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SPATIAL VARIABILITY OF PEDOZEMS PENETRATION RESISTANCE

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The spatial organization of land reclamation pedozem of Ordzhonikidze mine has been studied according soil penetration resistance knowledge at the pedon level. The groups of soil profiles (clusters) with the same type of penetration resistance change have been found which defined as soil individuals (pedone). The measures of similarities and differences between the clusters and their relative position have been established. Pedone quantitative characteristic has been obtained using metrics that are widely used in landscape ecology. The findings suggest that nonrandom nature of the relative position and shape of soil individuals.

Key words: soil penetration resistance, the spatial heterogeneity of soil properties, land reclamation.

Introduction. For the goals of this work the land reclamation is defined as the complex of measures for recreating the soils' features and fertility after some anthropogenic perturbation, open mining in particular. The significant spatial variability which causes the diversity of ecological background for the biocenosis is the characteristic feature of the "reclamizem" (*рекультизем*) [1]. Being a complex function of parent rock and organisms and climate and relief and time, any soil shows, consequently, some rate of diversity. The soil is defined as an open four-phase structured system in the surface layer of the parent rocks' crust of weathering. The soil individual (pedone, tessera, soil unit) is the structural increment of soil cover [2]. The pedones' borders are defined as the interfaces between the soil individuals, though the definition causes many difficulties of both theoretical and practical nature. When singled out, the soil individual must posses all the characteristics of the soil, which necessity makes the goal of its contours' sizes technical determination difficult to attain and puts limits to the methods' resolution [3].

The measuring of soil penetration resistance with the penetrometer is quite convenient a way for the soil structure diversity studying that makes it possible to obtain the data quickly on comparatively big a territory [1, 4, 5, 6]. As V.V.Medvedev (*В. В. Медведев*) mentioned the penetration resistance is an integrated characteristic of soil for which reason the spatial variability of that gives a possibility to analyze the complicated soil system's organization on different levels of the soil hierarchy [6].

The aim of this research is to study the pedozems' spatial organization on the level of pedone on the ground of their penetration resistance spatial variability.

Subjects and methods. The works were carried out on the science-research stationary of the Dnepropetrovsk State Agrarian University in the town of Ordzhonikidze. The experimental field for studying of the land reclamation optimal regimes was laid in 1968-1970. The sampling was carried out on the site of technozem with the filled-up layer of the soil mass 0,5 m deep over the technical clays mixture (pedozem). The geographical coordinates of the south-west corner of the field are – 47°38'55.24"N, 34°08'33.30"E.).

The field was divided into 8 sections of 20 sampling points each. The sections were situated along the line from West to East with intervals of 1,5 m. The sampling points were laid with the 1,5 m intervals also. Thus the experimental field was the regular net with the eye 1,5 m wide. The longer side of the field was 28,5 m long, the shorter one – 10,5 m.

The soils penetration resistance measuring was carried out in the field by the hand-operated penetrometer Eijkelkamp up to 50 sm deep with the interval of 5 sm. Average accuracy of the device is ±8 %. For the measuring the cone was used of 1 sm^2 in cross section; one replica was made in every eye.

For the statistical calculations the Statistica 7.0. program was used, while the pedones' forms and relative positions were described with the help of the Fragstat [8].

Results and discussion. Every point on the studied site surface has its characteristic data vector describing the soils penetration resistance on the various depths under that point. As a result of our researches the data were obtained concerning change in penetration resistance along the profile for 160 researched points. By the cluster analysis we combined our observations into three almost homogeneous groups (clusters) according to the profile features – *A, B, C* (Fig. 1).

