Use of Volumetric Soil Crushing Coefficient for Evaluation of Mechanical Action

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Abstract. The soil hardness is one of the most important indicators, which makes it possible to estimate the soil layer as the root germination medium and choose one or another method of tillage or the depth of tillage. Due to its informative value, the hardness is used to obtain information about the quality of the performance of cultural-technical and agricultural operations. The main difficulties hindering the objective quantification and comparison of results is a strong influence on the measurement results of the plunger immersion velocity, as well as its shape and cross section. Therefore, the hardness values in the form in which they are currently used represent difficult to compare data, which strongly depend on the human factor and require the elimination of a number of significant flaws. The objectivity of soil impact assessment is significantly increased when using the volumetric soil crushing coefficient instead of the hardness, which in most cases is devoid of the listed drawbacks. The volumetric soil crushing coefficient is quickly and easily measured by hardness diagrams. The assessment of the impact from the machinery on soil compaction according to the volumetric soil crushing coefficient was carried out on light gray forest, dark gray forest and derno-podzolic soils of the Kanash District of the Chuvash Republic.

1. Introduction

The soil hardness is the resistance to penetration into it under the pressure of any body (cone, cylinder, etc.). It’s largely influenced by the construction of soil aggregates and microaggregates, the content of soil moisture and air. Moisture affects the hardness as it’s a link for solid soil particles. For hardness measurements, both rather complex electronic-mechanical devices and primitive (deformers of different sizes and shapes that are thrown to the ground from certain heights) are used. In practice, however, the hardness measurement is often carried out by pressing a plunger into the soil, often having a cylindrical or conical tip [9]. The result of the measurement is on figure 1. Dividing the force of pressing by the cross-sectional area of the plunger, one can get the value of the hardness. When immersing deformers in the soil, various processes take place: soil compaction, friction of the deformers surface on the soil, and also shear deformation. It is possible to describe the processes of interaction between the plunger and the soil on the basis of the laws of deformation (under compression and shear): Hooke’s law that characterizes the elastic behavior of solids within the limits of small deformations, and Newton’s law (describing a viscous flow) with constant plunger velocity. Let’s briefly list the main difficulties arising in the determination of soil hardness and interfere with...
quantitative assessment and objective comparison of results: the need for regular calibration of springs and the construction of calibration curves; a strong influence of the plunger immersion velocity on the results of measurements, as well as its shape and cross section. In this regard, the hardness values, as they are currently measured, are difficult to compare data, which strongly depend on the human factor and require the elimination of a number of significant flaws. In accordance to standard methods and normative and technical documentation, there is a need to standardize measurements or develop alternative soil impact indicators [8].

Figure 1. Diagram of immersion resistance (— before tillage, - - after tillage).

When immersing an indenter, a number of processes take place in the soil. The main ones are soil compaction along and around the tip of the indenter, shear deformation (a cut through the soil layers) and, of course, friction of the indenter's lateral surface on the soil. The resulting parameter carries a lot of diverse but difficult to systematized information. The diagram is characterized by three stages of soil deformation. The soil hardness at different depths is not the same, so it can be determined for each depth.

2. Methodology

For the correct use of the hardness data, force measurements are required in the direct proportionality section of the \( P=f(h) \) diagram and the corresponding depth of immersion of the hardness tester cylindrical tip. The ability of the soil to resist crushing can be determined through the values of hardness. But, more logical is to use the coefficient of volumetric crushing of the soil. Since the hardness value \( T \) is the ratio of the force \( P \) required for the penetration of the plunger into the soil to the cross-sectional area \( S \) of the tip \( T=P/S \), the volume of the crushing soil \( V= h_u S \) one can determine the volumetric soil crushing coefficient \( (h_u \text{ is the length of the linear portion, } P_a \text{ is the force corresponding to the linear portion})\):

\[
t = \frac{dT}{dh} = \frac{P_a}{h_u S}.
\]  

With small deformations on the front side of tip base on the hardness tester, a cone-shaped outgrowth of over-compacted soil does not have time to form. In addition, with a small deformation, the effect of friction forces on the side surface of the hardness tip is small. Therefore, the use of \( t \) and the derivation of the dependences of \( t \) \((\Pi, \Omega, w)\) is very important in studying the soil state. The volumetric soil crushing coefficient, measured from the hardness diagrams, can be quickly and easily
used to estimate the crushing of the soil even when there is much more time-taking process of plotting compression curves.

