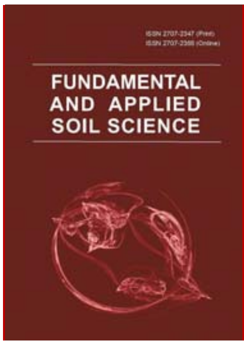

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Electrophysical characteristics and dielectric constant of soils of northern natural forests of Ukrainian steppe zone

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Currently in soil science the search for new methods and technologies for soil research is relevant, which in a short time allows to receive a large amount of information about its condition with the lowest financial cost. Methods for determining electrophysical parameters and dielectric constant of soils are conforming to these requirements. As a result of the investigations, it was found that the upper horizons of the soils of Glubokiy ravine, located in the Ukrainian steppe zone (Novomoskovsk district, Dnipropetrovsk region, Ukraine), differ to lower values of electrical resistance and dielectric constant compared to the lower horizons. The upper horizons are characterized by increased values of electrical conductivity, mineralization and salinity compared with the lower horizons. Sudden changes in the values of all investigated parameters at the boundary of the eluvial and illuvial horizons were found in Luvic phaeozem of northern exposition of ravine and in Luvic gleyic phaeozem of thalweg. In the Luvic phaeozem of the forest northern exposure of the ravine and in the Luvic gleyic phaeozem of the leveled area of the ravine, sharp changes were found in the values of all the investigated parameters at the boundary of the eluvial and illuvial horizons. In the eluvial horizons of Luvic phaeozem, which bordering on the illuvial horizons, a sharp increase in the dielectric constant is observed. The upper horizons of Calcic chernozem of the northern ravine exposition are characterized by increased values of electrical resistance, electrical conductivity and dielectric constant, as well as lower values of mineralization and salinity compared to the upper horizons of Calcic chernozem of the southern ravine exposition. The upper horizons of the Luvic phaeozem of the forest north exposition of the ravine are characterized by higher values of electrical resistance and dielectric constant compared to the upper horizons of the Luvic phaeozem of the forest south exposition of the ravine. In terms of electrical conductivity, mineralization and salinity, Luvic phaeozems practically don't differ. The upper horizons of Luvic phaeozems are characterized by lower values of electrical resistance and dielectric constant, as well as higher values of electrical conductivity, mineralization and salinity compared to Calcic chernozems. The results obtained indicate that the highest content of organic matter and water-soluble compounds, as well as the best structurally-aggregate composition, and also the best structural-aggregate composition is characteristic of forest chernozem. This is due to the one that formed on the southern exposition of the ravine and which is characterized by the lowest values of dielectric constant and electrical resistance, as well as the highest values of electrical conductivity, mineralization and salinity.

Keywords: electrical resistance; electrical conductivity; mineralization; salinity; dielectric constant; ravine forests

Introduction

Natural forests in the steppe zone of Ukraine occupy limited territories, located in river valleys and on the slopes of ravines. Specific soils are formed in these forests, which differ in their properties from Calcic chernozems in their better structural-aggregate state, increased content of organic matter, features of micromorphological features, etc. (Travleyev and Bilova, 2011).

The fact of the positive effect of forest vegetation on the steppe soils is currently proven and recognized (Travleev, 1996; Ritter et al., 2003; Lal, 2004; An et al., 2010; Gu et al., 2019).

However, most investigations are devoted to studying changes in the chemical properties of soil under the influence of artificial forest plantations (Clark, Johnson, 2011; Berthrong et al., 2012; Bárcena et al., 2014; Polláková et al., 2018).Significantly fewer works are devoted to studying the effect of forest stands on the physical properties of soils (Zhang et al., 2018) and even less to the effect of natural forests on steppe soils. Currently, more and more attention of soil scientists is attracted by the possibility of studying soil properties using express methods, which are provided by the use of compact instruments.

Such methods, in our opinion, include the determination of electrophysical parameters and dielectric constant of soils.

One of the main electrophysical indicators of the soil is electrical resistance. The electrical resistivity is used in soil science primarily to identify heterogeneities of soil properties. Geospatial resistivity survey is applied to diagnose the spatial variability of soil properties correlated to electrical parameters. Soil electrical properties are influenced by a complex interaction of edaphic properties including salinity, saturation, water content, structure, bulk density, organic matter, cation exchange capacity, clay percentage and mineralogy, and temperature (Bai et al., 2013; Simonova, Rusakov , 2019).