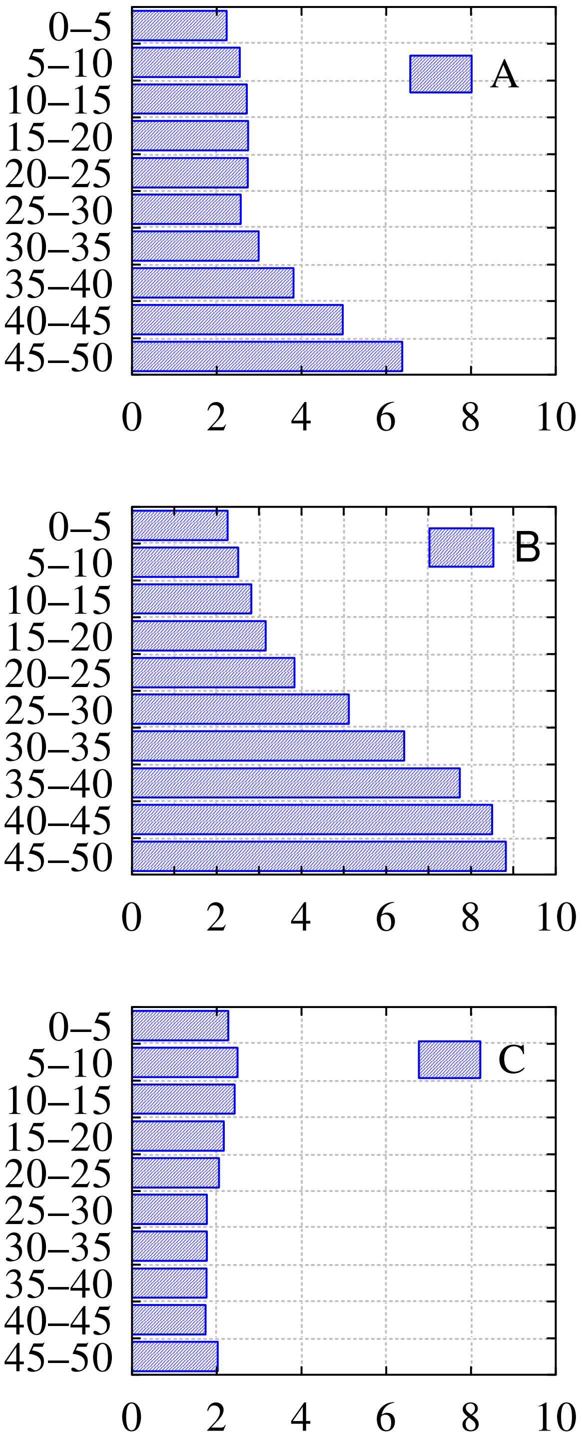

Fig. 1. Change in penetration resistance of pedozem along with the depth for clusters A, B, C.

Note: plotted as ordinates – depth from the soil surface (sm); plotted as abscises – soils penetration resistance (MPa).

For *A* and *B* clusters the increase of the penetration resistance with the depth is characteristic, the increase starting from 30 sm for the *A* cluster while for the *B* cluster the penetration resistance begins to rise regularly from the very surface and acquire it's maximum (near 9 MPa) at the depth of 0,5 m. On that same depth the maximum of penetration resistance in cluster *A* is observed, the value of it being a little more then 6 MPa. The penetration resistance data of *C* cluster is very stable, it decreases insignificantly with depth and varies slightly near 2 MPa all over the profile.

The discriminant analysis shows that the penetration resistance indices differentiate the clusters quite distinctly.

The differences between the clusters have been estimated through the Mahalonobis distance between the clusters' centroids (table 1).

1. Mahalonobis distance between the pedozem clusters' centroids (upper half-matrix) and F-ratios (lower half-matrix) according to the discriminant analysis

Cluster	A	B	C
A	0,00	10,19	6,97
B	47,98	0,00	18,12
C	7,67	19,87	0,00

The data of the table show that the shortest Mahalonobis distance observed is between *A* and *C* clusters while the longest is between *A* and *B*. *B* cluster differ from *C* cluster significantly and from *A* cluster less so. Thus, A and B clusters differs most intensely from each other in the type of penetration resistance formation while *C* is more like *A* then like *B*.

The clusters being relatively homogeneous in the characteristics of their origin, they may be identified as pedons. When trying to determine the existence of any interconnections inside the group and introduce any structure into it, the supposition might be made that pedons of *C* type are the transient form between pedons *A* and *B* and varied impacts are responsible for the developing of the bases highly resistant to penetration in the pedons *A* and *B*.

The Mahalonobis distances to the clusters' centroids inside the discriminant space of every point may be used for designing the map of clusters' location in two-dimensional (geographic) space. This gives a possibility to reflect the pedons in space and show their characteristic areas and forms and sizes and interposition (Fig. 2).

