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THE CONTENT AND TENDENCY OF ANTHROPOGENIC EVOLUTION OF SOIL COVER

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Abstract

Soils which were arable for a long time are typical polygenetic formations as the anthropogenic factors played the significant role in their formation alongside with natural ones. Under mechanical, chemical and ameliorative actions the natural soils lose a structure inherent in them, properties and modes. Amplifying anisotropy, spatial heterogeneity, preferential descending and ascending streams of a moisture, formed new types of horizontal and vertical soil profiles, the equilibrium density, ability to convertibility of properties and modes as the basic condition of counteraction to degradation processes is lost. Significant changes occur in thin dispersive mineral and organic parts. As a result of anthropogenous evolution for rather short historical time interval it is formed the new body - antropogenic transformed soil - agrozem which becomes a 4-dimensional body of the nature as its parameters are changed in space and time. This fact demands reflection in soil classification and corrective amendments in studying, management of their fertility and use. Possible scripts of the further anthropogenic evolution of soils are discussed: the degradation, balance and "smart" out-degradation transformation.

Key words: *agrozem, degradation, evolution, fertility, soil.*

INTRODUCTION

Anthropogenic factor is one of the soil-forming factors, but still it’s not found its place among other factors. This fact is recognized in a number of classifications of foreign countries (e.g. Russia, Belarus) and anthropogenically transformed soils or agrozems appeared. Similar proposals exist in the Ukraine (Tikhonenko, 2010). However, in the current soil classification of Ukraine (Izdatelstvo ‘Kolos’, 1977) and some attempts to improve it (Polupan et al., 2005), it is only possibility to correct the main process for long-used soil at the level of variant without changing the natural basic orientation of soil formation. According to Grinchenko et al. (1965), the process of soil amelioration is considered as an opportunity to preserve and improve the important agronomically properties of soils under conditions of long-term rational use with the invariability of the basic type of natural soil formation. Since the 60-ies of the XX century we conducted comparative research of predominantly chernozem soils under different conditions of use, from absolutely conservation virgin soil to variants where various agro-practices were applied. A significant amount of information was accumulated during the research of the basic properties and regimes of soils. An attempt to formulate regularities of anthropogenic transformation of arable soils, that were in conditions of long unbalanced and poor-quality use and to substantiate improved approaches to the research of old-arable soils for the purpose of their scientific monitoring were made in the article.

MATERIALS AND METHODS

The objects of research are arable soils of Ukraine. The analytical and field methods of soil research are classic methods adopted by Ukrainian standards (List of basic normative documents, 2017). Field methods include field research with situational maps, the field being divided into analytical units or parcels, the profiles are placed from which soil samples are collected in dependence on the pedological complexity, the mode of land use and the research purpose. The analytical methods are laboratory standard analysis of soil samples for selected indicators. Continuing the analysis and validation process of the results obtained by classical methods of soil analysis and carried out in the field takes place by completing with data obtained through GIS. Mathematical and geostatistical methods have been used for land quality using generalized covariance functions. Applied geostatistics techniques included Aerial Surveillance with Remotely Controlled Aircraft (DPLA).

RESULTS AND DISCUSSIONS

Factors of anthropogenic evolution. The main factors of anthropogenic evolution are mechanical, chemical, ameliorative impact on the soil cover, disturbance of the natural balance of substances and energy, weakening of soil cover stability through to excessive plowing and deficiency of forests and grassland, development of urbanization, industrial zones, etc. Natural soils changes their structure, properties and regimes and gradually transformed into new bodies of natural-anthropogenic (polygenetic) origin under the influence of the above factors.