The results of investigations of electrophysical indicators and dielectric constant are highly informative and often help to better study the features of the complex genesis that distinguish the soils of natural forests in the steppe zone of Ukraine. Verification of this statement is the goal of our work.

Materials and methods

The investigation of the thermal properties of soils of forest biogeocenoses was carried out using soil samples taken from five soil sections laid in five trial plots in the Glubokiy ravine.

A detailed description of the trial plots and soil sections is given in the work of V. M. Yakovenko (2014). Below we give a brief description (Yakovenko, 2017) of the studied objects using the above work.

Trial plot 1 is located on the virgin steppe, located on the northern exposition of the ravine. The area has a slope of 8° northern exposure. Soil – Calcic Chernozem.

Trial plot 2 is located on the middle third of the slope of the northern exposition of the ravine. The area has a slope of 15° northern expositions. Soil – Luvic Phaeozem.

Trial plot 3 is located on a leveled area of the ravine. Soil – Luvic Gleyic Phaeozem.

Trial plot 4 is located on the middle third of the southern exposition of the ravine. The area has a slope of 14° southern exposure. Soil – Luvic Phaeozem.

Trial plot 5 is located on the virgin steppe, located on the southern exposition of the ravine. The area has a slope of 3° southern exposure. Soil – Calcic Chernozem.

The electrical resistance of the soil was determined using a four-electrode setup with planar electrodes. For the investigation, soil paste was used, which was prepared by adding distilled water to the soil to saturate it to a value greater than the lowest moisture capacity.

Measurements in pastes are necessary in order to stabilize the moisture factor and homogenize the soil sample.

This makes it possible to obtain the values of electrical resistance with the elimination of the moisture factor, temperature, and sample heterogeneity. In this case, the values of electrical resistance most accurately characterize the texture-chemical and genetic traits of soils (Pozdnyakov et al., 2015).

The determination of electrical characteristics (electrical conductivity, mineralization and salinity) was carried out using a conductivity meter-salimeter-thermometer Ezodo-7021, which was used to measure these indicators in soil extract (in the ratio of 1 part of soil to 5 parts of distilled water).

The dielectric constant was determined using a digital capacitance meter CM-9601A, which provides capacitor capacitance measurement over a wide range from 10^{-12} to 10^{-3} farads. We used a operating range of 0.1–200 pF, the test frequency was 800 Hz. For measuring the dielectric constant, a cylindrical plexiglass capacitor was made. The diameter of the capacitor plates was 2 cm, the distance between them was 0.7 cm.

The soil and aggregates for the investigation were used in an air-dry state to level out the effect of humidity, the content of which significantly affects the dielectric constant (Liu et al., 2016; Wang et al., 2016). After placing the sample in the capacitor, it was compacted by pressure on top of a load weighing about 0.3 kg to creating better contact with the capacitor covers. At the end of the measurement, the soil sample was weighed to calculate its density. All measurements were performed three times with subsequent statistical processing. The obtained values of the capacitance of the capacitor with soil and aggregates were subsequently used to calculate the dielectric constant (Gorban, 2016).

Results and discussion

Investigations of the electrical resistance of Calcic chernozem of trial plot 1 showed that its minimum value (4.37 Ohm•m) is characteristic of the upper Ak1 horizon. With depth, a gradual increase in electrical resistance to 6.54 Ohm•m is observed in the Ck horizon (Fig. 1, *a*). Such a distribution of electrical resistance values indicates a higher content of salts in the upper horizons compared to the lower horizons. This phenomenon can be explained by the pulling up of water-soluble salts from lower horizons to upper ones due to the suction activity of plant root systems.

The upper eluvial horizons of the Luvic phaeozem of the forest trial plot 2 are characterized by lower values of electrical resistance in comparison with the lower illuvial horizons (Fig. 1, *b*). The minimum electrical resistance (1.90 Ohm•m) is observed in the At horizon, and the maximum (3.93 Ohm•m) in the Bt horizon. In this case, sharp changes in the values of electrical resistance in the At and Bt horizons (the difference is almost 2 Ohm•m) reflects the boundary between the prevailing eluvial processes and the illuvial ones.

