Interpretation of the results of particle-size distribution determination using various soil texture classifications

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Abstract. An analysis of discrepancies in methodological approaches as well as in determination of the boundaries of the main textural classes classified according to classifications of N.A. Kachinsky (Russia), US Department of Agriculture (USDA) and World Soil Reference Base (WRB) soil texture classification was made. A comparative analysis of the obtained data showed that the differences in the dimensions of the clay fraction in the classifications lead to a seeming increase in the content of this fraction by 1.5–2 times, and therefore, to a shift to heavier textural class according to USDA and WRB classifications. This circumstance inevitably affects the content of the silt fraction. Due to discrepancies in determination of the boundaries of the main textural classes in the classifications of Kachinsky, USDA, WRB, the distinctions in the diagnosis of soil on its textural composition are reflected in the name, while the real number of soil primary particles of various sizes in the sample does not change.

1. Introduction
The particle-size distribution is genetic characteristic that determines the fundamental properties and features of the soil. It sets the direction and nature of research. The importance of the research at all stages of the study of soil primary particles (SPP) cannot be neglected. The study of SPP starts from the classification approaches and the principles on which they are based and ends at the methods of sample preparation and the particle-size distribution measurements. This is especially important to us now when the universal globalization takes place and combines research results and efforts of scientists from many countries. More frequently, scientists from Russia as well as from foreign countries use the method of laser diffraction analysis for various scientific purposes.

Therefore, it is scientifically important to achieve mutual understanding in interpretation of the results of determination of particle-size distribution of soils obtained by this method. Thus, the goal is to conduct a comparative study of the quantitative measurement of SPP by fractions, and the peculiarities of interpretation of the results in Russian and international soil science.

In order to achieve this goal, we studied approaches to classifications and their evolution in various SPP scales used by scientists from Russia, the USA, and European countries. The research is based on the analysis of not only the classification features, but also of different understanding of the nature of SPP, the principles of identification of the main textural classes and dividing them into subclasses, and variation of the width of their boundaries. A comparative analysis of soil texture classifications is possible only in the condition of comparability of objects of the classification process, sample preparation and measurement methods, research results, and ultimately, objects of definitions.
2. Objects and methods

All soil samples were collected at the upper section of the Botanical Garden of Southern Federal University (Russia, Rostov region, the west part of Rostov-on-Don). The study area is located on a watershed plateau, the microrelief is poorly expressed, the land is fallow. The soil is Calcic Chernozem (Loamic) (according to [1]). The depth of the cut is 130 cm, effervescence from 10% HCl starts at a depth of 45–50 cm from the surface, with the appearance of carbonate mycelium (veins). Carbonate nodules (“beloglazka”) are observed at a depth of 90–95 cm. We have collected 57 individual soil samples according to genetic horizons from 3 soil pits (N 47.236002°, E 39.651090°; N 47.234234°, E 39.657186°; N 47.236620°, E 39.656863°).

Several samples were taken from each genetic horizon for representativeness. Thus, each horizon was characterized by 9 samples. At the article we have presented results of investigation of only 18 samples from horizons B1 and C. The choice of these horizons was explained by the following considerations. The middle part of the profile in virgin chernozem (horizon B1 50 – 80 cm) is most susceptible to various changes. These are the processes of carbonate migration, traces of which remain in the form of carbonate mycelium. These are the claying processes, accompanied by the accumulation of silt particles in the middle part of the profile. In contrast, horizon C (150–170 cm), the parent rock, is least affected by the external environment.

The investigation was carried out in several steps: 1. The step of soil sample preparation for the analysis – all air-dried soil samples were crushed in a mortar and sieved < 1 mm to obtain homogenous fine grain size distribution. Subsequently, 4% sodium pyrophosphate was added in order to destroy cements and to disperse soil samples to obtain greater soil primary particles yield. This sample preparation was chosen, as it allows to take the SPP of different nature into account, such as mechanical ones, as well as preserve the particles of organic-mineral and organic nature, which are necessary for the Russian classification.

2. The step of quantitative measurement of SPP by fractions – the laser diffraction method was chosen (the device “Analysette 22 NanoTec”, ISO 13320-1: 1999). This method is widely used for particle-size distribution analysis of soils by Russian [2; 3] as well as by foreign researchers [4–10]. This is explained by the objectivity of the instrumental method, which allows controlling confidently the duration of dispersion. The results of parallel measurements have good convergence due to the features of the measurement process. It is important that the chosen method is not fundamentally related to any of the compared classifications, that, in our opinion, makes it possible for it to be used independently from the existing stereotypes.

