Methodology for Monitoring the Quality and Fertility of Soils of Grape Agrocenoses Based on Multispectral Cosmic Data

I. Grishin[1],
Dr. of Technical Sciences,
Professor,
Corresponding Member
of the RANH

R. Timirgaleeva[1, 2],
Dr. of Economic Sciences,
Professor,
Corresponding Member
of the RANH

[1] Branch of Lomonosov Moscow State University, Sevastopol, Crimea

[2] Humanitarian and Pedagogical Academy of the V.I. Vernadsky Crimean Federal University, Yalta, Crimea

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The ways of creation and implementation of technologies of complex information support and monitoring of major agricultural territories are considered. These innovations are necessary to obtain basic thematically oriented tools for solving problems of managing sustainable development of territories. Such a process involves the use of the results of cosmic activities not only on Earth, but also under the conditions of the EcoCosmoHouse (ECH). The use of these technologies will allow, when creating a set of monitoring tasks, to use the results of cosmic activities, called "basic elements", to regulate the working out of methods for monitoring the humus content in the soil. Such an approach will foster the reduction of time required to develop basic elements, as well as to create a space monitoring system based on them to solve problems in various sectors of the economy. The method of soil fertility analysis on the example of grape agrocenoses is presented, which assumes the determination of the humus content remotely, based on the assessment of the spectral features of soils. The study was carried out using photography with a digital camera, as well as satellite multispectral equipment. It is shown that the proposed procedures for determining the humus content in the soil have high accuracy and can be used to create an automated system for monitoring the state of soils, including that for precision farming in enclosed ecosystems.

Keywords: *EcoCosmoHouse (ECH), geoinformation platform, humus, intelligent system, multispectral survey, remote probing of the Earth.*

Introduction

In the conditions of the EcoCosmoHouse (ECH), there is a need for the obtaining of plant products, when light potting soils are planned to be used as the main substrate for growing plants [1]. These substrates contain about 10 % of humus by volume; this characteristic is one of the most important, and it needs to be constantly monitored to maintain the biocenosis in balance. At the moment, chemical methods are used to analyze the humus content in the soil, which means its fertility. They are accurate, but require physical sampling from the site, as well as special equipment and additional personnel. In this article, in order to optimize the processes of biotechnological obtaining of plant products, it is proposed to monitor the humus content based on multispectral data. This technology (when having pictures from space) can be successfully used, including for monitoring the state of soils on the Earth's surface.

Today, satellite observation technologies allow getting objective quantitative information about various objects and phenomena. This, in particular, leads to the creation of new information technologies and systems for studying various processes occurring in biogeocenoses and agrocenoses. At the same time, it should be noted that the observation of various types of agrocenoses has its own specifics, which requires the development of specialized information systems providing for the collection and analysis of information homogeneous in time and space. This is especially important when it comes to the study of grape agrocenoses, since their main elements are perennial plants, as well as soils that contribute to obtaining a high-quality harvest. In this case, it is necessary to create special information technologies for monitoring such objects, which will allow in the future to form observations that are homogeneous in time and space, and provide the possibility of conducting an analysis with a high degree of reliability [2]. At the same time, various characteristics of the objects under study should be determined, the parameters of which can be restored on the basis of remote observation data and used to assess their condition and development forecasts. After the Industrial Space Necklace "Orbit" (ISN "Orbit") begins to function, it is also possible to conduct continuous monitoring of the state of soils on our planet on the basis of multispectral space data.

A significant number of articles of domestic [3–7] and foreign [8–12] scientists and researchers are focused on the issues of preserving and restoring the fertility of agrocenoses. There are works considering remote assessment of soil conditions; some experts have used the results of remote probing of the Earth from space to monitor soil fertility, soil mapping, as well as the condition of vineyards.

In the last decade, the institutes of the Russian Academy of Sciences and Lomonosov Moscow State University have developed unique methods, algorithms and technologies for working with satellite data, which made it possible to solve a significant number of scientific problems and create applied systems for remote monitoring [13].

In reference [14], the use of remote probing for terroir analysis in viticulture is considered and methods of object image analysis, spatio-temporal and hyperspectral analyzes and topoclimatology are described.

It should be noted that there are no comprehensive studies in the available publications aimed both at identifying and substantiating significant factors (indicators) that determine the fertility of grape agrocenoses, and at developing methods for their assessment based on Earth remote probing data from space, as well as at building complex models for the development of such agrocenoses and arranging measures to improve or preserve soils under the conditions of the south of Russia.