In the Luvic gleyic phaeozem of the trial plot 3, the upper eluvial horizons are also characterized by lower values of electrical resistance compared to the lower illuvial horizons (Fig. 1, *c*). The minimum electrical resistance (2.46 Ohm•m) is observed in the A1 horizon, and the maximum (5.11 Ohm•m) in the At horizon. In this case, sharp changes in the values of electrical resistance in the A3 and At horizons (the difference is almost 2 Ohm•m) also reflects the boundary between the prevailing eluvial processes and the illuvial ones.

In the Luvic phaeozem of the forest trial plot 4, as a result of the investigation of electrical resistance, no clear patterns were revealed in the distribution of its values (Fig. 1, *d*). In this case, the minimum value of electrical resistance (1.83 Ohm•m) is observed in the A1 horizon, and the maximum (3.98 Ohm•m) in the Btk horizon. The boundary between the change of eluvial processes to the illuvial ones in terms of electrical resistance in this soil is not identified.

The upper horizon of the Ak Calcic chernozem of trial plot 5 is characterized by a minimum value of electrical resistance (3.00 Ohm•m), and its increase is observed with depth (Fig. 1, *e*). The maximum value of electrical resistance (4.14 Ohm•m) was revealed in the Ck horizon.

As a result of the investigation of the electrical conductivity, mineralization and salinity of the Calcic chernozem of trial plot 1, it was found that the maximum values of these indicators are observed in the Ak1 horizon, and a decrease in their values is observed with depth (Table 1). The maximum values of the studied parameters reflect the increased content of water-soluble compounds in the soil. The minimum values of electrical conductivity, mineralization and salinity were found in the Ck horizon.

In the Luvic phaeozem of the forest trial plot 2, eluvial horizons are characterized by increased values of electrical conductivity in comparison with the illuvial horizons. At the same time, at the boundary of the eluvial and illuvial horizons (between the At and ABt horizons), a sharp decrease in the electrical conductivity is observed from 140 µS/cm to 60 µS/cm (Table 1). Mineralization and salinity are characterized by a similar distribution of values and a sharp change in values at the boundary of the eluvial and illuvial horizons. In the At horizon, bordering the first illuvial Abt horizon, an increase in the electrical conductivity, mineralization and salinity was found compared with other eluvial horizons.

