ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume 67 34 Number 2, 2019

COMPARISON OF DIFFERENT TEXTURE ANALYSIS FOR SOIL ERODIBILITY CALCULATIONS OF LOAMY AND SANDY-LOAM SOILS IN MORAVIAN REGIONS

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To link to this article: https://doi.org/10.11118/actaun201967020383
Received: 17. 1. 2019, Accepted: 23. 1. 2019

To cite this article: DUMBROVSKÝ MIROSLAV, LARIŠOVÁ LUCIE, SOBOTKOVÁ VERONIKA, KULIHOVÁ MARTINA. 2019. Comparison of Different Texture Analysis for Soil Erodibility Calculations of Loamy and Sandy-Loam Soils in Moravian Regions. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 67(2): 383–393.

Abstract

The subject of this article is a comparison of results of soil texture analysis of loamy and sandy-loam soils for soil erodibilty calculation using the Casagrande areometric method and results obtained by the laser diffraction method. A comparison was made of 27 samples taken from the Větřkovice locality, and 18 samples taken from the Hustopeče locality. On the basis of laboratory analysis of the soil samples, curves of grain composition were plotted, and the soils were divided into grain-size groups according to the ratio of individual fractions. For comparison of the results, the soils' regression dependence, with linear, exponential, quadratic and polynomic trends were derived. Applying these different methods for determining soil texture may affect the determination of K factor values and the value of soil loss. The results show that the laser diffraction method provides higher values of % silt and % silty sand at both model sites. Using the K values determining from Casagrande method measuring can led to the underestimation of soil erodibility. This underestimation can be explained by a change in particle size distribution between the described methods used.

Keywords: soil texture, soil grain fraction, areometric method, laser diffraction method, particle size distribution curve, soil erodibility factor, soil loss

INTRODUCTION

Soil texture is among the oldest recognised soil characteristics. It is determined by the proportional presence of various granular fractions of soil particles, expressed in percentage mass. Soil texture, or soil type, significantly influences the physical characteristics of the soil (structure, porosity and size distribution of pores in the soil), and therefore also the air-water ratio of the soil (Ledvina *et al.*, 2000).

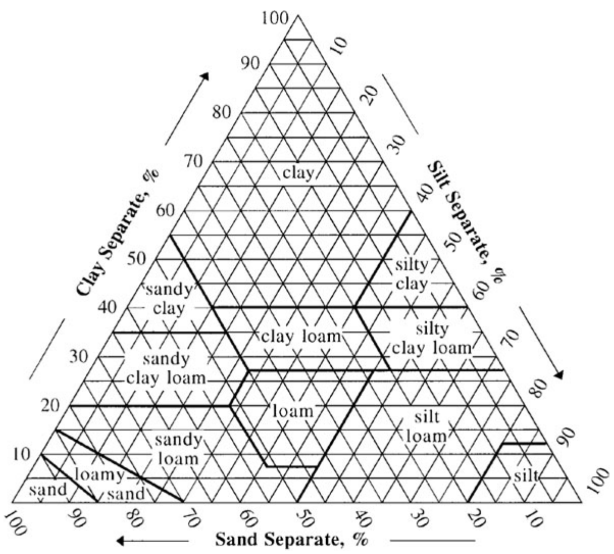
The importance of soil texture as an analytical characteristic and morphological feature is due to its influence on almost every other soil characteristic. It influences the air : water ratio in the soil, the ratio of capillary : non-capillary pores, the content and composition of soil biota, the total surface area and energy, adhesion and cohesion, chemical, physical-chemical and biochemical processes in the soil (Jandák *et al.*, 2007).

There are many methods of determining texture of soil profile. One of the standard, frequently used methods is the Casagrande's areometric method. This method falls into the group of non-repetitive sedimentation methods, i.e. all measurements are carried out during one, and the same, settling process (Sobotková, 2012). This is a very time-consuming method, where the results of measurement may be influenced by subjective errors, such as areometer readings, the temperature of the surrounding environment, etc. The current trend is to determine the particle-size distribution by means of direct and indirect optical methods. The direct methods include photographic and electronic recordings, while indirect methods make use of the relationship between grain size and the characteristics of scattered radiation. The laser diffraction method, advanced due to the development of computer technology (Jesenák, 2008), is among the most commonly used methods of analysis of particle size.

The presence of grain size fractions dictates the soil type, named according to the classification system used. In the Czech Republic the Kopecky's classification was used for a long time and is still used for the purpose of land amelioration (Valla *et al.*, 1980). However, for the purpose of complex soil research, grain size classification was carried out by means of the Novák's classification (Tab. I), which takes into consideration only the percentage of the first grain-size fraction, and divides soils as follows: 0–10% sand, 10–20% = loamy sand, 20–30% sandy loam, 30–45% loam, 45–60% clay loam, 60–75% clayey, 75–100% clay (Ledvina *et al.*, 2000). For the purposes of soil assessment, evaluation according to USDA soil texture triangle was used to categorise the main soil units in terms of grain characteristics of soil (Fig. 1). This soil texture triangle is based on the content of the three soil fractions: clay particles < 0.001 mm (according to international evaluation < 0.002 mm), fine and rough silt particles 0.001–0.05 mm, and fine

I: *Soil classes according to Novak's classification*

I. category (≤ 0,01 mm %)	Soil classes	Soil classification
0–10	sandy soil	light soil
10–20	loamy sand	light soil
20–30	sandy loam	medium soil
30–45	loam	medium soil
45–60	clay loam	heavy soil
60–75	clayey soil	heavy soil
≥ 75	clay	heavy soil



1: *Soil classes according to USDA soil texture triangle (Němeček et al., 2001)* and rough sand 0.05–2.0 mm (Mašát *et al.,* 2002). Němeček *et al.* (2001) recommend that the USDA soil texture triangle should be used in the Czech Republic as it features in the most recent taxonomic soil classification systems. In practice, the Novák's classification is most widely used.