Argillisation of soils - the initial stage of transformation of soils under the action of tillage. Krupenikov (1978) was first one, who paid attention to the manifestation of argillisation in chernozems (genetically undifferentiated soils) under the influence of prolonged agricultural use, later - Garifullin (1979), Korolev (2008). In our research (Medvedev, 1988), this process was also confirmed: according to the results of the granulometric analysis, it was difficult to prove an increase in the content of clay in a long-plowing arable land in comparison with an absolutely conservation virgin soil. However, if we determine the specific soil surface by sorption of water molecules from vapor with an elasticity of 0.2 (according to Kutilek), the total active surface (by sorption of water from vapors with an elasticity of 0.35 to 0.98 in accordance with the Obermiller range) and ultraporosity (by sorption of benzene molecules - a nonpolar liquid - with the elasticity of its vapor from 0.23 to 0.8 kPa) it is possible to obtain evidence of a change in the quality of the soil surface after a long tillage. These liquids reflect well enough even small changes in the state of the soil surface. Herewith, the most adequate representation of the magnitude of the soil surface can be obtained from sorption of moisture (Voronin, 1959), from the sorption of benzene - its ultraporosity (Antipov-Karataev et al., 1948), and by comparing these data - the hydro-philicity and hydro-phobicity of soils as sorbents (elasticity or rigidity of their structure). According to Medvedev (1988), chernozems are predominantly sorbents of a non-rigid elastic structure.

New horizontal and vertical profiles of anthropogenic soils. Because of the peculiarities of the technology of growing crops, turning and loading-unloading of vehicles, sewing machine, fertilizers and combines at the margins of the fields, soils are constantly subjected to a stronger influence of running systems of machine-tractor units (MTU). As a result is soil re-compaction, the reversibility and ability to restore modal parameters are gradually lost. These processes intensify the spatial variegation of the field. The coefficient of horizontal spatial diversification of the content of available phosphorus on the arable land in Forest-steppe amounts 0.56, while on the same virgin land it is only 0.09. According to our observations, more strengthened and deeper furrow bottom with a hardness of more than 30 kgf/cm^2 is formed precisely at the margins of the fields, which significantly limits the growth of roots in depth and reduces the adaptation of plants to a moisture lack. As a result, almost field variegation is marked on arable land (Medvedev et al., 2015).

In the lower parts of the field, where the level of moistening is higher, there is a similar re-compaction effect of MTU on the soil. Differences in the value of the equilibrium density of addition and hardness in different parts of the field are significant. Over a 30 years observation period, it was noted a significant increase in the thickness of furrow bottom from 30-40 cm to a depth of 70 cm. Thus, new horizontal and vertical profiles are gradually formed on old-plowed soil, and spatial heterogenization of soils increases eventually (Medvedev, 2011, 2012).

Physical degradation of soils is considered as a process that leads to soil re-compaction, loss of structure, its quality, the formation of lumps in the surface layer, crusts and cracks, and at the base of the plowed layer - the furrow bottom. Diagnostic indicators of degradation are: simplification of structure and pore space morphology, steady increase in the equilibrium density, decrease in inter- and especially intra-aggregate porosity, formation of preferential moisture flows that are uncharacteristic for natural soils. The main cause of physical degradation is the exceeding of the level of mechanical loading of the soil's ability to restore the modal parameters of the structure, properties and regimes.

The lumpiness of old-arable soil becomes almost an obligatory characteristic unlike virgin land, where lumps are absent. In a lumpiness arable land it is impossible to create a sufficient supply of available moisture: it either falls into the lower layers of the soil profile, or evaporates. Also, it is impossible to implement high quality sowing of field crops. Seedlings of plants turn out to be in homogeneous, and their development is uneven. For the destruction of lumps, additional tillage and investment of costs are necessary. Research by Bakhtin (1969) found that even a minor deviation of moisture at the time of tillage from the humidity of soil physical maturity leads to the formation of lumps. In this regard, more than 82% of the arable soils in Ukraine form lumps, and about 12% - to a large extent (Medvedev, 2008). These are alkaline soils of dry Steppe, Vinnytsia is land of eroded graypodzolized soils, gleyed soils of Precarpathian and Transcarpathian, and also throughout many regions of the Forest-Steppe and Steppe. This phenomenon is typical for almost all soils, except for sandy and loamy sand type. In the Steppe of Ukraine, where the residence time of the soil in the state of physical maturity is very short, the probability of formation of lumps during tillage is significantly increased.

The density of loamy chernozem soil on virgin soil is approximately 1.0-1.1 g/cm^3, the same arable chernozem - in the range from 0.8-0.9g/cm^3 immediately after tillage to 1.15-1.35 g/cm^3 in the equilibrium condition. The period of equilibration (relaxation), depending on the agrofond and precipitation, lasts from a few days to two weeks. During this period, the dynamics of water-air and biological properties of soil are noted, depending on the density of soil. Due to low density and humidity, close to physical maturity, in the spring there is a real threat of compaction of all soils without exception, which is in chernozems.

