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REVIEW PAPER

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METHODS FOR THE GRANULOMETRIC ANALYSIS OF SOIL FOR SCIENCE AND PRACTICE

Abstract. The publication contains the descriptions of two analyses of soil texture and the bed beneath (subsoil). For objective reasons, the first method – TA is very labor and time consuming, yet exact and verifiable, of a precisely defined indication error. It is conducted by a complete refractioning of a soil sample which have been dispergated in distilled or demineralized water. The analysis was based on the rule of refractioning the whole sample into clay, silt and sand fractions through floating the soil suspension. The sum of indicated fractions was at least 98% in percentage by weight which means that the analysis error did not exceed 2%; for the most of the analyses it still did not even exceed 1%. The method of whole sample refractioning, TA method for short, is one of the basic, classic method of soil texture analysis. The main aim of this method is the verification of shortened, partial or simplified methods such as pipette, areometric and laser methods, etc. TA method can be used in scientific research when exactness and reliability of texture analysis is especially important.

The second method of the granulometric analysis, ALP method for short, is based on pipette methods. Samples of soil suspension of 1000 ml are taken with a pipette of about 38.5 ml capacity, yet the pipetting capacity is determined by weight with 0.001 ml exactness. The pipette is constructed of four pipe probes of 1 cm diameter and placed at the depth of 9.5 cm the suspension is collected from the sphere of 9.5–10 cm. Sand fractions which were nor indicated with a pipette method (> 0.05 mm) were analyzed with TA method by floating the particles < 0.05 mm with a suction device. Pipette analysis error was between -3% and +3%. For most of the results, the error did not exceed 2%. Errors were divided proportionally onto each fraction. A pipette method may be used in scientific research but first of all – in those conducted for practical needs.

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INTRODUCTION

Texture analysis is – as it is commonly known – the basic and most often conducted soil analysis. The main target of this analysis is the determination of percentage content of each fraction of clay (< 0.002 mm), silt (0.002–0.05 mm), sand (0.05–2.0 mm) and soil skeleton particles (> 2.0 mm) in total – mineral and organic – soil mass. It forms the basis of laboratory determination of the soil texture, field organoleptic indication of texture as well as general characteristic of various physical soil properties such as water and air capacity, permeability, filtration, structure, compaction, viscosity, plasticity, consistency, mechanical resistance to distortion, etc.

Such wide and basic dependence of the state and changeability of physical properties on various percentage composition of the listed fractions is mainly the object of practical use of the results of soil granulometric analysis in numerous disciplines connected with soil sciences such as soil tillage and plan cultivation, mechanization of agriculture, water meliorations, etc. Moreover, the results of granulometric analysis are used in geology, geography, ground construction, ground mechanics, etc. Despite numerous opportunities of using the results of granulometric analysis, conducting the analysis is still a problem which requires further research and methodical solutions.

For the measurement of the granulometric composition of the soil, research centers use various methods of different accuracy. In particular, no common verification of the accuracy and exactness is carried out. Texture analysis lacks at least one method which would be sufficiently accurate and exact, verifiable and sufficiently fast. Such method has not been developed despite great efforts for 100 years.

However, the two decades between 1910 and 1930 stands out from this long period. It was then, that most of the equipment and methods for the measurement of texture were invented. Such research was conducted mainly in the European countries, especially in Germany and Norway. At that time, rules for fractioning a soil sample were elaborate and the complexity of sedimentation process and methods for preparation of soil samples for the analysis were presented. Moreover, methods for total defractioning, separating and marking fractions with appropriate appliances and cylinders (usually called separators) were developed. One of them was Atterberg's appliance [2], best known and most frequently used, which was manufactured using batch production. Some of the less known pieces of equipment were Wagner's [10] and Wahnschaffe's cylinders and appliances [21]. Areometer and the method of Bouyoucos [3] and Casagrande [4] were developed for areometric indication of texture on the basis of density changes occurring in sedimenting soil suspension. Also, a prototype of Sven Oden [5] sediment weight which was used for determining weight changes occurring on a scale hung in sedimenting suspension. Wiegener's appliance [22] was equally quaint; it worked as connected vessels. It consisted of a cylinder 1 m heigh, in which the sedimentation of a soil sample occurred. The bottom part of the sedimentation pipe was joined with a thin measurement pipe filled with water without sediment.

This period of time was also famous for the appearance of devices and methods for the measurement of the content of a given granulometric fraction on the basis of a representative amount of a fraction in a suspension sample mainly of 10 or 20 ml capacity, taken from the volume of 1000 ml. Among the numerous devices and probes (usually called pipette probes), special attention should be given to Köhn's pipette [9] and Robinson's pipette [16]. Köhn's pipette had been used in all the European countries, whereas Robinson's pipette – mostly in the USA – for many years. Moreover, the years 1910–1930 witnessed the creation of flow-through devices. The most important of them was, used in the past mainly in central and eastern Europe, Kopecki's device [8]. Nowadays, such appliances have a rather historical meaning.

After this period, no more appliances of practical significance were developed. Generally, the only interesting solution is the laser method and device adjusted to granulometric analysis. However, this method requires exact and appropriate control over the accuracy of its measurements, as well as appropriate documentation. Attempts to measure the soil texture with this method have been very problematic so far.

Therefore, the years from 1910 to 1930 were the most fruitful and creative period of finding solutions for the granulometric analysis. It was the time of implementation of the devices listed above, as well as of many other appliances, all of which are presented in an extremely valuable and well documented monograph of Gessner [5] which contains descriptions of appliances and methods. The descriptions of devices and methods for indication as well as a lot of information and interpretations of soil texture analysis may form the view on crucial difficulties connected with this analysis and on the opinion of numerous soil scientist who had spent at least part of their lives on solving this problem. Therefore, when undertaking the continuation of research and methodological solutions in this field, one should make use of the experience, ideas and achievements of this period and the stride in science and technology of the last decades.

Modern research, however, needs to clearly distinguish between two aims of granulometric analysis, which are connected with different possibilities and limits. One of the aims is developing a method which would intend to appropriately assess and verify the methods for practice. Furthermore, it would be meant strictly for scientific research. For many objective reasons, these analyses would be very intensive and long-term. The analytic process, way of conduct and the exactness of the outcome should be strictly controlled. Another aim of the anallysis is elaborating on a method for practice. In this case, granulometric analysis should be much less labor-intensive, far quicker, but still of defined and verifiable exactness of the measurements.

VALIDITY AND CONDITIONS OF DEVELOPING THE METHODS FOR GRAVIMETRIC SOIL ANALYSIS

The basic and most important justification for undertaking the research aimed at creating new methods of verified, and therefore verifiable, exactness of indications of acceptable speed and labor-intensiveness of the analysis is, as it was already emphasized, the lack of such methods. Methods known and incorporated so far meet the presented conditions mainly only in part. What is more, they have a lot of limitations.

Much more important than their validity are the conditions which enable undertaking and the success of the research process. In the Department of Soil Sciences of Poznań Agriculture University and now – the University of Life Sciences in Poznań, both in the past and nowadays, there have been appropriate conditions for the successful completion of such research aimed at creating new, original methods for the gravimetric soil analysis.

Even in the interwar times (1918–1939), as well as early after The Second World War (1945–1952), Soil Science Department has gathered – both for the didactic and research purposes – numerous crucial appliances and devices, i.e.: 24 Atterberg's applicance [2], 6 Wagner's appliances [10], 3 Wanschaffe's devices [21], Wiegner's device [22], pipette device with Köhn's tripod [9], Casagrande's areometer [4], Prószyński's areometer [13]. Practical know-how of usage, methods for indication as well as obvious advantages and disadvantages, were a vital motif for further reflection aimed at improvement, betterment and new methodological solutions.

The most elaborate and, first of all practical experience (also in various analytical details) was gathered during a long-term use of combined analytical methods – Köhn's pipette method [9] and Atterberg's method [2]. Before 1952 texture analysis in the Soil Science Department had been conducted only with Köhn's pipette method for smaller fractions (from 0.02 mm) and with Atterberg's method for larger fractions (from 0.02 mm). Soil sample in air-dry state of 10 g weight (without hygroscopic water) was being prepared for the analysis in accordance with an international method [13]. Pipettes of 10 ml capacity and 20 ml capacity were used. Times of collection were: for a 10 ml pipette – 20 seconds and for a 20 ml pipette – 30 seconds. Times of collection (suction) were strictly followed. Fraction of coarse silt (0.02–0.05 mm) was floated with Atterberg's device, whereas sand fractions larger than 0.05 mm stayed in the cylinder. Usually, a single analysis was done and the sum of indicated fractions from 98 to 102 percent served as a control of exactness. Therefore, an acceptable error of measurement did not exceed 2%. The value of error was divided proportionally among the fractions.

Long term indications of texture with the listed, combined methods allowed practical assessment of advantages and disadvantages and usefulness of other known pipette methods as well as other methods of total defractioning of soil samples. Theoretical bases for an appropriate assessment of the values and usefulness of these methods are contained in numerous monographs, especially in the ones of Gessner [5], Köster [11], Müller [14], Kaczyński [6] and Musierowicz [13].

The appearance of a new dispersive substance was an extremely beneficial condition for the successful, and aiming at creating new analytical methods, research process. The implementation of the substance did not require boiling a soil sample. This substance, according to Tyner [20], was sodium hexametaphosphate – *Calgon*, also known as cold launder. The properties of Calgon were examined in details by Kilmer and Aleksander [7] who claimed that sodium hexametaphosphate in the amount of 35.7g with the additions of 7.94 g of dry sodium carbonate in 1000 ml of water formed a basic set for the dispersion of soil samples. Calgon was added in small excess, of 20–25 ml of basic solution for 20–40 g of soil.

A very good and permanent enough dispersion of soil suspension in normal (laboratory) temperatures (cold, without boiling) is an especially important and extremely beneficial characteristic for the granulometric analysis, when compared to the dispensers frequently used so far. Boiling soil suspension influences loam fraction negatively, which was ascertained in many publications, including a comprehensive monograph by Langier-Kuźniarowa [12]. Calgon's characteristic which is even more important, is the possibility of achieving a sufficient dispersion for carbonate soils such as Jurassic and cretaceous rendzinas and sediments of various origin and high content of $CaCO_3$. Therefore, Calgon may be referred to as a universal dispenser, applicable in granulometric analysis both for carbonate and noncarbonate soils. In a few years after the publication of Klimer and Aleksander [7], Calgon was more and more often used by popular and significant laboratories as a very good, universal dispergator in the granulometric analysis of soil.

So, at the moment of undertaking the research focused on creating new solutions for soil texture measurement, such crucial problem of preparing soil for the analysis was successfully solved. The only problem that remained was designing new appliances and devices and methods for analysis applicable to this equipment.

The first, original methodological solution was an aspiratorless pipette (AL) which construction and basics were published in 1963 [17]. It was not a laboratory pipette as such, but a pipette probe used for collecting soil suspension of strictly defined capacity. The capacity was defined in weigh with the accuracy of measurement of 0.001 g. The basic element of the pipette was a pipe of 1 cm^2 section connected with a thin pipe of 5 mm section at the height of 11 cm. The latter pipe was connected with the valve, which either opened or closed the stream of air, at the height of 20 cm.

The mentioned publication contained the description of a few versions of pipettes made of mineral glass consisting of a single pipe of 10 cm length and a set of double and quadruple pipes of 20 cm. It was possible to "cut" cylindrical sample of 1 cm^2 cross-section and 10 or 20 cm length with pipe pipettes when a pipette with an open valve was immersed in the suspension. When the valve was closed, the pipette was taken out of the suspension and when the valve was opened the selected soil sample was transported to a weight cell.

There was also another method for collecting the samples. Namely, using a pipette with a closed tap, which was immersed in dispersive solution at the depth of 9.5 cm. After opening the tap, the solution from 9.5–10 cm filled the pipette automatically from the bottom. After closing the tap the pipette was placed above the solution which resulted, analogically, in putting the solution in a weight cell.

Another, equally important solution in the granulometric analysis of soils, was creating a device for total floating of each soil fraction [17]. It worked on similar basics as even better known but less frequently used Atterberg's cylinder [2]. However, this device functioned much more efficiently, owing to which the analysis was faster, easier and did not require any special laboratory equipment. Furthermore, it was applicable to numerous indications of texture.

The basic element of this device was a metal cone connected with a switch pipe with a suction gap where it joined the cone. The pipe was equipped with a centering slide which kept the suction device vertically. These elements were connected with a cone bottle (a flask) with a hose; soil solution was floated to the flask. Next, the bottle was connected to an aspirator with a hose. This set allowed proper and almost complete (around 90%) float of the solution from above the soil sediment.

The two basic solutions in the granulometric analysis presented here in a broad outline, were modified, simplified and controlled throughout decades. They tackled two different problems. One of them was an appropriate method for the texture analysis adjusted to the total defractioning of a whole analyzed soil sample. It was a labor-intensive and slow method but it was strictly verifiable and of an exact, minor measurement error. Another methodological problem was the analysis based on a small sample, yet relatively representative for the whole soil dispersive solution. These were mostly pipette methods, among which the method presented in this paper may be counted. Research conducted until the final creation and development of these two basic methods lasted for over 50 years, which was extremely long.

BASIC RESEARCH ASSUMPTIONS

For the appropriate and purposeful completion of the methodological research, a few assumptions were made:

1. On the basis of extensive practical experience in texture analysis, it was assumed that there are no possibilities of finding one method which would be quick, well-verifiable and, most importantly, exact and of a strictly defined

measurement error. Exceptional complexity, as well as extremely complicated soil granulation prompted us to develop at least two completely different, yet generally based on the similar rules, methods which would serve various purposes and uses, as well as possibilities for making use of the analysis.