MATERIALS AND METHODS

Experimental plots

The analysed disturbed soil samples were taken in the years 2013–2014 on experimental plots in the localities of Větřkovice and Hustopeče. Soil samples for assessment of soil erodibility factor were measured at a laboratory for soil texture – particle size distribution. (Tab. III).

Větřkovice

The first plot was located in the cadastral area of Větřkovice in the Vítkov district of the Moravia-Silesia region. The bedrock of the area comprises of greywackes and slates. The main soil units (MSU) present in the cadastral area are MSU 26 cambisol soils, acidic cambisol soils and their slightly gleizated forms on various slates and similar bedrock, moderately heavy, heavier in exceptional cases, generally gravelly with a good water ratio, even saturated.

Hustopeče

The second plot was located in the South Moravia region in the Břeclav district, and is part of the municipality of Hustopeče. The Hustopeče uplands, where the trial plot was situated, lie in the Moravian Flysch Belt. The dominant sediments are sandy, so-called Ždánické Sandstone with layers of marl. These are covered by layers of loess of various thicknesses. Loess is the soil-forming parent material in this area. Soils forming on this loess include carbonate chernozems, chernozems and carbonate meadow soils. In terms of the presence of MSU, the study area comprises: MSU 08 – modal, carbonate chernozem (CEmc), where the soil-forming substrate consists of loess, grain size – moderately heavy, predominantly without skeleton, the water ratio is favourable to dried-out; MSU 04 – arenic chernozem, soil-forming substrate of loess and neogene sands, grain size – moderately heavy to heavy, water ratio favourable, main characteristic – wash-off; MSU 22 – modal cambisol soil, soil-forming substrate – predominantly sandy sediments of marine Neogene, grain size – medium soil (Dumbrovský, 2014).

Casagrande's areometric method

Density of a suspension is measured in a graduated cylinder of 1000 ml capacity using a special areometer, and at given intervals the declining density of the suspension is determined as a function of time. The fall in density of the suspension is due to the gradual sedimentation of soil particles. The calibration of the areometer has a range of 1.000–1.030. The lower areometer limit defines the maximum concentration of the soil suspension at which the validity of Stokes law is not limited by the mutual interaction of particles. For practical purposes, in calculating the average grain size, the mean depth below the surface of the suspension is regarded as the sedimentation path (Kameníčková, 2013).

The percentage presence of the mass proportion of particles smaller than the enumerable average grain size in a given case:

$$O = \frac{100}{s} \times \frac{\rho_s}{\rho_s - 1}(R + c + m) \tag{1}$$

where s is the amount of soil for grain analysis converted into a solid (g), ρ_s is the particle density of the soil (g.cm^{-3}), R is the areometer reading (–), c is the meniscus correction of reading (–), m is the temperature correction ($m = 0.0055T^2 - 0.0373T - 1.44$) (–), T is the temperature of the suspension (°C), O is the proportional particle content at a given time of measurement (% density.) (Sobotková, 2012).

Grain size corresponding to the calculated density proportion (Stokes' ratio):

$$D = 10 \times \sqrt{\frac{18 \times \eta \times H_r}{g \times t \times (\rho_s - \rho_0)}} \tag{2}$$

where η is the dynamic viscosity of the liquid ($\eta = \nu \,.\, \rho$), (g.s^{-1}.cm^{-1}), H_r is the correction coefficient (cm), g is gravitational acceleration (cm.s^{-2}), t is the time measured (s), ρ_s is the particle density of the soil (g.cm^{-3}), ρ_o is the density of water (g.cm^{-3}), D is the average grain size (mm) (Sobotková, 2012).

Before measuring, the samples were free-dried in the laboratory, then ground and sieved through a 2 mm mesh. To ensure the homogeneity of the measured samples, the quartering method was used. A suspension was then prepared, to a volume of 1000 ml, containing 30 to 60 g of the prepared soil with an appropriate amount of dispersion agent (1 ml agent to 1 g of soil) topped up with water. The suspension was mixed thoroughly just before the start of measurement.

The temperature of the suspension was then measured, and the suspension was again mixed. Time t0 occurred after removal of the thermometer and completion of mixing. Measurement times from t0 were 30s, 1 min, 2 min, 5 min, 15 min, 45 min, 2.5 hours, up to a final measurement time of 24 hours. The areometer was withdrawn after each measurement and rinsed with distilled water. The density of the soil suspension was read at the upper capillary edge of the meniscus on the areometer stem.

