IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

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To cite this article: L G Smirnova *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **368** 012050

IOP Conf. Series: Earth and Environmental Science **368** (2019) 012050 doi:10.1088/1755-1315/368/1/012050

Analysis of spatial humus distribution in virgin and arable Chernozems in the eroding landscapes

L G Smirnova[1*], A S Shapovalov[3], P A Ukrainskiy[2], I I Mikhailenko[1] and G V Smirnov[1]

[1] Belgorod Agrarian Research Center of the Russian Academy of Sciences, Octyabrskaya str. 58, Belgorod, 308001 Russian Federation
[2] Belgorod National Research University, Federal and regional center for aerospace and surface monitoring of the objects and natural resources, Pobedy str. 85, Belgorod, 305015 Russian Federation
[3] Belogorye State Nature Reserve, Monastyrskii lane 3, Borisovka, Belgorod region, 309340 Russian Federation

[*]E-mail: lidya.smirnova@yandex.ru

Abstract. A statistical assessment of data on the content and spatial distribution of humus in virgin and arable Chernozems on slopes in the south of the forest-steppe zone of the Central Russian Upland was performed. The greatest number of statistically significant differences between arable and virgin Chernozems was found for the upper soil layer (0–20 cm). At the depths of 20–40, 60–80, and 80–100 cm, the differences between these two groups of soils regarding the humus content were statistically insignificant. Data on the spatial distribution of humus in the layer of 0–20 cm indicated that high- and medium-humus Chernozems (>9.0 and 6.0–9.0% of humus) predominate on the slopes under virgin vegetation; medium-humus Chernozems with small patches of low-humus (<4%) Chernozems compose the soil cover of the slopes under arable fields.

1. Introduction

Modern agricultural development of forest-steppe landscapes of the Central Russian upland exceeds 60% of the total area. Soil plowing is one of the major factors affecting soils in this region for a long time. This problem is among the top for the South of the Central Russian upland, where the widespread development of erosion and other processes of degradation of Chernozems significantly complicate the structure of the soil cover and require differentiated application of farming technologies, with their adaptation to the intra-field diversity of fertility, agronomic and agroecological properties of soils [1-4]. Spatial variation of the major properties of soils by the elements of mesotopography has a significant impact on the use efficiency and reproduction of soil fertility in erosion agricultural landscapes [5, 6]. The assessment of soil heterogeneity in terms of fertility can contribute to a more accurate determination of the level of anthropogenic load. Analysis of humus state of slope landscapes is an important and reliable criterion for identifying spatial changes in soil cover [7, 8].

The development of landscape-adaptive approaches to farming is based on the proper assessment of the spatial variability in the soil properties. In the second half of the 20th century information about spatial heterogeneity of soil properties began to accumulate and special studies in this field were

IOP Conf. Series: Earth and Environmental Science **368** (2019) 012050 doi:10.1088/1755-1315/368/1/012050

performed [9-14]. Thus, in the works of E. A. Dmitriev [15], various aspects of manifestation of soil variability and their influence on information of soil objects are considered. Spatial variability in the particular soil properties was discussed in the works of A. D. Voronin [16], Godelman [17] and others, but their works were of theoretical interest only. In recent years, this problem has moved into a practical area [10, 18-22]. Undoubtedly, this was facilitated by the development of the concept of precision agriculture [23-25].

Noteworthy are the studies conducted at the Dokuchaev Soil Institute [26], where methodological issues of study and evaluation of heterogeneity of soil fertility in the field and research of the laws of variability of individual properties of sod-podzolic soils were developed [27]. In the recent decade, spatial variability of soil fertility indices has been studied for gray forest soils [28] and Chernozems [29].

No less important issue, which is considered by scientists, is the assessment of spatial heterogeneity of fertility indicators and the identification of its impact on crop yields [27-33]. Special studies are devoted to the spatial variability of soil fertility. It is argued that it is mainly associated with heterogeneity of soil-forming rocks and with the influence of agricultural land use [20, 34-36]. However, the relief role at the micro level is less known. The study of spatial variation of fertility indicators in the development of active erosion processes is relevant and promising, especially for the South-Western forest-steppe province of the Central Chernozem zone, where most of the agricultural land is located on the slopes [37].