2. One basic and model method should be based on the rule of proceeding sedimentation in which, after a defined period of time, a total of at least five generally acknowledged fractions is floated: < 0.002 mm; 0.002–0.005; 0.005–0.02; 0.02–0.05 and > 0.05 mm. The sum of floated fractions in percent ought to be close to 100% and the measurement error for the five fractions should not exceed 2%. Such analyses, however, are time and labor consuming. Only 30–40 indications could be done in a month's time. Therefore, such analyses should be conducted mainly in specialist examinations, in which not only texture is indicated, but also a broad, technical analysis of the fractions is conducted. Nevertheless, what is even a more important aim of this analysis, is using it for the verification of the new as well as so far implemented, methodological solutions.

Pipette analysis adjusted to the indication of smaller particles from 0.05 mm ought to be completed with the method of total analysis (sand fractions – 2.0–0.05 mm), since only then is it feasible to verify the exactness of indications and the measurement error.

3. Another method, also based on the sedimentation of soil suspension, should analyze the soil granulation much faster, be checkable, of a defined measurement error. In this case, texture analysis ought to be based on a soil sample collected at a defined temperature of the solution and in the precise time (Table 1), as well as of a strictly defined capacity form the total of the analyzed solution, just as in popular pipette methods of e.g. Köhn's [9], Andreasen's *et al.* [1], Robinson's [16].

4. It was also assumed that in most of laboratories, texture is indicated in the rooms with no air conditioning, at the temperature of mainly about 17–25°C. Moreover, most of the used scales are those of 0.001 g measurement accuracy. Therefore, the exactness of indications and maximal errors of the implemented methods should be documented and defined for such conditions. Practical reasons are most important here. Yet, it needs to be stressed that conducting the analyses in strictly controlled conditions can only improve the accuracy of the methods.

5. For the acknowledgement of the universality of the developed methods, proper completing of soil samples is a crucial condition. These samples ought to represent both soils of normal, regular fraction arrangement and soils of various set of loam, silt and sand fractions. Such a set of samples should contain non-carbonate soils, of low carbonate content and of its high content.

TABLE 1. VELOCITY (v) AND SEDIMENTATION TIME (t) IN WATER OF PARTICLES OF VARIOUS DIAMETERS (d), TEMPERATURE (T) AND SOIL DENSITY (δ) [9]

Particle diameter d (mm)	Temperature T (^{o}C)	Velocity of sedimentation v (cm s^{-1}) at soil density δ			Time of sedimentation (t) at h=10 cm at soil density δ		
		δ = 2.7	δ = 2.5	δ = 2.3	δ = 2.7	δ = 2.5	δ = 2.3
0.5	5	4.226	3.928	3.611	2′37″	2′55″	2′77″
	10	4.322	4.023	3.705	2′31″	2′49″	2′70″
	15	4.403	4.104	3.784	2′27″	2′44″	2′64″
	20	4.467	4.167	3.845	2′24″	2′40″	2′60″
	25	4.527	4.227	3.908	2′21″	2′37″	2′56″
	30	4.478	4.277	3.956	2′19″	2′34″	2′53″
0.2	5	1.714	1.555	1.389	5′8″	6′4″	7′2″
	10	1.850	1.685	1.511	5′4″	5′9″	6′6″
	15	1.973	1.802	1.623	5′1″	5′5″	6′2″
	20	2.076	1.902	1.711	4′8″	5′2″	5′8″
	25	2.176	1.998	1.812	4′6″	5′0″	5′5″
0.1	5	0.570	0.506	0.442	17′5″	19′8″	22′6″
	10	0.647	0.577	0.505	15′5″	17′3″	19′8″
	15	0.726	0.649	0.569	13′8″	15′4″	17′6″
	20	0.799	0.716	0.628	12′5″	14′0″	15′9″
	25	0.878	0.788	0.696	11′4″	12′7″	14′4″
0.05	5	0.151	0.133	0.116	66′2″	75′2″	86′2″
	10	0.175	0.154	0.134	57′1″	64′9″	74′6″
	15	0.200	0.177	0.154	50′0″	56′5″	64′9″
	20	0.226	0.199	0.173	44′2″	50′3″	57′8″
	25	0.253	0.225	0.196	39′5″	44′4″	51′0″
0.02	5	0.0255	0.0215	0.0189	6′32″	7′45″	8′49″
	10	0.0290	0.0255	0.0216	5′45″	6′32″	7′43″
	15	0.0330	0.0290	0.0249	5′0″	5′45″	6′42″
	20	0.0375	0.0325	0.0281	4′27″	5′08″	5′56″
	25	0.0420	0.0365	0.0319	3′58″	4′34″	5′13″
0.01	5	0.00609	0.00538	0.00466	27′20″	31′00″	35′45″
	10	0.00707	0.00624	0.00541	23′35″	26′40″	30′50″
	15	0.00813	0.00716	0.00622	20′35″	23′15″	26′50″
	20	0.00918	0.00810	0.00702	18′10″	20′35″	23′45″
	25	0.01039	0.00917	0.00798	16′00″	18′10″	20′55″

TABLE 1. CONTINUATION

0.005	5	1.52 x 10^{-3}	1.34 x 10^{-3}	1.17 x 10^{-3}	1h 49′	2h 04′	2h 23′
	10	1.77 x 10^{-3}	1.56 x 10^{-3}	1.35 x 10^{-3}	1h 34′	1h 47′	2h 03′
	15	2.03 x 10^{-3}	1.79 x 10^{-3}	1.55 x 10^{-3}	1h 22′	1h 33′	1h 47′
	20	2.30 x 10^{-3}	2.03 x 10^{-3}	1.76 x 10^{-3}	1h 13′	1h 22′	1h 35′
	25	2.60 x 10^{-3}	2.29 x 10^{-3}	1.99 x 10^{-3}	1h 04′	1h 13′	1h 24′
0.002	5	2.44 x 10^{-4}	2.15 x 10^{-4}	1.86 x 10^{-4}	11h 25′	12h 55′	14h 55′
	10	2.83 x 10^{-4}	2.50 x 10^{-4}	2.16 x 10^{-4}	9h 50′	11h 10′	12h 50′
	15	3.25 x 10^{-4}	2.87 x 10^{-4}	2.49 x 10^{-4}	8h 30′	9h 40′	11h 10′
	20	3.67 x 10^{-4}	3.24 x 10^{-4}	2.81 x 10^{-4}	7h 35′	8h 35′	9h 55′
	25	4.16 x 10^{-4}	3.67 x 10^{-4}	3.19 x 10^{-4}	6h 40′	7h 35′	8h 40′
0.001	5	6.09 x 10^{-5}	5.38 x 10^{-5}	4.16 x 10^{-5}	45h 45′	51h 35′	59h 35′
	10	7.07 x 10^{-5}	6.24 x 10^{-5}	5.41 x 10^{-5}	39h 15′	44h 30′	51h 20′
	15	8.13 x 10^{-5}	7.16 x 10^{-5}	6.22 x 10^{-5}	34h 10′	38h 45′	44h 40′
	20	9.18 x 10^{-5}	8.10 x 10^{-5}	7.02 x 10^{-5}	30h 15′	34h 20′	39h 35′
	25	10.39 x 10^{-5}	9.17 x 10^{-5}	7.98 x 10^{-5}	26h 45′	30h 15′	34h 50′

RESEARCH MATERIAL

In the set of 24 analyzed soil samples, objects of average and utterly different graining were collected (Table 2, samples 1–24). They were mostly samples representing soils and their either shallow or deep bed (subsoil). So, samples of minimal (about 1% – object No. 1) and very high (more than 67% – object No. 24) content of loamy fractions were analyzed. A similar contrast is observed in the content of sand as it amounts to about 90% (object No. 2) and about 2% (object No. 23). A less extreme difference is observed in silt fractions. Minimal contents of this fraction oscillate around 9% (object No. 2) and maximal – around 75% (objects No. 8 and 9). Among these utter numbers, there are objects of less contrast, average and regularly distributed fractions.

Apart from high differentiation of objects' grain size distribution, special attention was drawn to the content of carbonates which used to be a vital problem in the texture analysis. Therefore, noncarbonate objects were considered in the analysis, as well as the objects of low carbonate content, ones of several percent of carbonates (objects 13 and 22) and of particularly high carbonate content – about 37% (object 19). The analyzed samples show low differentiation when the content of organic matter is considered, though. Most of the samples are collected from the humus horizon, usually of 1.0–2.5% humus content. Numerous samples (14 objects) collected from maternity rocks or deeper bed do not contain organic matter at all.

In the analyzed set of objects, there are sediments of various origins and development conditions. They are the youngest, alluvial sediments of mountain rivers (No. 1,18), alluvia of delta regions the River Wisła (No. 17), moraine sediments of north Poland glacial – Wűrm (No. 2, 3, 4, 5, 6, 10, 12), central Poland glacial – Riss (No. 13, 21), Aeolian sediments – Lubelski loesses (No. 8, 9), Trzebnicki loesses (No. 11). Sediments of older geological formations are Pliocene loams collected from the walls of lignite exposures (No. 23) and also their uplifts (No. 2, 4) and Pleistocene loams (No. 15, 20, 22). Furthermore, sediments of Carpathian Flysch belt (No. 7, 16), cretaceous sediments of high carbonates content (No. 19) and Jurassic sediments (No. 14) were analyzed.

All in all, the set includes objects of possibly high scale of texture diversity, origin and development period.

METHODS FOR THE ANALYSIS OF SOIL TEXTURE

Method of Total Analysis (TA)

Method of total analysis of texture and deeper bed indication consists in fractioning the total of sedimenting suspension. The main aim of this method is the analysis through floating and defining the content of each fraction of sand, silt and loam from the total of sedimenting suspension. The time of sedimentation and fractioning of each fraction is defined on the basis of Stoke's formula [5]. Floating starts with the smallest fractions, smaller than 0.002 mm, usually called loamy fractions or colloid fractions. Further, silt fractions are being floated and other sand fractions may be fractioned with sieve method, which is well known and often used in other methods of granulometric analysis. Floating clay fractions (< 0.002 mm) and silt (usually 0.002–0.005; 0.005–0.02; 0.02–0.05 mm) is done repeatedly until the whole fraction is collected. This part is very labor consuming.

This method, based on the same principle yet different in numerous important details, was already published thirty years ago [18,19]. In this method, a 20 g sample was dispersed in the identical way as in the modified and presented in this paper method. Floating was done in cylinders of 6 cm diameter and 35 cm height used in Casagrande's [4] and Prószyński's [13] areometric method analysis. Suction set also consisted of a cone of 1 cm height and 2 cm diameter with five holes at the bottom, however, suspension suction was done through a water pump which operations were regulated by stabilizing devices. These devices turned out to be useless and they slowed the suction down so now the pump has been replaced with an air aspirator. 1000 ml of suspension was floated thrice. Furthermore, many more details differed but the accuracy of measurement was similar. A short name of the method remained the same – the method of total analysis (TA).

The presented, modified method of total analysis works on the same basis as the best known and sometimes used method, especially combined with pipette methods, Atterberg's method [2], in which the total of an analyzed sample was fractioned with an apparatus, or a specialized Atterberg's cylinder. There are, however, a lot of differences between the two methods. The basic difference is one of the cylindrical containers in which the sedimentation occurs. In Atterberg's method, the sedimenting appliance was a special cylinder called *apparatus* of 30 cm sedimenting height and 8 cm inner diameter (or 4 cm in the most often used version). In the bottom part, there was an outflow pipe. Whereas, in the presented method, sedimentation is conducted in regular laboratory beakers of 600 ml capacity and the total height of 14–16 cm. The inner diameter of a beaker is about 8 cm and the height of sedimentation – 10 cm. The level of sedimentation is marked on a beaker – "0" is placed at 1 cm from the bottom and the top level is placed 10 cm above "0". Floating the fractions is conducted with a special suction set and occurs in the axel of a beaker which is marked with a special slide.

In the presented, modified TA method, the time of sedimentation is three times faster and the sedimentation suspension is about four times smaller when compared to Atterberg's method. Moreover, the way of sediment defractioning is more appropriate and also more accurate. Various simplifications results in real possibilities of using the TA methods, also in a large scale analysis.

What is crucial for the soil texture and bed analysis with the method of fractioning of the whole sample and percentage determination of the content of each fraction is the appropriate equipment and procedure.

Materials and Equipment

1. Soil sample collected from defined genetic horizons, layers or bed, made air-dry, ground in the mortar and sieved through 2 mm holes. Percentage content of water should be marked in a way that is generally known and used in soil science laboratories.

2. Distilled or demineralised water of 20 μS cm^{-1} conductivity.

3. Dispersive solution (dispergator) prepared in accordance with general regulations by Kilmer and Aleksander [7]: pour 500 ml of distilled water into a measurement container of 1000 ml capacity, add 35.7 g of sodium hexametaphosphate (Calgon $Na_6(PO_3)_6$) and 7.94 g of dry sodium carbonate (Na_2CO_3). After the dissolution of additions, there are 1000 ml of solution. It is the "basic" dispersive solution.

4. Laboratory beakers of 8 cm inner diameter, 14–16 cm height and 600 ml capacity. The number of beakers should at least be equal with the number of the samples. Beakers should be scaled: put about 300 ml of water in the beaker, drain the excess off with a suction device, of which the most important element is a suction cone of 1 cm height. After the draining, there ought to remain a layer

of 1 cm in the beaker. Put a template of 10 cm to the top level of the meniscus and draw a line of "0" level in the bottom part with a waterproof marker, and a line and a triangle sign of 10 cm level in the upper part (Fig. 1). There is a possibility that in the future, ready-made scaled laboratory containers will be produced especially for the granulometric analysis.

5. Electrical stirrer of about 3000 revolutions per minute for the dispersion of the solution in a beaker of 1000 ml. One also needs wash bottles of 250 or 500 ml for cleaning the elements of stirrers placed in the solution (Fig. 2).

