Outline of results concerning assessment of soil compaction in Estonia

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Abstract. In Estonia the effect of compaction on soil/subsoil is studied in two leading organizations: Estonian University of Life Sciences (EMÜ) and Estonian Research Institute of Agriculture (ERIA). An attempt has been made to methodologically harmonize them with methodological instructions given in the ISTRO (International Soil Tillage Research Organization). A novel methodology for complex assessment of the effect and influence of mobile technical means (MTM) on soil has been offered. The soil has been examined as a polydisperse body where certain changes occur in compactibility, vulnerability, achieving physical mellowness and in textural composition. The relevant assessment criteria were worked out and approved in three separately carried out tests. As it appears from the results, such an approach allows us to do the necessary generalizations in assessment of the effect of MTM on soil, to adequately value the respective factors (extent, character, sign systems), i.e. issue from soil physical properties and pedosemiotics characteristics at the same time, while also not excluding the energy consumption.

Key words: mobile technical means, soil/subsoil, compaction, pedosemiotics, pedosphere

Introduction

For a long time two Estonian leading institutions have been engaged in this work: Estonian University of Life Sciences and Estonian Research Institute of Agriculture, one in South Estonia and the other in North Estonia. Concerning assessment of soil compaction the first requirement is to specify which method is the most appropriate for the purpose. Having determined the method, the next requirement to follow is to identify the assessment characteristics which would be the most informative and a reliable way to know what kind of process has taken place in the soil due to the effect of heavy machines, in what direction they have proceeded and will proceed further.

Machinery traffic in arable fields causes formation of ruts and soil compaction, which may result in reduced crop yield (O'Sullivan et al., 1993; Soane and van Ouwerkerk, 1994; Hartge, 1994; Reintam, 2006; Reintam et al., 2009). By tradition, for Baltic and Northern countries arable fields are mouldboard ploughed in the autumn. When studying the properties of soil it is important to find out which growth medium is the most appropriate for plants. At soil tillage the soil properties may change.

Soil tillage may cause compression of soil bringing about changes in bulk density (Stepniewski et al., 1994).

The specific feature of our methods of the present research work is that with our limited possibilities, low cost approaches have been tried to enable us to obtain adequate answers to the questions that have arisen in connection with soil compaction. We look upon soil as a living being, so we can speak of the sign system, i.e. pedosemiotics (Nugis, 2011) and at the same time the state of its 'health'. It means that we can try to characterize it in some way through respective assessment criterion.

Concerning the influence of mobile technical means (MTM) on soil we have approached this topic since 1980 (Nugis, 1988; 1989). MTM consists of tractor and tool with corresponding digging boom (operative part).

As a result of the above mechanical influence the corresponding trace is formed. Our view is that for both there is case like signs. It is known that semiotics is a study of signs and sign systems (Kull, 1999). A hint to this can also be found from the etymology of the word: the Greek 'sêmeion' means 'sign' and '*pédon*' means 'soil'. In the results above we could obtain pedosemiotics (Nugis, 2011).

As a result, we can consider the soil compaction and soil tillage including soil physical properties with corresponding terms for physical and sign system, while also not excluding the energy consumption.

Materials and methods

According to this the relevant research methods have been worked out and appropriate test methods and equipment have been taken into use (Nugis & Kuht, 2000).

In the field conditions we have measured the bulk density, soil moisture content and penetration resistance in the two places at Eerika (Estonian University of Life Sciences) and Kuusiku (field experiments of Estonian Research Institute of Agriculture). In both places soil compaction was done by wheel of tractor MTZ-82 (with loader). For all traffic applied uniformly to cover the entire experimental plots: 1 time and 3 times.

The inflation pressure 50 kPa, 100 kPa and 150 kPa were appropriated.

In order to assess soil properties before and after influence of MTM on soil we have worked out a special method.

The parameters for observation and describing the soil physical properties are as follows: 1) bulk density (Mg m^{-3}) before (γ_a) and after (γ_i) impact of MTM vehicle system; 2) bulk density (Mg m^{-3}) of the worst soil properties (γ_w) after the compaction (by oedometer) at which plants (laboratory conditions) are unable to grow more.