If the chernozem typical and chernozem ordinary of medium-loamy granulometric composition are plowing in a state of physical maturity, the content of agronomically valuable aggregates (particles 10.00-0.25 mm in size) is 60-80%. Herewith, even a slight compaction or a deviation from the moisture of physical maturity significantly impairs the tillage soil quality.

The water-stability of macro-aggregates of chernozems on the virgin soil, as a rule, reaches 70-80%, and in arable soils - no more than 50%, which is a consequence of the loss of organic matter with constant loosening of the soil and the dominance of aerobic microorganisms. Reduction of water-stability and aggregation potential on arable soils in comparison with virgin soil testifies to the existence of processes of physical degradation in old-arable chernozems (Medvedev, 2008).

Preferential flows of moisture (or extensive filtration over large pores) are formed in arable soils due to the presence of lumpy particles in it. Comparative research of the filtration capacity of different structural fractions indicates that for instantaneous downward traffic of moisture, a small amount of lumpy particles and large pores are needed. In the arable layer, preferential flows are formed by lumpy particles, in the depth of the profile – due to large pores of biological genesis (Medvedev et al., 2003).

The research confirms the multiple increasing filtration, as soon as only a small number of lumps appears in the soil (Vershinin, 1959).

Quite reasonably the ascending flow of moisture can be attributed to preferential, which leads to unproductive losses of productive moisture as a result of physical evaporation processes due to the presence, of lumps in the surface layer (Medvedev et al., 2004; Medvedev, 2008).

Chemical degradation of soils. The content of total humus in the arable layer of almost all soils according to different data is 20-50% lower than in their virgin analogues (Medvedev, 2012). Losses of humus are characteristic for unbalanced land use. The deficiency balance of organic matter actually lasts on arable soils from the moment of their development. As a result the soil is degraded and this is a universally recognized fact. The characteristic lane of the increased content of humus in chernozems which forms an axis from the southwest to the northeast (Odessa, Kirovograd, Poltava and Kharkov regions) was disappeared. It's well known the northern boundary of this lane coincides with the barometric maximum which divides the territory of Ukraine into two parts: north-western (moistened and cooler) and south-eastern (warmer and arid). According to the Institute of Soil Protection of Ukraine, the annual loss of humus in the period 1965-1990 reached 1, now - about 0.5 t/ha per year. Old-arable chernozem is destructed, its anti-erosion resistance is reduced due to a decrease in the amount of organic matter and its labialization in comparison with natural chernozem (Figure1).

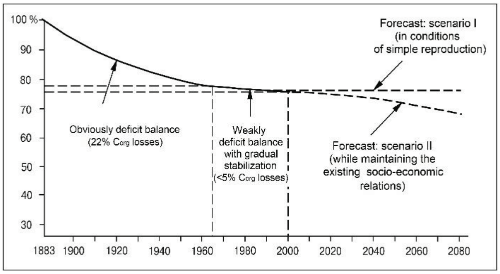

Figure 1. Dynamics of humus content in chernozem soils and forecast of its changes

Reversibility of soils is an important soil property, meaning its ability to restore its modal (most likely for these local conditions) parameters after removing the mechanical or chemical load. There is many reason to believe that the long-plowed soil has lost its reversibility, because the new parameters have become stable. Such soil has acquired a different morphological profile, other properties and regimes. If plowed soil will be taken out from arable land for a sufficiently long period, its properties can be restored (Medvedev, 2008). Soil observations conducted in Argentina and Brazil under conditions of zero tillage are evidence of this (Medvedev, 2010). Active erosion manifestations and other signs of degradation are practically absent in such soil. In this regard, the removal of old-plowed soils from arable land that have acquired signs of degradation and lost economic value is an important task.