The aim of our study was to quantify the content of humus in the soils of slope landscapes on arable land and in virgin lands. the study, the task was to carry out a statistical assessment of the significance of the humus content and to identify the spatial pattern of its distribution in the soils of slope landscapes in the associated analysis on virgin lands and arable land.

2. Methods

The studies were carried out on chernozem soils on a gentle straight slope of the southwestern exposure of the reserve Yamskaya steppe and adjacent to its border arable land, which are located in the Gubkin district of the Belgorod region. The studied objects were chernozem voronic soils confined to spatially contiguous lands: arable land and steppe protected area (virgin land). On 6 catenas were laid 60 wells with a depth of 1 m. The distance between the lines of catenas is 50 m, the distance between points along catenas is 50 m. Soil samples for analysis were selected by layers: 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, 80-100 cm. 300 samples were analyzed - 30 samples for each layer in the virgin steppe and 30 samples for each layer on the arable land. Preparation of the soil for the determination of humus was performed according to the standard procedure. The humus content was determined by the wet combustion method (Tyurin's method) agreeing with GOST (State Standard) 26213-91.

Actual position of the soil sampling points has a number of deviations from the planned sampling scheme – a regular rectangular grid. Therefore, it is necessary to check whether the size of these deviations is sufficient to recognize the actual scheme of selection uneven. This paper uses the Clark-Evans test, implemented in ArcGIS as a tool "Average distance to the nearest neighbor" (included in the set of tools "Spatial statistics").

Test of Clark and Evans is based on the calculation of average nearest neighbor distances (ANN). The null hypothesis for the Clark-Evans test is complete spatial randomness, that is, random distribution of points.

An alternative hypothesis is a group or even distribution. The actual ANN is compared with the ANN required for random distribution at the current area of the study area and the current number of sampling points. If the ratio of the actual ANN to the theoretical ANN of random distribution (R, the Clark–Evans criterion) is reliably less than 1, then we deal with the aggregated distribution. If it is reliably more than 1, a tendency for an even distribution is observed. When R is 1 or is statistically unreliable, the objects are placed randomly [38]. This test was applied to the entire set of sampling points, and separately to the sampling points within the virgin and arable catenas.

Cartograms of the humus content in separate layers were obtained via of interpolation of data obtained at sampling points using the barrier spline method in the ArcGIS software. The boundary of the reserve was taken as a barrier in the interpolation.

The R programming language [39] was used for data analysis and statistical graphics creation. The choice of the criteria for testing statistical hypothesis are based on the algorithm described by A.M. Grzybowski [40]. Deviation of the distribution of studied statistical samples from the normal distribution was analyzed using the Shapiro–Wilk test [41]. This methods used to check the deviation from normal distribution with GOST R ISO 5479-2002, which is an analogue of the international standard ISO 5479-97.

3. Results and Discussion

The average humus content in the 1 m layer of virgin soils in the protected area of studied catenas was 5.48 %. Long-term anthropogenic impact on plowed soils resulted a shortage of fresh organic residues in the soil profile, which led to a significant change in the humus content: the average humus content in the 1 m layer of arable soils decreased to 4.48 % (table 1). The main mass of roots in the studied soils concentrated in the layer 0-20 cm. The average humus content in this layer reached 9.05% in the virgin soils and 6.87% in the arable soils. Deeper in the profile, a gradual decline in the humus content was observed; it was more pronounced in the arable soils.

The coefficient of spatial variation in the humus content in the layer of 0–20 cm was 9.34 and 8.87% in the virgin and arable soils, respectively. In the layer of 20–40 cm, the average humus content markedly decreased to 6.27 and 5.68% in the virgin and arable soils, respectively. The coefficient of variation remained low (11.7 and 13.35% in the virgin and arable soils, respectively). In the layers of 40-60 and 60-80 cm humus content varies to 4.83 and 4.13 % in virgin lands and to 4.26 and 3.19 % in arable land. The coefficient of variation somewhat increased and was within 12.05–16.89 and 16.93–25.52% in the virgin and arable soils, respectively. In the layer of 80–100 cm, the average humus content was 3.15% in the virgin areas and by 0.73% lower (2.42%) in the arable soils. The coefficient of variation increased to the moderate level in the virgin soils (21.52%) and was close to the high level (34.04%) in the arable soils (table 1).

Table 1. Quantitative assessment of humus content (%) in soils of slope landscapes on arable land and in virgin lands.

