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APPLICABILITY OF UNIDIMENSIONAL SOIL PARTICLE SIZE DISTRIBUTION CHARACTERISTICS TO PLANT ECOLOGY*

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A b s t r a c t. The subject of the research was unidimensional indices (characteristics) of mineral soil particle size distribution: mass fractal dimension of soil particle size distribution, grain-size distribution index, mean particle diameter and the product of the two latter. Among the four above-mentioned indices, the three former are known from previous studies and the latter was proposed by the authors. The work is an attempt to answer the question which of these indices best describes the granulometric composition of mineral soils as a factor differentiating the species composition of vegetation. The experimental area was a one hectare fallow composed of soils of five different textural classes. The ruderal plant cover of the fallow was mechanically destroyed and several dozen semi-natural grassland species were sown on bare soil. The seeds were thoroughly mixed and evenly distributed over the entire experimental area. Then, 39 permanent plots were regularly deployed across the experimental area. In the following year, the frequency of the emerging seedlings and juveniles of the sown plant species was estimated and the texture of the soil surface layer was analysed in the permanent plots. Statistical analysis performed by fuzzy set ordination method indicated that the product of grain-size distribution index and mean particle diameter is the most appropriate unidimensional granulometric characteristic of the soil particle size distribution as a plant community assembly driver.

K e y w o r d s: soil particle size distribution, seedling and juvenile recruitment, grain-size distribution index, fractal dimension of soil particle size distribution, mean particle diameter

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CHARACTERISATION OF PROBLEM SITUATION AND OBJECTIVE OF THE STUDY

The particle size distribution of mineral soil and, closely related with it, structure of the soil and its hydrophysical properties, constitute an important factor differentiating vegetation. In the most extensive and commonly cited collection of information on the conditions of occurrence of plant species in Poland - *Ecological indicator values of vascular plants of Poland* by Zarzycki *et al.* (2002), the ecological role of soil granularity is considered in parallel to the role of such soil factors as moisture, trophy/fertility, acidity and organic matter content.

Due to the abundance of factors differentiating (and differentiated by) vegetation, frequently interrelated and with large ranges of variation, in ecological statistical analysis we tend to express particle size distribution by means of unidimensional characteristics. The literature provides several such unidimensional characteristics that can be expressed in a ratio scale and that can, at the same time, represent the particle size distribution of soil over the whole range of its variation (Tyler and Wheatcraft 1992, Ryżak *et al.* 2009). However, information concerning exclusively the weight shares of standard particle size fractions (Polish Society of Soil Science 2008, Soil Survey Staff 1999) constituting a given formation permits the determination of only two of those characteristics: the mass fractal dimension of particle size distribution and the statistical mean diameter of soil particle. In the study presented here we propose a third characteristic meeting these criteria – the product of the grain size distribution index and the mean particle diameter.

Mass fractal dimension of particle size distribution

Methods of describing soil by means of the fractal theory (Mandelbrot 1982) have been developed since the end of the 20th century when it was demonstrated that the soil, as a porous medium, has fractal properties (Turcotte 1986, Tyler and Wheatcraft 1992). According to that theory, the fractal dimension is a value describing the whole geometric object under study, i.e. in the case of soil it represents the particle size distribution throughout the range of particle sizes forming the solid phase of soil. Bittelli *et al*. (1999) demonstrated, however, that for standard ranges of particle sizes (Polish Society of Soil Science 2008, Soil Survey Staff 1999) the fractal dimension assumes various values, and therefore the fractal theory does not permit the description of the whole particle size distribution of a mineral soil by means of a single value of fractal dimension. In spite of that, results of such research are still being published (Gui *et al.* 2010, Liu *et al.* 2009).

For the 39 soil formations analysed in this study (see Appendix), the fractal dimension values had low coefficients of determination assigned, mean of 0.84 and in the case of two soils even below 0.70 (see Appendix), which in the light of the conclusions formulated by Bittelli *et al.* (1999) puts in question the correctness of application of the method. Nevertheless, this relatively new and mathematically "elegant" method appears to be prospective, as it applies also to organic soils and one can hope for its improvement in the future. For these reasons it was also subjected to the test of applicability for the description of the relationship between soil particle size distribution and the species composition of vegetation.

