Soils in space and evaluation of their changes in time: experience in studying the soils in two regions of Russia.

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Abstract
Under consideration are results obtained in an evaluation of soil changes that have taken place in the second half of the 20th century in two regions of Russia. The regions are characterized by different natural conditions, soil cover and effects of human activities. The soils have been thoroughly studied in space at several hierarchical levels using traditional and digital mapping techniques, thus reflecting vertical differentiation of the soil profile, randomized variety within the soil area, spatial regularities of changes in soil combinations.

Keywords
Solonetz complex, chernozem, short-term evolution, soil in space and time, monitoring.

Introduction
The current stage of soil science development has risen to a qualitatively new level in evaluating or monitoring evolution of soils and geosystems for the first hundred years owing to detailed studies carried out by trained specialists in the 20th century.

Such an approach (retrospective monitoring) allows study of processes, and rate of soil changes. At the same time, the study of present soil changes in time for the period have accumulated vast experimental data obtained during previous decades, depending on natural peculiarities of soils and environmental conditions as well as available information presented by the other authors.

The objective of this paper is to demonstrate the necessity of studying soil distribution in space for solving the tasks relating to the study of present tendencies for soil changes over time.
This study has been carried out in two regions of Russia characterized by different natural conditions, soil cover and human interventions: (1) soils of the light-chestnut solonetz complex within the Pre-Caspian lowland and (2) agro-forest landscapes predominated by chernozems in Kamennaya Steppe.

Objects and methods
The solonetz complex in the Pre-Caspian lowland has been studied at the territory of Dzhanybek experimental station located in 30 km north of Elton Lake in the Volga and Ural interfluve on frontier between Russia and Kazakhstan. Since the time of its foundation in 1949 the complex investigations have being conducted with the aim at compiling maps of microrelief (Mozeson 1955), vegetation and soils (Kamenetskaya *et al.* 1955). The soils have been studied in detail (Rode, Polskiy 1961) including water and salt regimes in them (Rode, Polskiy 1967; Maximyuk 1966). The solonetz complex consists of solonetzes and earth hummocks formed by animals under wormwood-cypress vegetation in convex, light-chestnut solonetzic and non-solonetzic soils under matricary-esparto grass associations on microslopes and meadow-chestnut soils under herbaceous vegetation with concave relief (Rode, Polskiy 1961). The parent material is represented by loess-like loams of marine origin (the early Khvalynian transgression of the Caspian Sea). In the 1950s the groundwater table was at a depth of 6-7 m (Rode, Polskiy 1961), since the 1980s it is 3.5-5 m deep. This territory is used for extensive grazing.

Investigation methods of the solonetz complex
The territory under consideration was surveyed in detail according to a grid of 1-2 m and additional special points (extremum, folds) by theodolite, level and metal measuring tape (50 and 100 m) with the aim at identifying a test area which has been studied earlier and overlaying the obtained factual picture of microrelief with the maps published in the 1950s. Changes in microrelief for 50 years were measured twice in 1950 and 2004 by algebraic subtraction of digital relief models in the grid 0.5 m. Independent from each other the soil and geobotanical surveys at a scale of 1: 200 were carried out in some key plots. The data obtained in 2000 observation points were comprehensively analyzed to gain a spatial overview of changes in

the thickness of different soil horizons with the kriging approach. The salt content in soils to the groundwater depth was determined in a 1:5 water extract, a potentiometric method was employed to measure the activity of sodium ions in paste with 40% of moisture.

The main results obtained to study changes in the solonetz complex in the Pre-Caspian lowland in the second half of the 20th century.

1. Changes taken place in virgin solonetz complex for 50 years reveal a combination of all-round evolution of its different components on positions closely located in space. Such trends are rather peculiar in dependence on the microrelief type. The half a century of changes in the solonetz complex are mainly induced by the groundwater rise from 6-7 to 4.5-5 m.
2. General pattern of relative spatial position and configuration of the most contrasting microrelief elements (convex and concave) remains almost unchanged, as is evidenced by field observations and overlaying of former and newly obtained cartographic materials.

The surface of the virgin solonetz complex shows some changes in microrelief of watershed and flat types. Stable unchanged positions of microrelief occupy about 50% of the total area, thus forming a tracery net-like frame with mosaic inclusion of some areas, which became lower to 3-20 cm (30-33%) and elevated up to 3-25 cm (14-18%). This is the action of several mechanisms responsible for changing the microrelief, which and functioned simultaneously and/or in consecutive order.

It was possible to observe uneven surface sinking to 10-20 cm in microrelief of radial-convex type (80-90% of the total area) probably due to rising groundwater table and capillary fringe resulted in moistening of dry salt horizons in the aeration zone.

3. As distinct from the widely used opinion about homogeneity of the solonetz complex and homogenous inter-convex watersheds at the given territory (Rode, Polskiy 1961) the obtained results serve as evidence of its heterogeneity and dependence on microrelief type.

Statistical indices of soil horizon depth in the main components of this solonetz complex reveal no changes for the half of century.

4. It is evident that the surface carbonate light-chestnut (solonetzic and non-solonetzic) soils and crust solonetzes without features of mixing the soil material by living organisms should be considered as newly formed components of this soil complex. These soils have a convex surface with the fine cracks due to accumulation of calcium carbonate in the initially carbonate-free topsoil.
5. At present, it is feasible to find any soil within the virgin solonetz complex at different spatial positions and under different plant associations with a probability of 0.3-0.8.
6. One third of inversions are connected with changes in microrelief that have taken place over 50 years, while two thirds of inversions are confined to stable unchanged areas, thus testifying their mobility during this period.