Materials and Methods

The intensive land use often leads to the development of adverse processes (water and wind erosion, secondary salinization and waterlogging, soil pollution by industrial emissions and pesticides), which significantly degrades the properties of the soil cover. In this regard, there is a need to monitor the indicators of soil condition in order to assess, predict and map it, as well as substantiate measures to increase fertility. Monitoring of the soil cover includes systematic observations of the level of its pollution, the processes of migration of chemicals, the dynamics of soil fertility indicators in space and time. However, this process cannot be limited only to the study of soil samples, since it is inseparable from the study of other components of the landscape, all ways of accumulation of pollutants in both natural and anthropogenic complexes.

In the vast majority of cases, the most important complex characteristic of soil fertility is the content of organic matter in it and its qualitative state. At the same time, it is known that the properties, composition and amount of organic matter determine the biological indicators of soil fertility, the presence of agronomically valuable soil microorganisms. Humus makes up 85–90 % of the organic matter of the soil.

Humus substances are dark-colored high-molecular compounds with a complex chemical structure. The types of soils differ in humus content, the amount and ratio of humic acids and fulvic acids, which significantly affects their reflectivity in different ranges of electromagnetic waves.

The main morphological feature of the soil is its color, which depends on the chemical composition, and above all on the content of humus. There is a sufficient number of publications focused on the development and study of ways for assessing the state of vegetation cover by remote probing methods available. However, these approaches are oriented on application in laboratory conditions and have a high computational complexity for use in real information systems for soil quality monitoring.

That is why in this paper an attempt is made to develop the basics of the methodology for assessing humus on the example of grape agrocenoses. At the same time, the assessment of humus was carried out both in laboratory conditions and by means of space spectrosonal imaging.

The objects of research at the first stage were the soils of grape agrocenoses of the southern regions of Russia. The features of the soil cover and geographical data are given in Table 1.

In each case, sampling was carried out from the upper layer (5–15 cm depth). The humus content was determined by the method of I. Tyurin in accordance with GOST 26213-91 "Soils. Methods for determination of organic matter".

The spectral characteristics of the studied soils were determined using the equipment of the multispectral survey system (460–860 nm spectral range) of the Canopus-V satellite (the survey was synchronized with the time of soil sampling; archival data was used), as well as under laboratory conditions using a Canon DS126181 digital camera. The focal length of the camera lens is 55 mm, the resolution is 4,272 × 2,848 pixels, the spectral range of the matrix is 400–780 nm.

Four of the 22 test sites were selected for decryption. They were not occupied by vegetation. In addition, at the time of sampling and satellite imaging, there was no atmospheric interference.

Analysis of the data from the archives of weather stations showed that the surface layers of the soil of all four studied sites were in an air-dry state. This circumstance made it possible not to take into account the influence of soil moisture on its color during decryption and subsequent analysis.

Table 1 – Characteristics of sites and soil

Sample number	Farm, site	Description of soil	Soil type
1	Enterprise "Zolotaya Balka", Blagodatnoye village, Balaklava district of Sevastopol, Crimea. Grape variety – Chardonnay	Relief – undulating plain; humus (0–20 cm layer) – 1.2 %; parent rock – deluvium; HCl boiling – from the surface; salinization – none; pH – 6.9; P_2O_5 – 1.4 mg/100 g of soil; K_2O – 17.5 mg/100 g of soil; Ca – 19.4 mg/100 g of soil	Southern low-humus high-carbonate chernozem
2	Enterprise "Zolotaya Balka", Vilino village, Bakhchisarai district, Crimea. Mother plantation of grape variety Kober	Relief – lowering; humus (65 cm layer) – 1.55 %; parent rock – deluvium; HCl boiling – from the surface; salinization – none; pH – 8; P_2O_5 – 0.9 mg/100 g of soil; K_2O – 20.1 mg/100 g of soil; Ca – 14.5 mg/100 g of soil	Southern low-humus chernozem
3	Enterprise "Magarach", Vilino village, Bakhchisarai district, Crimea	Carbonates (0–60 cm layer) – about 7 %, (1.5 m layer) – 17–19 %; humus content in the soil profile – 2.5 %; pH – 8.1; volume weight of the soil (upper horizon) – 1.29–1.33 g/cm^3; total nitrogen (at the depth of the plantage) – 0.12–0.13 %	Southern low-humus chernozem
4	Enterprise "Chernomorets", Uglovoe village, Bakhchisarai district, Crimea. Grape variety – Pinot Noir and Cabernet Sauvignon	Humus horizon – 80–90 cm; humus (0–20 cm layer) – 3.5 %; gross nitrogen – 0.21–0.3 %; hydrolyzable nitrogen – 5–11 mg/100 g of soil, which indicates a high availability of mobile nitrogen	Ordinary micellar-carbonate foothill chernozem