6. Manual stirrer in the form of a round plate of 7 cm diameter with 1 cm wholes placed on a rod of 20 cm (Fig. 3).

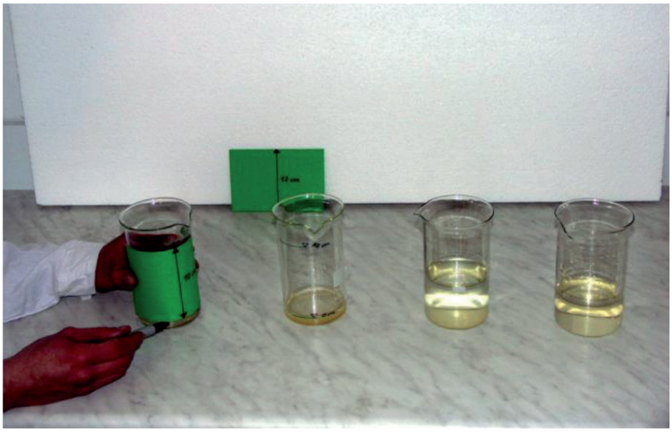

Fig. 1. Indicating "0 cm" and "10 cm" sedimentation levels on the beakers of 8 cm diameter.

Fig. 2. Laboratory set: – weight vessels, – manual stirrers of 7 cm and 9 cm plate diameter, – wash bottles for cleaning the mixer's tip.

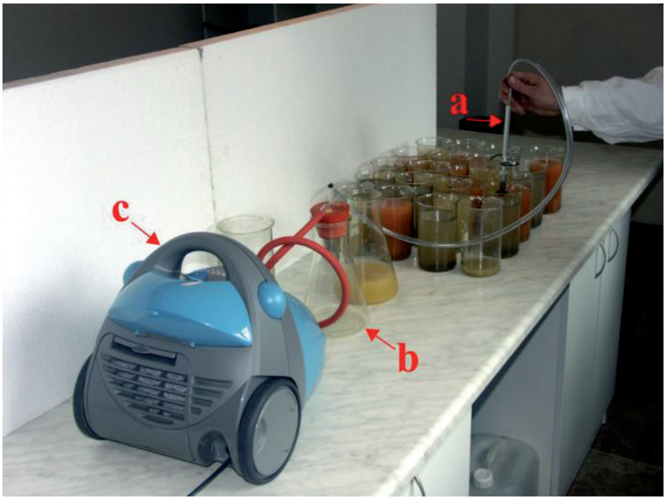

Fig. 3. Suction set composed of three basic elements: a – a metal cone with a suction slot, an extension cord and a slide, b – a cone bottle with a rubber cork and a link, c – an aspirator.

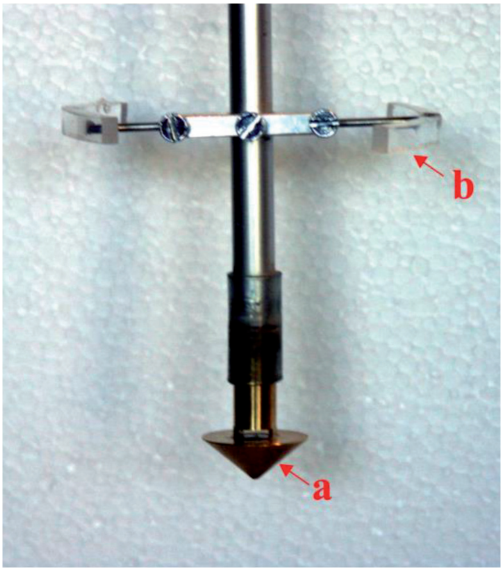

Fig. 4. A tip of a suction device: a – a metal cone of 2.5 cm diameter and 1 cm height with a suction slot, b – a centralizing slide.

7. Suction set for fraction floating of the analyzed solution composed of three basic elements: the suction tip (Fig. 3a), the cone bottle where the solution is collected (Fig. 3b) and the aspirator of the suction device (Fig. 3c). The suction tip is composed of a metal cone of 2.5 cm diameter and 1 cm height on which bottom

there is a short, 4-cm long part of a pipe of 1 cm outer diameter and 0.58 cm inner diameter. There is a 2 mm slot in the pipe at the bottom of the cone (Fig. 4a). Moreover, the final pipe is connected to the metal pipe of 25 cm length and 0.8 cm inner diameter with a rubber line (an extension cord). On this pipe, several centimeters from the joint with a tip, there is a movable slide which serves for vertical immersion of the tip in the beaker with the analyzed solution (Fig. 4b). The device is connected to a cone bulb with a transparent hose of 1–1.5 m length. The bulk is closed with a rubber plug with two links. The second link placed in the plug connects the cone bulk of 1000 ml with the aspirator. The description and figures facilitate the understanding of how the device for fraction floating of a solution works.

8. Scale containers, preferably made of thin sheet metal and about 7 cm in diameter and 3.5 cm in height for the final evaporation and drying of the marked fraction (Fig. 2).

9. Laboratory automatic scales of 0.001 g accuracy or analytic scales of 0.0001 g accuracy.

10. Standard soil science laboratory equipment such as: laboratory drier (especially the winding one), heating plates or heating chambers fitted for the evaporation of solutions, sieves, desiccators, wash bottles, glass rods, etc.

Analysis Process

1. Soil samples of 20 g weight including hygroscopic water are put in the beaker of 1000 ml. 450 ml of distilled water are added and next 20 ml of basic dispersive solution (Calgon). Next, the beaker is put under an electrical stirrer. The suspension is dispersed for 5 minutes, next the stirrer is lifted above the suspension, cleaned with the wash bottle and the content of the beakers is poured to a beaker of 8 cm diameters with the marked level of sedimentation. These activities are repeated with other samples in order to group an optimal series of analyses (20–30 samples).

2. Samples with suspension are set in accordance with serial numeration, filled with distilled water to the top level of sedimentation (10 cm). Next the temperature of suspension is measured and noted. Time of sedimentation at this temperature is defined on the basis of Stoks' formula, first for the clayey fraction (<0.002 mm). The faster and easier solution is using Köhn's tabular set. Köhn calculated, using Stokes' formula, the sedimentation time and speed for a 10 cm height of particle fall for a broad spectrum of temperatures and soil density (Table 1). Sedimentation times for intermediate temperatures are calculated at the basis of interpolation. The most optimal sedimentation temperature should oscillate between 18 and 24°C and temperature change while sedimentation should not exceed 2°C. About 30 minutes before the end of the arranged sedimentation time fixed for the initial suspension temperature, the temperature is checked again and possible differences are taken into consideration at the correction of a proper sedimentation time.

3. Mixing the suspension with a manual stirrer described in point 2 should be done as follows: a manual stirrer is placed inside the set number of beakers positioned in the form of a rectangle (4x5) or square (5x5) forming a complex series of analyses, starting with the initial beaker. The suspension is mixed by moving the stirrer vertically from the bottom of the beaker to around 1 cm below the solution layer for 1 minute, not to create foam, which is unfavorable. At the last revolution of a stirrer towards the top, a stop-watch is turned onto count the time of sedimentation. Before taking the stirrer out of the solution, at the depth of 1 cm, 2–3 semi-revolutions are made so that sand particles or thick silt were washed out. After taking the stirrers out, they are washed with a wash bottle. Such procedure is conducted with other beakers. Time gap between the beginning of sedimentation of each sample should amount to 1 minute, which is enough for conducting the described actions.

4. Floating fractions of the suspension is the most important action which is conducted starting with the clay fractions (< 0.002 mm): the aspirator is set on the smallest, lowest suction; next, 5 seconds before the start of suction, a tip of the suction set is vertically put in the beaker and deepened following the preceding sedimentation. At the end of sedimentation time (floating lasts for about 9 seconds), the tip of a cone reaches the bottom of a beaker. Immediately after the end of the floating, the tip of the cone is lifted vertically and washed, so that the suspension is washed from the pipes to a cone bottle; next the cone tip is placed in distilled water twice for a fraction of a second so that the link pipe of the measurement set is washed with a minimal amount of water (several centimeters). Suspension collected in a cone bulk is taken to a beaker of, most favorably, 600 ml. The identical procedure is applied to the suspension from other prepared solutions composing a complex series at the intervals of 1 minute after the time of manual mixing.

5. For the complete collection of loamy fraction, 6 floatings should be conducted. After three floatings of a loamy fraction, 5 ml of the basic dispersive solution should be added to each sample. For the fractions larger than 0.002 mm it is enough to do five floatings with no additions of the basic dispersive solution.

6. After the floating of the total loamy fraction, the beaker with the collected suspension is placed in the heating chamber, ventilation chamber or on a heating plate in order to have the water evaporated. Evaporation lasts until the suspension from 6 floatings reaches the capacity of 50 ml. Then, the content of the beaker is poured and washed out to a metal scale vessel which is placed in the ventilation dryer. The evaporation is continued and next the drying is conducted at the temperature of 105°C. After drying and cooling, the scale vessel is weighed and the percentage content of the fraction is calculated by multiplying the weigh of the fraction by 5, first subtracting the weigh of the added dispergator.

7. The next fraction (0.002–0.005 mm) is floated five times and the suspension is collected in two or three beakers where the indicated fraction falls on the

bottom and pure solution is floated as useless, usually another day. The suspension is moved together with the sediment from the beakers to the scale vessel until it reaches 50 ml capacity. Analogical procedure is conducted with all the samples from a given series. Next, scale vessels are placed into ventilation dryer in order to have them evaporated and dry. After cooling, the vessels are weighed and next a percentage content of the indicated fraction is calculated using the formula presented in point 6 with the accuracy to two decimal places.

8. The third fraction of 0.005–0.002 mm particle diameter is also floated five times, after a five minute sedimentation time. In this case the organization of floating undergoes certain modifications. Therefore, floating is conducted for the series of three samples (1–3, 4–6, 7–9, etc.). After manual mixing of a suspension in beaker 1 for 1 minute, a stop-watch is turned on, after 2 minutes of mixing of the sample no. 2 is finished, and after 4 minutes – of sample no. 3. After 5 minutes, floating of sample 1 begins and after the following 2 and 4 minutes – of samples no. 2 and 3. Having finished the floating of the first series, other floatings are conducted up to the fifth floating, analogically to the previous fraction. After 1.5–2 hours from the suspension collected in two or three beakers, when the indicated fraction falls down completely, clean water is filtrated from the sediment. The floated fraction is taken to the weighed weight vessel, evaporated, dried in the temperature of 105°C, cooled, weighed and a percentage content of fraction is calculated with the accuracy to two decimal places.

9. The fourth fraction of 0.02–0.05 mm particle diameter, is floated even after 50 seconds. In this case, five floatings for each sample are done. The suspension is collected in beakers from which “clean” water is floated after about 10 minutes, when the fraction falls down completely. When the capacity of the suspension reaches 50 ml, analogical procedure is conducted: it is taken to a weighed weight vessel, evaporated, dried, cooled, weighed and a percentage content of fraction is calculated, as previously.

10. Having floated particles smaller than 0.05 mm, a fraction of sand is left in the beaker which is collected in weigh vessels in the identical way as previous fractions. After weighing it can be defractioned, with a popular dry sieve method, with an appropriate set of sieves.

Results of TA Method and Interpretation

Texture, calculated in percentages, was compiled in the table form (Table 2). It should be mentioned that the number of repetitions (column 3) where the objects were set according to the increasing content of loamy fraction – from sands to loams. In next columns (4–8) revised to 100%, the percentage content of each fraction was compiled. Column 9 contains the measurement error composed mainly of losses connected with a certain number of floatings, especially of the loamy fraction. Further evaporation and floating of minimal parts of this fraction should definitely be treated as ineffective and problematic. Some losses may also stem from floating of silt fractions as 21 floatings are conducted for each sample.

Whereas appropriate but impossible to omit analysis errors are connected with washing, drying, weighing etc., column no. 10 contains the results of the analyses indicating a percentage content of calcium carbonate in the samples of the humus horizon.

All in all, table 2 contains the results of texture analysis of 24 samples which represent a broad and complete scope of the texture of the most important types of soils and their beds in Poland.

When analyzing the results, it is crucial to take into consideration mainly the exactness of the presented method of texture analysis defined with the size of error at a given number of fractions. For most of the samples, measurement error does not exceed 1% and only in eight cases (per 72 analyzed) is between 1 and 1.45%. Generally, it is a very minor error as, on average, it is up to 0.2, rarely 0.2–0.3% per given fraction.

Another method for identification and assessment of the exactness of the conducted analysis is the comparison of results within every repetition, which means the vertical diversity of the measurements. When analyzing several hundreds of results (3 replications, 5 fractions, 24 objects) one may conclude that the repetition of results is extremely high, especially in silt and sand fractions with a little higher diversity in loam fraction. Therefore, it may be assumed that the presented method of total analysis separates the fractions very precisely and fully satisfyingly.

In the case of the TA method, there are two possibilities of the assessment of the texture analysis exactness. One, as presented above, is the size of an error which rarely exceeds 1% and very seldom oscillates between 1 and 1.45%. One may assume that the error in this method should not exceed 2%. In case of a larger error, which may occur in samples of high loam fraction, of intensive colloid activity and of very high carbon content, texture analysis with TA method may be done once and is fully reliable. In repetitions, a reliable result of the analysis is the repetition with a smaller measurement error, not the one with the average error as every repetition is a specific total in which separating fractions is not ideal but which also represents a general rule where a bit smaller content of a given fraction results in slightly larger content of a bordering fraction. In each repetition, there is a characteristic formation, size and sum of single errors. The results of the repetitions may be counted as average for a specific purpose and not as final results of the texture analysis.