The structure formation is markedly inhibited and its quality is further significantly reduced as a result of long tillage. We proposed soil aggregation norms showing the amount of aggregates of agronomically useful size and their water-stability, which account for 10% of the physical clay (Medvedev, 2008), which differ significantly on the virgin land and plowland. So, for example, for typical and ordinary chernozems loamy granulometric composition, they are 1.75 and 1.60 for structural aggregates with sizes from 10.00 to 0.25 mm and 1.60 and 1.00 for water-stability aggregates larger than 0.25 mm.

Scenarios for further anthropogenic soils evolution:

- degradation is the most likely scenario while preserving modern unbalanced and inequality agriculture. Degradation in these conditions can gradually become a factor that forms an agro-soil;
- seeming equilibrium is the most likely scenario because the evolution of soils cannot be balanced in conditions of a long deficit balance of biophilic elements and excessive mechanical stress;
- stability development is a scenario that should be pursued („smart, intelligence, agriculture");
- scenario for the near future is instead of zonal generalized technologies one should use precise agriculture with considering spatial variegation, field history and the stage of its anthropogenic evolution.

On the regeneration and „equilibrium" of soil fertility in modern agriculture

The first scientific conclusions about the degradation of soil properties under conditions of long plowing were made by the researchers of domestic and foreign pedology and agriculture even more than 100 years ago (Dokuchaev, 1892; Russell, 1955). They noted a sharp degradation in the physical properties of soils, the loss of organic matter, the intensification of erosion processes in arable soils compared with the virgin soil. Even then the system of farming was found to be unsuitable, requiring replacement. Now we began to calculate the balance of nutrients in the production environment relatively regularly, so we obtained data on changes of soil properties and regimes during the tillage, agrochemicals, irrigation and drainage. The statements of the classics were confirmed. Moreover, balance in the fertility of soils at this stage in the development of agriculture cannot be achieved.

According to generalized data (Medvedev, 2012), the most characteristic processes in soil changes over the past 40-50 years are:

- dehumification of plowed soils;
- increasing deficit of the balance of available nutrients, especially nitrogen and potassium (respectively 41.5-56.4 kg/ha in 2001, 32.9 and 64.2 kg/ha in 2009);
- acidification of chernozem soils (in some region of the forest-steppe zone);
- soil compaction of 40% of arable land (especially in the western Forest-steppe), destruction, lumpiness and crusting;
- reduction in the depth of the topsoil with erosion, which reaches several centimetres in chernozem soils and over dried soils of Polissya;
- secondary alkalinisation and salinization of irrigated soils.

The main cause of degradation is the underestimation of the real threat that forms this phenomenon for present and future generations, the lack of effective mechanisms for implementing laws on soil conservation, unbalanced and scientifically groundless land use. The problem was aggravated due to the termination (in fact, since 1991) of the state and regional land protection programs. Significant results were achieved until the end of the 1980s.

By main program parameters. In the following years, volumes of soil fertility improvement works have decreased to the minimum values: agroforest amelioration has not been carried out, volumes of fertilizer application have decreased, considerable areas of chernozem soils have not been tillage, and as a result, the content of nutrients has decreased, acidification of chernozems has occurred, and their physical properties have deteriorated.

Decrease of soil cover stability. The use of arable land with unfavorable properties is economically inefficient and creates a threat of further deterioration of soil properties due to the imbalance of modern agriculture. According to Dobrovolsky et al. (2002) about 30-40% of the territory must be supported in an virgin natural state. About the same amount of land can be plowed with an erosion-resistant agricultural landscape (Svetlichniy et al., 2004). According to Guidelines (1983), there should be a ratio of 1: 1 between the ecologically stable land (forest, pasture land, hayland, pond) and lands that destabilize the landscape (arable). It meets these recommendations of FAO in most countries of the world, with the exception of Hungary, Ukraine, some USA states and some countries of Southeast Asia.

Monitoring of the plowed soil. It is necessary to take into account new characteristics in monitoring - the dynamics of the main properties and regimes (moisture, air and other characteristics), relaxation as a period of balancing. New phenomena inherent in the plowed soil - drift and inertia (in English transcription [lag] or literally „retard”) or the time during which the soil restores its modal characteristics requires careful analysis.