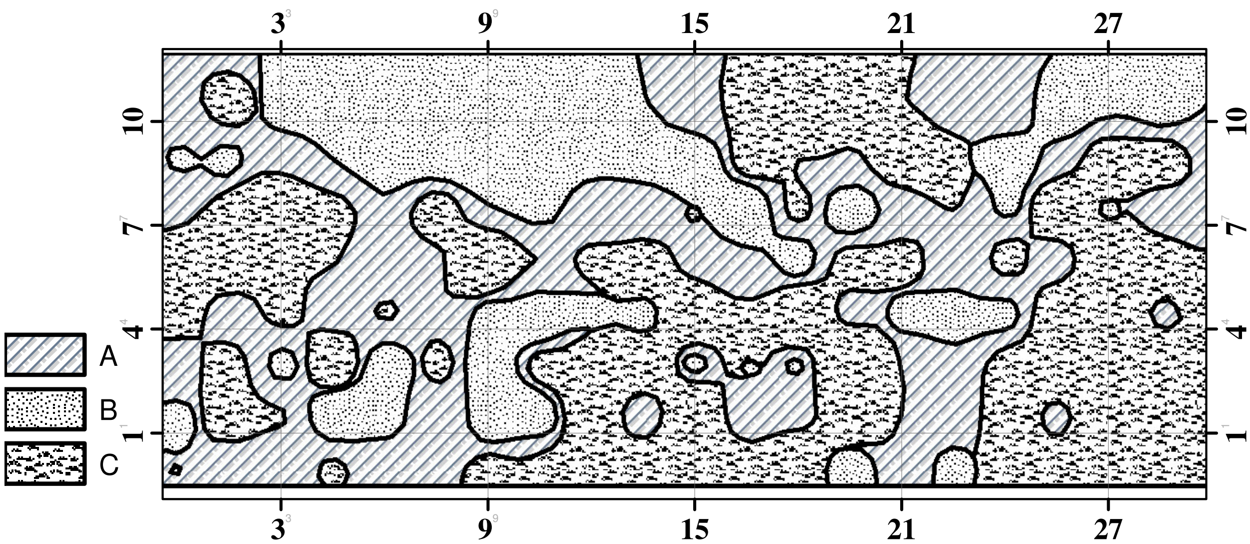

Fig. 2. The map of the clusters' spatial location

The clusters form some spatial structure. To describe that we propose to use the methods which are widely used in landscape topology for the polygonal objects' topology description [7]. For metrics describing the shape and interposition of the clusters in space their area is chosen together with the number of pedons in the cluster, gyrate radius, indices of shape, proximality, contrast-weighted edge density, connectivity [8] (table 2).

As the analyzing show, the territories occupied by the clusters on the field are approximately equal. The average value of area for pedons of *A* type is 43,61, for *B* type pedons – 47,79, for *C* type pedons – 8,60 %. The comparatively small-area pedons of *C* type (average area of pedon is 3,00 m^2) prevail quantitatively over pedons of all the other types.

2. Landscape indices of pedozem clusters

Index	Clusters (groups of pedons)					
	A		B		C	
	Average	CV, %	Average	CV, %	Average	CV, %
Area, %	43,61	–	47,79	–	8,60	–
Number of pedons	5,00	–	7,00	–	13,00	–
Average area of pedon, m^2	41,00	156,05	32,00	177,92	3,00	145,58
Gyrate radius (GYRATE)	2,28	119,07	2,23	112,92	0,65	96,90
Shape index (SHAPE)	1,95	63,61	1,59	26,96	1,28	19,64
Proximality index	235,95	93,17	76,67	139,41	6,69	116,68
Contrast-weighted edge density (CWED)	0,27	–	0,21	–	0,10	–
Connectivity index (CONNECT)	60,00	–	71,43	–	61,54	–

The gyrate radius reflects the pedon's area elongation. Greater gyrate radius is the characteristic of a pedon with more elongated and less compact (more extensive) area [9]. On the field under research elongation is almost the same for the pedons of *A* and *B* type (the gyrate radiuses are accordingly 2,28 m and 2,23 m) while the pedons of *C* type have much less values of the gyrate radius (0,65 m) with less diversity of those.

The shape index is based on the perimeter/area ratio of the pedon's area [9]. This metric have the value of one when the pedon's area is maximal compact or all the territory lies under one type of area. That index increases when the areas shape begins to differ from a circle. According to our data, the pedons of *C* type are most compact, their average index of shape being 1,28, while the shape of the pedons of *A* type is the most elongated, their shape index being 1,95. The intermediate rate belongs to the pedons of *B* type with index of shape 1,59 (table 4).

The proximality index is a landscape characteristic which reflects the sizes and proximity rate of all that areas edges of which lies inside a diapason of some established distance from the focal area. The proximality index evaluates quantitatively the areas' spatial context concerning the areas of the same type, namely it differentiates a diffuse disposition of the small-sized areas from a cluster configuration [9]. In our research for the distance of 10 m the pedons of the *A* type have the biggest proximality index (235,95). The pedons of *B* type have much less index of proximality (76,67) while the minimal rate of that belongs to the pedons of *C type* (6,69). Thus we may assert that among the *C* type pedons a remoteness from each other is characteristic. The pedons of *A* and *B* type shows the tendency of one-type pedons accumulating, some of them forming groups.