3. The step of the results interpretation was carried out according to the following generally accepted classifications (the features of classification approach, succession and evolution of Russian and international scales were studied in advance [11]: Kachinsky’s classification of soil mechanical composition [12]; US Department of Agriculture soil texture classification [12]; classification of the World Soil Reference Base [1]).

4. The step of comparative analysis of soil texture classifications of Russia, USDA and WRB.

3. Results and discussion

The differences of the compared classifications, Russian and foreign classifications, in particular, the one by US Department of Agriculture (USDA) and World Reference Base for Soil Resources (WRB), are summarized in table 1.

Inconsistency appears not only in different ideas about the nature of SPP but also in classification approaches based on the grain size. However, the most significant discrepancies are noted not so much in the fraction dimension or the displacement of the boundaries of the textural classes, but in the approaches to the soil particle-size analysis performance. That influences the study of the composition and properties of SPP and the determination of the soil particle-size distribution in general.

The particle-size distribution of C horizon of the Calcic Chernozem measured by the laser diffraction method is examined in order to illustrate the need to consider the type of soil formation in the soil textural class determination (figure 1).
Table 1. Difference in the classifications of soil textural classes according to Kachinsky system, World Soil Resource Base (WRB) and US Department of Agriculture (USDA).

| Classification                  | N.A. Kachinsky [11] | USDA [12] | WRB [13] |
|---------------------------------|----------------------|-----------|----------|
| **Object of the particle-size distribution analysis** |                       |           |          |
| Particles of mineral, organic-mineral and organic nature |                       |           |          |
| Boundary between fractions of fine sand and silt | 0.05 mm           | 0.05 mm (sometimes 0.02 mm) | 0.06 mm |
| Fraction boundary               |                      |           |          |
| Fraction name                   | Size of fractions of SPP, mm |            | Fraction name |
| Clay                            | < 0.001              | < 0.002   | < 0.002  | Clay |
| Fine silt                       | 0.005–0.001          |           |          |      |
| Medium silt                     | 0.01–0.005           | 0.05–0.002| 0.063–0.002| Silt |
| Coarse silt                     | 0.05–0.01            |           |          |      |
| Fine sand                       | 0.25–0.05            | 0.1–0.05  | 0.125–0.063| Very fine sand |
| Medium sand                     | 0.5–0.25             | 0.25–0.1  | 0.20–0.125| Fine sand |
| Coarse sand                     | 1.00–0.5             | 0.5–0.25  | 0.63–0.20 | Medium sand |
| Gravel                          | 3.00–1.00            | 2.00–1.00 | 2.00–1.25| Very coarse sand |

During interpretation of the results of particle-size distribution analysis, the non-Russian scientists neglect the peculiarities of the soil formation process, while in the classification of Kachinsky the pedogenesis is considered by the use of different scales for different type of soil formation, such as solonetz, podzol and steppe soils. The studied C horizon lies at the considerable depth of 100 – 145 cm and, therefore, it is the least affected by the environment. The interpretation was executed according to the classification of Kachinsky that considers the pedogenesis. The sum of particles, whose diameter is less than < 0.01 mm, in the examined sample is 65.09 ± 1.06%. Considering that this soil has a steppe type of soil formation, the texture is determined as light clay. If the soil type was Podzol, the results would be interpreted as medium clay, and if Solonetz – it would be heavy clay. Thus, interpreting the experimental data, it is necessary to take into account the type of soil formation, since, depending on this parameter the class of textural clays varies from light to heavy. Whereas, according to WRB and USDA classifications, the sample under consideration is determined as silt loam.

An analysis of the statistically averaged results of determining the particle-size distribution is shown in figure 1. In the context of the examined classifications, it was shown that due to a change in the gradation of the clay fraction an increase in its quantity by 1.5–2 times in the foreign classifications occurs. There are also differences for silt, since the upper clay limit is shifted. The boundary of the sum of sand fractions is approximately at the same level in all considered classifications, thus, the amount of material of this fraction is often the same.

Differences in the interpretation of the results in terms of the silt content are presented with the example of a sample from horizon B of Calcic Chernozem (table 2).

The integration of fraction was realized into three general soil texture classes. It allows using “the triangle classification” of soil texture by Ferre, that is based on the sum of soil fractions such as clay, silt and sand. The comparison results are shown in table 2. There are similar names for soil texture classes, but their boundaries are different. Whereas in the USDA and WRB classifications just silt is
emitted, in the Russian one – silt particles are divided into three fractions. And vice versa: in the Russian classification fine sand is not divided into more fractions, while in the USDA and WRB classifications fractional division into fine and very fine sand is used.

