggested a new methodological viewpoint, i.e. to use of express-diagnostic evaluation for the assessment of soil vulnerability and corresponding index (ι_p) excess of level the penetration or cone resistance. The bulk density and moisture content for soil layer 0–0.20 m of sandy loam soil at winter rape field "Peedimäe" in spring after the soil shallow tillage and deep cultivation in previous autumn are no significant difference ($P < 0.05$, Student's test), but for layer 0.21–0.30 m is significant difference. The results of penetration resistance were shown that can be identified a typical three different characteristics zones or so-called as pouches: I pouch – is result of moderate compaction of the shallow layer, II pouch compaction of the ploughing layer, III pouch – cumulative compaction of subsoil layer. The analogical diagram of penetration resistance we have received in result of laboratory test. The results assessment of soil structure were shown that soil compression in laboratory conditions by uniaxial apparatus enables to record of changes of soil normal stress at bottom of cylinder. The soil fraction and corresponding index of soil structure (k_{str}) were calculated. The index of soil structure is significant difference for topsoil and subsoil thereby the value of k_{str} is significant higher which were indicated to artificial soil structure in results of high soil pressure and increasing of bulk density in the test-cylinder. These investigations still did not finished therefore we would be continued the laboratory and field experiments.

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Streszczenie: *Wyniki badań metodą szybkiej oceny diagnostycznej gleby na podstawie pomiaru oporu penetracji.* Przedstawiona metoda pozwala na ocenę wpływu oddziaływania maszyn rolniczych na glebę. Do oceny wybranych właściwości fizycznych gleby wykorzystano wskaźnik oporu penetracji gleby (*PR*). Za pomocą kilku metod zbadano gęstość gleby, zawartość wody w glebie, opór penetracji oraz strukturę gleby. Badania polowe przeprowadzono w pobliżu Tartu. Stwierdzono zmienny wpływ ciągnika i współpracujących z nim zespołów do uprawy gleby na ugniatanie poszczególnych warstw gleby w badaniach przeprowadzonych wiosną 2012 roku. Takie same wyniki badań i obserwacji uzyskano w 2013 roku. Rozpatrzono zjawiska związane z ugniataniem w trzech warstwach gleby, związanych z działaniem zespołów roboczych maszyn. Wskazano, że wykorzystanie wskaźnika optymalnej zwięzłości gleby, bazującego na badaniach stożka oporu penetracji, pozwala na relatywnie łatwą ocenę fizycznych właściwości badanej warstwy gleby o danym poziomie wilgotności.

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