TABLE 2. TEXTURE OF SOILS AND SUBSOILS ANALYZED WITH THE METHOD OF TOTAL ANALYSIS (TA)

Sample No.	Place, type and depth of sample collection (m)	Repetitions	Particle size (in mm) distribution (%)					Measure-ment error	$CaCO_3$ C total	Granulometic group
			2.0–0.05	0.05–0.02	0.02–0.005	0.005–0.002	<0.002			
1	Świeradów Zdrój Aluvia of fluvial terraces of the River Izera, 0.0–0.2	1	75.8	13.2	8.7	1.1	1.2	-0.95	0.0 2.3	loamy sand (LS)
		2	77.3	12.7	7.9	1.1	1.0	-0.05		
		3	77.5	13.2	7.6	0.9	0.8	-0.64		
		$TA_{śr}$	76.9	13.0	8.1	1.0	1.0	-0.55		
2	Szamotuły Fluvio-glacial forms of glacial Würm, 0.0–0.2	1	89.1	3.9	3.2	1.6	2.2	-0.37	0.2 0.0	sand (S)
		2	89.3	4.0	3.9	1.1	1.7	-0.86		
		3	89.7	3.6	3.7	1.1	1.9	-1.13		
		$TA_{śr}$	89.4	3.8	3.6	1.3	2.0	-0.79		
3	Poznań – Złotniki Moriane material of glacial Würm, 0.1–0.3	1	81.7	8.0	5.6	1.8	2.9	-0.80	1.5 1.4	loamy sand (LS)
		2	81.8	8.0	6.4	1.1	2.7	-1.27		
		3	82.5	7.5	6.4	1.2	2.4	-0.86		
		$TA_{śr}$	82.0	7.8	6.1	1.4	2.7	-0.98		
4	Bąblin Moriane material of glacial Würm, 0.0–0.3	1	81.4	7.5	5.4	1.9	3.8	-0.70	0.7 0.9	loamy sand (LS)
		2	80.8	8.2	6.4	1.3	3.3	-1.28		
		3	80.7	8.3	6.4	1.3	3.3	-0.31		
		$TA_{śr}$	81.0	8.0	6.1	1.5	3.5	-0.77		
5	Poznań – Złotniki Moriane material of glacial Würm, 0.0–0.3	1	77.6	8.2	6.7	3.4	4.1	-0.40	0.0 1.1	loamy sand (LS)
		2	77.7	8.5	6.7	2.9	4.2	-0.67		
		3	77.4	8.5	6.6	2.8	4.7	-0.58		
		$TA_{śr}$	77.6	8.4	6.7	3.0	4.3	-0.55		

TABLE 2. CONTINUATION

6	Szczepankowo Moriane material of glacial Würm, 0.0–0.3	1	76.2	7.9	6.2	2.8	6.9	-0.67	0.1 1.1	loamy sand (LS)
		2	76.4	8.0	6.4	2.6	6.6	-0.86		
		3	76.2	8.1	6.3	2.8	6.6	-0.53		
		TA$_{\text{śr}}$	76.3	8.0	6.3	2.7	6.7	-0.69		
7	Ruda Kameralna Carpathian Flysh belt, 0.0–0.2	1	41.2	29.1	17.1	4.7	7.9	-0.62	0.0 0.9	silty loam (SiL)
		2	42.3	28.9	16.8	4.9	7.1	-0.99		
		3	41.7	29.3	16.7	4.9	7.4	-0.53		
		TA$_{\text{śr}}$	41.8	29.1	16.9	4.8	7.5	-0.72		
8	Czesławice Lubelski loess, 1.6–2.0	1	15.4	53.6	19.5	2.2	9.3	-0.51	2.5 0.0	silty loam (SiL)
		2	15.8	54.4	18.8	2.1	8.9	-0.75		
		3	14.3	55.6	19.1	2.2	8.8	-0.40		
		TA$_{\text{śr}}$	15.2	54.5	19.1	2.2	9.0	-0.56		
9	Żulice Lubelski loess, 0.0–0.3	1	13.4	48.6	19.6	5.4	13.0	-0.88	0.0 2.4	silty loam (SiL)
		2	13.4	49.6	19.6	5.7	11.7	-1.54		
		3	12.6	50.2	19.7	5.8	11.7	-0.45		
		TA$_{\text{śr}}$	13.2	49.5	19.6	5.6	12.1	-0.96		
10	Szczepankowo Moriane material of glacial Würm, 0.4–0.5	1	66.3	10.7	7.4	2.2	13.4	-0.01	0.1 0.0	sandy loam (SL)
		2	67.8	9.6	7.6	1.9	13.1	-0.72		
		3	67.2	10.1	7.5	2.3	12.9	-0.73		
		TA$_{\text{śr}}$	67.1	10.2	7.5	2.1	13.2	-0.49		
11	Trzebnica Trzebnicki loess, 0.0–0.3	1	22.1	44.3	17.2	3.2	13.2	-0.22	0.4 1.6	silty loam (SiL)
		2	22.8	43.6	17.0	3.1	13.5	-0.49		
		3	23.6	43.3	17.0	3.1	13.0	-0.33		
		TA$_{\text{śr}}$	22.8	43.7	17.1	3.1	13.2	-0.32		

TABLE 2. CONTINUATION

12	Poznań – Naramowice Moriane loam of glacial Würm, 0.4–0.5	1	68.8	7.7	6.9	2.5	14.1	-0.77	4.4 0.0	sandy loam (SL)
		2	68.3	7.7	6.9	2.3	14.8	-0.61		
		3	69.2	8.1	6.9	2.2	13.6	-0.32		
		$TA_{śr}$	68.8	7.8	6.9	2.3	14.2	-0.57		
13	Tomisławice Moriane loam of glacial Riss, 20.0–21.0	1	55.2	8.9	11.9	5.2	18.8	-0.19	11.1 –	sandy loam (SL)
		2	55.4	9.0	11.8	5.3	18.5	-0.44		
		3	56.3	8.9	11.9	5.3	17.6	-0.74		
		$TA_{śr}$	55.6	8.9	11.9	5.3	18.3	-0.46		
14	Olsztyn – Częstochowa Cretaceus material, 0.0–0.3	1	61.2	4.9	8.3	6.0	19.6	-0.21	0.1 2.2	sandy loam (SL)
		2	60.9	5.2	8.3	5.9	19.7	-0.17		
		3	61.8	5.2	8.4	5.7	18.9	-0.65		
		$TA_{śr}$	61.3	5.1	8.3	5.9	19.4	-0.35		
15	Gniew Pleistocene loam, 0.0–0.5	1	40.2	14.2	15.6	9.3	20.7	-0.83	0.5 0.0	loam (L)
		2	41.1	14.3	15.5	8.9	20.2	-0.66		
		3	41.7	14.1	15.6	9.0	19.6	-0.93		
		$TA_{śr}$	40.9	14.2	15.6	9.1	20.2	-0.81		
16	Ruda Kameralna Carpathian Flysh belt, 0.4–0.5	1	33.5	25.1	16.5	4.0	20.9	-0.61	0.1 0.0	loam (L)
		2	34.4	25.2	16.0	4.1	20.3	-0.78		
		3	34.4	25.1	16.1	4.0	20.4	-1.05		
		$TA_{śr}$	34.1	25.1	16.2	4.0	20.5	-0.82		
17	Stare Pole Żuławski alluvia, 0.0–0.3	1	28.7	23.4	18.6	6.9	22.4	-1.18	0.3 0.0	loam (L)
		2	28.8	23.6	18.1	6.6	22.9	-0.75		
		3	28.5	23.7	18.2	6.6	23.0	-1.02		
		$TA_{śr}$	28.7	23.6	18.3	6.7	22.8	-0.99		

TABLE 2. CONTINUATION

18	Ruda Kameralna Alluvia of the River Dunajec, 0.0–0.3	1	17.8	20.6	25.8	11.7	24.1	-0.80	0.2 1.4	silty loam (SiL)
		2	18.1	21.5	25.9	11.2	23.3	-0.60		
		3	18.3	21.5	26.6	11.3	22.3	-1.37		
		$x_{śr}$	18.1	21.2	26.1	11.4	23.2	-0.93		
19	Kąty Lubelskie Cretaceus material, 0.3–0.5	1	33.3	12.9	16.0	12.3	25.5	-0.17	36.7 0.0	loam (L)
		2	34.5	12.8	18.7	12.2	21.8	-1.45		
		3	33.7	12.6	18.3	12.1	23.3	-0.56		
		$TA_{śr}$	33.8	12.8	17.7	12.2	23.5	-0.73		
20	Gniew Pleistocene loam, 0.0–0.3	1	14.9	16.1	20.0	12.8	36.2	-0.14	0.1 0.0	silty clay loam (SiCL)
		2	16.1	17.0	20.1	11.7	35.1	-0.25		
		3	15.6	17.4	20.3	11.8	34.9	-0.76		
		$TA_{śr}$	15.6	16.8	20.1	12.1	35.4	-0.39		
21	Tomisławice Moriane clay of glacial Riss, 40.0–41.0	1	33.5	7.8	9.2	4.7	44.8	-0.22	2.4 0.0	clay (C)
		2	34.2	7.9	9.4	4.5	44.0	-0.92		
		3	32.7	8.1	9.5	4.5	45.2	-0.56		
		$TA_{śr}$	33.5	7.9	9.4	4.6	44.6	-0.57		
22	Poznań – Kotowo Pleistocene clay, 1.8–2.0	1	2.8	1.4	25.8	20.9	49.1	-0.36	15.9 0.0	silty clay (SiC)
		2	3.1	1.2	28.3	19.8	47.6	-0.55		
		3	2.5	1.2	30.0	19.0	47.3	-0.37		
		$TA_{śr}$	2.8	1.3	28.0	19.9	48.0	-0.43		

TABLE 2. CONTINUATION

23	Tomisławice Pliocene clay, 55.0–56.0	1	2.1	2.5	25.6	14.6	55.2	-0.66	0.2 0.0	silty clay (SiC)
		2	2.3	2.6	25.3	14.5	55.3	-0.51		
		3	2.1	2.4	25.8	14.9	54.8	-0.54		
		$TA_{śr}$	2.1	2.5	25.6	14.7	55.1	-0.57		
24	Poznań – Naramowice Pliocene clay, 3.0–3.5	1	16.8	3.8	6.7	5.8	66.9	-1.10	1.4 0.0	clay (C)
		2	16.4	3.6	6.9	6.3	66.8	-0.73		
		3	16.0	3.5	7.2	6.2	67.1	-0.98		
		$TA_{śr}$	16.4	3.6	6.9	6.1	67.0	-0.94		

Presented in table 2, the results of the analysis of 2 objects of vast texture diversity show broad and versatile correctness of fractioning and exactness in the global set of fractions. This result, however, is reached owing to the great labor and long time of the analysis. The processes of sedimentation and evaporation of the loam fraction's solution are most time-consuming. Nevertheless, there are no problems or complications while conducting the analyses as the procedures are not complicated. An estimated labor and time consumption in one analysis by a pair of researchers may be marked at 40–50 analyses per month.

Implementation of the TA Method

High labor and time consumption of some cycles on the one hand and high exactness, simplicity and reliability of the results verification, defined size of error, simple procedures and laboratory equipment on the other, are the most important features which determine the usefulness and purpose of this method. Owing to these features, the TA method may be used for the verification and assessment of usefulness of other methods which incorporate various simplifications, shortcuts, limitations, etc. making granulometric analysis faster. This possibility of using the TA method is crucial and primary as there are practically no other ways of verifying the exactness and error of other methods, and each method should be verified, checkable and have an acceptable size of error for the texture analysis.

Therefore, the TA method gives genuine opportunities for the verification and assessment of usefulness of other methods within just one month of comparing and analyzing the results of both methods. It requires the completion of 12–15 granulometric analyses in two or three repetitions for possibly diverse soils – from sands, clay sands, silts and loams. The diversity of texture, set in table 2, may serve as an example. In a comparative analysis of results of the confronted methods, it is crucial to pay attention to the accordance and discrepancy between the particular fractions in basic sets of fractions – loams, silts, sands and in the summary amount of the measured fractions. It can be simplified by entering the results onto the Feret's triangle and onto the chart of cumulative granulation.

Comparative analysis should be applied to pipette and areometric methods which are most often used for texture analysis, especially those that come down only to these methods. As it is known, pipette methods may indicate the content of particles smaller than 0.05 mm. Sand fractions – which means fractions greater than 0.05 mm – are treated as residues which can be counted as follows: 100 – fractions measured with a pipette. The non-measured part of the texture contains errors of the pipette or areometric methods. There is also no possibility of defining the exactness of the analysis results. Therefore, the pipette and areometric methods need to be combined with the methods in which the content of fractions over 0.05 mm is marked with a direct weigh method, having floated fractions smaller than 0.05 mm.

Another vital aim and use of the method of global refractioning and indication of texture fractions with direct measurement are specialized scientific research studies where texture is analyzed and interpreted with other equally important soil characteristics. A broad documentation for the solution of even complicated soil science problems may be collected within several months. The results of the TA method analysis are exact, reliable and transparent. However, if the texture analysis is not strictly combined with the interpretation of the analyzed problems, the results of the analysis with a pipette method are fully satisfying.

Method of Pipette Analysis (ALP)

The main aim of this method is the indication of soil texture and its subsoil on the basis of collecting a pipette sample from the sedimenting solution. The capacity of the sample is about 38.5 ml and the exact determination of capacity is marked by weight with the exactness of 0.001 ml every time.

The presented method is a modification and partly simplification, development and supplement of the original method [18]. Moreover, new equipment was developed for mass production and normal use and implementation of the method.

The original AL method was a rough version which used various equipment adapted for a pipette method. In the method published in 1983, a pipette was produced from mineral glass and composed of two probe pipes of total capacity of 20 ml and was not resistant to mechanical action. Furthermore, the method did not use the original tripod, only Köhn's tripod or other adapted devices. There were also no devices for floating the fractions marked with a pipette method from sand fractions. The current, final version of the pipette method is as follows:

The pipette or precisely – the pipette device – is composed of four pipe probes made from organic glass (plexi) of 1 cm^2 diameter and 11.5 cm length. Probes are installed vertically within a square shape of 4.5 cm side. Probes are joined with a plate of 8 mm thickness with inner canals joining the probes with a metal pipe of 25 cm length. In its top part, the pipe is combined with a tap which either closes or opens the pipette device. These elements are presented in Fig. 5 and 6.

The pipette is joined with a tripod which enables vertical movement when the pipette is put in the soil solution and taken out with the collected sample. A tripod is made of a vertical axle installed on a rectangular plate. Two sliding heads (top and bottom) are fixed at the heights of 50 cm and 2 cm. There is a pipette fixed on the top head, whereas the bottom head is a depth limiter.