Figure 1. The particle-size distribution of C horizon of Calcic Chernozem in the context of the discussed classifications: A – N.A. Kachinsky; B – USDA; C – WRB.
Table 2. The particle-size distribution of B1 horizon of Calcic Chernozem in the context of the discussed classifications.

| Classification | N.A. Kachinsky [11] | USDA [12] | WRB [13] |
|----------------|----------------------|-----------|-----------|
|                 | Fraction name | Particle size, mm | Particle content, % | Fraction name | Particle size, mm | Particle content, % | Fraction name | Particle size, mm | Particle content, % |
| Clay            | <0.001 | 2.26±0.18 | Clay       | 2.26±0.18 | <0.002 | 6.75±0.76 | Clay       | 6.75±0.76 |
| Fine silt       | 0.005–0.001 | 15.97±0.76 | Silt       | 86.89±   | 6.75±0.76 | Silt       | 86.89±   |
| Medium silt     | 0.01–0.005 | 15.74±2.78 | Sand       | 10.86±6.06 | 0.1–0.05 | 10.83±6.04 | Medium sand | 10.86±6.04 |
| Coarse silt     | 0.05–0.01 | 55.18±3.29 | Coarse sand | 1.00–0.5 | 0.00±0.00 | Coarse sand | 1.00–0.5 |
| Fine sand       | 0.25–0.05 | 10.86±1.11 | Gravel     | 0.00±0.00 | 0.00±0.00 | Gravel     | 0.00±0.00 |
| Medium sand     | 0.5–0.25 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 |
| Coarse sand     | 1.00–0.5 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 |
| Gravel          | 3.00–1.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 |
| Loam medium     |          |          | Silt       | 0.00±0.00 | 0.00±0.00 | Silt       | 0.00±0.00 |

The USDA and WRB systems do not separate silt into smaller fractions according to the Kachinsky’s classification. However, if we compare the total amount of silt calculated by the Kachinsky’s system – 86.89% – with the content of silty particles by USDA – 82.40%, and by WRB – 88.30%, the difference is obvious. According to the USDA, the reduction in the amount of silt is explained by the increase of the sludge boundary by 1 μm. Thus, the silty part loses 4.49% and falls into the sludge fraction. Comparing the amount of silt according to the Kachinsky’s and WRB systems, it should be noted that in the international classification the silt yield in the former one is higher than in the latter one – 88.30 and 86.89, respectively, despite the fact that some of the silty particles (0.001 – 0.002) passed into the sludge fraction. This was due to an increase in the upper limit of total silt according to the WRB version in comparison with the Kachinsky’s classification – 0.063 versus 0.05, respectively. As a result, all particles with a size of 0.063–0.05 mm, which according to Kachinsky are sandy, replenished themselves with a silt fraction, which is 5.90%. However, if we look at the difference in sand fractions, the situation changes due to a more detailed fractional division into subclasses in the classification of N.A. Kachinsky. Due to changes in the boundaries of the main textural classes, and accordingly, changes in the quantity of SPP, that make up these classes, the soil texture is assessed as finer or coarser depending on the type of classification system used by the researcher. It is natural that the terminology discrepancies do not reflect the real situation, since in reality the quantity of SPP of various sizes in the studied soil does not change. Thus, the research data presented in figure 1 show that the use of different classifications for diagnosis of the same soil sample characterized by the same relative content of SPP.
leads to a shift of the textural class in the direction of heavier classes during the interpretation of the analysis results according to non-Russian classifications.

Nevertheless, the noted facts should not be considered in any way as an advantage or, on the contrary, disadvantage of this or that classification system. However, they must be taken into account when working with the scientific literature on soil science, since otherwise a false idea is created both about the subject of research—the soil—and about the results obtained using different methods. The advantage of determination of the textural classes of soil according to the classification of Kachinsky is the consideration of the conditions of soil formation, since the neglect of them leads to errors in the soil diagnosis according to its particle-size distribution.

4. Conclusion
The lack of a unified methodological approach to the SPP classifications is the reason for the discrepancy in the interpretation of the results of the particle-size distribution analysis obtained by laser diffraction, since the same term, for example, “silt” stands for different particles not only in terms of size, but also nature.

A comparative analysis of the obtained data for Calcic Chernozem showed that the difference in the dimensions of the clay fraction in the foreign classifications, in comparison to the Russian one, lead to a seeming increase in the content of this fraction by 1.5–2 times, and therefore, to a shift to heavier textural class, according to foreign classifications. This circumstance inevitably affects the content of the silt fraction. Due to discrepancies in determination of the boundaries of the main textural classes according to the classifications of Russia, USDA and WRB, the unconformity in the diagnosis of soil textural classes is reflected in the name, while the real number of SPP of various sizes in the sample does not change.

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