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Application of UAV and spectrometric survey results to determine agrochemical parameters of zonal soils used in agriculture (East of European Russia)

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ABSTRACT

To determine the degree of degradation of agricultural lands for a key values (humus content, mobile potassium, mobile phosphorus, PH), the use of multispectral UAV materials synchronized with ground-based spectrometric imagery is proposed. Spectroradiometer HandHeld 2, soil acidity (pH) meter, satellite GLONASS-GPS receiver of geodetic class were used for field survey. Multispectral orthophoto obtained at the time of ground surveys using multispectral cameras Tetracam Micro-MCA 4 and Tetracam ADC-micro installed on board of the Supercam-S350F UAV. In parallel with the spectrometric work, samples of soils of different soil varieties and washout degree were taken, in representative sites of elementary soil areas. Laboratory studies were carried out with the selected samples, in order to determine the main agrochemical parameters: humus (%), mobile phosphorus (mg), mobile potassium (mg), pH (H_2O). The work was tested on two field sites located in the Chuvash Republic (Russia), on cultivated (arable land) forest-steppe zonal soils (leached chernozems, dark gray forest soils). As a result of mathematical data processing, statistically significant relationships were obtained between certain groups of agrochemical indicators and spectral data in different channels of UAV images for specific soil varieties. In the course of the study, relationships were found between the green, NDVI, NIR, red channels obtained using the Supercam-S350F unmanned aerial vehicle and laboratory data: humus, phosphorus, potassium and soil pH. In general, the results of the experiment prove the fundamental possibility of using multispectral UAV materials, together with ground spectrometric imagery for automated express determination of agrochemical indicators of agricultural lands.

Keywords: UAV, spectrograms, agrochemical indicators, soil analysis

1. INTRODUCTION

The issues of agricultural land degradation are currently not only of scientific importance, but to a greater extent civilizational and practical[1]. Humanity cannot abandon traditional agriculture in favor of hydroponics, no matter how much it wants to conserve natural biogeocenoses, following the trend of decarbonization and the fight against global climate change. All the same, there will be significant territories with a soil cover periodically cultivated by agricultural machinery, artificial application of mineral components in the form of fertilizers and pesticides. With a lack of essential trace elements, primarily nitrogen, phosphorus, potassium, plants will not develop and soil fertility, as the main factor in agricultural crop production, will be depleted. Agro-melioration and the use of green manure also cannot completely solve this problem, because it is required to conserve agricultural areas for a considerable time, which is not always possible. A definite way out of this situation is provided by the use of a multi-field structure of sown areas with a carefully thought-out on-farm land management. In any case, high-intensity crop production with a large increase in biomass during the growing season is impossible without the introduction of a certain amount of mineral fertilizers. Moreover, with an overabundance of microelements in the soil, the surrounding areas will be polluted, first of all, the deposit environment (reservoirs). The material costs associated with overspending of mineral fertilizers will also

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increase. The so-called technology of "precision farming" seems to be a definite solution to this situation. But without initial and periodically updated data on the content of trace elements in soils, it is quite difficult to implement it. Taking into account the priority of sustainable development of territories, it is necessary to clearly and efficiently control the parameters of cultivated agricultural lands. This problem is already being solved at the legislative level. In the Russian Federation, there is a Resolution of the Government of the Russian Federation No. 612 of July 22, 2011 "On the approval of criteria for a significant decrease in the fertility of agricultural land"[2]. As these criteria in this regulatory document, it is proposed to use: a decrease in the content of organic matter in the arable horizon by 15 percent or more; decrease in acidity in acidic soils (pH_{KCl}) by 10% or more; an increase in alkalinity in basic soils (pH_{H2O}) by 10% or more; a decrease in the content of mobile phosphorus (mg/kg of soil) by 25 percent or more; reducing the content of exchangeable potassium (mg/kg soil) by 25% or more. A significant decrease in the fertility of agricultural land is understood as a change in the numerical values of at least 3 of these indicators. In most of the available generally accepted methods for determining of the soil erosion[3,4], the content and dynamics of humus, mobile phosphorus, exchangeable potassium are also taken as basic values indicating the erosion or degradation of agricultural lands, since they limit the vital activity of agricultural plants.

Accordingly, in most developed countries there is an objective need to develop inexpensive and sufficiently accurate methods for determining these indicators[5]. Until recently, the practical implementation of these works was quite problematic due to the high labor intensity, high cost and low representativeness of the obtained data. According to the traditional technology, the territory was divided into conditional areal units from which soil samples were manually taken and their subsequent study in an agrochemical laboratory. As a rule, the sampling standard is on average 1-3 samples per square kilometer, if the researchers are not faced with specialized tasks. Given the mosaic nature of the soil cover, such a sampling density is actually not representative at scales of 1: 10,000 and larger. Meanwhile, the scale of 1:10 000 is the main scale of detailed mapping of agricultural lands in Russia and the CIS countries. Therefore, land-based agrochemical soil sampling is rather laborious and expensive, which does not allow us to speak of complete coverage of all agricultural land, and is also not representative for relatively large fields (from several hectares or more).