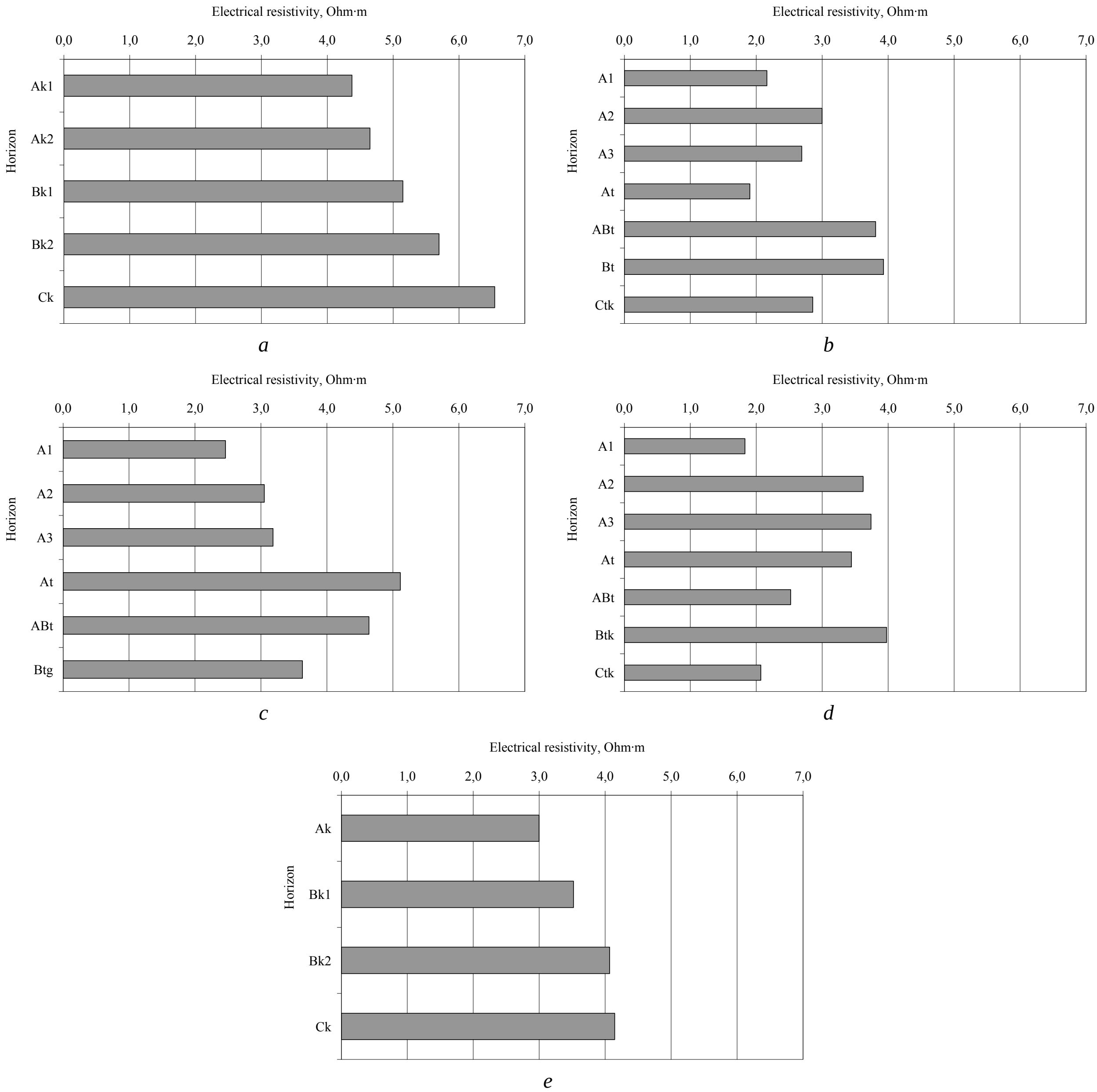

Fig. 1. Electrical resistance of the studied soils:
a – trial plot 1; *b* – trial plot 2; *c* – trial plot 3; *d* – trial plot 4; *e* – trial plot 5

In the Luvic gleyic phaeozem of the trial plot 3, the upper eluvial horizons are also characterized by increased values of electrical conductivity, mineralization and salinity compared with the illuvial horizons. At the boundary of eluvial and illuvial horizons, a sharp change in the studied parameters is also observed (Table 1).

In the Luvic phaeozem of the forest trial plot 4, the maximum values of electrical conductivity, mineralization and salinity were found in the upper eluvial horizon A1 (Table 1), and the minimum values were found in the eluvial horizon A3, which borders on the illuvial horizons. The studied indicators in eluvial horizons decrease with depth, and in illuvial horizons, on the contrary, increase.

The maximum values of electrical conductivity, mineralization, and salinity in Calcic chernozem of trial plot 5 were found in the Ak horizon, and their gradual decrease was observed with depth (Table 1).

The minimum value (17.61) of dielectric constant in Calcic chernozem of trial plot 1 was found in the upper Ak1 horizon, and its increase is observed with depth (Fig. 2, *a*). The lowest values of dielectric constant indicate an increased content of organic matter and an optimal structural-aggregate composition of the soil.

The minimum value of the dielectric constant in the Luvic phaeozem of the forest trial plot 2 (7.01) is associated with the A1 horizon, and its increase is observed with depth (Fig. 2, *b*). In this case, a sharp increase in the dielectric constant was found in the At horizon, which bordering on the illuvial ABt horizon. Starting from the ABt horizon, an increase in the dielectric constant is observed with depth in the illuvial horizons. The sharp change in the values of the dielectric constant is observed on the boundary between the eluvial and illuvial horizons.

In the Luvic gleyic phaeozem of trial plot 3, the minimum dielectric constant was revealed in the A1 horizon (Fig. 2, *c*), and an increase in its values is observed with depth. The sharp increase in the dielectric constant is observed on the boundary of the eluvial and illuvial horizons.

The minimum value of the dielectric constant in the Luvic phaeozem of the forest trial plot 4 was revealed in the A1 horizon (6.80), and its increase is observed with depth (Fig. 2, *d*). The A3 horizon is characterized by a sharp increase in the dielectric constant compared to other eluvial horizons. The first illuvial At horizon has a lower dielectric constant than the ABt horizon. An increase in the dielectric constant is observed with depth in the illuvial horizons, which is associated with the saturation of these horizons with a clay fraction.