The mass fractal dimension of the particle size distribution was calculated according to the formula (Tyler and Wheatcraft 1992):

$$\frac{P_i}{P} = \left(\frac{S_{i,max}}{S_{max}}\right)^{3-D_m}, \tag{1}$$

where: D_m – mass fractal dimension of particle size distribution (-),
P_i – cumulative mass of soil particles (% w.) with diameters smaller than S_i,
P – total mass (%) of analysed soil formation, here: 100% w.
$S_{i,\,max}$ – maximum equivalent diameter of particles (mm) of *i*-th particle size fraction,
S_{max} – maximum equivalent diameter of particles (mm) from the range of diameters for which the fractal dimension is calculated (here: S_{max} = 2.0 mm),

Statistical mean diameter of soil particles, defined by the formula (Walczak 1984):

$$D_{cz} = \frac{\sum_{i=1}^{n}\left[\frac{S_{i,max} + S_{i,min}}{2} * \left(P_{i+1} - P_i\right)\right]}{100\%}, \tag{2}$$

where: D_{cz} – mean particle diameter of the mineral soil formation (mm),
$S_{i,\,min}$ – minimum equivalent diameter of particles of *i*-th fraction (mm).
(P_{i+1} - P_i) – content of *i*-th fraction (% w.),
n – number of fractions (-),
and remaining symbols as in formula (1).

The limitation of this measure is that – like any mean value – it only informs about a centric tendency and does not provide any information about the scatter of the value being characterised. Complete description of particle size distribution would require the supplementation of the statistical mean particle diameter with a certain measure of scatter, i.e. variance or standard deviation.

Product of grain size distribution index and statistical mean diameter of particles composing the soil formation

The grain size distribution index has been developed by Giesel *et al.* (1972). It constitutes a mathematical description of the cumulative distribution function of particle size distribution, plotted in a Cartesian system of coordinates, where both the axis of ordinates and the axis of abscissa represent values in a logarithmic scale. In the graph of the curve of particle size distribution, the axis of abscissa represents the values of equivalent diameters (S_i), and the axis of ordinates the values of percentage content by weight of the particle size fractions composing a given soil formation. The grain size distribution index is calculated from the formula:

$$f = \frac{\sum_{i=1}^{n}\left(\left(P_{i+1} - P_i\right) * \frac{\log_{10}(P_{i+1} / P_i)}{\log_{10}(S_{i+1,max} / S_{i,max})}\right)}{\sum_{i=1}^{n}(P_{i+1} - P_i)}, \tag{3}$$

where: f is the grain size distribution index (-) and the remaining symbols are as in formulae (1) and (2).

The mathematical construction of the grain size distribution index limits its application to the characterisation of particle size distribution of formations composed of the same particle size fractions, i.e. it cannot be used for the comparison of a formation composed e.g. of only fine earth particles (d ≤ 2 mm) with a formation with a considerable content of rock fragments (d > 2 mm). To be able to characterise the particle size distribution of soils throughout the whole range of its variation one should construct an index that would be a product of the particle size distribution index calculated for the fine earth and some measure of distribution calculated for all fractions composing a given soil formation. Such a measure could be the statistical mean particle diameter described above, or a median of the diameters of soil particles composing a given soil formation. An accurate readout of a median value is possible under the condition that the share by weight of the finest or the coarsest grain fractions does not exceed 50%, and for the standard fraction intervals (Polish Society of Soil Science 2008, Soil Survey Staff 1999) that condition is not always fulfilled. This observation relates not only to the median, but also to all other centiles. For this reason, in this study we consider only the product of the grain size distribution index and the mean particle diameter.

METHODS

In the estimation of the applicability of various characteristics of soil particle size distribution for the description of its relations with vegetation we adopted the assumption that the better characteristic is that which provides better explanation of the species composition of vegetation. The experimental object in that estimation was a former fallow with an area of 1 ha, situated in the “Serebryskie Mire” Nature Reserve near the town of Chełm (51°10'16'N, 23°32'01”E), covering soil formations representing five different soil textural classes: sandy loam, light loam, loam, loamy sand, and clayey sand (see Appendix). The ruderal plant cover of the experimental area was destroyed through the application of deep ploughing in 2008, and systematic tillage treatments with harrows and cultivators conducted from June till October 2009. At the end of 2009 seeds of several dozen species of plants were sown on the experimental area, the seeds having been collected in that year by means of petrol leaf vacuums, two handheld and one wheeled. The seed collection was conducted on *Molinia* meadows and xerothermic grasslands, situated within the Reserve or close to its boundaries. Prior to the sowing, the seeds were thoroughly mixed, thanks to which at any point of the experimental area the same species were sown, with the same numbers of seeds. In 2010, on the experimental area 39 permanent experimental plots were established, each in the form of a square with area of 4 m^2. The permanent plots were uniformly distributed over the whole experimental area. In January 2011, from each permanent plot soil samples were taken, using a spade, from the layer of 0-8 cm. The weight of a fresh sample was ca. 0.5 kg. The soil samples were subjected to the standard analysis of particle size distribution (PN-R-04032:1998 1998). The results were used for the calculation of the abovementioned characteristics of particle size distribution (see Appendix). The analysis revealed that all the formations were composed almost solely of fine earth particles; rock fragments appeared only in a few samples and accounted in them for less than 0.5% of the mass of the soil formation (see Appendix), which is why they were not taken into account in the calculations.

