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THEORETICAL AND APPLIED BASIS FOR CREATION OF SPATIALLY-DIFFERENTIATED SYSTEMS OF SOIL QUALITY MANAGEMENT BASED ON SPACE SCANNING DATA

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Abstract

Global trends in agricultural production and environmental management require the mandatory use of geoinformation technologies and Earth remote sensing data as a basis for informational support for effective management of land and soil resources. Therefore, it is important to develop a methodology for using space scanning data to create spatially-differentiated soil quality management systems, which take into account the quantitative estimates of spatial soil variation and the results of pedotransfer modeling to evaluate soil quality and create optimal agrotechnologies. Experimental studies in different regions of Ukraine showed the effectiveness of the developed technology for soil decoding by multispectral space data with high spatial resolution to determine soils, which are different in complex assessment of soil physical quality for the diagnosis of especially valuable, optimal and modal parameters of soils, their degraded and underproductive kinds. Coherent analysis of the results of space image classification and geostatistical processing of soil field surveys is effective for a reasonable extrapolation of evaluation results at large territories and the development of agrotechnologies, which provide optimal conditions for development of agricultural plants and increase their productivity.

Key words: *geoinformation technologies, geostatistical processing, soil quality, remote sensing.*

INTRODUCTION

The need to integrate our country into the European systems of environmental monitoring and ecological land use, as well as the need to implement the sustainable development of market relations in the agrarian sector of Ukraine, require a development of the modern information support system for soil cover studies, especially in agricultural lands.

Every facet of the landscape can be accurately characterized by conventional soil survey but this is time-consuming, some areas are hard to reach and it is not practicable to analyse long-term soil change using field data alone. Remote sensing (RS) and geographic information systems (GIS) allow us to meet the challenge thanks to continual instrumental improvement and computerised image interpretation in GIS, elaboration of theoretical foundations for assessing the structure of soil cover and spatial heterogeneity, and application of geo-statistics to provide testable estimates of reliability (Goldshleger et al., 2010). In particular, high-resolution multispectral satellite imagery offers objective data with the accuracy (geometric and geographic) and detail that we need to soil diagnose and map soil degradation. The use of high-resolution multispectral satellite images, which typically have geographical compliance, continuity, and are regularly updated, seems to be the promising approach to ensuring compliance to high requirements for the accuracy and impartiality of the data on the national soil resources. Additionally, satellite images, as up-to-date digital materials, in conjunction with modern GIS, provide means of precise determining the soil heterogeneity, both in detailed and large-scale surveys, which defines the basics of precision farming (Medvedev, 2007; Godwin et al., 2003; Havrankova et al., 2006; Mouazen et al., 2006; Medvedev et al., 2009).

Backed by numerous publications in many countries we can make a conclusion that precision agriculture is a very promising application of remote sensing methodology, not only as a new agricultural technology, but also for the formation of sustainable environments. The concept of precision agriculture is intended to achieve a stability state of agrarian landscapes, risk minimization of incorrect agricultural activities (Mouazen et al., 2007). Precision farming involves calculation of the optimal parameters of agricultural activities, including the doses of fertilizers and methods of cultivation, which affect the overall environmental condition of soil and vegetation cover. Most of the parameters required for the selection of certain agricultural technologies are diagnosed by means of remote sensing. The task of remote sensing for precision agriculture is to identify similar parts of a field that require specific methods of cultivation or fertilization. Because precision farming involves restriction of fertilizers and other means of chemicals, it can be regarded as an admission of ecologisation, i.e. removal or prevention of negative effects of excessive treatment, pollution and other degradation processes on such a non-renewable resource as soil. The use of remote sensing methods is most important on the initial stage of elaboration of precision farming technologies in order to measure soil indicators (the main environmental constants). Additionally, the measuring point indicators based on remote sensing data allow to track a crop's status, i.e., to see whether diseases are developing, if the crop is suffering from water stress, nitrogen stress and so on. Soil physical measurements combined with soil analysis make it possible to precisely map agro-pedological conditions (Truskavetsky et al., 2015).