Table 1
Electrophysical characteristics of the studied soils

Horizon	Depth, cm	Electrical conductivity, μS/cm	Mineralization, ppm	Salinity, ppm
Trial plot 1 – Calcic Chernozem				
Ak1	0–8	150±2,0	84±3,1	72±2,3
Ak2	8–23	100±1,8	71±2,9	64±2,1
Bk1	23–51	112±2,0	76±3,0	61±2,2
Bk2	51–80	102±1,9	76±3,0	63±2,1
Ck	80–120	86±1,7	63±2,4	56±1,9
Trial plot 2 – Luvic Phaeozem				
A1	0–12	212±3,1	150±3,7	118±3,8
A2	12–33	125±2,3	94±3,2	75±2,3
A3	33–67	102±2,1	76±2,9	65±2,0
At	67–96	140±2,5	88±3,0	69±2,0
ABt	96–140	60±1,6	46±2,1	41±1,7
Bt	140–166	43±1,4	35±2,0	32±1,6
Ctk	166–230	97±2,0	77±3,0	63±1,8
Trial plot 3 – Luvic gleyic phaeozem				
A1	0–8	151±2,1	82±2,9	67±2,0
A2	8–34	111±1,9	66±2,5	55±1,7
A3	34–60	87±1,7	48±2,3	41±1,6
At	60–118	32±1,2	32±2,0	24±1,3
ABt	118–132	41±1,4	34±2,0	31±1,5
Btg	132–166	44±1,5	36±2,1	32±1,5
Trial plot 4 – Luvic Phaeozem				
A1	0–9	212±3,2	152±3,4	117±3,1
A2	9–46	96±2,1	81±2,5	60±2,4
A3	46–88	49±1,5	43±2,0	35±1,6
At	88–138	58±1,7	48±2,1	38±1,7
ABt	138–160	83±1,8	54±2,3	45±1,8
Btk	160–187	71±1,6	54±2,3	45±1,7
Ctk	187–230	88±1,8	64±2,5	54±1,8
Trial plot 5 – Calcic Chernozem				
Ak	0–6	143±2,0	100±3,0	82±2,9
Bk1	6–27	118±1,9	87±2,6	75±2,4
Bk2	27–40	119±1,8	90±2,8	73±2,5
Ck	40–120	107±1,8	82±2,5	64±2,1

The minimum dielectric constant was found in the Ak horizon in Calcic chernozem of trial plot 5, and its increase is observed with depth (Fig. 2, *e*).

The upper horizons of the Calcic chernozem of the ordinary trial plot 5 and the Luvic phaeozem of the forest trial plot 4, which are located on the southern exposure of the ravine, are characterized by lower values of the dielectric constant compared to the upper horizons of the Calcic chernozem of the trial plot 1 and the Luvic phaeozem of the forest trial plot 2, which are located on the northern exposure of the ravine. This indicates that the soils under the conditions of southern exposure of the ravine are characterized by a high content of organic matter and a better structural-aggregate composition in comparison with soils in the conditions of the northern exposure of the ravine.

Conclusion

The upper horizons of all studied soils are characterized by lower values of electrical resistance and dielectric constant compared to lower horizons. However, the upper horizons are characterized by increased values of electrical conductivity, mineralization and salinity compared to the lower horizons. The sharp changes were found in the values of all the studied parameters at the boundary of the eluvial and illuvial horizons in the Luvic phaeozem of the forest trial plot 2 of the northern exposure of the ravine and in the Luvic gleyic phaeozem of the trial plot 3 of the thalweg. The sharp increase in the dielectric constant is observed in the eluvial horizons of the Luvic phaeozem of the forest trial plots 2 and 4, which borders on the illuvial horizons. The upper horizons of the Calcic chernozem trial plot 1 of the northern exposure of the ravine are characterized by increased values of electrical resistance, electrical conductivity and dielectric constant, as well as lower values of mineralization and salinity compared to the upper horizons of the Calcic chernozem trial plot 5 of the southern exposure of the ravine. The upper horizons of the Luvic phaeozem of the forest trial plot 2 of the northern exposure of the ravine are characterized by higher values of electrical resistance and dielectric constant compared to the upper horizons of the Luvic phaeozem of the forest trial plot 4 of the southern exposure of the ravine. In values of electrical conductivity, mineralization and salinity, Luvic phaeozems practically do not differ. The upper horizons of Luvic phaeozems are characterized by lower values of electrical resistance and dielectric constant, as well as higher values of electrical conductivity, mineralization and salinity compared to Calcic chernozems. The results obtained indicate that the highest content of organic matter and water-soluble compounds, as well as the best structurally-aggregate composition, are characteristic of Luvic phaeozem, especially that formed on the southern exposure of the ravine and which is characterized by the lowest values of dielectric constant and electrical resistance, as well as the highest values of electrical conductivity, mineralization and salinity.