Laser diffraction method

The laser diffraction method is an optical method used to measure particle size distribution and the scattering of electromagnetic waves by the particles. Two different theories can be used to calculate the particle size distribution: the Mie and Fraunhofer methods (Mie, 1908; Fraunhofer, 1815). The Mie theory is used to count smaller particles of an average size within the laser wavelength, similarly, particles with a lower refractive index, or a lower absorption coefficient. Larger particles with unknown optical parameters are counted using the Fraunhofer theory (Fritsch, 2016).

In order to measure the size of a single particle, a laser beam is directed at the particle. With the partial deflection of the laser beam, a characteristic circular division of intensity appears beyond the particle. This is measured by a specially shaped detector. The size of the particle is calculated from the spacing of these circles: large particles create circles close together, while the circles created by small particles are further apart (Fritsch, 2016).

An optimally dispersed sample is the basic requirement for reliable determination of particle distribution according to size. In most cases, the agglomerates must be spread out, and it is necessary to establish the correct concentration of particles of the sample material. Basically, the process of dispersion can be carried out either in an air-stream (dry dispersion), or in a liquid (wet dispersion) (Fritsch, 2016).

Grain size analysis by laser diffraction was carried out by wet dispersion, using Analysette 22 Microtec plus equipment from the Fritsch company, in the Department of Biometeorology and Hydrology at the Slovak University of Agriculture in Nitra, SK.

Before measuring, the samples were dried in the laboratory, then ground and sieved through a 2 mm mesh. To ensure the homogeneity of the measured samples, the quartering method was used. From this finely-prepared soil, a quantity of 10 g of soil was added to 10 ml of sodium metaphosphate to create a thick soil suspension. Dispersion took place over the course of 24 hours to ensure the disruption of bonds between aggregates. Just before measurement, the soil samples were exposed to the effect of ultrasound for the duration of 5 minutes. Thus the samples were ready for laser analysis (Kondrlová *et al.,* 2011).

Laser analysis was carried out according to MaScontrol guidelines, where a relevant range of standard operational processes were chosen. First of all, a measurement was taken of the light diffraction in the dispersion liquid without the presence of particles. This determined any impurity in the measuring cell, which could then be deducted from the subsequent measurement of the analysed sample. A small amount of the soil sample was measured into an ultrasound bath. Measurement was carried out over the entire range of the equipment. The Fraunhofer theory was chosen, with an automatic calculation model. The Analysette pump ensured the steady flow of dispersion liquid carrying the dissolved sample in the ultrasound bath and the measuring cell. Analysis of the measured samples was carried out in three repetitions and the suspension was then drained from the dispersion unit, which was cleaned out in preparation for the next measurement (Kondrlová *et al.*, 2011).

Determination of soil erodibility factor K and soil loss A

Applying these methods for determining texture (particle size distribution curve) may affect the determination of K factor values and the value of soil loss A (Tab. III).

The soil erodibility factor K values of these soil samples were calculated using the formula (3) assuming that the content of silt and silty sand (0.002–0.1 mm) does not exceed 70% (Wischmeier and Smith, 1978; Vopravil *et al.,* 2007; Janeček *et al.,* 2012):

$$100\,K = 2.1 \cdot M^{1.14} \cdot 10^{-4} \cdot (12 - a) + 3.25 \cdot (b - 2) + 2.5 \cdot (c - 3) \qquad (3)$$

where K is soil erodibility factor - must be multiplied by the coefficient 1.32 (Vopravil *et al.,* 2007; Janeček *et al.,* 2012) to get it in SI units (t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}), M is texture from the first 15 cm of soil surface M = (%silt + %silty sand) · (100%−%clay), a is soil organic matter content, b is soil structure code and c is permeability class.

If the content of silt and silty sand of these soil samples exceeded 70%, the K factor was determined using a nomogram (Janeček, 2012; Dufková *et al.*, 2005), where it is necessary to know the content of sand (0.1–2.0 mm).

Soil loss in the Czech Republic is estimated using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and is currently predicted using modified version for the soil erosion assessment in the process of Land Consolidation (Janeček *et al.*, 2012). Soil erodiblity factor K is one of the factors of the USLE (Wischmeier and Smith, 1978; Janeček *et al.*, 2012):

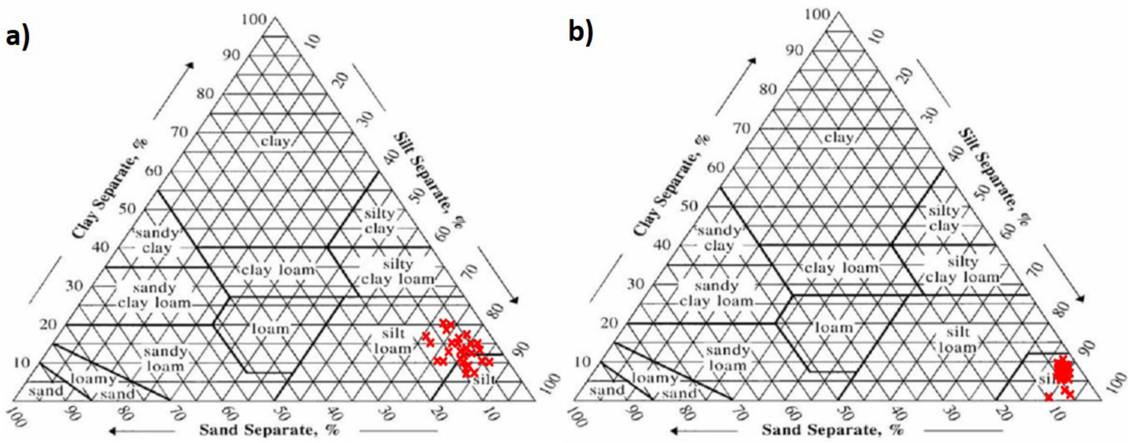
$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \tag{4}$$