The results of our researches have shown that integrated use of high quality satellite images can provide a necessary amount of numerical information for the correct recognition of soil-contours that have differences over the content of soil parameters, such as humus, agro physical soil indicators (Byndych, 2017).

Cartographic materials obtained this way are used to determine quantitative estimates of soil anisotropy, and to development of optimal agricultural technologies.

In our opinion, the above necessitates the use of a systematic approach for a land use optimization on arable land, which actualizes the need to development the methodological bases for a creation of spatially differentiated of soil quality management systems.

Nowadays, in Ukraine there is no spatially differentiated soil quality management system that will objectivize the evaluation of the quality of arable soils on the basis of taking into account updated data on the basic properties of arable soils, the latest methods of forecasting and modeling, the implementation of differentiated agrotechnologies taking into account zonal and regional peculiarities of soil heterogeneity.

Significant disadvantages of existing approaches in the world is a limited number of evaluation criteria (Agricultural land classification survey of England and Wales, 1974), actually ignoring the most important factors of land productivity - moisture and heat supply, stocks of available nutrients (Petrasovits, 1978), the artificial nature of the division of criteria into basic and modification, unreasonableness of most correction coefficients, incorrect description of complex soil-crop system only with paired correlation analysis (Polupan et al., 2008), absence of production testing techniques (Methods of soil evaluation in Ukraine, 1992), as well as disregarding the heterogeneity of the soil cover (Glover et al., 2000; Granatstein, 2016).

MATERIALS AND METHODS

An practicing of a create a spatial-differentiated soil quality management system based on space scanning data was carried out on the example of the Korotych polygon. This polygon occupies 30 ha in Kharkiv Region. It lies within the Zolochiv-Chuguev physiogeography region of the Left-Bank Dnieper forest-steppe province of the Ukraine (Popov et al., 1968), which characterized by erosion-tree combinations of typical chernozems of deep middle and low humus and podzolized chernozem (Chernozem Chernic in WRB*)* and leachate chernozem (Chernozem Luvic in WRB).

We have tested modern technologies for creation of spatially-differentiated systems of soil quality management using Landsat 8 satellite data that provides digital images of the Earth's surface in the panchromatic (with a resolution of 15 m) and multispectral bands (with a resolution of 30 m) (https://www.usgs.gov/land-resources/nli/landsat/landsat-8).

This imagery may be interpreted to monitor land use and crop rotation compliance, calculate the total area of crops, identify stages of crop development, detect soil erosion and salinity, study natural conditions that affect agricultural activities (waterlogging, sharp changes in relief) and identify agricultural land that has suffered losses due to adverse natural conditions.

Imagery was acquired from the bare, dry soil surface (11.05.18). Research activities included: statistical analysis of the image, creation of a provisional soil map and system of soil sampling, field investigation of the soil pattern and laboratory analysis of soil samples, expert assessment of image complexity and analytical results as the basis for image classification and soil-cover models, derivation of mathematical models describing the relationship between optical characteristics of soil and other soil attributes, parameterization and geo-statistical analysis of the spatial variation of soil indicators, and extrapolation procedures based on interpretation of spectral signatures. A generalization of experimental data and calculations of soil, climate and land assessment, the fundamental and current value of arable soils were important parts of research.

With the aid of a GPS, a regular grid of elementary sites was established (one per 1 ha) for 35 soil sampling were collected from the 0-10 cm layer, and 3 soil pits were dug to characterise the soils (morphological structure of the soil profile, depth of humus profile, spatial configuration of plow layer) in the field. Samples were collected according to Soil Survey Standards of Ukraine (ISO 10694-1995, DSTU 4287:2004, DSTU 4728-2007, DSTU 4730-2007). Also in the field it was investigated the physical soil properties (density of structure, hardness - according to DSTU 5096:2008, specific resistance during plowing), the crop yield was recorded.