In August 2011, on each permanent plot vegetation was described, noting the frequency of individuals of all species sown. The frequency was estimated with the use of a square frame, with side of 2 m, divided into 16 squares, each with side of 0.5 m. Adequately to the frequency of occurrence, the particular species were assigned frequency ratings as follows:

0 – species did not appear at all,

1/16 – species appeared in one square,

3/16 – species appeared in 2-4 squares,

6.5/16 – species appeared in 5-8 squares,

12.5/16 – species appeared in 9-16 squares.

Statistical analysis was performed for those species sown that did not grow on the fallow prior to the experiment, and in 2010 occurred significantly more frequently than in the neighbourhood, where they were not sown. There were 32 such species (see Appendix).

The estimation of particle size distribution characteristics in terms of their applicability for representing the particle size distribution as the factor differentiating the vegetation of the permanent plots was performed according to the following statistical procedure:

1. Matrix of dissimilarity was created for the phytosociological relevés representing the particular permanent plots. The Euclidean dissimilarity was selected as the index of distance (Dzwonko 2007), as that measure includes information on simultaneous absence of a given species in both relevés from a pair for which it is calculated (Anderson *et al.* 2011).

2. The matrix was subjected to the Hellinger transformation which is recommended in the case of utilisation of Euclidean dissimilarity in the construction of matrices of ecological data (Legendre and Gallagher 2001)

2. A test was conducted to find out to what degree the particular indices of particle size distribution ordinate the matrix created. The test included all three indices of particle size distribution described above, the fractions of clay, silt, sand and all of their possible combinations, and the grain size distribution index. The test was performed with the method of fuzzy set ordination (Borysławski 1991). The significance of results (*p*-values) was estimated with the permutation test at 10000 iterations (Roberts 2008).

RESULTS AND DISCUSSION

In the test (Tab.1) four statistically significant correlations were obtained (p-values < 0.05). This result confirms that the particle size distribution significantly affects the species composition of vegetation.

Table 1. Relationship between the tested characteristics of soil particle size distribution and vegetation species composition (estimated with fuzzy set ordination of Euclidean dissmilarity matrix after Hellinger's transformation); symbols: r – correlation coefficient, p – p-value (probability of obtaining the correlation by chance), f - soil particle size distribution index, D_{cz} – mean particle diameter, D_m – mass fractal dimension of soil particle size distribution.

Index of soil particle size distribution	r	p
f * D_{cz}	0.40	0.011
f	0.35	0.023
Clay and sand	0.32	0.036
Silt	0.32	0.032
Sand	0.27	0.059
Clay and silt	0.27	0.061
D_{cz}	0.27	0.058
Silt and sand	–0.12	0.623
Clay	–0.12	0.629
D_m	0.01	0.413

The highest value of the coefficient of correlation (r) and the lowest *p*-value were obtained for the product of the grain size distribution index and the mean particle diameter of a given soil formation ($r = 0.40$ and $p = 0.011$). Therefore, the test shows that that index is the best for the description of the relation between vegetation and the particle size distribution of the soil. Probably the coefficient of correlation (r) would be higher still after the "calibration" of the product consisting in raising one or both of the factors to a power with exponent different than 1.

On its own, the grain size distribution index, in spite of the relatively high value of the coefficient of correlation ($r = 0.35$), is not representative for formations composed of various particle size fractions (see above), and thus cannot be considered as a universal characteristic of particle size distribution. The other characteristics: fractal dimension and mean particle diameter, describe that relation less accurately than selected particle size fractions or some of their combinations, and thus are not applicable for the purpose.

The design of this experiment and the research methods and techniques applied permitted precise determination of the applicability of various unidimensional characteristics of particle size distribution for the description of its relation with vegetation, mainly with species commonly occurring in communities belonging to the orders *Molinietalia*, *Arrhenatheretalia* and to the class *Festuco-Brometea* (Matuszkiewicz 2001). However, the applicability of those characteristics to other plant communities or soils may differ, as (1) this study was concerned with plants at the stage of their germination and emergence, and the relation between vegetation and soil texture at the stage of colonization of bare soil may be different from that after the plant cover has become dense, when inter-species relations, competition in particular, assume greater importance, and (2) the experiment was conducted on a single and relatively small area, due to which the differences in the texture of the particular soil formations were relatively small, and thus we do not know whether the results would be similar in the case of formations not included in this analysis, e.g. loose sands or gravels.