Layer of soil, cm	Average content of humus, %		Standard deviation		Coefficient of variation,%	
	virgin land	arable land	virgin land	arable land	virgin land	arable land
0-20	9.05±0.27	6.87±0.19	0.84	0.61	9.34	8.87
20-40	6.27±0.23	5.68±0.24	0.73	0.75	11.7	13.35
40-60	4.83±0.18	4.26±0.23	0.58	0.72	12.05	16.93
60-80	4.13±0.22	3.19±0.25	0.69	0.79	16.89	25.52
80-100	3.15±0.21	2.42±0.25	0.67	0.81	21.52	34.04
Average by catena	5.48	4.48	0.70	0.74	14.30	19.74

The results of testing samples for normal distribution are shown in the table 2. In most of the samples studied, the distribution of humus content does not differ significantly from the normal distribution. The exception is the upper (0–20 cm) layer in the arable soils. For this layer, the distribution differs from normal. Accordingly, when comparing this sample with others, it is necessary to use nonparametric methods.

Table 2. Shapiro-Wilk test results for the studied samples.

Depth, cm	Wetland	W	p-value
0-20	Virgin	0.98	0.84
	Arable	0.90	0.01
20-40	Virgin	0.96	0.23
	Arable	0.99	0.95
40-60	Virgin	0.96	0.36
	Arable	0.96	0.29
60-80	Virgin	0.97	0.61
	Arable	0.94	0.10
80-100	Virgin	0.95	0.13
	Arable	0.97	0.47

When visualizing the obtained cartographic model of spatial distribution of humus in soils of slope landscapes, certain regularities are revealed. According to the humus content in the topsoil (0–20 cm), high-humus and medium-humus Chernozems (more than 9% and from 9 to 6 %) are found on the slope within the reserve, and medium-humus Chernozems alternating with small "wedges" of low-humus Chernozems (3.0–4.5%) predominate on the slope within the arable field (figure 1).

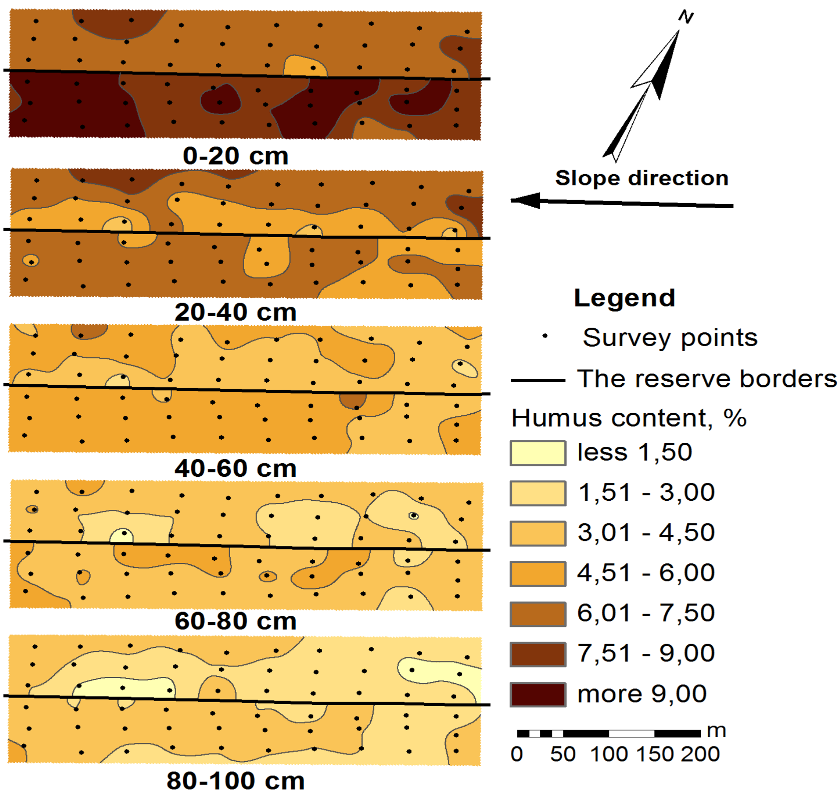

Figure 1. Spatial distribution of humus in the soils of the study area according to the depth of selection (upper field –arable land, lower-virgin soil).