At the laboratory-analytical stage of the research, it was determined: granulometric composition of the soil (DSTU 4730:2007); total humus content (DSTU 4289: 2004); the content of mobile forms of phosphorus and potassium (DSTU 4115-2002; DSTU 4114-2001); pH (DSTU ISO 10390:2007) and structural-aggregate composition (DSTU 4744:2007).

Analytical data were compiled in a regional database. Statistical and data processing methods used GIS TNT-lite for geo-referencing of space image, NDVI calculation, primary image processing, transformation, general statistical analysis and image classification; and STATISTICA 10 for variance, correlation and regression analysis.

RESULTS AND DISCUSSIONS

Numerous studies have shown that an important feature of the soil cover is its heterogeneity, which is due to the heterogeneity of the terrain, parent rock, uneven fertilization and meliorants, tillage etc. (Dmitriev, 2001; Medvedev, 2007; Friedland, 1978; Wei Xue et al., 2019). As a result, the heterogeneity of soil physical, biological and agrochemical properties is observed within one field (Tittonell et al.). Therefore, taking into account the spatial heterogeneity of the soil cover is a necessary component for the optimal organization and use of agricultural land and the implementation of innovative agro-technologies for growing crops, which contribute to the conservation of soil from degradation and pollution, saving costs and obtaining competitive products.

Many works are devoted to the use of geoinformation technologies, which provide for mandatory use of space scanning data, as an objective information basis for determining the state of the Earth's surface, as well as geoinformation systems and to assess the spatial heterogeneity of arable soil properties.

Comprehensive analysis of theoretical bases for determining the soil cover heterogeneity and taking into account the specificity of space scanning data allows to group theoretical and methodological bases of the use of space imagery for spatial differentiation of a soil cover as a basic issue in the development of modern soil quality management systems (Figure 1).

The first group of methods consists generally scientific and classical research methods, which allow to process quantitative characteristics of a large number of studied objects and phenomena and to evaluate the reliability of the conclusions obtained. When using space survey data, researchers collide with an additional set of uncertainties of all kinds, which is related both to the multifactorial formation of the optical characteristics of the soil surface during survey and to the lack of knowledge of the nature of the relationship between soil properties and its spectral characteristics. In this regard, the fundamentals of probability theory, a statistical theory of pattern recognition and information theory are of particular importance.

A particular group of methods constitutes of multivariate statistical procedures (factor, discriminant and cluster analyzes) for interpreting and classifying images during a thematic decryption, since space images are sensing in several bands of the spectrum. This group includes a geostatistica, which proves the regular nature of the variation and covariance of spatially distributed data.

The soil science foundations and methods are a separate group. For example, theories of soil cover organization and qualitative assessment of soil properties. For example, this group includes the complex of soil science techniques for using of space scanning data to determination of soil properties (total humus content in the arable layer, the content of fractions of physical clay, iron compounds), which determine the optical characteristics of the soil surface.

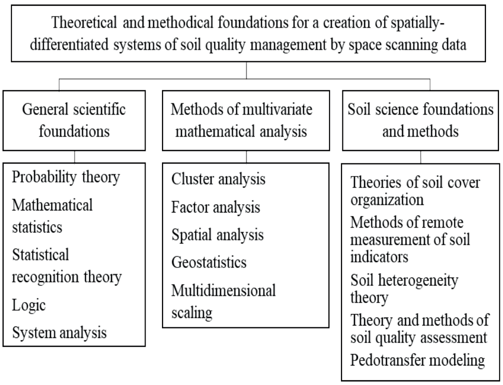

Figure 1. Scientific foundations for a creation of spatially-differentiated systems of soil quality management by space scanning data

A systematic approach to optimizing land use on arable land, which actualizes the need to develop methodological foundations for creating spatially-differentiated systems of soil quality management (Figure 2).