CONCLUSIONS

1. The particle size distribution of mineral soil has a significant effect on the species composition of vegetation.
2. The unidimensional index of particle size distribution proposed here, i.e. the product of the grain size distribution index and the mean particle diameter, is a characteristic more applicable in plant ecology than the mass fractal dimension of soil particle size distribution, statistical mean particle diameter, or the content of clay, silt or sand fractions or any combination of those fractions.
3. In the case of soil formations with rock fragments content above 5%, the characteristic proposed should be the product of the grain size distribution index calculated for the fine earth particles ($d \leq 2$ mm) and the mean particle diameter calculated for the full range of particle sizes making up a given soil formation.
4. The characteristic proposed requires further studies on its applicability for grassland communities with dense plant cover (not at the stage of vegetation establishment), and for non-grassland communities and soils with more varied texture, especially with a higher content of rock fragments ($d > 2$ mm).

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Appendix: Soil particle size distribution, and various indices of the soil granulometric composition and average occurrence of analysed species on the permanent plots

Table A. Soil particle size distribution and various indices of the soil granulometric composition in the permanent plots. Symbols as in the previous tables

Permanent plot	Clay (%)	Silt (%)	Sand (%)	Clay and silt (%)	Clay and sand (%)	Silt and sand (%)	D_{cz} (mm)	f (-)	f x D	D_m (-)	R^2 Determination coefficient for D_m	Soil textural class	Share of the particles > 2 mm (%)
A1	11	12	77	23	88	89	0.79	0.38	0.30	2.68	0.99	gp	0.0
E1	11	11	78	22	89	89	0.80	0.39	0.31	2.68	0.99	gp	0.0
A3	15	9	76	24	91	85	0.78	0.36	0.28	2.72	0.99	gp	0.0
C3	11	8	81	19	92	89	0.83	0.43	0.36	2.68	1.00	pg	0.0
E3	15	21	64	36	79	85	0.66	0.31	0.21	2.71	0.96	gl	0.0
G3	17	33	50	50	67	83	0.52	0.28	0.14	2.74	0.88	gz	0.0
A5	16	19	65	35	81	84	0.67	0.28	0.19	2.73	0.96	gl	0.0
C5	16	26	58	42	74	84	0.60	0.27	0.16	2.72	0.93	gl	0.0
E5	19	33	48	52	67	81	0.50	0.24	0.12	2.76	0.87	gz	0.0
G5	14	39	47	53	61	86	0.49	0.30	0.15	2.71	0.83	gz	0.3
A6	15	29	56	44	71	85	0.58	0.29	0.17	2.72	0.91	gl	0.0
E6	19	33	48	52	67	81	0.50	0.24	0.12	2.76	0.87	gz	0.0
I4	17	46	37	63	54	83	0.39	0.33	0.13	2.74	0.75	gz	0.0
I8	15	52	33	67	48	85	0.35	0.33	0.12	2.72	0.68	pyi	0.3
I10	20	48	32	68	52	80	0.34	0.27	0.09	2.76	0.69	gz	0.0

K4	19	36	45	55	64	81	0.47	0.26	0.12	2.75	0.84	gz	0.0
K6	15	41	44	56	59	85	0.46	0.29	0.13	2.72	0.80	gz	0.0
K10	17	46	37	63	54	83	0.39	0.29	0.11	2.75	0.74	gz	0.0
K14	24	39	37	63	61	76	0.39	0.22	0.09	2.79	0.77	gz	0.0
M6	12	43	45	55	57	88	0.47	0.31	0.15	2.69	0.80	gz	0.0
M8	15	41	44	56	59	85	0.46	0.29	0.14	2.72	0.81	gz	0.0
M10	12	36	52	48	64	88	0.54	0.33	0.18	2.68	0.86	gl	0.0
M14	18	36	46	54	64	82	0.48	0.25	0.12	2.75	0.84	gz	0.4
O6	18	43	39	61	57	82	0.41	0.26	0.11	2.75	0.76	gz	0.0
O10	25	41	34	66	59	75	0.36	0.24	0.08	2.79	0.73	gz	0.0
O12	21	39	40	60	61	79	0.42	0.26	0.11	2.77	0.80	gz	0.0
O16	19	29	52	48	71	81	0.54	0.25	0.14	2.75	0.90	gz	0.0
Q8	14	40	46	54	60	86	0.48	0.28	0.14	2.72	0.82	gz	0.5
Q10	17	37	46	54	63	83	0.48	0.26	0.13	2.74	0.84	gz	0.5
Q14	13	45	42	58	55	87	0.44	0.36	0.16	2.69	0.78	gz	0.1
Q16	19	36	45	55	64	81	0.47	0.24	0.12	2.76	0.84	gz	0.0
S10	12	29	59	41	71	88	0.61	0.32	0.19	2.69	0.92	gl	0.0
S12	17	36	47	53	64	83	0.49	0.26	0.13	2.74	0.84	gz	0.0
S16	12	39	49	51	61	88	0.51	0.31	0.16	2.70	0.81	gz	0.0
U10	10	29	61	39	71	90	0.63	0.34	0.22	2.65	0.90	gl	0.0
U14	18	31	51	49	69	82	0.53	0.24	0.13	2.74	0.87	gl	0.0
U16	14	36	50	50	64	86	0.52	0.28	0.14	2.72	0.84	gz	0.0
W12	12	40	48	52	60	88	0.50	0.30	0.15	2.70	0.83	gz	0.2
W16	15	36	49	51	64	85	0.51	0.34	0.17	2.70	0.82	gz	0.0