Results and discussion

Regarding compactedness of soil, it can be characterized by an index of compaction. The index of compaction (*A*) is taken as the basic diagnostic characteristic. It is calculated by the formula (Nugis, 1988; 2004; Nugis & Kuht, 2000):

$$A = \frac{(\gamma_i - \gamma_a)\gamma_w}{(\gamma_w - \gamma_a)\gamma_i} \quad (1)$$

Here γ_i – current value of the soil bulk density after influence of MTM on soil; γ_a – bulk density of soil in the most loosened properties (after the Spring pre-sowing soil tillage); γ_w – limit bulk density of soil in the state of maximum possibilities of compaction. This limit was determined by guttadiagnostical method if the soil was compacted by an oedometer.

If we substitute in the formula the values of bulk density by the respective values of coefficient porosity (Troitskaia, 1961):, we get the following formula for calculating the index *A*

$$A = \frac{\varepsilon_a - \varepsilon_i}{\varepsilon_a - \varepsilon_w} \quad (2)$$

Where ε_a is the coefficient porosity of soil in the most loose properties, ε_ι is the coefficient porosity of soil in the intermediate, i.e. actual state after the effect of the wheels and diging booms of the soil tillage machines, ε_a is the coefficient porosity of soil in the most compacted states (Nugis & Kuht, 2000).

Taking the above mentioned principle of assessment as a basis formula (2) we can calculate the respective formulas for assessment of the index of tillage availability W_{fc} through coefficient of soil physical mellowness (or maturity, when the soil moisture content = 0.6FC..0.8FC, where FC – Field Capacity). If soil field capacity is k_{fc} ($k_{fc} = 1$) and index of soil structural composition S_{str} through coefficient of soil structure K_{str} ($K_{str} = 1$) then the corresponing indices appears as:

$$\mathrm{W}_{\mathrm{fc}} = \frac{\phi_a - \phi_i}{\phi_a - \phi_w} \quad (3) \qquad S_{str} = \frac{K_{str} - K_{si}}{K_{str} - K_{sw}} \quad (4)$$

$$\text{or } \mathrm{W}_{\mathrm{fc}} = \frac{1 - \phi_i}{1 - \phi_w} \quad (5) \qquad S_{str} = \frac{1 - K_{si}}{1 - K_{sw}} \quad (6)$$

Where ϕ_a, ϕ_{i} and ϕ_{w} (formulas 3 and 5) are values corresponding soil relative moisture content (in accordance best, current and worst) which is calculated (Table 1) through the suitable values of moisture content (%) which is obtained by dividing the soil moisture content corresponding to the limit value of the field capacity (FC) of a particular soil. Concerning formulas (4) and (6) K_{str} , K_{si} and K_{sw} are coefficients of soil structure (in accordance best, current and worst).

With all the necessary input data the limit values of the respective degrees of soil porosity, soil physical mellowness, structural composition - (best/worst) are given to enable to calculate the assessment criteria characterizing the physical properties of soil/subsoil, to assess the extent of the negative influence exerted to soil by MTM or mobile technical means (Table 1).

It appears from the Table 2 that we could give a comparative assessment of both experimental objects (EMÜ and ERIA or South and North) proceeding from the main characteristics of soil properties, i.e. bulk density and coefficient of soil porosity.

If to accept, that as a result of mechanical influence of MTM on soil the condition of the last can either worsen after which the soil is vulnerable, then we have respective character of mechanical influence which could be described by sign VuS – vulnerable soil (Nugis, 2011).

Table 1. The extreme (best/worst) values of the factors needed for calculation of the degrees characterizing porosity, humidity and textoral composition of automorphic soils

Factor	Character of degree	
	best	worst
Bulk density, γ (Mg m^{-3})	0.88	1.89
Coefficient porosity, ε	1.95	0.38
Value of soil physical mellowness, $\phi^{*)}$	1.00$^{*)}$	0.16
Coefficient of soil structural composition, K_{str}**$^{)}$	1.00**$^{)}$	0.28

$^{*)}$ If Field Capacity (FC) or ϕ_a = 1.00 or 18% and for current soil (loamy sand or sandy loam) the limit of wither is 3% (worst), then ϕ_w = 3/18 = 0.16;

**$^{)}$ If K_{str} $=s_{2\text{-}5}/s_{<2}+s_{>5}$ =1, if $s_{2\text{-}5}$ = 50% and $s_{<2}+s_{>5}$ is the same. where $s_{2\text{-}5}$ – content of textural varieties in soil, in per sent, which are agriculturally most valuable aggregates, i.e. the size of soil particles remains within the limits 2 to 5 mm; $s_{>5}$ – content of over 5mm clods in soil, in per cent; $s_{<2}$ – content of textural varieties in soil, in per cent, with diameter less than 2 mm (excessively crumble structure with predominance of dust-like fractions.