As a result of the research, a system of quality management of arable soils in Ukraine was developed, which represented a complex of interrelated methods, principles, and methods of purposeful impact on arable soils for their rational use, protection and increase of their fertility on the basis of detailed consideration of the regularities of spatial variation of soil properties, that was defined and evaluated based on thematic decryption of satellite imagery data.

The information unit of the developed system is a set of information about the properties of arable soils from different sources, the use of which allows to evaluate the quality of the soil. In this case, the main source of information for the spatial differentiation of the soil cover on arable agricultural lands is data of multispectral space scanning of high spatial resolution. The results of contour decryption of space images are supplemented by data on soil sample surveys, determination of the main climatic indicators (by administrative areas), yield data of major crops and the results of scientific research using pedotransfer modeling, that allows to obtain the required amount of data on the main agro-physical indicators.

The analytical evaluation unit includes the assessment of the quality of arable soils by updated data to establish the parameters of particularly valuable soils, determining the area of degraded and unproductive soils. At this stage there are estimates by the improved soil evaluation method and the highly cultivated and low fertile soils are identified, their ecological functions are evaluated and their evaluation changes as a result of increasing the intensity of cultivation or availability of land degradation are predicted. Based on the results of the evaluation, zonal and regional features are established to justify the transition from zonal to spatially differentiated agro-technologies by the set of physical, chemical and agrochemical properties of soils.

The management unit provides the implementation of space-differentiated agro-technologies taking into account the local heterogeneity of the soil cover, as well as the determination of such economic estimates as the value of arable soils and their agro-investment attractiveness, providing land users with sufficient information to reduce the risk from attracting investment in the development of the country's agricultural sector. This unit also provides for the legal and regulatory support of the functioning of the developed system for the possibility of its implementation in the field of land tenure and the development of measures to increase the level of fertility, rational use and protection of arable soils of the country. In addition, organizational and coordination activities require mandatory background (reference) and production monitoring of soils by a broad program of indicator parameters to control the quality of arable land in the country.