Table B. Average frequency of occurrence of analysed species on the permanent plots

Permanent plot	*Anthoxanthum odoratum*	*Anthyllis vulneraria*	*Briza media*	*Campanula sibirica*	*Carex hirta*	*Carex sp.*	*Cynosurus cristatus*	*Deschampsia cespitosa*	*Dianthus superbus*	*Epilobium palustre*	*Euphrasia rostkoviana*	*Festuca rubra*	*Galium album*	*Galium boreale*	*Galium uliginosum*	*Galium verum*	*Geum rivale*	*Holcus lanatus*	*Juncus articulatus*	*Leontodon autumnalis*
A1	0.06	0.41	0.19	0.00	0.19	0.00	0.06	0.41	0.00	0.00	0.00	0.06	0.00	0.78	0.00	0.78	0.00	0.41	0.78	0.00
E1	0.19	0.41	0.19	0.00	0.00	0.00	0.06	0.19	0.19	0.00	0.00	0.19	0.19	0.19	0.00	0.78	0.00	0.78	0.06	0.00
A3	0.00	0.00	0.06	0.00	0.19	0.00	0.00	0.41	0.00	0.00	0.19	0.00	0.06	0.78	0.06	0.78	0.00	0.78	0.78	0.00
C3	0.00	0.41	0.41	0.00	0.00	0.00	0.00	0.06	0.19	0.00	0.00	0.19	0.19	0.19	0.00	0.78	0.06	0.78	0.00	0.00
E3	0.06	0.78	0.41	0.00	0.00	0.00	0.00	0.19	0.19	0.00	0.19	0.06	0.19	0.78	0.00	0.78	0.19	0.78	0.00	0.00
G3	0.19	0.41	0.00	0.06	0.00	0.00	0.19	0.19	0.06	0.00	0.19	0.19	0.19	0.19	0.00	0.78	0.06	0.41	0.00	0.00
A5	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.06	0.00	0.00	0.78	0.00	0.78	0.00	0.78	0.00	0.00
C5	0.00	0.19	0.06	0.00	0.00	0.00	0.19	0.00	0.19	0.00	0.00	0.19	0.19	0.41	0.00	0.78	0.00	0.78	0.00	0.00
E5	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.06	0.00	0.00	0.19	0.00	0.41	0.00	0.78	0.06	0.00	0.00	0.00
G5	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.19	0.06	0.00	0.06	0.00	0.00	0.78	0.00	0.78	0.00	0.78	0.00	0.00
A6	0.00	0.78	0.06	0.00	0.41	0.00	0.19	0.19	0.00	0.00	0.78	0.00	0.00	0.78	0.00	0.78	0.00	0.78	0.00	0.00
E6	0.06	0.41	0.06	0.00	0.00	0.00	0.19	0.41	0.00	0.00	0.06	0.06	0.19	0.41	0.00	0.78	0.19	0.78	0.00	0.00
I4	0.06	0.19	0.41	0.00	0.19	0.00	0.19	0.19	0.06	0.00	0.00	0.00	0.00	0.78	0.00	0.78	0.19	0.78	0.19	0.00
I8	0.00	0.78	0.06	0.00	0.00	0.00	0.00	0.41	0.19	0.00	0.00	0.41	0.19	0.78	0.00	0.78	0.19	0.78	0.00	0.00
I10	0.00	0.41	0.78	0.00	0.00	0.00	0.19	0.19	0.19	0.00	0.19	0.19	0.41	0.78	0.00	0.78	0.19	0.78	0.00	0.00
K4	0.00	0.78	0.19	0.00	0.00	0.00	0.06	0.41	0.00	0.00	0.19	0.41	0.06	0.78	0.00	0.78	0.06	0.78	0.19	0.00
K6	0.06	0.78	0.00	0.00	0.00	0.00	0.19	0.41	0.19	0.00	0.06	0.41	0.19	0.78	0.00	0.78	0.41	0.78	0.00	0.06