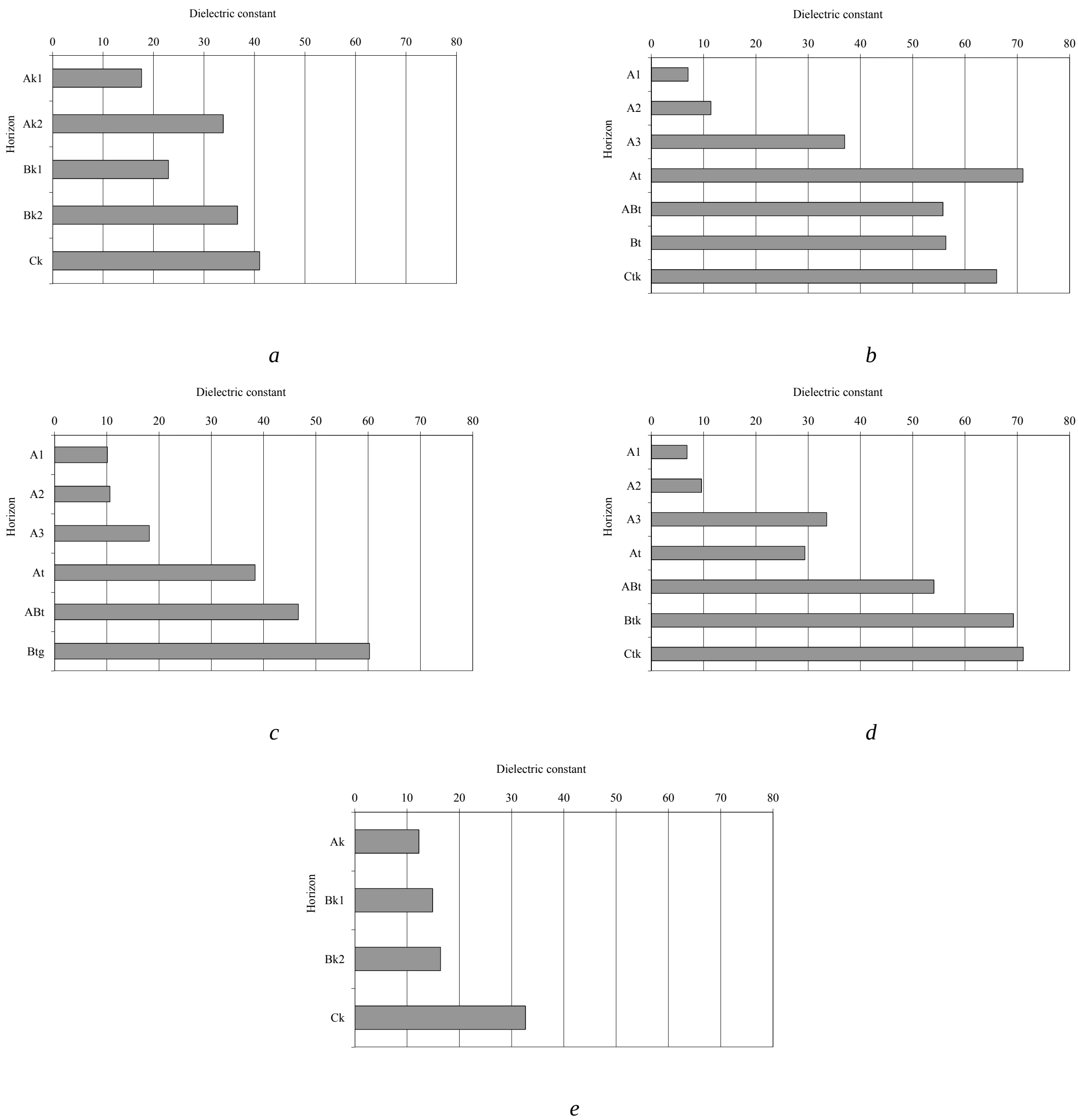

Fig. 2. Dielectric constant of the studied soils:
a – trial plot 1; *b* – trial plot 2; *c* – trial plot 3; *d* – trial plot 4; *e* – trial plot 5

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