In most studies related to the soil hardness study before and after the tillage, the value of $P_b$ is used, from which it is not always possible to calculate correctly $t=dT/dh$. However, it is possible to bind the longitudinal and transverse hardness through porosity and specific surface. If, by composing a combination of $w/\rho P^i \Omega^j \Pi^k$ or $w/r^i \Omega^{*j}$ (i, n, m, k are some numbers, P is the force determined in the portion of direct proportionality of the solidogram $P=f(h)$, H; $\Pi$ is the soil porosity (in fractions); $\Omega$ – the specific surface area of the solid soil phase, $m^2/m^3$; w is the bulk moisture content of the soil (in fractions), and having selected certain values of n, m and k, one can plot generalized curves for $w/\rho P^i \Omega^j \Pi^k$, then practically all of them will merge into one generalized curve.

Relative universality of the considered value of $t$ was used in the development of such a soil parameter that characterizes the mechanical effect in agro-meliorative and cultural-technical measures as a potential for deformability of soils. This potential is the ratio of the energy expended for the deformation and mass transferring processes to the soil mass unit in the specific conditions of its occurrence. To calculate the deformability potential, it is necessary to have the calculated basic hydrophysical characteristic [11, 12].

Quite often there is the appearance of a compacted layer of soil, which has a significant effect on root growth and water absorption [1, 2, 6]. Anthropogenic compaction on land allocated for cereals and a number of other crops, mostly appears after the passage of machine and tractor units [10, 13]. That is, the appearance and accumulation of compaction in the soil is influenced by running systems of machine-tractor units.

3. Results
To assess the effect of the multiplicity of the machinery runs on soil compaction, we tested the impact of the tractor AGROMASH 90TG on the soil (OOO “Sormovo”, the Kanash District of the Chuvash Republic, dark gray forest soil $\Omega=62.2$ m$^2$/g, $\rho_f =2.61$ g/cm$^3$, the starting density $\rho = 1.03$ g/cm$^3$), the results are shown on Figure 2.

![Figure 2](image)

**Figure 2.** Distribution of the volumetric soil crushing coefficient $t$ values according to a depth for a different number of runs.

Figure 3 shows the results of studying the compaction for tractors with structural differences in running systems and different weighting parameters K 701, AGROMASH 90TG (upgraded DT-75)
and T-150 from measurements of the volumetric soil crushing and density coefficient. The studying was carried out on dark gray forest soil ($\Omega = 62.2 \text{ m}^2/\text{g}$, $\rho_{sf} = 2.61 \text{ g/cm}^3$, initial density $\rho = 1.03 \text{ g/cm}^3$) [3, 4, 5].

On figure 3, the compaction did not penetrate deeper than on 26-34 cm, and the multiplicity of the runs was reflected in the corresponding higher values of the volumetric soil crushing coefficient.

![Figure 3](image_url)

Figure 3. Assessment of compaction according to the values of the volumetric soil crushing and density coefficient $t$.

If the values of the volumetric soil crushing coefficient undergo a sharp jump at a depth of 24-27 cm, the increased values of the density (weight by volume) after the runs of machinery first fluctuate around the values determined for each case, and then decrease uniformly in the depth of 24-35 cm, then stabilize. In the depth of 0-27 cm, the weight-by-volume values indicate a compaction.

4. Conclusions
The article presents the results of studies of the volumetric soil crushing coefficient, aimed at improving the assessment of agrotechnical and cultural-technical measures. The use of values of the
volumetric soil crushing coefficient instead of the hardness values is an important point of effective testing, since the soil with spatial heterogeneity is an interesting and complex subject for a study. Field studies made it possible to expand the base of the experimental data to trace changes in the volumetric soil crushing coefficient, depending on the number of runs of different tractors on light gray forest, dark gray forest and derno-podzolic soils of the Kanash District of the Chuvash Republic in 2015-2017.

5. References
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