K10	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.78	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.19	0.19	0.00	0.78	0.00
K14	0.00	0.19	0.06	0.00	0.00	0.00	0.19	0.41	0.06	0.00	0.00	0.00	0.19	0.78	0.00	0.78	0.00	0.78	0.00	0.06
M6	0.00	0.19	0.00	0.00	0.00	0.00	0.06	0.19	0.06	0.00	0.41	0.19	0.06	0.78	0.00	0.78	0.19	0.78	0.00	0.19
M8	0.00	0.41	0.19	0.00	0.06	0.00	0.19	0.78	0.00	0.00	0.00	0.41	0.19	0.78	0.00	0.78	0.19	0.78	0.78	0.06
M10	0.00	0.78	0.06	0.00	0.00	0.00	0.19	0.19	0.06	0.00	0.00	0.41	0.41	0.78	0.00	0.78	0.19	0.78	0.41	0.19
M14	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.19	0.19	0.78	0.00	0.78	0.06	0.00	0.00	0.06
O6	0.00	0.41	0.06	0.00	0.00	0.00	0.06	0.06	0.06	0.00	0.19	0.41	0.19	0.78	0.00	0.78	0.06	0.41	0.00	0.00
O10	0.00	0.78	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.19	0.41	0.41	0.78	0.00	0.41	0.19	0.19	0.00	0.00
O12	0.00	0.19	0.06	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.41	0.19	0.00	0.78	0.00	0.78	0.00	0.41	0.00	0.00
O16	0.00	0.19	0.06	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.19	0.19	0.00	0.78	0.00	0.78	0.06	0.06	0.00	0.00
Q8	0.00	0.41	0.00	0.00	0.00	0.00	0.06	0.78	0.00	0.00	0.19	0.78	0.19	0.78	0.00	0.78	0.06	0.41	0.00	0.00
Q10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.06	0.19	0.19	0.78	0.00	0.78	0.00	0.19	0.00	0.00
Q14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.06	0.00	0.00	0.41	0.00	0.78	0.00	0.78	0.00	0.19	0.00	0.06
Q16	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.78	0.00	0.00	0.06	0.19	0.19	0.78	0.00	0.78	0.00	0.41	0.00	0.19
S10	0.00	0.78	0.19	0.00	0.00	0.00	0.00	0.41	0.06	0.00	0.00	0.78	0.41	0.78	0.00	0.78	0.19	0.41	0.00	0.06
S12	0.00	0.41	0.06	0.00	0.06	0.06	0.06	0.78	0.00	0.00	0.19	0.78	0.00	0.78	0.00	0.78	0.00	0.41	0.00	0.00
S16	0.06	0.19	0.06	0.00	0.00	0.06	0.00	0.41	0.06	0.00	0.19	0.19	0.00	0.78	0.00	0.78	0.19	0.19	0.00	0.06
U10	0.06	0.78	0.19	0.00	0.00	0.06	0.19	0.78	0.19	0.00	0.19	0.78	0.41	0.78	0.00	0.78	0.41	0.78	0.00	0.00
U14	0.00	0.00	0.06	0.00	0.00	0.06	0.00	0.78	0.00	0.19	0.00	0.00	0.06	0.78	0.00	0.78	0.19	0.06	0.78	0.19
U16	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.78	0.00	0.06	0.00	0.00	0.00	0.78	0.00	0.78	0.19	0.19	0.78	0.19
W12	0.06	0.19	0.00	0.00	0.19	0.41	0.00	0.78	0.00	0.00	0.78	0.19	0.06	0.78	0.00	0.78	0.06	0.41	0.78	0.06
W16	0.00	0.19	0.00	0.00	0.19	0.41	0.00	0.78	0.00	0.00	0.06	0.19	0.19	0.78	0.00	0.78	0.00	0.41	0.78	0.19

Table B. (continued)