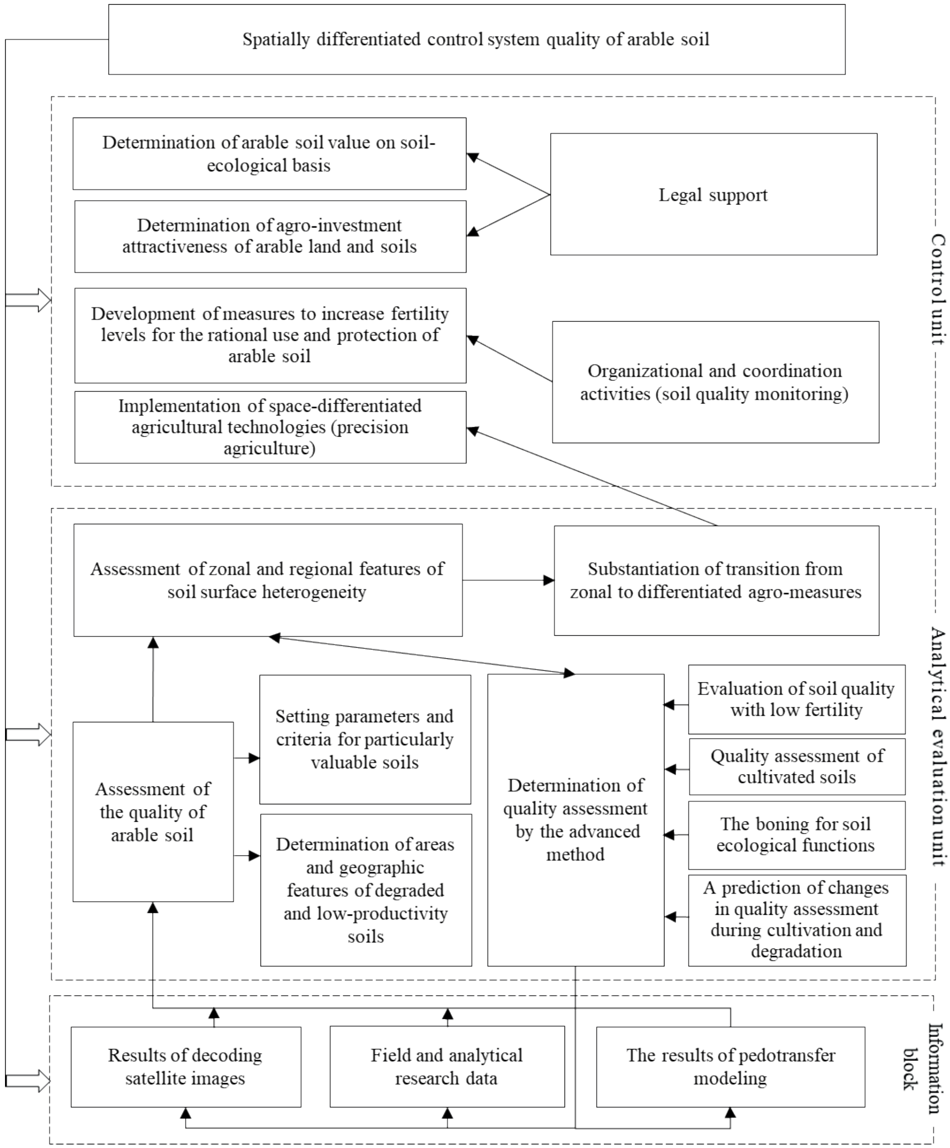

Figure 2. Scheme of spatial-differentiated quality management system of arable soil

The proposed system was elaborated taking into account the heterogeneity of the basic properties of arable soils in different natural and climatic zones of Ukraine. Here is an example of its use for Korotych test site. According to the results of contour decryption of of Landsat-8 satellite data, three soil contours were identified within the test site, which presented varieties of dark gray podzolized soil according to the national classification of soils, which corresponds to the Haplic phaeozem according to the WRB classification (Figure 3).

The provisional soil map was created in the final stage of image processing by the K-means method of cluster analysis. This map was the basis for soil sampling and positioning of soil pits for field observations. Further, we observed correspondence between soil delineations and individual elements of the micro-relief so the map reflects a certain orderliness of the soil cover; its boundaries separate soil bodies with specific internal structure and variability characteristics.

Figure 3. Soil map of the Korotych polygon, which derived from classification of Landsat-8 satellite data:

 - the soil sampling location;

1 - conformed with dark gray podzolized soil on loess-like parent material (Haplic Phaeozems in WRB);

2 - conformed with dark gray podzolized soil on loess-like parent material, lightly eroded (Phaeozems Turbik in WRB);

3 - conformed with dark gray podzolized soil on loess-like parent material (Phaeozems Huperhumic Lamellic in WRB)

Following the field examination, analytical determinations of soil properties were conducted. The results, compiled in the regional database, revealed correlation between the brightness of multispectral image in different bands and various soil attributes including humus content and soil texture, for the infra-red range, correlation coefficients (r^2) between the brightness of the soil surface and total humus content and clay content were -0.78 and - 0.69, respectively.

The taxonomic units represented by the mapping units are listed below, according to the Ukrainian soil nomenclature and the World Reference Base (WRB), using the scheme for harmonisation drawn up by Medvedev and others (2003).

The digital map was then used to analyse the structure of soil indicators (granulometric composition of the soil, total humus content, the content of mobile forms of phosphorus and potassium, pH and structural-aggregate composition): visual field analysis and testing stationarity of the expected value; smoothing functions, determination of the nature of a trend and random function approximation; finding an analytical expression of regionally-correlated component and removing the trend; correlation analysis and identification of significant periodic components; analysis of the spectral density of the dispersion; verification of the allocation and estimates of the indicator distribution parameters.