Soil samples intended for photographing in laboratory conditions were pre-dried to an air-dry state, and also crushed to a size of 0.2–0.25 mm.

During the shooting, artificial lighting with a stabilized voltage source was used, ensuring the accuracy of the supply voltage ±1 %. The soil sample was poured into a glass cuvette, compacted and leveled. The reference white sample was placed nearby and later used to correct the white balance in preparation for shooting and image processing.

The images obtained during the shooting in RAW (digital camera) and GeoTIFF (satellite images) formats were processed for subsequent analysis using the SIPS software package and the Photoshop CS6 graphic editor, which allow determining the average brightness value in spectral channels (R, G, B). To increase the reliability of the images, they were issued in an automatic series of five images, and then averaged. Spectral coefficients were calculated relatively to the brightness of the reference, their averaged values are shown in Table 2.

Table 2 – Spectral characteristics of soils

Sample number	R	G	B	Humus content, %
1	75.6	65.1	51.2	1.2
2	76.1	67.3	53.6	1.55
3	64.3	52.9	42.1	2.5
4	62.9	56.8	45.7	3.5

Results and Discussion

It is advisable to analyze the data obtained during the experiment both based on the results of laboratory shooting with a digital camera and remote probing from a satellite.

From Table 2, it can be concluded that according to the results of laboratory studies, the highest brightness value is observed in the red range (R), the lowest is in the blue range (B).

Comparative characteristics are shown in Figure 1.

Analysis of the results of statistical processing of laboratory survey data suggests that the greatest correlation is observed between the content of humus (H) and the brightness of the red channel of the digital image, the value of the correlation coefficient is $r = -0.93$. Thus, the R channel is the most informative for monitoring the level of humus in the soil.

For optimal assessment of the humus content of the soil, an analytical formula (regression equation) of the dependence of the humus content in the soil on the brightness level of the R channel is obtained:

$$H = -0.136R + 11.651. \quad (1)$$

At the same time, $r^2 = 0.87$, which indicates a high level of correlation; the standard error $m = 2.6$. The values of H calculated by the R level in accordance with (1) are shown in Figure 2.