Table 2. The comparable results (best/worst) values of the factors needed for calculation of the degree characterizing (In North and South Estonia) of bulk density and porosity

Factor		Character of degree	
		best	worst
North Estonia (Kuusiku)	Bulk density, γ (Mg m^{-3})	1.22	1.60
	Coefficient porosity, ε	1.17	0.66
South Estonia (Eerika)	Bulk density, γ (Mg m^{-3})	1.24	1.68
	Coefficient porosity, ε	1.24	0.66

Note: dry soil density δ = 2,65 Mg m^{-3} for North Estonia and for South Estonia where δ = 2,78 Mg m^{-3}

It seems quite evident that the wheels of a tractor and tracks of a caterpillar generally make the soil more compact but digging booms (DB) or an operative part loosen the soil. Therefore, we can be expressed as a sign system – WT DB.

If we have respective character of mechanical influence which could be described by sign SpS (sparing soil), then this means that we are dealing with sparing soil, i.e. it remains unchanged or changes so little it can be neglected.

In such a way, the overall result of conventional mechanical influence from spring to autumn can be expressed by sign system as follows (Nugis, 1989):

/WT VuS + DB SpS/ ... /WT SpS + DB SpS/ ... /WT VuS + DB SpS/ and so on.

In case of conventional agricultural technology which is more widespread in Estonia, under the conditions of average soils (loamy sand & sandy loam) can be represented as follows (Table 3).

Table 3. The semiosphere and suitable signs in the field of conventional agricultural technology after the influence of MTM on soil during the spring sowing (Nugis et al., 2004; Nugis, 2011).

Technical and technological parameters					
Mark of the Tractor	Dynamic normal stress of wheel, kPa	Soil agrotechnical bearing capability, kPa	Depth of soil tillage without subsoiler, cm	Index of soil compaction (A)	Index of soil struc-ture (S_{str})
Case IH CX MXM 155	260	120	12	0,78	0,84
Pedosemiotics signs					
WT	VuS		DB	VuS	VuS

Notes: 1) WT – *wheels and tracks*; VuS – *vulnerable soil*; DB – *digging booms*; ImS – *improving soil*; SpS - *sparing soil*; 2) backed up by long-term results of our experiments. The admissible limits of the above indices are: A =0.75 for index of soil compaction (± 0.07); S_{str} =0.52 for index of soil structure (±0.06).

From Table 3 it can be seen that the present results show that the conventional technology is not sustainable. At the same time pedosemiotics signs are clearly seen, and technical and technological elements are more appropriate as a choice of suitable MTM and agricultural technology.

Conclusions

As a result of the complex investigations it should be underlined that:

1) Investigation of the process of the effect and prognosticating the level and character of corresponding influence of mobile technical means (MTM) on soil have been carried out. At the same time we have tried to characterize it in some way through respective pedosemiotic criterion;

2) the effect of soil compaction is studied in two leading organizations (ERIA & EMÜ). An attempt has been made to methodologically harmonize their experiments. We tried to confine ourselves to a minimum number of indices, i.e. soil compaction, soil physical mellowness or maturity and soil structural composition;

3) the extreme (best/worst) and admissible values of indices that characterize the porosity, humidity and textoral composition for automorphic soils have been calculated. The principles of the calculations of the above mentioned formulas have had the same;

4) the sign system and finally corresponding pedosemiotic characteristics could enable a more adequate way to assess the extent of influence exerted to soil by MTM. It was possible due to long-term investigations, and by sign system the overall result of conventional mechanical influence from spring up to autumn can be expressed;

5) it appeared from the results of theoretical analysis that pedosemiotics signs mostly depended on the type of wheel or track of the MTM, and that is not considering the type of digging boom or in other words operative part.

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