IOP Conf. Series: Earth and Environmental Science **368** (2019) 012050 doi:10.1088/1755-1315/368/1/012050

In the deeper layers, the humus content decreases, and this decrease is less noticeable and more gradual in the virgin soils. At each depth, the distribution of polygons with a certain content has a more uniform pattern in the virgin soils. In the arable soils, areas with a very low humus content (<1.5%) appear already from the depth of 60–80 cm.

As seen from figure 1 the humus content decreases with depth throughout the study area. Also, from the areas occupied by areas with different humus content, it is clear that the average humus content in the virgin soils is higher than that in the arable soils, and this is true for all the studied depths. However, visual analysis of the spatial patterns of soil humus does not allow us to reveal definite regularities. For this purpose, application of spatial statistics tools is necessary.

The results of the Clark-Evans test show that the distribution of points in space can be considered uniform (table 3). This is true both for the whole set of points and separately for the points located in the steppe and on the arable land. Thus, the actual position of the soil sampling points satisfies the principle of regular rectangular grid sampling. This ensures the correctness of cartograms of humus content created by interpolation.

Table 3. Clark-Evans test results.

Wetland	The actual ANN, m				The expected average ANN, m	R	p-value
	minimum	average	maximum	Standard deviation			
Steppe	13.06	22.03	31.90	4.49	18.56	1.19	0.05
Arable	20.45	25.29	31.37	2.91	18.56	1.36	0.0002
Whole territory	13.06	23.41	31.90	3.84	18.56	1.26	0.0001

We calculated the percent of the area occupied by the soils with different humus contents at different depths. In the layer of 0–20 cm, Chernozems with the humus content >9% occupy 47%, and Chernozems with the humus content of 6–9% occupy the remaining 53% of the slope area under steppe vegetation. Within the arable part of the slope, 93% is occupied by Chernozems with the humus content of 6–9%, and 7% is occupied by the Chernozems with the humus content of 4–6% (table 4).

Table 4. Percentage of soils with different humus content ranges at sampling depths.

The range of humus content, %	Percentage of samples									
	Arable land					Virgin land				
	0-20	20-40	40-60	60-80	80-100	0-20	20-40	40-60	60-80	80-100
> 9	-	-	-	-	-	47	-	-	-	-
9.0-6.0	93	30	3	-	-	53	77	4	-	-
5.99-4.00	7	70	67	10	-	-	23	90	50	10
< 4	-	-	30	90	100	-	-	6	50	90

At the depth of 20–40 cm within the virgin steppe, 77% of the area is occupied by Chernozems with the humus content of 6–9%, and 23% of the area is occupied by Chernozems with the humus content of 4–6%. In the layer of 40–60 cm under virgin steppe, 90% of the area is occupied by Chernozems with the humus content of 4–6%; on the arable field, such soils occupy only 67%, and 30% of the area is occupied by Chernozems with the humus content of less than 4%. In the deeper layers, the area of the soils containing less than <4% of humus increases. In the layer of 60–80 cm, it reaches 50% under virgin steppe and 90% under arable field. In the layer of 80–100 cm, it increases to 90% under virgin steppe, although the remaining 10% of the area have the humus content of 4–6%. Under arable field, the humus content in this layer is less than 4% throughout the entire studied area.

4. Conclusions

The average humus content in the 1-m-deep layer of studied Chernozems constitutes 5.48% under virgin steppe and 4.48% under arable field. In the topsoil (0–20 cm), the humus content reaches 9.05% and 6.87%; the degree of variation is low (12 and 13% under virgin steppe and arable field, respectively). In the deeper layers, the soil humus content decreases, and the degree of its spatial variability increases up to 22% under virgin steppe (moderate variation) and up to 34% (close to high variation) under arable field.

The results of quantitative analysis indicate that the greatest number of statistically significant differences is found in the upper layer (0 - 20 cm). In the layers of 20–40, 60–80, and 80–100 cm, the differences are statistically insignificant.

Regarding the spatial distribution of soils with different humus content in the upper (0–20 cm) layer, high-humus and medium-humus chernozems (>9% and 6–9% of humus) predominate under virgin steppe, whereas medium-humus chernozems predominate under arable field and alternate with small areas of very low-humus (<4%) chernozems.

Acknowledgements

The study was supported within the intra-university grant of Belgorod State National Research University to support the creation and development of scientific departments – centers of excellence.

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