Permanent plot	*Leontodon hispidus*	*Leucanthemum vulgare*	*Lotus corniculatus*	*Lychnis flos-cuculi*	*Medicago lupulina*	*Myosotis palustris*	*Pimpinella saxifraga*	*Plantago media*	*Poa compressa*	*Potentilla erecta*	*Prunella grandiflora*	*Sanguisorba officinalis*	*Selinum carvifolia*	*Serratula tinctoria*	*Stachys officinalis*	*Succisa pratensis*	*Thalictrum minus*	*Trifolium hybridum*	*Trifolium montanum*	*Trifolium pratense*	*Viola arvensis*
A1	0.00	0.19	0.41	0.00	0.19	0.00	0.19	0.19	0.00	0.00	0.00	0.19	0.19	0.06	0.00	0.06	0.00	0.00	0.41	0.19	0.00
E1	0.00	0.78	0.19	0.06	0.19	0.00	0.78	0.41	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00
A3	0.19	0.19	0.41	0.06	0.78	0.00	0.19	0.19	0.00	0.00	0.00	0.19	0.06	0.19	0.00	0.19	0.00	0.00	0.00	0.06	0.00
C3	0.00	0.78	0.19	0.00	0.19	0.00	0.78	0.41	0.00	0.00	0.00	0.19	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.19	0.00
E3	0.06	0.78	0.41	0.00	0.06	0.00	0.78	0.78	0.00	0.00	0.00	0.41	0.19	0.19	0.06	0.19	0.00	0.00	0.19	0.41	0.00
G3	0.06	0.78	0.41	0.06	0.41	0.00	0.78	0.41	0.00	0.00	0.00	0.19	0.06	0.06	0.00	0.19	0.00	0.00	0.00	0.19	0.00
A5	0.00	0.78	0.41	0.00	0.41	0.00	0.78	0.19	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.41	0.00
C5	0.00	0.78	0.19	0.06	0.06	0.00	0.78	0.19	0.00	0.00	0.00	0.19	0.00	0.19	0.06	0.19	0.00	0.00	0.00	0.19	0.00
E5	0.19	0.78	0.00	0.00	0.19	0.00	0.78	0.19	0.00	0.00	0.00	0.00	0.06	0.06	0.00	0.19	0.00	0.00	0.00	0.19	0.00
G5	0.19	0.41	0.00	0.06	0.00	0.00	0.41	0.19	0.00	0.00	0.00	0.41	0.19	0.06	0.06	0.19	0.00	0.00	0.00	0.19	0.00
A6	0.00	0.41	0.78	0.06	0.78	0.00	0.78	0.06	0.00	0.00	0.00	0.00	0.19	0.19	0.00	0.19	0.00	0.19	0.19	0.19	0.00
E6	0.19	0.78	0.41	0.00	0.00	0.06	0.78	0.41	0.00	0.00	0.00	0.41	0.00	0.06	0.00	0.41	0.00	0.00	0.00	0.06	0.00
I4	0.19	0.78	0.78	0.19	0.19	0.00	0.19	0.78	0.00	0.00	0.00	0.19	0.19	0.41	0.00	0.19	0.00	0.00	0.06	0.19	0.00
I8	0.06	0.78	0.78	0.00	0.06	0.00	0.78	0.19	0.00	0.19	0.00	0.19	0.00	0.19	0.19	0.41	0.00	0.00	0.00	0.00	0.00
I10	0.19	0.78	0.19	0.00	0.19	0.00	0.78	0.78	0.00	0.00	0.00	0.41	0.19	0.41	0.06	0.41	0.00	0.00	0.00	0.19	0.00
K4	0.19	0.41	0.19	0.00	0.41	0.00	0.78	0.41	0.00	0.00	0.00	0.41	0.19	0.41	0.06	0.41	0.00	0.19	0.00	0.78	0.00
K6	0.06	0.41	0.41	0.00	0.06	0.00	0.78	0.41	0.00	0.06	0.00	0.41	0.19	0.41	0.00	0.41	0.00	0.00	0.00	0.19	0.00