At the territory under study the rate of change in microrelief seems higher than for soil morphology but it is comparable with the changing rate of the salt state in soils.

7. In view of what has been said one should assume that the virgin solonetz complex in the Northern Pre-Caspian lowland correspond to a *nonstationary, fluctuent regime of evolutional development*. The only possible reason is periodical cycles of groundwater fluctuation (duration from a few ten years to 1-1.5 century). Moreover, the solonetz complex is invariant according to the relative ratio between the main soil and vegetation components as well as its principal configuration. By this reason, a part of the territorial position is occupied by components corresponding to a quasi-stationary regime of functioning or close to it. In the other part of Territorial position the same components are found at different stages of their development. In total, we observe a mosaic picture of spatial arrangement of quasi-stationary soil components and those developed through different trends, which relaxes the close connection between soil, relief and vegetation.

<u>The agro-forest landscape of Kamennaya Steppe</u> is situated in central part of the East-European plain in the interfluve between Bityug and Khoper tributaries of the Don river within the transitional zone from Kalatch upland to Oka-Don lowland in the southeast of Voronezh region. This is one of three test areas taken for research by a special expedition under V.V. Dokuchaev’s guidance in 1892. In the XX century this test area was used as a polygon for elaborating and approving general strategy of agricultural management under conditions of frequent droughts in the chernozem zone of Russia.

Since 1892 there have existed meteorological and since 1933 hydrogeological stations. Repeated soil investigations have been conducted at this territory (Glinka *et al.* 1894; Tumin 1930; Pershina *et al*. 1947; Antipov-Karataev *et al*. 1963; Aderikhin *et al*. 1984; Khitrov 2009). The vegetation (Maltsev 1923),

hydrogeology, the groundwater regime (Basov, Grishchenko 1963) and the landscapes (Milkov *et al.* 1971, 1992) have been also studied in detail. The initial steppe landscape was found to be transformed into an agro-forest one as affected by human interventions. At present, the major part of this landscape is under crop surrounded by protective forest belts. The surface runoff was completely regulated and transformed into an underground one. The soils derive from loess-like clays as the parent material.
The soil cover is represented by typical, ordinary, leached and zooturbated chernozems in flat watersheds and sloping areas as well as by solonetzic chernozems, chernozem-like meadow solonetzes and meadow-chernozem soils in depressions.

Investigation methods in Kamennaya Steppe.
43 key plots including above 950 observation points helped compile a map of the soil cover structure in Kamennaya Steppe as a GIS-project. The relief in 6 key plots from 0.2 to 6 ha in size has been surveyed at a scale of 1:1000. Some key plots were specially confined to that place, where soil profiles were analytically studied by other specialists 50 years ago. They embraced not only the soil profile described in detail earlier but also adjacent areas. Digital maps have been compiled to show the microrelief, the soil cover, changes in the depth of soil horizons and analytical characteristics of soils taking into account the soil profile form. The main objectives of this study were aimed to identify spatial regularities in distribution of soil properties and to select factual objects for evaluating the changes in properties of the same soil over time.

Some conclusions of this study
1. The soil cover of flat watersheds in Kamennaya Steppe is represented by a soil combination consisting of three components of chernozems including typical (40-70%), zooturbated (20-50%) and leached (10-15%) ones; it promotes the spatial regularities of changes in the depth of soil horizons and should be certainly taken into consideration for evaluating soil changes in time.
2. It was established that after 50 years the bulk density of the middle part of arable layer (10-20 cm) became higher from 1.0 to 1.2 g/cm^3 as well as a part of the humus horizon at a depth of 35-50 cm disturbed not by tillage but by animals. This is explained by repeated use of heavy agricultural machines in the 1960-1980s.
3. For 50 years a tendency to decreasing organic carbon content in the arable horizon (0-22 cm) from 5.2 to 4.6% was statistically substantiated.
4. After discontinuance of annual plowing 55 years ago the morphological configuration of hydromorphic chernozemic solonetz revealed its regeneration within the former arable layer, thus preserving physical-chemical features of the solonetz process (EC_{se} < 2-4 dS/m and ESP > 10%) for the period of observations since 1952.
5. Application of gypsum and manure exerted a short-term (not more than 5-7 years) positive effect. 50 years later it was impossible to find any morphological and analytical indication of this effect.
6. Due to mulching of the solonetz surface by materials taken from the humus horizon of chernozem the regeneration of morphological solonetz properties seemed to be slower at least for 30-50 years. However, under hydromorphic conditions the mulching layer acquires the physical-chemical and morphological properties of solonetz soils.
7. Monitoring of the soil state as based upon data obtained at different times within an area exceeding some square kilometers doesn't allow conclusions about soil change in time. The difference in statistical distribution is conditioned, on the one hand, by the diverse soil cover and combination of soil-forming factors over the large territory under study, on the other hand, by the arrangement of observation points to solve definite tasks in every period of observation as well as by methods of statistic and criteria for specific objectives and subjective data. Small test areas are required to carry out a detailed survey at different periods of time and to obtain information about the diversity, regularities of the soil cover organization and statistical indices of properties of soils in the test area.

Conclusion
When evaluating soil changes over time it seems reasonable to use information about the distribution of soil properties at several hierarchical levels:
- differentiation of soil properties throughout the vertical profile in every genetic horizon (but not in layers with a fixed depth);
- randomised variety of soil properties within the rather homogeneous soil cover or their trend changes according to the interaction the studied soil with adjacent soils;
- qualitative and quantitative difference of properties in various soils as components of any soil combination;

- different relationships between soil components in identical (as well as different ones) soil combinations and the possible quantitative difference in the same property of soils of the same type in different soil combinations.

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