Where A is soil loss (t. ha^{-1}.y^{-1}), R is rainfall erosivity factor (MJ.cm.ha^{-1}.h^{-1}.y^{-1}), K is soil erodibility factor (t.ha.h.ha^{-1}.MJ^{-1}.cm^{-1}), L is slope length factor (–), S is slope gradient factor (–), C is cropping cover management factor (–), P is management practice factor (–).

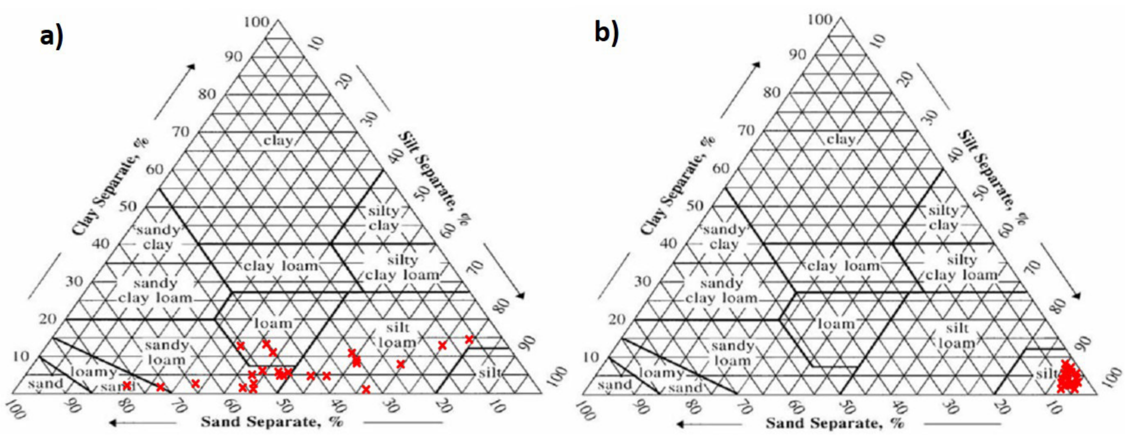
RESULTS AND DISCUSSION

On the basis of laboratory analysis of soil samples, particle - size distribution curves were calculated and soils were allocated to soil classes. Figs. 2, 3 show the results of analysis soil classes according to the USDA triangle.

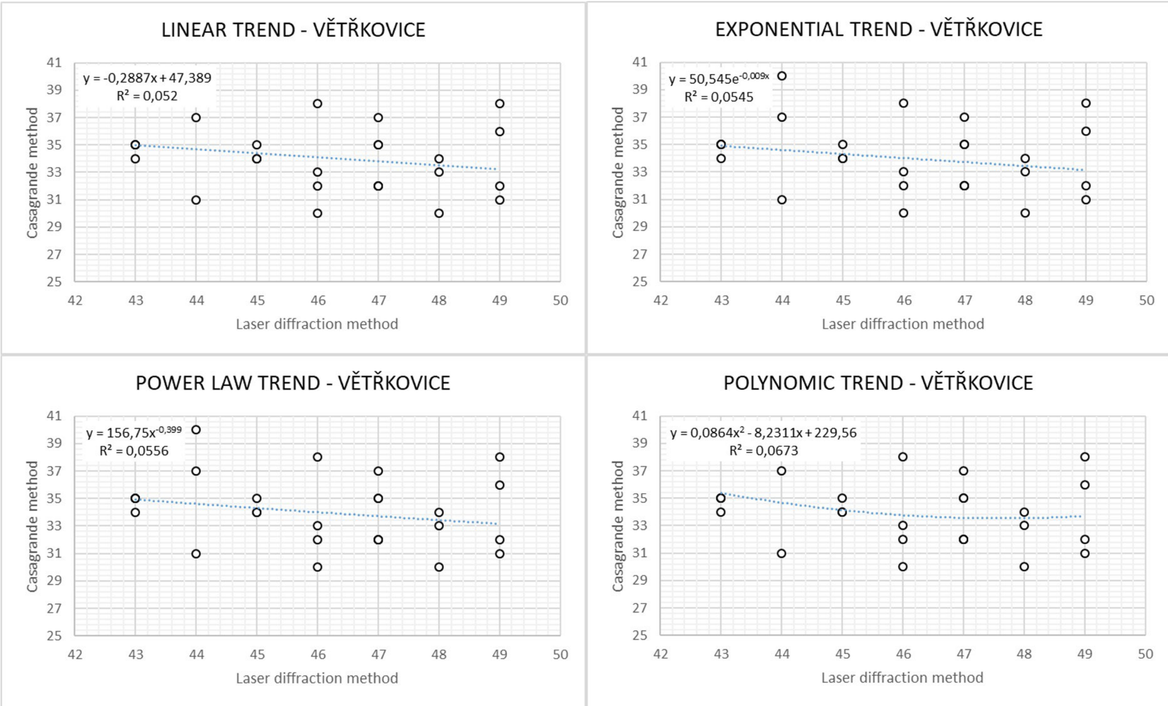
In order to compare the results of grain composition determined by the Casagrande method and the laser diffraction method, the I. fraction was evaluated according to Novák's classification (soil fraction < 0.01 mm). Their derived regression dependences with linear, exponential, power and polynomic trends are given in Figs. 4, 5 and in tabular form in Tab. II.