There is no established opinion in the literature about the recovery time. According to Litvin et al. (1974), soil needs about 2 weeks with optimum temperature and humidity conditions to reach the maximum level of soil conditioning and to restore the bulk density of addition after tillage - from several days to 2 weeks, depending on agrofonds and precipitation (Medvedev et al., 2004). Based on the data of agrochemical certification of arable soils in Ukraine, it can be concluded that by 1990, in Ukraine, after 25 years of intensive chemicalization, a simple reproduction of fertility was achieved. The fall of humus has sharply slowed down in the soils and the inertial phase has come, Zubetz et al. (2007). In the central belt of the USA, where chernozem like soils (mollic soils) are prevailed, it took almost 60 years, since the losses of humus were 2 times more intense than in Ukraine (Lal et al., 1998).

Smagin (2012) confirmed that the degradation of chernozems does not end even after 200 years of their exploitation. He used the original method of reconstructing the dynamics of the development of chernozems. In subsequent years, it extends to deeper horizons, resulting in a gradual mineralization of more than 70% of the original humus stock. For the first 100-200 years it is lost from 30 to 50%, later the process continues more slowly. Only for 2-3 thousand years a new stationary state can be formed, which corresponds to a 3-4-fold decrease in the source of humus substances in comparison with the virgin land.

Thus, the soil has several mechanisms that allow resisting anthropogenic interference. This is a biological mechanism, that is, the ability to self-purification, and a physic-mechanical mechanism that reveals the essence of such processes of maintaining soil properties as buffering power, adsorption, barrier function. Due to the existence of these mechanisms, the soil is able to reduce the negative consequences of plowing. Any soil has a certain resistance, after exceeding which irreversibly degrades.

If the soil is able to restore characteristic parameters, it remains in an intermediate apparent equilibrium state. If the soil has lost its ability to return to its original state, then it has become degraded. And in this case, it is necessary to take appropriate measures: removing from the arable land or raising its fertility level. Monitoring of the arable land should provide for an appropriate set of tools to address these issues. Preference should be given to data obtained: *in situ* (directly in the field) and *on-line* (continuous registration of soil properties). Such regimes eliminate the need to select and transport soil and plant samples to the laboratory, making all preparatory operations and analytical work unnecessary. These regimes *in situ* and *on-line* will eliminate the inevitable discrepancy between field and laboratory measurements, taking into account the constant dynamics of the main soil regimes in time, depending on humidification, temperature, microbiological activity. It is difficult to describe correctly the peculiar rhythm of the soil formation processes inherent in the plowed soil, based on the results of traditional monitoring. Today, the opportunities for studying the real daily, seasonal, annual and long-term dynamics of soil processes are rapidly expanding.

To describe the processes of soil formation in arable land, it is important to conduct scientific monitoring, and obtain information of maximum accuracy and capacity, suitable for predictions and sound management decisions.

It is also necessary to establish soil-ecological polygons in order to study of following tasks:

- study of the spatial distribution of chemical elements, indicators of soil properties and processes, depending on the landscape situation and anthropogenic factors (the task of „geostatistics");
- observations of changes in main characteristics of soils under the influence of natural and anthropogenic factors (the task of „dynamics");
- study of quantitative and qualitative parameters of redistribution of chemical elements, surface and intrasoil run off (the task of „migration");
- carrying out experiments with artificially given parameters of anthropogenic load (the task of „modelling and forecasting").

To conduct research the land polygon is equipped with drainage and microstock sites, lysimeters, observation wells, precipitation gauges, gauging stations, detailed soil mapping is carried out.

It is ideal variant when the soil-ecological polygon is supplemented by long-term (stationary) field experiments to research different level sand types of anthropogenic load (with tillage, fertilizers, land melioration and others). Usually such experiments are conducted with the purpose of developing an optimal technology for obtaining crop production and observations of changes in soil parameters in them look like not mandatory application to crop yield data or ecological and economic interpretations.

Such observations can and should become an independent and extremely important assessment in a variety of ways:

- the definition of characteristic indicators of properties and processes at different levels of anthropogenic pressure (starting from the minimum, on the control, to the maximum, not having a place today, but expected in the future);
- determination of the rate of change of properties and processes under the same loads;
- the establishment of a general orientation of the change in indicators and processes (a quantitative description of the anthropogenic evolution of soils).