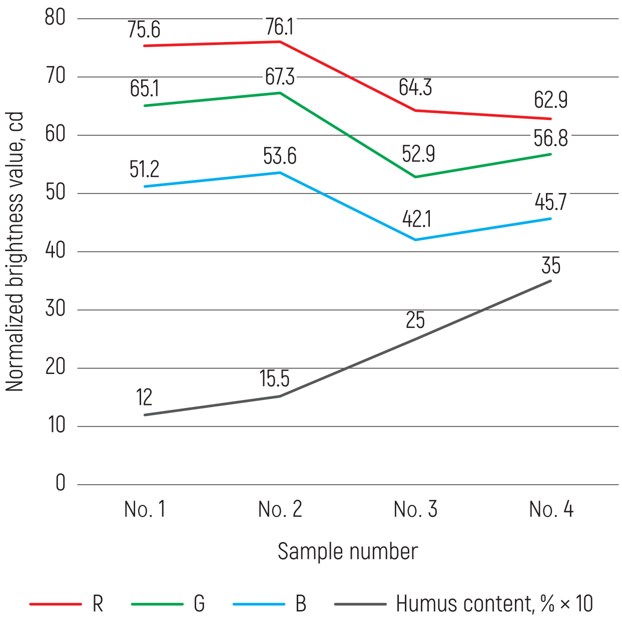

Figure 1 – Channel brightness values and humus content

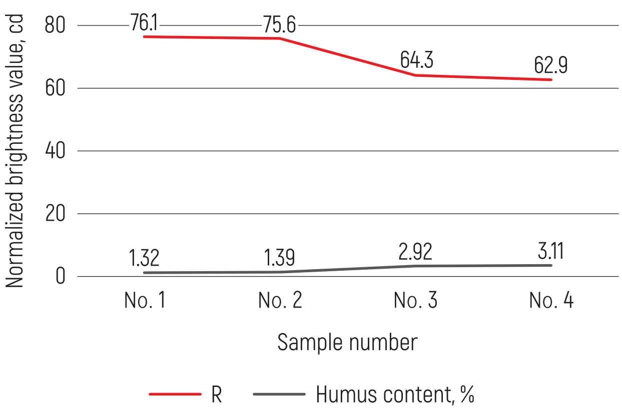

Figure 2 – Brightness of the R channel and calculated values of humus content

In addition, images of the analyzed sites were obtained from the Canopus-V satellite using multispectral equipment (Figure 3).

A similar list of actions related to the above-mentioned processing of photographic images and statistical analysis of the results was carried out with satellite images.

The following regression dependence is obtained:

$$H = -0.011R + 9.21. \quad (2)$$

Statistical indicators of the obtained regression dependence r^2 = 0.79, which indicates a high level of correlation; standard error m = 4.7, which suggests a fairly good approximation of the actual results to the obtained regression (Figure 4).

a)

b)

Figure 3 – Satellite images of the analyzed sites:
a – Sample No. 1; b – Samples No. 2–4

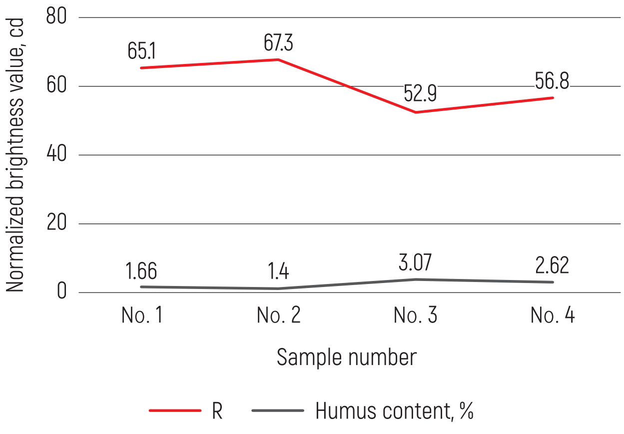

Figure 4 – Brightness of the R channel and calculated values of humus content (based on satellite images)

From the analysis of the data obtained, it follows that the error in the humus content does not exceed 20 % (for laboratory images – 8.5 %). These values indicate the possibility of remote monitoring under consideration.

It should be noted that the research shows only the first results of remote monitoring of the fertility of grape agrocenoses. In the future, it is planned to deploy more test sites for sampling and remote diagnostics. To determine the spectral properties of soils, it is proposed to use a mobile spectrometer that allows measurements to be made directly in the field, based on preliminary forecasts of monitoring specified territories by required satellites, as well as weather forecasts. More reliable results can be achieved by using images obtained with the help of hyperspectral satellite equipment, which makes it possible to identify narrower, particularly informative sections of the spectrum.

Conclusions and Future Work

As a result of the conducted research, a conclusion can be made about the sufficiently high efficiency of cosmic and laboratory methods of measuring the spectral reflectivity of soils for analyzing their fertility by remotely determining the humus content in them.

A method of using a modern digital camera to determine the humus content in the soil has been developed. It is revealed that the accuracy of determining this value practically corresponds to analytical methods. However, particularly important is carrying out these measurements directly in the field, which is possible when using mobile spectrometers. It is shown that it is reasonable to use the spectrum of the red channel of a digital camera photograph to calculate the amount of humus rate in the soils in the southern regions of Russia.

The introduction of a similar methodology for processing and interpreting satellite images also makes it possible to detect the percentage of humus in the soil with sufficient accuracy. This monitoring method should be considered the most optimal, since it requires less labor effort to carry out continuous monitoring of the grape agrocenoses soil cover state and can be used as the basis for automatic analysis of soil quality.

Given the relatively small amount of equipment that is involved in this monitoring of soil condition, the proposed methodology can be successfully applied under the ECH conditions. The analysis of multispectral indicators will allow carrying out the appropriate dosage of humus, liquid humus in various zones of plant cultivation to obtain optimal results.

In the course of further research, it is reasonable to pass from multispectral monitoring methods over to hyperspectral ones, which can improve the accuracy and quality of observations.