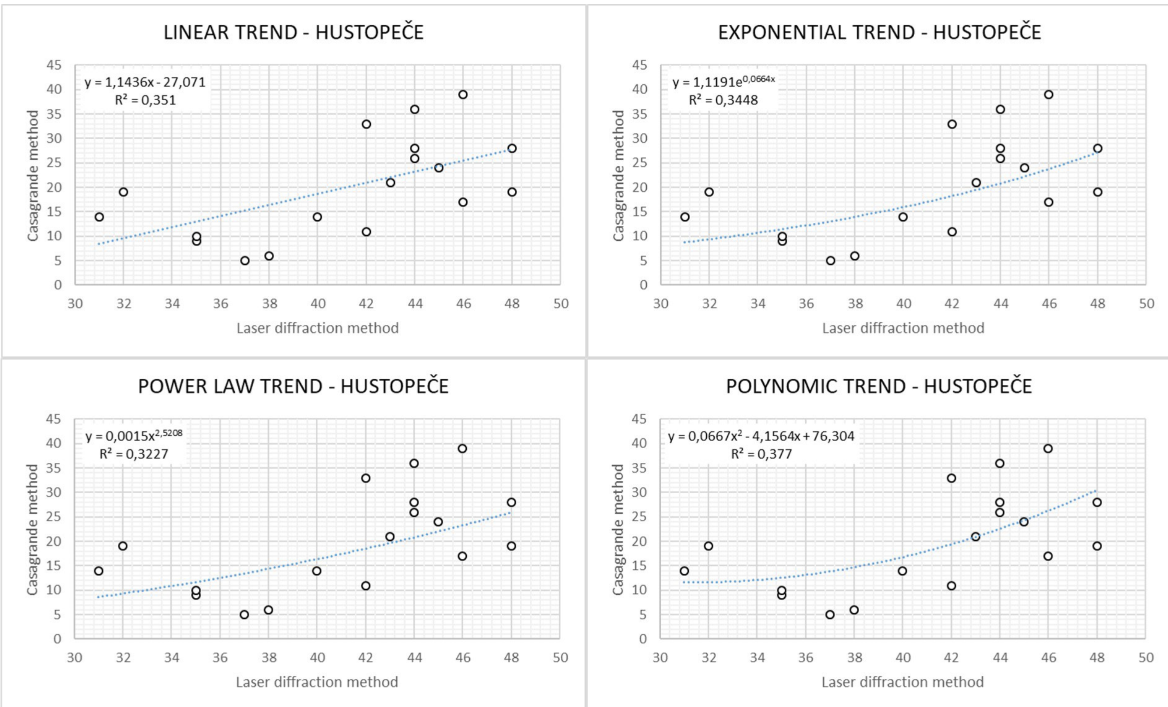
2: *Soil classes according to USDA soil texture triangle for the Větřkovice locality*
a) Casagrande method b) laser diffraction method
Source: own



3: **3:** *Soil classes according to USDA soil texture triangle for the Hustopeče locality*
a) Casagrande method b) laser diffraction method
Source: own



4: *Regression dependence values of grain fraction < 0.01 mm in % with linear, exponential, power law and polynomic trends for the Větřkovice locality.*



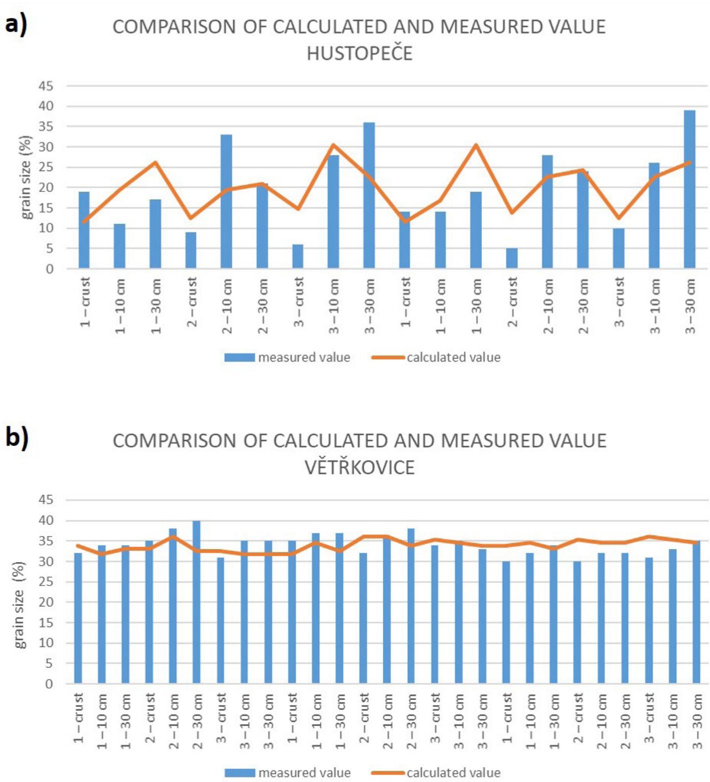
5: *Regression dependence values of grain fraction < 0.01 mm in % with linear, exponential, power law and polynomic trends for the Hustopeče locality.*