Basic activity, connected with the collection of a pipette sample is conducted as follows: the tripod, which is equipped with rolling devices and brackets under the plate, is rolled along ordered beakers with the solution. Having set the pipette in a central spot under the beaker, the top head is activated so that the probes of a closed pipette touch the surface of the solution. Next, the depth marker, which is a post of 9.5 cm height and 1 cm diameter, is moved under the top head, while the bottom head is moved to the meter and next the meter is detached. Within 2 seconds before the time of fraction pipetting, the top head with a pipette is slid to the limiter.

The pipette will be placed at the depth of 9.5 cm. In time for sedimentation, the pipette is opened by turning the tap so that the solution from the 9.5–10 cm layer floats down into the pipette within 1–2 seconds. Having filled the pipette, the pipette is closed by turning the tap and next the pipette probes are lifted to the height of several centimeters above the beaker. The crucial moments of adjusting the pipette device for pipetting, as well as the way of collecting the solution sample, are presented in Fig. 5 and 6. After lifting the pipette above the beaker, the weigh vessel is placed underneath, the pipette is opened again, and the tap is turned, so that the solution flows into the weigh vessel from which water is evaporated while the rest is dried in the temperature of 105°C and weighted. The weight of the vessel with the solution minus the weight of a vessel with a dried fraction equals the capacity of the pipette.

Fig. 5. A pipette lowered to the point of contact with the suspension sufrace; indication of pipetting depth.

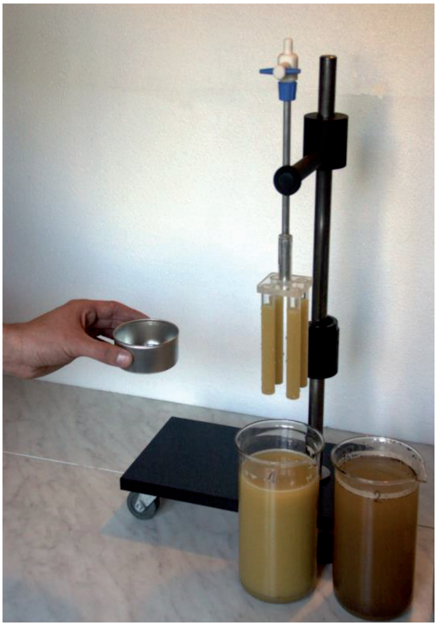

Fig. 6. A pipette with collected suspension before putting it in a weigh vessel.

Managing the pipette device requires high attention especially directed to three crucial conditions of correct functioning. The pipette device, especially the probes, must be set vertically, which should be verified and corrected with the appended level if needed before the analysis. Another condition is using only gentle, smooth, vertical movements with no shakes and spurts, when collecting a sample. The third condition is tightness of the pipette device which should be checked with distilled water during a check-out pipetting before the analysis. If the device is not tight, distilled water or soil solution drops off the probes as the pressure over the meniscus of the collected solution is changed because of the air flow from the outside. The leak in the pipette device may be caused by an unexpected mechanical impact. The pipette needs to be tightened (usually in a joint with the tap) or exchanged. In regular conditions, the performance and efficiency of the pipette are high and practically unlimited.

The measurement of texture with the pipette method (ALP) requires specific soil preparation and collecting appropriate materials and equipment.

Materials and Equipment

1. The soil sample, collected from defined genetic horizon layers or a bed, air-dried, sieved through 2 mm holes with a laboratory number and a marked according to the level of hygroscopic water.

2. Distilled or demineralised water of conductivity no higher than 20 µS cm^{-1}.

4. Laboratory measurement beakers of 1000 ml capacity and 10 cm inner diameter. Levels of sedimentations needed for floating the solution formerly measured with the pipette method for particles smaller than 0.5 mm should be marked on the beakers. The solution should be floated in such a way that only fractions of sand >0.05 mm are left in the beaker. In order to determine the sedimentation levels, 300 ml of water needs to be poured into beakers, the excess should be floated with a suction device connected to a water pump. After draining, 1 cm of water is left in the beaker. A pattern of 10 cm height is put to the top meniscus of this layer. A line marks the top and bottom levels of sedimentation along the top and bottom edge of the pattern. 0 cm is written on the bottom line and 10 cm on the top line with a waterproof marker.

5. Electrical stirrer adjusted to the dispersion of the solution in a beaker of 1000 ml, the same as in the TA method.

6. Manual stirrer in the form of a round plate of about 9 cm diameter with 1 cm wholes placed on a rod of 25 cm (Fig. 2).

7. A pipette set composed of a pipette on a sliding tripod presented in the previous chapter (Fig. 5, 6).

8. Weight vessels of thin sheet metal and of 120 ml capacity (Fig. 2).

9. Automatic laboratory scales of 0.001 g exactness or analytic scales of 0.0001 g exactness.

10. Laboratory beakers of 1 liter measurement capacity with additional marking of sedimentation and floating levels.

11. Suction set used for floating, built of a cone connected with a pipe rod with a slide adjusted to floating from a liter beaker of 10 cm diameter and a plastic hose connected with a liter cone bottle which is joined to a suction device – a water pump.

12. Stop-watch with a scale of at least 12 hours.

13. A table set (Table 1) designed by Köhn [9] on the basis of Stoke's formula, for the measurement of the sedimentation time at the depth of 10 cm and depending on the temperature, density and the diameter of soil particles.

14. Standard soil science laboratory equipment such as: exsiccators, wash bottles, glass rods, laboratory glass, ladles, shovels, brushes, cloths and, most importantly, ventilation dryers.

The Analysis Process

1. Soil samples of 40 g (with hygroscopic water) are put into a beaker of 1000 ml capacity, poured with distilled water up to the capacity of 600 ml and 25 ml of basic dispersive solution are added. In case of very compact materials, especially loam, the sample should weigh 20 g (with hygroscopic water) with the same amount of dispersive solution. Next, the beaker with the solution is placed under an electric stirrer and mixed for 5 minutes. Having mixed the solution, the stirrer is washed and the beakers are ordered in a line according to the series. Next, the solution is completed with water up to 1000 ml.

2. The temperature of the solution in ordered beakers is taken and the sedimentation time for the first pipetting is calculated (for particles of 0.05 mm diameter and sedimentation depth of 10 cm), next the suspension is mixed with a manual stirrer for 1 minute. Once the stirrer is taken out of the suspension, the stop-watch is switched on to take the sedimentation time when the tripod with a pipette is brought nearer, the pipette is lowered so that the probes touch the suspension's meniscus and the meter of the pipette's probes' dip is placed under the top head of the tripod (9.5 cm); the bottom head is pushed under the meter. When the meter is removed, the head with the pipette can lower itself by 9.5 cm.

3. About 2 seconds before a given sedimentation time is up, the top head with a pipette is lowered until it sits on the bottom head. Then, at the indicated moment of sedimentation, a pipette is at the depth of 9.5 cm ready to collect a layer of suspension from the depth of 9.5–10 cm.

4. At a defined time, the pipette is opened by turning the valve. The suspension fills the probes within 1–2 seconds, when the pipette is closed and placed above the beaker. Opening, filling, closing and placing the pipette above the beaker should not take more than 5 seconds.

5. The weight vessel (previously weighed) is placed under the pipette's probes and the pipette is opened with a valve so that the suspension flows into the vessel. The remains of the suspension which are left on the walls of probes

are drained with a cotton tampon – washing is not necessary here. In order to calculate the percentage content of a given fraction, one only needs the amount of suspension which is in the weight vessel.

6. The weight vessel with the suspension is weighed, placed in the ventilation dryer or on a hotplate in order to evaporate the water. Next, it is dried in the temperature of 105°C, cooled and weighed. The weight of the evaporated water shows the capacity of the pipette and the dried rest – the base for the percentage calculation of the content of a given fraction. Moreover, the capacity of the evaporated water is used for calculating the amount of dispergator which must be subtracted from the dry mass. Pipetting for the other beakers is done in the identical way as for the first one.

7. Second pipetting for the measurement of the number of particles smaller than 0.02 mm starts with setting the sedimentation time for these particles, which usually is 5 minutes. In this case, pipetting and mixing of the suspension is done in the following series, each composed of three samples 1–3, 4–6, etc. One begins with sample no. 1 which is mixed with a manual stirrer for 1 minute. When putting the stirrer in the suspension, the stop-watch is switched on. Exactly after 1 minute, sample no. 2 is mixed. Mixing ends after 2 minutes. The same procedure is applied to sample no. 3. Therefore, within 4 minutes with 2-minute separations, 3 samples are mixed. In the set time, pipette samples are collected, also in 2-minute intervals, starting with sample no. 1. Other procedures resemble the collection for the previous fractions (Fig. 6).

8. The third pipetting for the determination of particles smaller than 0.005 mm also begins with setting the sedimentation time for particles of diameter smaller than 0.005 mm. The time is about 70–80 minutes. In this case, mixing and pipetting is done with 2-minute breaks for the series of 25 to 30 samples. Further activities are performed in accordance with those of previous pipetting actions (point 6 and 7).

9. The fourth and final pipetting for the determination of particles smaller than 0.002 mm also starts with setting the sedimentation time for this diameter and further activities are performed in accordance with the actions for particles smaller than 0.005 mm (point 8).

10. When the pipette analysis is finished, the collected suspension is evaporated, dry mass is dried and weighed and the content of the dispergator is subtracted. The content of each fraction of texture is calculated as follows: when the weight of dry mass from the second pipetting is subtracted from the first one, one obtains the content of fraction 0.05–0.02 mm; when the content of dry mass from the third pipetting is subtracted from the second one, one obtains the content of fraction 0.02–0.005 mm; and when the content from the fourth collection is subtracted from the third one, one obtains the content of fraction 0.005–0.002 mm. The weight of a dry sample from the fourth (final) pipetting shows the content of fraction of the diameter smaller than 0.002 mm. Weight

value of each fraction is calculated in percent values with a simple calculation sheet. The results are presented in a table, according to the order from Table 2.

11. Having conducted the pipette analysis, there are still unmarked fractions of sand in the beakers as well as remains after the indication of fractions smaller than 0.05 mm. In order to measure the sand fractions, one needs to dispose of the fractions smaller than 0.05 mm which were measured previously. To do this, one uses a set composed of a suction cone, an extension cord with a slide connected to a water pump with a rubber hose; the water pump is located on a water supply cord. Floating is done as follows: turn the aspirator on and put the cone tip with a slide of 9 cm arms span fitted on a joint pipe. The suspension is floated to the level marked previously for the measured floating. The suspension is floated to the level of 10 cm for all the samples in the analyzed series. After this initial action, measured floating begins. First, one takes the suspension's temperature, next sedimentation time for particles of 0.05 mm is set and then the suspension is mixed for 30 seconds. The stop-watch is switched on once the manual stirrer is placed in the suspension. When taking the stirrer out of the suspension, it is important to make a rotation movement so that the remains can fall off the stirrer. The stirrer is washed with a wash bottle when taken out. 4–5 seconds before the sedimentation time is over, a suction cone is put in the suspension and the top layer of suspension is floated. When the time finishes, the cone tip is put on the bottom of the beaker (floating lasts for 14 seconds). Collected suspension is poured out as already marked. The first floating is followed by the second, third, fourth and fifth which are identical as the first one. Regular, running water of stable temperature may be used here. Five floatings should not take more than 10 minutes. Other beakers with samples are handled the same way.

12. When particles smaller than 0.05 mm are floated, in the beaker there is a sand fraction which is washed to a weighed weight vessel of 120 ml capacity. The excess water is drained with a suction set with 1cm layer left for the evaporation in a ventilation dryer. Dried and cooled, the vessel is weighed and then a percent content of sand is calculated and written in a table set of the results of the granulometric analysis. Furthermore, when needed, dried sand can be separated into fractions of fine, medium and coarse sand, etc. with a small sieve of 10–15 cm diameter.

13. Percent content of fraction up to two decimal places needs to be summed up, and the sum should be compared with the value of 100%. The sum lower than 100% and the result will determine the result of the analysis with a "-" sign whereas the result over 100 will be marked with a "+" sign. Both deficiencies and surpluses ought to be distributed into fractions proportionally. Having done this, one should round up the number to one decimal place.

14. The results of the texture analysis grouped in three basic fractions of sand, silt and loam are placed onto Feret's triangle with texture classification in

order to determine the type and granulometric name which should be noted in the last column of the table.

15. The table set of texture analysis results using the ALP pipette method should the content of calcium carbonate and organic carbon of the humus horizon. These numbers are usually placed in the columns with texture, just as it was in the table set of the total analysis.

Results of ALP Method and Interpretation

The results of texture analysis with the ALP pipette method form a broad and comparable documentation of the same 24 soils which were analyzed with the method of whole sample fractioning – TA (Table 3).

The results of the ALP pipette analysis were set in accordance with the growing content of loam fraction in five repetitions for each sample. Average values were calculated from five repetitions. Having distributed the errors among the fractions, they were rounded up to one decimal place (to 0.1%). The errors in column 9 are marked with pluses and minuses. The values marked with a minus were added, and the ones marked with a plus – subtracted from each fraction when the sum of indicated fractions was lower or higher than 100%. Defined errors of ALP pipette analysis did not exceed 3%. They were a bit higher in the values marked with a minus than in the plus ones. In most of the cases, the errors of the method oscillated between -2.0% to +1.5%.

When compared to the TA method, the errors of the ALP method were much higher and almost three times broader as they included both positive and negative numbers. Furthermore, one can observe greater diversity in the value of errors among the repetitions.

Larger diversity and higher values of errors in the ALP analysis are visible in samples of relatively high content of loam and silt fractions of high carbonate content. Samples of a balanced fraction arrangement and also most often analyzed soils such as clay sands, sandy and silt clay of various compactness, etc., the errors in texture indication are relatively small, usually between -1.5% and +1.0%.

Various values of errors in each repetition is a result of previously presented facts and many complex and hard to control factors which should not be treated as the average of the repetitions.The most correct result of texture analysis with the ALP method is the repetition with the lowest error. For instance, for sample No. 1, the result is the best in 2nd repetition, and for sample No. 24 – in 5th repetition.