On the map of the penetration resistance clusters (Fig. 3) we may see that the pedons of *A* type border upon the *B* and *C* pedons while for the *B* and *C* ones edges in common are almost absent. Such a visual observation may be confirmed by determining the cluster's portion of perimeter to it's portion of edges ratio. Indeed, the length of edges in common between pedons *A* and *B* or *A* and *C* is 6–8 time bigger then length of edges between *B* and *C* pedons (table 3).

3. Matrix of the pedozem clusters neighborhood
(the ratio of cluster's portion of perimeter to it's portion of edges)

Cluster	*A*	*B*	*C*
A	–	0,93	1,14
B	1,30	–	0,20
C	1,62	0,21	–

Value of the contrast-weighted edge dencity is minimal for the pedons of *C* cluster, which speaks of the C type pedons' tendency to minimize an intensity of contacting with environment. This confirms the unrandom character of the obtained configuration of the soil body's structural units.

4. The standardized matrix of Mahalonobis distance between pedozem clusters' centroids
(matrix of weights of the contrasts)

Кластер	A	B	C
A	0,00	0,56	0,38
B	0,56	0,00	1,00
C	0,38	1,00	0,00

The distribution of the pedosem clusters' edges contrast index is not normal; the smallest values of the average belongs to pedons of *C* type. The connect index shows a high rate of connect for the pedons of clusters A and C and a low one for cluster B.

Thus, the quantitative characteristics of the pedons spatial distribution, those being contoured on the basis of the soil penetration resistance, show unrandom character of their interposition and shape. The fact must be marked that here we speak of two-dimensional projection of the three-dimensional soil body structure and this causes some uncertainty of the between-object borders. This model is adequate if grounded on the supposition of the structural formations extending all over the soil profile. In reality the structural singularities might be shaped like globules and inserted inside the amorphous soil layer. The globules may continue through the whole soil layer, in that case pedons would be characteristically homogeneous in structure. With globules of a vertical dimension shorter then the soil profile we may speak of the vertical mosaic structure of the soil profile. The specific combination and shape of the structure globules will be characteristic for the pedons.

The soil characteristics' spatial variability is connected with the structure of the Earth surface soil cover and results from the horizontal interaction of the soil masses under effect of the soil-forming factors, one of which being a relief of the territory (landscape). Changes in the landscape (mezostructure of soil cover) are connected with the local soil evolution. This connection is caused first of all by community of the climatic and some anthropogenic factors' effect upon the geosystem and it's constituents. Also, the processes under discussion are connected by far-reaching analogy of the geographic and geochemical and biological processes developing on the scale of the geosystem and of most part of the soils within it. Usually, it is such soil-geosystem processes that form both local soil evolution and soil cover differentiation [10]. The relief corrects actively the soil-forming process, thus intensifying it's spatial diversity. In this connection the spatial redistribution of water and of various compounds under gravitation impact (from high sites to low ones) leads to compaction or decompaction of the soil. The aeration and microbiological regimes undergo changes which in their turn effect the forming of the soil structural diversity and cause the soil's differentiation and developing of the structural units - pedons. Their sizes and shapes may be most varied in relation with relief, with structure and character of the rocks, with the hydrological conditions [4, 5]. Pedon is divided vertically into genetic soil horizons and horizontally - into the homogeneous elements named "pedonelles" by F.I.Kozlovsky (*Ф. И. Козловский*) [11] by analogy with the live cells' organelles. The pedons rate of diversity may be characterized quantitatively by the methods of statistic analysis. The quantitative characteristics of the pedons might be obtained via methods of the landscape ecology.

Conclusions

1. The cluster analysis has made it possible to contour some spatially homogeneous groups of the soil profiles with same-type vertical change of penetration resistance;

2. The quantitative evaluation of the similarity/difference ratios between clusters were made via the Mahalonobis distance. The *A* and *B* clusters differ in penetration resistance most of all between each other while the *C* cluster is more similar to *A* one then to *B* one.

3. The metrics widely used in landscape ecology are proposed for quantitatively characterization of the spatial location of pedons which were contoured out on the basis of penetration resistance. The results of this study show unrandom character of interposition and shapes of the spatially homogeneous groups of soil profiles (pedons) obtained.

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