Research has shown that certain soil contours are different in quality characteristics of basic physical properties. For each part of the test site, there were developed recommendations for the use of different intensities of pre-sowing and basic tillage, namely: a - no-till (the parameters are close to the requirements of the crops); b - with moderate tillage of zonal type (parameters close to modal values); c - with high intensity tillage (the parameters are unsatisfactory and more intensive pre-sowing of the soil is required).

According to the results of geostatistical analysis of data of ground-based tests of soils, which proves the presence of a regular component in the spatial variation of the investigated soil properties, the conclusion was made about the correctness of the map model created by the data of the space scanning of the local structure of the soil cover of the test site and the expediency of its implementation within precision tillage.

Statistical and geostatistical parameters of the investigated soil properties are given in Table 1. It was established that by 27% from the total area of the test site the density of the structure exceeded the value of 1.30 g/cm^3, which was an obstruction for quality soil tillage and germination of agricultural crops. Localization of these parts of the test site is the basis for differentiated tillage in the form of additional tilling, the rest of the area does not require additional tillage.

Table 1. Statistical and geostatistical indicators of some properties of dark gray podzolized heavy loamy soil (Korotych test site)

Indicator	The bulk density in the sowing layer of soil, g/cm^3	Hardness in the layer of 0-10 cm, kgf/cm^2	Content of mobile forms of nutrients in the soil		
			N	P_2O_5	K_2O
Swing range	0.47	9	2.2	62.4	55.6
Average value	1.31	27	1.1	15.6	20.0
Median	1.31	27	1.1	11.1	16.0
The coefficient of variation	0.08	0.09	0.42	0.81	0.59
Dispersion	0.01	5.9	0.21	158.6	140.4
Asymmetry coefficient	0.43	0.2	0.54	2.74	2.11
Nougat effect	0.0004	0	0	0	0
The dispersion threshold	0.004	-	0.23	73	41
Correlation radius, m	300	-	300	280	230

Most of the test site area has a hardness in the sowing layer of more than 20 kgf/cm^2, which prevents the germination of most cereals. Hardness in the plow sole reaches quite high values (30-40 kg/cm^2 and above). Due to the fact that these indicators do not have a solid configuration, deep tillage also requires differentiation.

It was established that the range of observed agrochemical parameters was quite clearly divided, in particular, had three classes and, accordingly, contours with three levels of supply of mobile nutrients: 1 - close to optimal, 2 - above the optimum level; 3 - level with a very low content. It was established that 2/3 of the test site can be classified as the 1st class, 15% - as the 2nd class, about 23% - to the 3rd class, which substantiates practical proposals for differentiation of doses of phosphate fertilizers. Moreover, it is possible to achieve regulatory returns on fertilizers and at the same time reduce their total application rate by saving fertilizers on sites of the area with the high availability.

The heterogeneity of the investigated soil properties indirectly testifies to the prospect of implementation of precision agriculture elements at the investigated test site. It is established that the higher the variability of soil properties, the more it is necessary to study it and identify spatial patterns, which allows to justify the boundaries between sites with different levels of fertility and to obtain economically justified results in the implementation of spatially differentiated agro-measures.

In the course of the research, the evaluation of the qualitative state of the investigated soils of the test site was carried out according to an improved method of assessing the quality of arable soil, which was developed by NSC ISSAR (Medvedev and Plisko, 2006).

Figure 4 shows the geostatistical indicators of spatial heterogeneity of the structural composition (for example, a fraction of 0.25-10 mm in size) of the Korotych test site.