Implementation of the ALP Method

One of the basic aims of developing the ALP method was the need for practice which had used unverifiable results of the texture analysis. There are no reliable and generally acknowledged ways of verification and assessment of these methods as science itself suffers from a lot of lacks. So finding a solution through practice is based on the results of the granulometric analysis achieved with imposed methods in a form of advice or branch regulations with no essential basis. In such a situation, the ALP method becomes particularly important.

For the solution of practical tasks, where texture analysis is needed only for the indication of the soil texture, the indication of only three basic fractions: sand (2.0–0.05 mm), silt (0.05–0.002 mm) and clay (< 0.002 mm) is fully satisfying. The analysis is done once and during laboratory works, technical scales are used with the measurement exactness of 0.001 g. The measurement error should not exceed -3.0% and +3.0%. 400 such analyses may be done by a person or a pair within a month.

When the solution of a practical task or the interpretation of the results require a detailed analysis, there are at least two possibilities: one of them is the indication of five fractions (sand, coarse, medium and fine silt, clay), the other one is the additional separation of a sand fraction into fine, medium and coarse sand with a sieve method. The analysis is conducted once, yet for weighing empty weight vessels and weight vessels with a dried sample in 105°C and after cooling, analytic scales are used with the exactness of 0.0001 g. The analytical error should not exceed 2% if the content of loam and fine sand fractions and of carbonates is not too high. In this case, the error must be a bit higher, but cannot exceed 3%. If it does, the analysis should be conducted once again. 300–400 such analyses may be done by a pair of researchers within a month, depending on the number of indicated fractions. Another vital implementation of ALP method is texture analysis for documentation and the solution of scientific problems. This method is equally useful and looked forward in scientific research.

For scientific purposes, when only texture indication is required, the analysis can be done once as such a result shows the accuracy of performance and the size of an error. Weigh indications must be done on analytic scales of 0.0001 g exactness. The result should contain the measurements of at least five fractions, just as in table 3. The measurement error should not exceed ± 2% or, exceptionally, ± 3% for the samples of high content of loam and silt or sodium carbonate.

Research whose results are to various extent used for solving theoretical and practical issues are a vital and basic aim of the ALP pipette method. In such cases, texture details are crucial. The analysis should then contain the indications of all the fractions than can be possibly separated. The analysis should be done twice, so with the repetitions. The material ought to be weighed on analytical scales with 0.0001 g exactness, apart from the weight vessel with suspension, in order to find the capacity of a collected sample. The result of a smallest error is treated as a reliable one. The error should not exceed 2%. Texture analysis ought to be complemented with the indication of carbonates and general carbon in humus horizons. Having distributed the errors proportionally, the results ought to be rounded up to one decimal place.

TABLE 3. TEXTURE OF SOILS AND BED MARKED WITH ALP PIPETTE METHOD

Sample No.	Place, type and depth of sample collection (m)	Repetitions	Grain size (in mm) distribution (%)					Measure-ment error	CaCO$_3$ C total	Granulometic group
			2.0–0.05	0.05–0.02	0.02–0.005	0.005–0.002	<0.002			
1	Świeradów Zdrój Aluvia of fluvial terraces of the River Izera, 0.0–0.2	1	79.1	11.6	7.2	2.0	0.1	-1.50	0.0 2.3	loamy sand (LS)
		2	78.2	11.7	8.2	1.6	0.3	+0.30		
		3	78.1	12.7	7.5	1.1	0.6	-1.90		
		4	77.9	13.4	7.1	0.7	0.9	-1.00		
		5	77.0	13.8	7.4	0.8	1.0	-0.50		
		$x_{śr}$	78.1	12.6	7.5	1.2	0.6	-0.92		
2	Szamotuły Fluvio-glacial forms of glacial Würm, 0.0–0.2	1	88.1	5.5	4.2	0.7	1.5	+0.90	0.2 0.0	sand (S)
		2	89.5	4.2	4.1	0.9	1.3	-0.50		
		3	89.7	3.8	3.5	1.6	1.4	-1.20		
		4	90.6	3.3	3.5	2.1	0.5	-1.90		
		5	89.8	3.6	3.6	1.5	1.5	-1.60		
		$x_{śr}$	89.5	4.1	3.8	1.4	1.2	-0.86		
3	Poznań – Złotniki Moriane material of glacial Würm, 0.1–0.3	1	81.4	8.2	5.3	2.6	2.5	+0.20	1.5 1.4	loamy sand (LS)
		2	82.2	7.5	5.3	2.7	2.3	-0.70		
		3	82.5	7.4	5.7	2.0	2.4	-0.40		
		4	82.8	7.5	5.2	2.3	2.2	-1.10		
		5	82.5	7.5	5.1	2.0	2.9	-0.10		
		$x_{śr}$	82.3	7.6	5.3	2.3	2.5	-0.42		

TABLE 3. CONTINUATION

4	Bąblin Moriane material of glacial Würm, 0.0–0.3	1	81.0	7.5	6.2	2.1	3.2	-0.80	0.7 0.9	loamy sand (LS)
		2	81.4	7.5	6.8	1.1	3.2	-1.00		
		3	80.3	8.2	5.7	2.2	3.6	+0.70		
		4	81.6	7.2	5.8	2.6	2.8	-0.60		
		5	80.5	8.4	5.5	2.0	3.5	-0.40		
		$x_{śr}$	81.0	7.8	6.0	2.0	3.3	-0.42		
5	Poznań – Złotniki Moriane material of glacial Würm, 0.0–0.3	1	77.2	9.0	7.3	3.3	3.2	+0.40	0.0 1.1	loamy sand (LS)
		2	77.9	8.4	8.6	1.8	3.3	-0.01		
		3	77.1	9.3	6.8	3.2	3.6	+0.10		
		4	77.6	9.0	7.8	2.2	3.4	-1.20		
		5	78.0	8.9	7.0	3.0	3.1	-0.40		
		$x_{śr}$	77.6	8.9	7.5	2.7	3.3	-0.22		
6	Szczepankowo Moriane material of glacial Würm, 0.0–0.3	1	75.3	8.6	7.5	4.3	4.3	-0.10	0.1 1.1	loamy sand (LS)
		2	76.8	7.3	9.3	1.1	5.5	-1.70		
		3	75.4	8.4	7.3	3.5	5.4	-0.20		
		4	74.8	8.7	7.7	3.2	5.6	+0.20		
		5	76.2	8.1	7.8	3.3	4.6	-1.50		
		$x_{śr}$	75.7	8.2	7.9	3.1	5.1	-0.66		
7	Ruda Kameralna Carpathian Flysh belt, 0.0–0.2	1	41.9	31.4	15.9	8.3	2.5	+1.20	0.0 0.9	silty loam (SiL)
		2	42.7	28.0	19.1	3.7	6.5	+0.20		
		3	41.2	28.5	18.7	4.5	7.1	-2.10		
		4	40.1	28.6	18.9	5.0	7.4	+0.70		
		5	40.9	28.5	18.3	5.2	7.1	-0.80		
		$x_{śr}$	41.4	29.0	18.2	5.3	6.1	-0.16		

TABLE 3. CONTINUATION

8	Czesławice Lubelski loess, 1.6–2.0	1	15.2	54.8	19.2	2.3	8.5	+0.20	2.5 0.0	silty loam (SiL)
		2	13.1	55.2	20.3	2.4	9.0	-2.44		
		3	10.8	54.5	23.2	1.8	9.7	+0.67		
		4	12.6	54.8	21.9	2.3	8.4	-2.18		
		5	11.6	53.6	23.3	2.4	9.1	-1.56		
		$x_{śr}$	12.7	54.6	21.6	2.2	8.9	-1.06		
9	Żulice Lubelski loess, 0.0–0.3	1	13.5	48.9	21.3	6.8	9.4	-2.40	0.0 2.4	silty loam (SiL)
		2	14.4	47.7	23.0	5.3	9.6	-0.61		
		3	10.9	46.8	24.6	5.7	12.0	-2.37		
		4	11.1	47.7	24.7	4.5	12.0	-2.62		
		5	11.7	48.3	23.9	5.3	10.8	-2.78		
		$x_{śr}$	12.3	47.9	23.5	5.5	10.8	-2.16		
10	Szczepankowo Moriane material of glacial Würm, 0.4–0.5	1	65.6	11.5	6.8	2.6	13.5	-0.96	0.1 0.0	loamy sand (LS)
		2	65.7	9.9	8.0	4.0	12.4	-1.22		
		3	64.7	10.7	8.3	2.5	13.8	-0.91		
		4	65.4	10.4	7.7	2.7	13.8	-2.06		
		5	65.7	10.1	7.9	2.5	13.8	-2.84		
		$x_{śr}$	65.4	10.5	7.7	2.9	13.5	-1.60		
11	Trzebnica Trzebnicki loess, 0.0–0.3	1	22.3	43.5	18.0	3.3	12.9	-1.72	0.4 1.6	silty loam (SiL)
		2	23.0	43.3	18.6	3.2	11.9	+0.41		
		3	21.3	43.7	18.9	3.7	12.4	-1.33		
		4	21.5	43.3	19.6	3.2	12.4	-2.42		
		5	20.3	44.6	19.0	2.9	13.2	-2.32		
		$x_{śr}$	21.7	43.7	18.8	3.3	12.6	-1.46		

TABLE 3. CONTINUATION

12	Poznań – Naramowice Moriane loam of glacial Würm, 0.4–0.5	1	69.5	8.4	7.2	3.0	11.9	-0.14	4.4 0.0	sandy loam (SL)
		2	70.2	7.5	7.4	3.2	11.7	-1.52		
		3	68.3	8.9	7.2	3.2	12.4	+0.27		
		4	70.9	7.0	7.8	3.5	10.8	-2.25		
		5	68.6	8.5	7.5	3.5	11.9	+0.91		
		$x_{śr}$	69.5	8.1	7.4	3.3	11.7	-0.54		
13	Tomisławice Moriane loam of glacial Riss, 20.0–21.0	1	55.4	8.7	11.7	6.4	17.8	-0.02	11.1 0.0	sandy loam (SL)
		2	55.4	8.2	11.7	7.3	17.4	+0.10		
		3	55.8	8.4	11.7	7.8	16.3	-2.24		
		4	55.5	7.6	14.3	6.1	16.5	-1.44		
		5	55.4	7.6	12.8	7.6	16.6	-1.37		
		$x_{śr}$	55.5	8.1	12.4	7.0	16.9	-0.98		
14	Olsztyn – Częstochowa, Cretaceus material, 0.0–0.3	1	61.1	6.1	8.8	5.7	18.3	-0.33	0.1 2.2	sandy loam (SL)
		2	61.1	6.6	9.5	5.8	17.0	-0.42		
		3	61.5	5.7	8.2	6.1	18.5	-0.61		
		4	60.5	5.9	9.0	5.2	19.4	+0.57		
		5	61.3	6.1	8.6	5.9	18.1	-0.82		
		$x_{śr}$	61.1	6.1	8.8	5.7	18.3	-0.30		
15	Gniew Pleistocene loam, 0.0–0.5	1	39.7	13.5	15.8	10.4	20.6	+2.41	0.5 0.0	loam (L)
		2	41.2	13.5	15.2	9.8	20.3	+0.74		
		3	41.9	14.2	15.1	9.0	19.8	-0.56		
		4	40.9	14.7	15.3	9.6	19.5	-1.02		
		5	41.4	13.7	16.0	8.5	20.4	+0.79		
		$x_{śr}$	41.0	13.9	15.5	9.5	20.1	+0.46		

TABLE 3. CONTINUATION

16	Ruda Kameralna Carpathian Flysh belt, 0.4–0.5	1	35.2	23.8	16.3	5.1	19.6	-2.08	0.1 0.0	loam (L)
		2	34.0	23.4	18.0	4.0	20.6	-2.15		
		3	34.5	23.2	17.8	4.6	19.9	+0.51		
		4	33.2	23.7	16.8	7.1	19.2	-2.90		
		5	31.7	25.3	16.5	6.0	20.5	-0.08		
		$x_{śr}$	33.7	23.9	17.1	5.4	20.0	-1.34		
17	Stare Pole Żuławski alluvia, 0.0–0.3	1	27.9	23.0	19.3	7.4	22.4	-2.34	0.3 0.0	loam (L)
		2	28.1	23.8	19.9	8.0	20.2	-1.48		
		3	28.8	23.0	18.3	7.7	22.2	-2.11		
		4	28.4	23.5	18.6	7.0	22.5	-1.50		
		5	27.8	23.3	19.3	6.2	23.4	-1.25		
		$x_{śr}$	28.2	23.3	19.1	7.3	22.1	-1.74		
18	Ruda Kameralna Alluvia of the River Dunajec, 0.0–0.3	1	18.9	21.0	27.0	13.8	19.3	-3.00	0.2 1.4	silty loam (SiL)
		2	18.9	19.2	29.3	12.3	20.3	-2.30		
		3	17.5	19.7	29.4	12.7	20.7	-2.42		
		4	16.8	19.0	30.0	14.4	19.8	-2.90		
		5	17.7	19.2	28.6	13.1	21.4	-1.64		
		$x_{śr}$	18.0	19.6	28.9	13.3	20.3	-2.46		
19	Kąty Lubelskie Cretaceus material, 0.3–0.5	1	33.2	14.0	18.7	11.7	22.4	-1.49	36.7 0.0	loam (L)
		2	34.4	15.4	18.7	9.3	22.2	-2.83		
		3	33.3	14.3	20.3	9.2	22.9	-1.63		
		4	34.4	15.0	16.7	10.8	23.1	-1.87		
		5	34.4	13.2	19.2	9.7	23.5	-1.78		
		$x_{śr}$	34.0	14.4	18.7	10.1	22.8	-1.92		