Of the stated relationships, one relationship with the highest R^2 value of determination was chosen for the Hustopeče locality and for the Větřkovice locality. The measured values of grain fraction < 0.01 mm were substituted into the selected equations for the term x. Thus, the estimated values were calculated for the Casagrande method. A comparison of calculated and measured values of grain fraction < 0.01 mm for the Casagrande method is shown in Fig. 6.

Statistical regression analyses (Figs. 4, 5) as well as particle size distribution curve (Figs. 7, 8) show the differences between the two methods used - laser diffraction and Casagrande. Differences can be caused by differences in the preparation of samples, or an error caused by human factor in reading

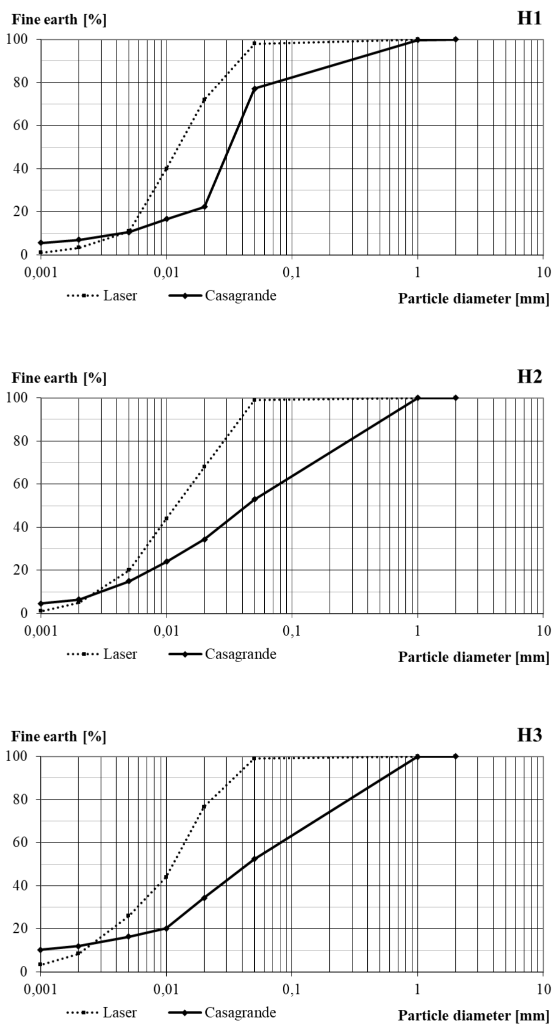
II: *1 Regression dependence and R^2 reliability value for grain fraction values < 0.01 mm*

	VĚTŘKOVICE	
Trend	**Equation on trend line**	**Value of determination R^2**
Linear	$y = -0{,}2887.x + 47{,}389$	0,0520
Exponential	$y = 50{,}545.e^{-0{,}009x}$	0,0545
Power law	$y = 156{,}75.x^{-0{,}399}$	0,0556
Polynomic	$y = -0{,}0864.x^2 - 8{,}2311.x + 229{,}56$	0,0673
	HUSTOPEČE	
Trend	**Equation on trend line**	**Value of determination R^2**
Linear	$y = 1{,}1436.x - 27{,}071$	0,3510
Exponential	$y = 1{,}1191.e^{0{,}0664x}$	0,3448
Power law	$y = 0{,}0015.x^{2{,}5208}$	0,3227
Polynomic	$y = 0{,}0667.x^2 - 4{,}1564.x + 76{,}304$	0,3770