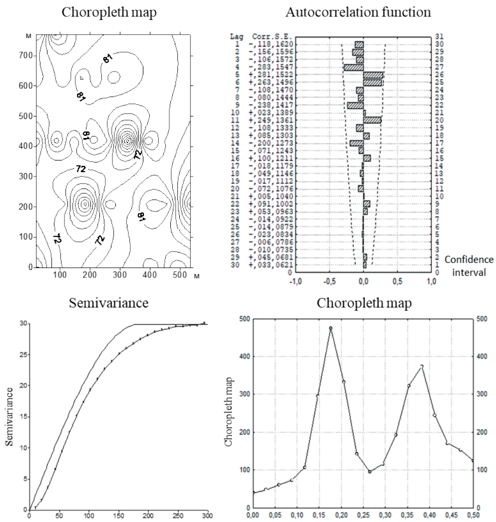

Figure 4. Spatial heterogeneity of the content of an agronomically valuable fraction of a structure in size 0.25-10 mm (Korotych test site)

The methodology allows to evaluate the productive and ecological functions of soils and has advantages over existing analogues due to: the use of an extended number of soil, climatic criteria and technological characteristics of the land site (field); distribution of soil variety as elementary spatial unit instead of soil agro-group; a unified 100-point country-wide rating scale instead of country-specific assessment scales; a new way of calculating points - as the mean geometric ratio of real and optimal parameters. It was established that the soil quality points of the studied soils ranged from 39 to 51. At the same time, the highest points had dark gray podzolized soil, the score points of lightly washed kind were lower by 7 points compared to its full-profile counterpart.

The agroinvestment attractiveness of arable land of the test site for growing crops on the basis of an integrated assessment of soil quality, climatic and agricultural production of the land (test site) was determined. It was established that soils of the test site in terms of soil and climate properties can be considered attractive for investing and growing of agricultural crops.

CONCLUSIONS

In the course of the research, a spatially differentiated system of arable soil quality management was developed, which represents a complex of interrelated methods and techniques, principles, processes of purposeful influence on arable soils for their rational use, protection and increasing of their fertility level on the basis of taking into account the heterogeneity of the soil cover.

A coherent analysis of satellite images decoding results and data obtained from field surveys in the Forest-Steppe region of Ukraine proved the soil decoding technology for multispectral satellite imagery data in the optical range, developed herein, to be highly effective for determining the elements of soil cover heterogeneity, which vary in the vertical soil structure;

According to the results of regional studies, the coherent analysis of a satellite image and it classification results, as well as the autocorrelation analysis of the soil indicators of land survey data, is proven to be informative enough to identify soil variations to the development of spatially - differentiated soil quality management systems.

Directions for further research include:

- Systematization of equations which explain the relationship of optical properties of the soil surface with fundamental physical and chemical properties, so as to make real and useful differentiation of soil quality from satellite imagery.
- Methods, techniques and rules for the use of remote sensing data for diagnosis and quantitative assessment and mapping of the soil cover in our region.

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REFERENCES

Byndych, T. (2017). Using Multispectral Satellite Imagery for Parameterisation of Eroded Chernozem. *Soil Science Working for a Living: Applications of soil science to present-day problems*, Part II, 57–65.

Dmitriev, E.A. (2001). A chapter from the unfinished book “Soil heterogeneity*”. Large-scale effects in soil research*, Moscow: Moscow State University, 8–39.

Fridland, V.M. (1972). Soil cover structure. Moscow: Thought, 423 s.

Glover, J., Reganold, J., Andrews, P. (2000). Systematic method for rating soil quality of conventional, organic and integrated apple orchards in Washington State. *Agriculture, Ecosystems, and Environ., 80*, 29–45.

Godwin, R.J., Wood, G.A., Taylor, J.C., Knight, S.M., Welsh, J.P. (2003). Precision Farming of Cereal Crops: a Review of a Six Year Experiment to develop Management Guidelines. *Biosystems Engineering*, *84*(4), 375–391.

Goldshleger, N., Ben-Dor, E., Lugassi, R., Eshel, G. (2010). Soil degradation monitoring by remote sensing: examples with three degradation processes. *Soil Science Society of America Journal*, *74*(5), 1433–1445.