Gratitude

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References

1. *Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.: il.*
2. *Grishin, I. Remote Sensing: The Method of GIS Application for Monitoring the State of Soils / I. Grishin, R. Timirgaleeva // E3S Web of Conf. – 2020. – Vol. 175, No. 06009. – P. 1–15.*
3. *Blokhina, S.Yu. Primeneniye distantsionnogo zondirovaniya v tochnom zemledelii [Application of Remote Probing in Precision Agriculture] / S.Yu. Blokhina // Vestnik Rossiyskoy sel'skokhozyaystvennoy nauki. – 2018. – No. 5. – P. 10–16.*
4. *Yergina, Ye.I. Dinamika termodinamicheskikh svoystv i zapasov energii v gumuse pochv Krymskogo poluostrova [Dynamics of Thermodynamic Properties and Energy Reserves in the Humus of Soils of the Crimean Peninsula] / Ye.I. Yergina // Geopolitika i ekogeodinamika regionov. – 2012. – No. 8 (1–2). – P. 62–72.*
5. *Kiryushin, V.I. Problema minimizatsii obrabotki pochvy: perspektivy razvitiya i zadachi issledovaniy [The Problem of Minimizing Soil Treatment: Prospects for Development and Research Tasks] / V.I. Kiryushin // Zemledeliye. – 2013. – No. 7. – P. 3–6.*
6. *Kozubenko, I.S. Sputnikovyye dannyye v upravlenii agropromyshlennym kompleksom regiona [Satellite Data in the Management of the Agro-Industrial Complex of the Region] / I.S. Kozubenko, I.Yu. Savin // Vestnik rossiyskoy sel'skokhozyaystvennoy nauki. – 2017. – No. 5. – P. 9–11.*
7. *Kulik, K.N. Metodicheskaya osnova agrolesomeliorativnoy otsenki zashchitnykh lesnykh nasazhdeniy po dannym distantsionnogo monitoringa [Methodological Basis of Agroforestry Assessment of Protective Forest Ranges According to Remote Monitoring Data] / K.N. Kulik, A.V. Koshelev // Lesotekhnicheskiy zhurnal. – 2017. – No. 3. – P. 107–114.*
8. *Elbasiouny, H. Assessment of Environmental Sensitivity to Desertification, Soil Quality and Sustainability in an Area of the North Nile Delta, Egypt / H. Elbasiouny // Egyptian Journal of Soil Science. – 2018. – Vol. 58, No. 4. – P. 399–415.*
9. *Chervan', A. The Assessment of Resource Potential of Agro-Landscapes with Use of Geo-Information Systems on the Basis of Soil Cover Structure / A. Chervan' // The Proceedings of the 10th International Soil Science Congress on "Environment and Soil Resources Conservation", Almaty, 17–19 Oct. 2018 / Soil Science Society of Kazakhstan Cooperation with the Federation of Eurasian Soil Science Societies; eds A. Saparov, R. Kizilkaya, M. Mustafayev. – Almaty: Poligrafservis i K, 2018. – P. 19–20.*
10. *Bonfante, A. Refining Physical Aspects of Soil Quality and Soil Health when Exploring the Effects of Soil Degradation and Climate Change on Biomass Production: An Italian Case Study / A. Bonfante, F. Terribile, J. Bouma // SOIL Discussions. – 2019. – No. 5. – P. 1–14.*
11. *Von Braun, J. Land Use Change and Economics of Land Degradation in the Baltic Region / J. von Braun, A. Mirzabaev // Baltic Region. – 2016. – Vol. 8, No. 3. – P. 33–44.*
12. *Nature-Similar Technologies of the Biogeosystem Technique in Solvinga Global Social and Environmental Problem / A.P. Glinushkin [et al.] // Biogeosystem Technique. – 2018. – Vol. 5, No. 2. – P. 164–196.*
13. *Sovremennyye podkhody i tekhnologii organizatsii raboty s dannymi distantsionnogo zondirovaniya Zemli dlya resheniya nauchnykh zadach [Modern Approaches and Technologies for Arranging Work with Earth Remote Probing Data for Solving Scientific Problems] / E.A. Lupyan [et al.] // Sovremennyye problemy distantsionnogo zondirovaniya Zemli iz kosmosa. – 2012. – Vol. 9, No. 5. – P. 21–44.*
14. *Hall, A. Remote Sensing Application for Viticultural Terroir Analysis / A. Hall // Elements. – 2018. – Vol. 14, No. 3. – P. 185–190.*