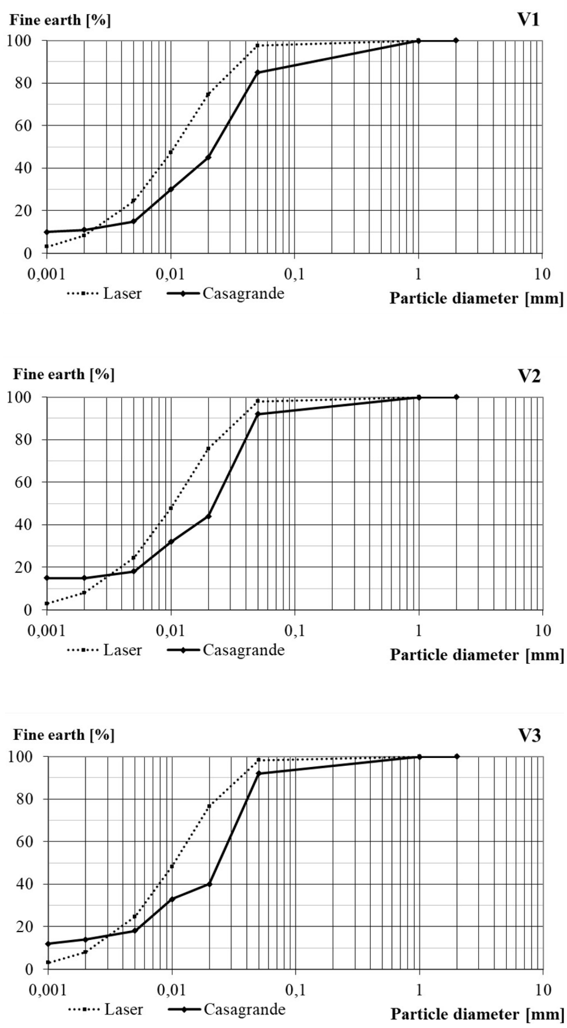


6: *Comparison of calculated and measured values of grain fraction < 0.01 for the Casagrande areometric method for a) Hustopeče and b) Větřkovice locality* the areometer, or error due to the surrounding environment. Also other foreign authors (Centeri, 2002; Centeri *et al.,* 2015; Kondrlová *et al.,* 2013) deal with a comparison of the standard methods with the laser diffraction method by means of regression analysis. Most commonly, the laser diffraction method is compared with the pipette method. Foreign authors use various ranges of measurement, various methods of preparation of soil samples, various types of equipment (Analysette 22 MicroTec plus, MalvernMasterSiz E, Coulter LS100, Coulter LS230, among others) with various ranges of measurement, and grain fraction results are evaluated according to various classification systems (Kopecký, Novák, USDA / FAO). According to Eshel *et al.* (2004), the laser diffraction method is advantageous in terms of the short time required for analysis of soil samples, the small amount of the sample required, the high reproduction rate, the range of measurement and the wide range of fraction classes. The disadvantage is the problematic interpretation of results due to the relatively low number of analyses carried out in comparison with the great number of analyses carried out using the classical methods. Despite the many advantages, there is no unified approach to the preparation of soil samples for analysis. A further problem is that the distribution of grain fractions determined by the laser method is not comparable with that of classical methods in the ratio of 1:1 (Vandecasteele, 2001).

Soil erodibility depends on the set of soil properties of a specific soil analysis (especially texture analysis – particle size distribution curve) for soil loss predictions.



7: *Particle size distribution curve – Hustopeče localities H1–H3 – depth 10 cm*



8: *Particle size distribution curve – Větřkovice localities V1–V3 – depth 10 cm*

Three plots were selected in each case study area (Hustopeče H1–H3, Větřkovice V1–V3). The particle size distribution curve was generated from the collected samples (Tab. III) and K factor and soil loss were determined based on the values were obtained (Tab. IV).

Views of soil loss for Laser diffraction method and Casagrande's areometric method for the both locality Hustopeče and Větřkovice are shown in Fig. 9. At the figures it is possible to see soil loss generated using GIS systems.

The results show that the laser diffraction method provides higher values of % silt and % silty sand at both model sites (Figs. 7, 8). This influences the K factor value as one of the important USLE factors, as well as the total value of the soil loss (Tab. IV).

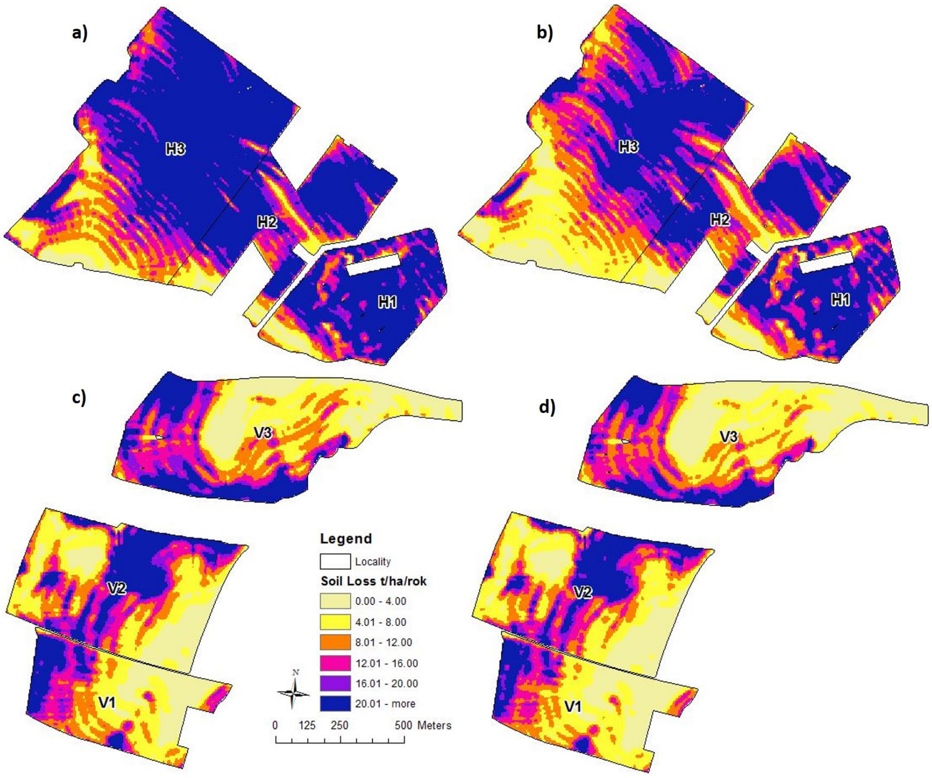
III: *Soil texture - particle size distribution curve in %*