The implementation of projects of the scientific monitoring will allow using advantages of the pedotransfer modelling for forecasting of soil processes. The control of elementary soil-forming processes, productive and ecological functions, proactive information on the state of soils, migration of substances and contaminants to adjacent environments should become important tasks of scientific monitoring and at the same time a tool for the development of experimental soil science of increased information content.

In soil science and agrochemistry, there are many models that can reliably predict the behavior of soluble salts (accumulation or leaching), organic substances (mineralization or humification), moisture (diverse migrations), development of root systems, cycles of individual elements (C, N, P etc.), fertilizer efficiency, crop productivity. More complex, non-equilibrium models make it possible to predict the direction and parameters of the evolution of the soil cover to a distant future under the influence of global climate change.

The forecast is an extrapolation in time, the calculation of future values. This part of the soil science is especially in need of development due to the absence of a long series of equidistant observations, as an indispensable condition for the development of a correct „long-term" forecast. Methods of the forecasting should be developed with the development of the monitoring in the soil science, since the widespread ones (simplified regression models, models of exponential smoothing of Brown, moving averages etc.) turned out to be untenable. The methods of Boxing and Jenkins should get a preference, approbation of which gave positive results (Medvedev, 2012).

Methodology for managing the fertility of long - term plowing soil. Appropriate agrotechnology should be used on long-term plowing soil. If the parameters of the properties are in a favorable range of values, then the main thrust of agricultural technologies should be the use of such processing methods that would contribute to their preservation. As the properties of these soils deteriorate, the saturation with improving tillage should increase. If the soil is irreversibly worsened (the relevant criteria are known - Novakovsky et al., 2000), then it must be taken out of arable land. This is only a general scheme, in which it is necessary to introduce refinements depending on the real state of soils, genetic, climatic, orographic, lithological and many other features of the soil cover, as well as on the direction and intensity of its economic use.

Given the exceptional role of soils, especially chernozem, in creating economic and environmental well-being, it is necessary to have a clearly defined strategy for their protection This means effective functioning of soil protection programs and laws, strict monitoring of their implementation, monitoring using a broad program of indicators, mandatory rationing of all types of loads, observance of recommended and introduction of the newest soil protection technologies

The program for the development of the agro-industrial complex of Ukraine posed very ambitious tasks regarding agricultural products. We are sure that traditional approaches based only on fertilizers and intensive tillage cannot solve these problems. We need to learn how to regulate not only the nutritional regime, but also the moisture and air regimes, not to allow the root-inhabited layer to be re-compacted and, most importantly, to reduce the unproductive loss of moisture. It is here that the newest agricultural technologies could be useful - conservative, accurate, zero, other treatments that have a soil and economic effect.

CONCLUSIONS

As a result of anthropogenous evolution it is formed the new body - antropogeneous transformed soil, which, in comparison with the virgin lands has different structure, properties and regimes. Anisotropy, spatial heterogeneity, preferential descending and ascending streams of a moisture are amplified, new types of horizontal and vertical soil profiles are formed, the equilibrium density, consolidation and the amount of false aggregates are increased (grow), the structure of the pore space is changing, there is an obvious slowdown of aggregation processes, ability to convertibility of properties and modes as the basic condition of counteraction to degradation processes is lost. Significant changes occur in thin dispersive mineral and organic parts.

Agrosoils as soils with a structure, properties and regimes, that differ from natural, should receive an appropriate place in the classification, and their use and management of fertility must correspond to the degree of their transformation and the stage of anthropogenic evolution.

Possible scenarios of anthropogenic evolution of soils: degradation is the most probable - while preserving modern unbalanced and poor-quality agriculture, seeming balance is the least probable, likely it is the erroneous scenario resulting from short-term observations, sustainable development, as „reasonable” (smart) agriculture.

The organization of studies using in situ and on-line regimes, landscape soil-ecological polygons, complex stationary experiments using experimental planning methods, the use of effective methods for predicting soil processes is necessary for a favorable scenario of anthropogenic evolution of soils.

The purpose of modern agropedology is to justify the transition from zonal generalized technologies to precise agrotechnologies adapted to the characteristics of each field and the degree of their transformation.

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