Granatstein, D. (2016). Measuring soil quality: indicators of soil quality-developing a quantitative index. Tilth Producers Quarterly, URL: https://www.researchgate.net/publication/237611194_Measuring_Soil_Quality_Indicators_of_Soil_Quality_Developing_a_Quantitative_Index (date of the application: 05.03.2017).

Havrankova, J., Godwin, R.J., Wood, G.A. (2006). Ground Remote Sensing Systems for Determining Canopy Nitrogen in Winter Wheat. International Soil Tillage Research 17th Triennial Conference, Kiel, Germany, 910–915.

Medvedev, V.V., Plisko, I.V. (2006). *Valuation and qualitative assessment of arable land in Ukraine*. Kharkov: 13th Printing House, 386.

Medvedev, V.V., Laktionova, T.M., Kanash, O.P. (2003). *Soils of Ukraine (genesis and agronomic characteristics)*. Kharkiv, 68 s.

Mouazen, A.M., Malaki, M.R., Merckx, R., De Baerdemaeker, J., Ramon, H. (2006). Primary results on on-line measurement of some selected soil properties using a VIS-NIS sensor. International Soil Tillage Research Organization, 17th Triennial Conference, Kiel, Germany, 839–844.

Mouazen, A.M., Maleki, M.R., De Baerdemaeker, J., Ramon, H. (2007). On-line measurement of some selected soil properties using a VIS-NIR sensor. *Soil & Tillage Research*, *93*(1), 13–27.

Petrasovits, I. (1978). A foldhasznalat es a melioracio osszefuggeseirol. Gazdalkodas. Evf. 22, Sz. 8, 9–16.

Polupan, M.I., Velychko, V.A., Solovey, V.B. (2008). Fertility of soils and soil cover of the Steppe of the Southern and Dry according to agricultural potentials of agricultural crops and bonus criteria. *Bulletin of Agrarian Science*, *2*, 18–25.

Popov, V.P., Marynich, A.M., Lan'ko, A.I. (1968). *Physical geographic regions of the Ukrainian SSR*. Kiev University Publishing House, Kiev.

Tittonell, P., Muriuki, A., Klapwijk, C.J., Shepherd, K.D., Vanlauwe, B., Coe, R.D. (2020). Soil heterogeneity and soil fertility gradients in smallholder farms of the East African highlands. http://worldagroforestry.org/publication/soil-heterogeneity-and-soil-fertility (date of the application 05.02.2020).

Truskavetsky, S., Byndych, T., Sherstyuk, A., Viatkin, K. (2015). Studying the condition of soil protection Agrolandscape in Ukraine using Remote Sensing Methods. *Journal of Agricultural Science and Technology A*., *5*(4), 235–240.

Wei Xue, T., Martijn Bezemer & Frank Berendse (2019). Soil heterogeneity and plant species diversity in experimental grassland communities: contrasting effects of soil nutrients and pH at different spatial scales. *Plant and Soil*, *442*, 497–509.

***Agricultural land classification survey of England and Wales (1974). Ministry of Agr., Fisheries and Food. *Press Notice*, *195*(25), 1–3.

***Methods of appraisal of Ukrainian soils (1992). L.Ya. Novakovsky, Kiev, 102 s.

***Soil heterogeneity and precision farming. Part 2 (2009). Research results/Medvedev, V.V., Melnik, A.I., Plisko, I.V., Shevchuk, M.Y., Zinchuk, N.I., Pashchenko, V.F., Dorozhko, I.N., Onishko, M.I., Dontsova, L.V., Zavadsky, A.M.; under the editorship of Medvedev, V.V., Kharkov: KP "City Printing House", 260 s.

***https://www.usgs.gov/land-resources/nli/landsat/landsat-8 (date of the application: 16.04.2018).