	Ø [mm]	1.0	0.1	0.05	0.02	0.01	0.005	0.002	0.001	< 0.001
H1	**Laser**	0.0	1.0	1.0	25.3	31.7	29.6	7.7	2.3	1.4
	Casagrande	0.3	17.7	4.8	54.9	5.6	6.2	3.5	1.4	5.6
H2	**Laser**	0.0	1.0	1.5	30.5	23.3	23.7	15.0	4.0	1.0
	Casagrande	0.1	34.9	12.1	18.5	10.4	9.1	8.4	1.9	4.6
H3	**Laser**	0.0	0.5	0.5	22.4	32.6	18.0	17.5	5.2	3.3
	Casagrande	0.2	37.8	9.6	18.0	14.2	3.8	4.4	1.8	10.2
V1	**Laser**	0.0	1.9	0.5	22.9	27.4	22.6	16.3	5.3	3.1
	Casagrande	0.1	11.9	3.2	39.7	14.5	14.3	3.8	2.5	10.0
V2	**Laser**	0.0	1.9	0.5	22.9	27.4	22.6	16.3	5.3	3.1
	Casagrande	0.1	5.9	8.7	39.8	14.3	15.7	4.2	1.3	10.0
V3	**Laser**	0.0	1.0	0.8	21.6	28.3	23.6	16.7	5.0	3.0
	Casagrande	0.1	5.9	1.1	52.9	7.2	14.5	4.8	1.5	12.0

IV: *Soil properties for soil erodibility factor assessment*

Methods	Locality	M	a	b	c	K	A
		%	%	-	-	$t.ha.h.ha^{-1}.MJ^{-1}.cm^{-1}$	$t.ha^{-1}.year^{-1}$
Laser	**H1**	9177.4	2.3	2	3	0.70	28.00
	H2	8930.0	2.1	2	3	0.69	25.58
	H3	8326.5	2.0	2	3	0.64	30.54
	V1	8216.5	1.6	3	2	0.70	10.72
	V2	8216.5	1.2	3	2	0.72	13.56
	V3	8372.0	1.4	3	2	0.70	12.53
Casagrande	**H1**	6975.0	2.3	2	3	0.57	22.80
	H2	5469.8	2.1	2	3	0.50	18.54
	H3	4400.0	2.0	2	3	0.39	18.61
	V1	6606.3	1.6	3	2	0.62	9.50
	V2	7335.5	1.2	3	2	0.65	12.25
	V3	6963.3	1.4	3	2	0.60	10.74

Where M is texture from the first 15 cm of soil surface M = (% silt+% silty sand) · (100–% clay), a is soil organic matter content (V1–V3: medium or coarse granular = 3, H1–H3: fine granular = 2), b is soil structure code and c is permeability class (V1–V3: moderate to rapid = 2, H1–H3 moderate = 3), K is soil erodibility factor ($t.ha.h.ha^{-1}.MJ^{-1}.cm^{-1}$), A is soil loss ($t.ha^{-1}.y^{-1}$).



9: *Determination of Soil loss using a) Laser diffraction method and b) Casagrande's areometric method for Hustopeče localities H1–H3 and by c) Laser diffraction method and d) Casagrande's areometric method for Větřkovice localities V1–V3.*

CONCLUSION

Standard methods of determining soil texture, including the Casagrande method, are being progressively replaced by the laser diffraction method in research carried out abroad. The advantages of this method are the short time required for analysis, the use of small soil samples, the use of results for tasks in various classification systems, and the wide range of measurement and classification of fractions. The laser diffraction method, unlike the standard methods, is also capable of evaluating the percentage presence of very small clay particles. Additionally, using different methods in sampling particle size distribution measuring and modelling leads to differences in the estimate of K factor. The different values of K factor affect the prediction of soil loss. According to the Czech Methodology of Soil Erosion Control (Janeček *et al.*, 2012) the K factor value for Cambisol soils is 0.41 and for modal Chernozem soils is 0.49 $t.ha.h.ha^{-1}.MJ^{-1}.cm^{-1}$. Using the K values determining from Casagrande method measuring can led to the underestimation of soil erodibility. This underestimation can be explained by a change in particle size distribution between the described methods used. These differences might be important when erosion estimates are required for design of soil and water conservation measures.

Acknowledgements

This paper was supported by the Czech National Agency for Agricultural Research (Project No. QJ1520268 and Project No. QK1720303).

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