K10	0.00	0.41	0.06	0.00	0.00	0.00	0	0.19	0.00	0.06	0.00	0.19	0.06	0.78	0.00	0.19	0.00	0.00	0.00	0.06	0.00
K14	0.19	0.19	0.78	0.00	0.19	0.00	0.78	0.19	0.00	0.00	0.00	0.19	0.06	0.41	0.00	0.41	0.00	0.06	0.00	0.19	0.00
M6	0.19	0.78	0.41	0.00	0.41	0.00	0.78	0.19	0.00	0.00	0.00	0.41	0.19	0.19	0.19	0.19	0.00	0.06	0.00	0.19	0.00
M8	0.06	0.41	0.78	0.00	0.41	0.00	0.41	0.78	0.00	0.00	0.00	0.19	0.19	0.41	0.06	0.78	0.00	0.00	0.41	0.00	0.00
M10	0.41	0.78	0.19	0.06	0.78	0.00	0.78	0.78	0.00	0.19	0.00	0.41	0.19	0.78	0.00	0.78	0.00	0.00	0.19	0.41	0.00
M14	0.06	0.19	0.41	0.00	0.19	0.00	0.78	0.78	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.06	0.00	0.00	0.00	0.41	0.00
O6	0.19	0.78	0.19	0.00	0.78	0.00	0.78	0.78	0.00	0.19	0.00	0.41	0.19	0.19	0.19	0.41	0.00	0.00	0.19	0.19	0.00
O10	0.00	0.41	0.41	0.00	0.41	0.00	0.78	0.78	0.19	0.00	0.00	0.00	0.00	0.06	0.00	0.19	0.00	0.00	0.00	0.19	0.06
O12	0.06	0.41	0.19	0.00	0.19	0.00	0.78	0.41	0.00	0.00	0.00	0.19	0.06	0.00	0.06	0.19	0.06	0.00	0.19	0.19	0.00
O16	0.00	0.19	0.41	0.00	0.41	0.00	0.78	0.41	0.19	0.00	0.00	0.06	0.00	0.19	0.00	0.06	0.00	0.00	0.06	0.06	0.00
Q8	0.19	0.78	0.41	0.00	0.78	0.00	0.78	0.78	0.06	0.00	0.00	0.19	0.00	0.41	0.06	0.00	0.00	0.00	0.19	0.00	0.00
Q10	0.00	0.78	0.41	0.00	0.41	0.00	0.78	0.78	0.06	0.00	0.00	0.19	0.06	0.00	0.19	0.00	0.00	0.00	0.06	0.19	0.00
Q14	0.06	0.06	0.41	0.06	0.41	0.00	0.41	0.06	0.00	0.00	0.00	0.19	0.00	0.06	0.00	0.06	0.00	0.00	0.41	0.19	0.00
Q16	0.41	0.19	0.41	0.00	0.78	0.00	0.78	0.19	0.00	0.00	0.00	0.19	0.00	0.19	0.00	0.41	0.00	0.00	0.19	0.00	0.00
S10	0.19	0.78	0.78	0.00	0.19	0.00	0.78	0.78	0.00	0.00	0.00	0.41	0.00	0.19	0.06	0.19	0.00	0.00	0.00	0.41	0.00
S12	0.06	0.41	0.41	0.00	0.19	0.00	0.78	0.41	0.00	0.00	0.00	0.78	0.06	0.06	0.06	0.41	0.00	0.00	0.19	0.19	0.00
S16	0.00	0.41	0.41	0.00	0.41	0.00	0.78	0.19	0.41	0.00	0.00	0.00	0.00	0.19	0.00	0.41	0.00	0.00	0.41	0.00	0.00
U10	0.41	0.78	0.41	0.00	0.41	0.00	0.78	0.78	0.19	0.00	0.00	0.41	0.19	0.41	0.41	0.19	0.00	0.00	0.06	0.41	0.00
U14	0.00	0.19	0.41	0.06	0.19	0.00	0.19	0.19	0.00	0.00	0.00	0.06	0.41	0.78	0.00	0.41	0.00	0.41	0.06	0.00	0.00
U16	0.06	0.19	0.19	0.00	0.06	0.06	0.06	0.19	0.00	0.19	0.41	0.19	0.19	0.19	0.00	0.41	0.00	0.41	0.00	0.00	0.00
W12	0.19	0.78	0.41	0.00	0.06	0.00	0.78	0.78	0.00	0.00	0.41	0.19	0.06	0.19	0.00	0.19	0.00	0.06	0.19	0.06	0.00
W16	0.06	0.41	0.41	0.06	0.06	0.00	0.41	0.41	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.06	0.00	0.06	0.19	0.00	0.00

PRZYDATNOŚĆ JEDNOLICZBOWYCH WSKAŹNIKÓW ROZKŁADU GRANULOMETRYCZNEGO GLEBY W EKOLOGII ROŚLIN

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Streszczenie. Przedmiotem pracy są jednoliczbowe wskaźniki (charakterystyki) rozkładu granulometrycznego gleby mineralnej: masowy wymiar fraktalny rozkładu granulometrycznego, średnia statystycznie średnica cząstek, wskaźnik uziarnienia oraz iloczyn średniej statystycznie średnicy cząstek przez wskaźnik uziarnienia. Pierwsze trzy z czterech ww. wskaźników są znane z dotychczasowej literatury, zaś ostatni został zaproponowany przez autorów. Praca stanowi próbę odpowiedzi na pytanie, które z tych wskaźników najlepiej opisują skład granulometryczny gleby mineralnej jako czynnik różnicujący kompozycję gatunkową szaty roślinnej. Obiekt doświadczalny stanowił odłóg o areale 1 ha, obejmujący gleby z pięciu różnych podgrup granulometrycznych. Na odłogu mechanicznie zniszczono synantropijną szatę roślinną, a na nagą glebę wysiano nasiona kilkudziesięciu gatunków roślin łąkowych i murawowych. Wysiewane nasiona były dokładnie zmieszane i zostały równomiernie rozprowadzone na całej powierzchni obiektu doświadczalnego. Na odłogu rozmieszczono regularnie 39 stałych poletek, a w kolejnym roku oszacowano na nich frekwencję siewek wysianych gatunków roślin i oznaczono rozkład granulometryczny wierzchniej warstwy gleby. Test statystyczny przeprowadzony metodą porządkowania rozmytego wykazał, że najbardziej odpowiednią jednoliczbową charakterystyką rozkładu granulometrycznego gleby jako czynnika fitoekologicznego jest zaproponowany przez autorów iloczyn średniej statystycznie średnicy cząstek przez wskaźnik uziarnienia.

Słowa kluczowe: uziarnienie gleby, granulometrycznego, średnia statystycznie średnica cząstek rekrutacja siewek, wskaźnik uziarnienia, wymiar fraktalny rozkładu