TABLE 3. CONTINUATION

20	Gniew Pleistocene loam, 0.0–0.3	1	14.4	17.4	20.2	12.6	35.4	-1.60	0.1 0.0	silty clay loam (SiCL)
		2	15.8	16.5	20.3	13.4	34.0	-0.15		
		3	16.3	16.1	20.1	12.9	34.6	-1.63		
		4	15.7	17.2	19.3	12.5	35.3	-1.70		
		5	15.3	17.6	19.9	11.4	35.8	-2.11		
		$x_{\text{śr}}$	15.5	17.0	20.0	12.6	35.0	-1.44		
21	Tomisławice Moriane clay of glacial Riss, 40.0–41.0	1	32.7	7.3	9.5	5.9	44.6	-2.21	2.4 0.0	clay (C)
		2	32.1	8.2	9.7	5.6	44.4	+0.76		
		3	33.4	6.6	10.4	5.3	44.3	-2.76		
		4	31.9	7.2	10.4	5.7	44.8	-2.26		
		5	31.7	6.6	10.4	7.6	43.7	-1.04		
		$x_{\text{śr}}$	32.4	7.2	10.1	6.0	44.4	-1.50		
22	Poznań – Kotowo Pleistocene clay, 1.8–2.0	1	2.6	2.4	19.2	25.6	50.2	+2.00	15.9 0.0	silty clay (SiC)
		2	2.1	2.2	14.6	23.2	57.9	-1.09		
		3	1.6	1.7	15.5	23.5	57.7	-1.81		
		4	1.5	1.1	16.5	24.1	56.8	-1.66		
		5	1.6	2.0	15.4	23.8	57.2	-1.22		
		$x_{\text{śr}}$	1.9	1.9	16.2	24.0	56.0	-0.76		
23	Tomisławice Pliocene clay, 55.0–56.0	1	1.7	2.2	24.3	16.3	55.5	+1.63	0.2 0.0	silty clay (SiC)
		2	1.7	2.1	22.7	17.6	55.9	+0.86		
		3	1.6	1.3	23.1	18.1	55.9	-1.43		
		4	1.8	2.1	24.0	16.9	55.2	-0.73		
		5	1.5	1.4	24.6	17.1	55.4	-0.09		
		$x_{\text{śr}}$	1.7	1.8	23.7	17.2	55.6	+0.06		

TABLE 3. CONTINUATION

24	Poznań – Naramowice Pilocene clay, 3.0–3.5	1	15.0	3.3	4.5	8.1	69.1	-2.61	1.4 0.0	clay (C)
		2	13.4	3.1	6.0	8.0	69.5	-2.33		
		3	14.8	3.4	6.2	7.4	68.2	-2.86		
		4	16.0	3.8	6.3	6.7	67.2	-2.70		
		5	12.9	3.9	6.3	7.5	69.4	-0.48		
		$x_{\text{śr}}$	14.4	3.5	5.9	7.5	68.7	-2.20		

Comparative Analysis of the Results Obtained with the TA and ALP Methods

When the results of the TA analysis, which is considered a standard, basic method, are compared with the results of the ALP pipette analysis (Table 4; Fig. 7), one general conclusion may be drawn, namely, the ALP results are very similar both in each fraction and in the sum of indicated fractions. As it was already noticed, in the pipette method, there is a broader scale of errors. However, after proportional distribution of mistakes, the differences in comparative results of he ALP method are relatively small, unimportant for the interpretation of texture in practical and theoretical solutions.

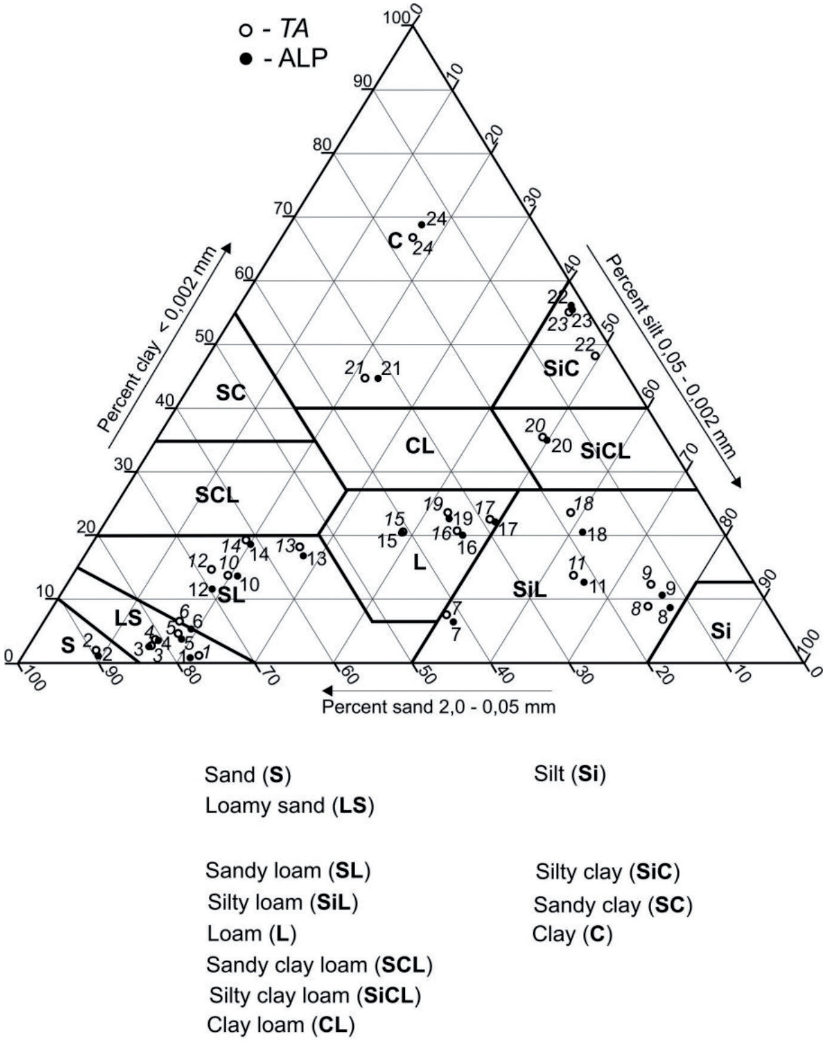

Fig. 7. Texture of examined soils indicated with TA and ALP methods in a graphic interpretation on Feret's triangle.

TABLE 4. AVERAGE VALUES OF FRACTIONS OBTAINED WITH TA AND ALP METHODS

Sample No.	Place. type and depth of sample collection (m)	Repetitions	Percentage content of fractions in (mm)				
			2.0–0.05	0.05–0.02	0.02–0.005	0.005–0.002	<0.002
1	Świeradów Zdrój Aluvia of fluvial terraces of the River Izera, 0.0–0.2	TA_{mean}	76.9	13.0	8.1	1.0	1.0
		ALP_{mean}	78.1	12.6	7.5	1.2	0.6
		Difference */	+1.2	-0.4	-0.6	+0.2	-0.4
2	Szamotuły Fluvio-glacial forms of glacial Würm, 0.0–0.2	TA_{mean}	89.4	3.8	3.6	1.3	2.0
		ALP_{mean}	89.5	4.1	3.8	1.4	1.2
		Difference	+0.1	+0.3	+0.2	+0.1	-0.8
3	Poznań – Złotniki Moriane material of glacial Würm, 0.1–0.3	TA_{mean}	82.0	7.8	6.1	1.4	2.7
		ALP_{mean}	82.3	7.6	5.3	2.3	2.5
		Difference	+0.3	-0.2	-0.8	+0.9	-0.2
4	Bąblin Moriane material of glacial Würm, 0.0–0.3	TA_{mean}	81.0	8.0	6.1	1.5	3.5
		ALP_{mean}	81.0	7.8	6.0	2.0	3.3
		Difference	0.0	-0.2	-0.1	+0.5	-0.2
5	Poznań – Złotniki Moriane material of glacial Würm, 0.0–0.3	TA_{mean}	77.6	8.4	6.7	3.0	4.3
		ALP_{mean}	77.6	8.9	7.5	2.7	3.3
		Difference	0.0	+0.5	+0.8	-0.3	-1.0
6	Szczepankowo Moriane material of glacial Würm, 0.0–0.3	TA_{mean}	76.3	8.0	6.3	2.7	6.7
		ALP_{mean}	75.7	8.2	7.9	3.1	5.1
		Difference	-0.6	-0.2	+1.6	+0.4	-1.6
7	Ruda Kameralna Carpathian Flysh belt, 0.0–0.2	TA_{mean}	41.8	29.1	16.9	4.8	7.5
		ALP_{mean}	41.4	29.0	18.2	5.3	6.1
		Difference	-0.4	-0.1	+1.3	+0.5	-1.4

TABLE 4. CONTINUATION

8	Czesławice Lubelski loess, 1.6–2.0	TA_{mean}	15.2	54.5	19.1	2.2	9.0
		ALP_{mean}	12.7	54.6	21.6	2.2	8.9
		Difference	-2.5	+0.1	+2.5	0.0	-0.1
9	Żulice Lubelski loess, 0.0–0.3	TA_{mean}	13.2	49.5	19.6	5.6	12.1
		ALP_{mean}	12.3	47.9	23.5	5.5	10.8
		Difference	-0.9	-1.6	+3.9	-0.1	-1.3
10	Szczepankowo Moriane material of glacial Würm, 0.4–0.5	TA_{mean}	67.1	10.2	7.5	2.1	13.2
		ALP_{mean}	65.4	10.5	7.7	2.9	13.5
		Difference	-1.7	+0.3	+0.2	+0.8	+0.3
11	Trzebnica Trzebnicki loess, 0.0–0.3	TA_{mean}	22.8	43.7	17.1	3.1	13.2
		ALP_{mean}	21.7	43.7	18.8	3.3	12.6
		Difference	-1.1	0.0	+1.7	+0.2	-0.6
12	Poznań – Naramowice Moriane loam of glacial Würm, 0.4–0.5	TA_{mean}	68.8	7.8	6.9	2.3	14.2
		ALP_{mean}	69.5	8.1	7.4	3.3	11.7
		Difference	+0.7	+0.3	+0.5	+1.0	-2.5
13	Tomisławice Moriane loam of glacial Riss, 20.0–21.0	TA_{mean}	55.6	8.9	11.9	5.3	18.3
		ALP_{mean}	55.5	8.1	12.4	7.0	16.9
		Difference	-0.1	-0.8	+0.5	+1.7	-1.4
14	Olsztyn – Częstochowa Cretaceus material, 0.0–0.3	TA_{mean}	61.3	5.1	8.3	5.9	19.4
		ALP_{mean}	61.1	6.1	8.8	5.7	18.3
		Difference	-0.2	+1.0	+0.5	-0.2	-1.1

TABLE 4. CONTINUATION

15	Gniew Pleistocene loam, 0.0–0.5	TA_{mean}	40.9	14.2	15.6	9.1	20.2
		ALP_{mean}	41.0	13.9	15.5	9.5	20.1
		Difference	+0.1	-0.3	-0.1	+0.4	-0.1
16	Ruda Kameralna Carpathian Flysh belt, 0.4–0.5	TA_{mean}	34.1	25.1	16.2	4.0	20.5
		ALP_{mean}	33.7	23.9	17.1	5.4	20.0
		Difference	-0.4	-1.2	+0.9	+1.4	-0.5
17	Stare Pole Żuławski alluvia, 0.0–0.3	TA_{mean}	28.7	23.6	18.3	6.7	22.8
		ALP_{mean}	28.2	23.3	19.1	7.3	22.1
		Difference	-0.5	-0.3	+0.8	+0.6	-0.7
18	Ruda Kameralna Alluvias of the River Dunajec, 0.0–0.3	TA_{mean}	18.1	21.2	26.1	11.4	23.2
		ALP_{mean}	18.0	19.6	28.9	13.3	20.3
		Difference	-0.1	-1.6	+2.8	+1.9	-2.9
19	Kąty Lubelskie Cretaceus material, 0.3–0.5	TA_{mean}	33.8	12.8	17.7	12.2	23.5
		ALP_{mean}	34.0	14.4	18.7	10.1	22.8
		Difference	+0.2	+1.6	+1.0	-2.1	-0.7
20	Gniew Pleistocene loam, 0.0–0.3	TA_{mean}	15.6	16.8	20.1	12.1	35.4
		ALP_{mean}	15.5	17.0	20.0	12.6	35.0
		Difference	-0.1	+0.2	-0.1	+0.5	-0.4
21	Tomisławice Moriane clay of glacial Riss, 40.0–41.0	TA_{mean}	33.5	7.9	9.4	4.6	44.6
		ALP_{mean}	32.4	7.2	10.1	6.0	44.4
		Difference	-1.1	-0.7	+0.7	+1.4	-0.2

TABLE 4. CONTINUATION

22	Poznań – Kotowo Pleistocene clay, 1.8–2.0	TA_{mean}	2.8	1.3	28.0	19.9	48.0
		ALP_{mean}	1.9	1.9	16.2	24.0	56.0
		Difference	-0.8	+0.6	-11.8	+4.1	+0.8
23	Tomisławice Pliocene clay, 55.0–56.0	TA_{mean}	2.1	2.5	25.6	14.7	55.1
		ALP_{mean}	1.7	1.8	23.7	17.2	55.6
		Difference	-0.4	-0.7	-1.9	+2.5	+0.1
24	Poznań – Naramowice Pliocene clay, 3.0–3.5	TA_{mean}	16.4	3.6	6.9	6.1	67.0
		ALP_{mean}	14.4	3.5	5.9	7.5	68.7
		Difference	-2.0	-0.1	-1.0	+1.4	+1.7

An additional way which simplifies the comparison of the results of both methods may be a chart of grain size distribution (Fig. 8), which also illustrates the process of sedimentation and where the results of a low compaction (No. 3), semi-compaction (No. 11, 13) and high compaction (No. 23) samples analyses were placed as an example. The chart contains average values of grain size analyses of five repetitions obtained with the ALP method and three repetitions obtained with the TA method. Charts of cumulative granulation illustrate and prove very high similarity of texture also in completely different samples.

There are, therefore, at least four possibilities of confrontation and comparison of the results of a simplified analysis with the results of a basic, reliable and complete texture analysis which should be treated as model. The first possibility is the comparison of size and sum of appropriately marked fractions of texture. The second one is the size of an acceptable error defined for each method. These two ways are essential and most important. The third opportunity is a cumulative granulation chart which may illustrate the regularities and discrepancies in the results. Figure 8 may serve as an example, where the results of the analyses of four significantly different soils were presented. The fourth possibility is the comparison of the results localized in Feret's triangle in a way that is presented in Fig. 7, which was previously used for the illustration of texture diversity in the analyzed soils. The triangle was also used for a comparative analysis with TA and ALP methods.

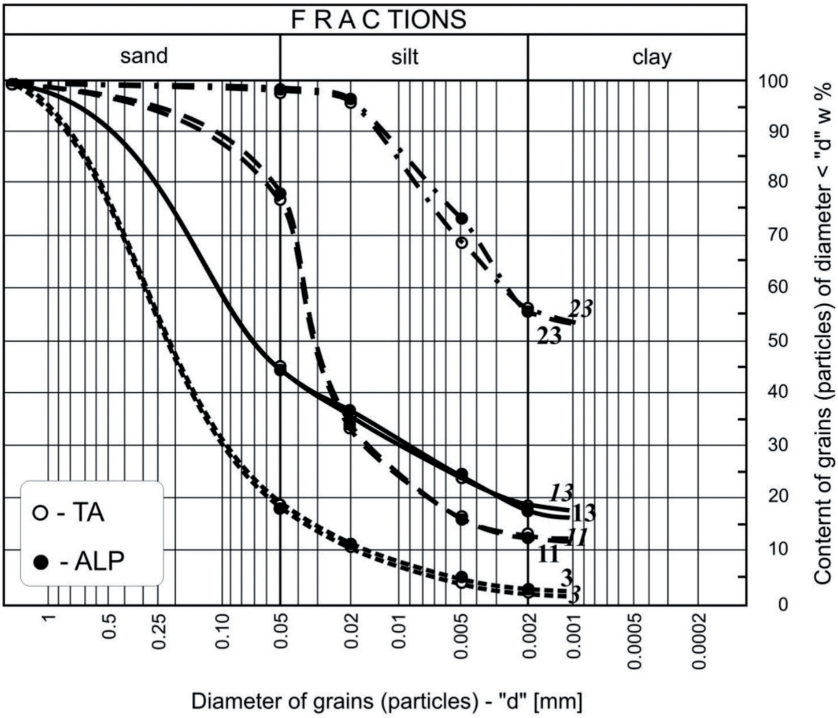

Fig. 8. Examples of cumulative curves of soil granulation No. 3, 11, 13, 23.

Localization presented in this triangle confirms very high similarity of the results of both methods, which is presented with points placed near one another. Only a sample No. 22 outstands with a characteristic origin; it represents stratified loam of high content of medium or fine silt (0.02–0.002 mm) and high content of sodium carbonate and the points are placed far away from one another. In this case, ALP method shows lower (of several percent) reduction of silt fraction.

The four ways of confrontation, comparison and assessment of the granulometric analysis obtained with pipette method allow a general claim that this method, with its small and relatively minor results differences from a model TA analysis, lets the researchers conduct ten times more analyses. Furthermore, these possibilities, which are developed to various extent, may serve as an example for a necessary verification of other simplified, shortened or partial methods such as pipette, areometric, laser method, etc.

The analysis of the results from Table 4 contain also numerous tiny regularities and details which are not, however, crucial for the development of important theories and generalizations. The interpretation of the results may be concluded with a very important thought, though: the results of texture analysis conducted with the ALP method are almost identical as those obtained with TA method, when errors are distributed proportionally onto various fractions. On the basis of this assumption it may be inferred that the ALP method is fully appropriate for implementation with no conditions and limitations.

DISCUSSION

Both presented methods of texture analysis are the result of long-term research, when both the equipement, as well as the analysis process were modified, complemented and simplified. Atterberg's method [2] was a significant model for the total analysis and Köhn's method [9] – for the pipette analysis. These model methods have been used since 1952 in research and academic (master's, doctoral and postdoctoral) works in the Soil Science Department at Poznań University. Yet, these were not separate methods: Köhn's pipette method for the indication of fractions smaller than 0.02 mm was supplemented with Atterberg's method for fractions larger than 0.02 mm. At that time, a lot of experience in floating and pipetting soil suspension was gained.

Differences in equipment and the analytical process between Atterberg's and Köhn's methods and the TA and ALP methods are vast. When comparing e.g. Atterberg's method and a basic device (cylinder) of 8 cm diameter and 30 cm sedimentation height with the TA method, one needs to emphasize that in the TA method, sedimentation height is three times lower (10 cm) and so is the amount of floated suspension. Moreover, in the TA method, a special suction cone in the axis of the sedimentation column allows the collection of 90% of the suspension whereas floating in Atterberg's method is about 80% and therefore requires more floatings. Because of these two basic differences, and a number of other minor details, the amount of collected suspension necessary for the evaporation of loam fraction is 3 liters in the TA method while in Atterberg's method it is at least four times higher. Another crucial advantage of the TA method is the possibility to use standard laboratory beakers of 8 cm inner diameter, 600 ml measurement capacity and appropriate marks as sedimentation cylinders.

Furthermore, the TA method, as a model method, gives real opportunities to conduct exact verification of various methods for texture analysis. At first, the verification should be conducted on these methods which do not have a possibility to indicate the exactness of their results as well as the scope of the analysis error. Such verification may be done through confrontation and verification of the results of texture analysis received with a verifiable and model TA method. For such a comparison of the results it is necessary to conduct texture analyses of various soils, in a scope similar to these in sets in tables 2 and 3. The TA analysis should be done in two repetitions, whereas when used as a verification for the results of other methods – in five repetitions. In the comparison and assessment of the confronted results it is crucial to analyze the accordance and discrepancy in the indications of each fraction and then the sum of indicated fractions and the size of analysis error. Moreover, the repetition of the results must be assessed as well as the universality of the methods, namely the independence of the results from various content of sand, loam, silt fractions, the content of sodium carbonate etc. Apart from table sets, the analysis of confronted results may be simplified by putting them on Feret's triangle and on the charts of cumulative soil granulation.

Equally important and basis differences appear in the comparison of the ALP pipette device and Köhn's pipette [9] of 10 or 20 ml capacity, which is more popular and better known in Europe. The capacity of the ALP pipette device is either almost four times or twice bigger – which is 38.5 ml – and the collection of a soil sample is done within 1–2 seconds after the release of a tap. In Köhn's pipette the collection lasts for 20 or 30 seconds owing to which the fraction of coarse silt (0.05–0.02 mm), which usually sediments for 45–50 seconds, should not be collected but marked e.g. with Atterberg's method. Furthermore, Köhn's pipette is set on a movable tripod, whereas the ALP pipette – on a sliding tripod of a totally different construction. Apart from the listed differences, the rules for pipetting, the depth of sample collection (9.5–10 cm) and a general exactness of indication are the same for both methods.

Taking Atterberg's method [2] and Köhn's method [9] as standards and examples in the solution of soil texture problems, the following issues were concerned: what should be genuinely changed, improved, modified or completely replaced with new methodological solutions so that the problem of texture analysis is solved in a satisfying manner. Following these considerations within a long period of time, it was feasible to reach the final version of soil texture analysis. The TA and simplified method – elaborated and verified in many different ways two methods for total refractioning – will solve the problem of texture analysis for some time.

The TA and ALP methods, with their broad documentation and detailed descriptions, differ from the previous methods in numerous characteristics:

– high exactness of the results defined mostly with the analysis error which does not exceed 2% (TA) or 3% (ALP) and is even lower after the proportional division onto various fractions;

– high repetitiveness of results which may be assessed by the comparison of the results of each analysis repetition; an idea of the repetition scope may be created on the basis of an example granulation chart (Fig. 8);

– universality. i.e. the independence from various textures of the analyzed samples; sand soil samples, clay, silt and loam ones, those of small, large and even very large diversity, non-carbonate samples and those of low and also high sodium carbonate content – are all analyzed with the same exactness;

– simple in construction and use devices which should be implemented in soil science laboratories;

– simple conduction of the analyses which does not require specially trained technical staff and where basic activities are: floating, evaporating, drying and weighing.

These advantages of the presented methods as well as their other beneficial traits, create different and vast opportunities for the research which solve current and perspective problems of science and practice connected with the soil texture analysis. Research and indications may be limited to three basic fractions of clay, silt and sand or conduct them in a broader – 5-fraction – and most often implemented scope which is presented in the tables 2 and 3. Moreover, it is possible to freely define the ranges of sample fractioning in accordance with the needs. There are also various possibilities in the choice of the amount of the analyzed samples. Analysis may be done for a single sample, for small series and for very large series which, however, do not exceed 50 samples. Sets composed of 20–30 samples are the most beneficial. Nevertheless, it depends on organizational conditions.

In case of the analyses conducted with the TA method, a number of separated fractions which may be used in further – especially mineralogical – research is defined as fractions bigger than 0.002 mm are in the favorable condition for such analyses whereas the loam fraction containing Calgon may complicate the investigation. Nevertheless, there are possibilities of receiving the amounts of fractions (also clayey fractions) which are appropriate for mineralogical analyses by a partial modification of the TA method. Soil samples are dispergated mechanically, with an electrical stirrer and no addition of Calgon, whereas evaporation is replaced with the sedimentation of suspension as within 10–30 days the suspension falls down and a transparent liquid from above the sediment is floated with a suction device. The rest is evaporated and dried in the temperature of maximum 65°C. Appropriate number of fractions is received by multiplying the number of repetitions and not of the surplus weight (20 g). Usually, 3–4 repetitions are enough.

TA and ALP methods create various broad possibilities of texture analysis implementation as well as texture research as a crucial element which broadly shapes soils' productivity. Analyses may be done separately, but also for small and large sample series, with the low expenditure on special equipment by using standard soil science laboratory equipment. Therefore, it is possible to analyze soil texture in a simple manner which does not require special preparation, qualifications and is verifiable, reliable and of small measurement error.

The authors are open to any inquiries, especially those regarding the organization of a laboratory, implementation of the methods, etc.

CONCLUSIONS

1. The presented methods of texture analysis are the result of long-term research, when both the equipement as well as the analysis process were modified, complemented and simplified.

2. TA method, as a model method, gives real opportunities to conduct exact verification of various methods for texture analysis. At first, the verification should be conducted on these methods which do not have a possibility to indicate the exactness of their results as well as the scope of the analysis error.

3. TA and ALP methods, differ from the previous methods in numerous characteristics: (i) high exactness of the results defined mostly with the analysis error which does not exceed 2% (TA) or 3% (ALP); (ii) high repetitiveness of results which may be assessed by the comparison of the results of each analysis repetition; (iii) universality, i.e. the independence from various textures of the analyzed samples; (iv) simple in construction and use devices which should be implemented in soil science laboratories; and (v) simple conduction of the analyses which does not require specially trained technical staff.

4. These advantages of the presented methods as well as their other beneficial traits, create different and vast opportunities for the research which solve current and perspective problems of science and practice connected with the soil texture analysis.

5. In case of the analyses conducted with TA method (the method of total refractioning), a number of separated fractions which may be used in further – especially mineralogical – research.

6. TA and ALP methods create various broad possibilities of texture analysis implementation as well as texture research as a crucial element which broadly shapes soils' productivity. Analyses may be done separately, but also for small and large sample series, with the low expenditure on special equipment by using standard soil science laboratory equipment.

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METODY GRANULOMETRYCZNEJ ANALIZY GLEBY DLA NAUKI I PRAKTYKI

W publikacji przedstawiono dwie metody analizy składu granulometrycznego gleby i zalegającego pod nim podłoża. Pierwsza metoda – TA jest z obiektywnej konieczności niezwykle pracochłonna, a szczególnie czasochłonna, ale dokładna, oczywista, sprawdzalna, o ściśle określonym

błędzie oznaczania. Polega ona na całkowitym, pełnym rozfrakcjonowaniu próbki glebowej zdyspergowanej w wodzie destylowanej lub demineralizowanej. Analiza opiera się na zasadzie rozfrakcjonowania całości próbki na frakcje iłowe, pyłowe i piaskowe, przez odpławianie zawiesiny glebowej. Suma oznaczonych frakcji, wyrażona w procentach wagowych, wynosiła co najmniej 98%. Zatem błąd analizy nie przekraczał 2%. Dla większości analiz nie przekraczał 1%. Metoda rozfrakcjonowania całości próbki określona skrótem TA, należy do podstawowych, klasycznych metod analizy składu granulometrycznego. Głównym przeznaczeniem tej metody jest sprawdzenie i weryfikacja metod skróconych, czy uproszczonych, czy częściowych, takich jak metody pipetowe, areometryczne, laserowe itp. Metoda ta może być wykorzystana w specjalistycznych badaniach naukowych, gdy ścisłość, poprawność i wiarygodność wyników analizy składu granulometrycznego jest szczególnie wysoka.

Druga metoda analizy składu granulometrycznego gleby określona skrótowo ALP, to metoda oparta na zasadzie metod pipetowych. Próbki z zawiesiny glebowej 1000 ml pobierane są pipetą o objętości około 38.5 ml, przy czym objętość pipetowania określana jest wagowo z dokładnością do 0.001 ml. Pipeta składa się z czterech rurkowych próbników o średnicy 1 cm i zagłębianych na głębokość 9.5 cm, pobierana zawiesina ze strefy 9.5-10.0 cm. Nieoznaczone metodą pipetową frakcje piasku (> 0.05 mm) analizowano metodą TA, odpławiając cząstki < 0.05 mm urządzeniem ssącym. Błąd analizy pipetowej mieścił się w przedziale -3% i +3%. Większość wyników miała błąd nie przekraczający 2%. Błędy były rozdzielne proporcjonalnie na poszczególne frakcje. Metoda pipetowa nadaje się do stosowania w badaniach naukowych, a przede wszystkim przeznaczonych dla potrzeb praktyki.