The use of multispectral satellite imagery for solving this problem has limitations on weather (cloudiness), long interval (from 3 to 16 days), insufficient resolution (accuracy of 15 meters or more) to identify specific land plots, the need to pre-order a survey. Interpretation features of agricultural vegetation could be various due to poorly conducted sowing activities, bad overwintering conditions (for winter crops), plant diseases and pests. Thus, soil fertility interpretation based on a single satellite image is difficult[6]. Information on soil fertility can be obtained from the vegetation cover state. Based on the calculation of vegetation indices, images are constructed that provide information about the general state of the vegetation cover, soil characteristics and its water regime. The use of different channels of multi-temporal multispectral images makes it possible to predict the dynamics of soil fertility. But almost all common vegetation indices use only the ratio of the red and near infrared channels. Despite the rather serious theoretical and methodological substantiation of these methods, they do not give a direct solution to the problem of determining the content of trace elements and humus in soils. Numerous attempts by various Russian and foreign companies (Sovzond, ScanEx, USGS, etc.) to solve similar problems using various soil indices (NDVI, RVI, SAVI, etc.) do not provide an acceptable solution. They have severe distortions caused by the influence of the atmosphere. Also, to determine the soil degradation, the phytomass value is used, which is not always directly related. Accordingly, it becomes necessary to use a new mapping technology to solve the assigned tasks on the indicated scales.

An alternative to traditional methods of agrochemical analysis seems to be ground-based spectrophotometric surveying, but it has significant limitations inherent in all ground-based methods – laboriousness and significant time consumption (although they are much less than traditional sampling and laboratory analysis), respectively, insufficient territorial coverage and, as a consequence, expensiveness. The situation is further complicated by the fact that for the territory of Russia there are no spectrograms and spectrographic markers of various soil parameters of the main zonal agricultural soils[7]. At the same time, the agricultural industry in Russia is on the rise, in the expected future, due to the use of previously abandoned territories, the problem of rational use of agricultural land will become acute. Spectrographic non-contact methods should replace agrochemical methods. But without a representative sample, without mathematical algorithms and proven techniques, their use in Russia will be impossible[8]. A simple mechanical transfer of data and methods from abroad to Russia will not solve this problem. What is needed is the data obtained on those soils that are the basis of agricultural crop production in the Russian Federation. To solve this problem, aerial imagery from a UAV with a multi-zone camera can be used in combination with ground spectrophotometric imagery. The possibility and perspectiveness of using non-contact spectrometric methods for studying the soil cover is confirmed by numerous foreign studies[9,10,11]. Infrared spectroscopy methods based on the interaction of molecules with electromagnetic energy in the spectrum infrared region. A feature of the mid-infrared range is that it includes the so-called fundamental molecules vibrations. This information can be used as a unique soil characteristic.

Technological advances have made the near and mid-infrared regions of the spectrum very popular for determining soil parameters for various purposes, most often for assessing trace elements and soil organic matter. Soil mineral elements such as C, N, P, K, S, Ca and trace elements play the first role in the development of crops. Determining their concentrations is critical to applying the precision farming concept. Viscarra-Rossel et al. prepared one of the best reviews of studies that use spectroradiometric methods[12]. In most studies, carbon is most often determined, and, in particular, organic carbon. The overwhelming majority of studies show very good results of correlation coefficients between actual and estimated values (more than 0.9). Good results were obtained for the determination of the total nitrogen content (R> 0.80). No correlation was found for nitrates[12]. This conclusion is refuted by the good results obtained by the Linker et al.[13], Borenstein et al.[14] and Jahn et al.[15]. Contradictory results have been obtained for potassium, phosphorus and organic matter. In Bertrand et al.[16] the correlation coefficient for potassium concentration was 0.85. Acceptable results were also obtained by Du et al.[17]. Lower (R = 0.6 and R = 0.76, respectively) correlation coefficients were obtained by McCarty et al.[10] and Reeves et al.[18]. For phosphorus, values of R = 0.87[19] and R = 0.81[20] were obtained. For organic substances – very good results with correlations above 0.90[19,21]. However, Canasveras et al. [22] identified a very weak correlation between spectra and organic matter content. Thus, to date, the current state of research in this area is somewhat controversial. There is a need for standardization of soil sampling and analysis, as well as geographic localization for specific types and subtypes of zonal soils. In any case, all foreign researchers emphasize the need for further study of soil properties by spectroscopic methods.

In order to confirm the possibility of using the proposed methodology, a field experiment was carried out on the territory of the Chuvash Republic. Two test sites were selected due to the difference in soil composition. The first is located in the Komsomolsk district of the Chuvash Republic, in its southeastern part at the agricultural production cooperative "Slava". Chernozem soils are widespread within this polygon. The second polygon is located in the Opytniy village, Tsivilsky district, in central part of the Chuvash Republic. Dark gray forest soils are widespread here.

2. METHODS

We used aerial imaging from a UAV with a multi-zone camera in combination with ground spectrophotometric survey with their verification by traditional technology in key areas. The principal possibility of using UAVs with Tetracam Micro-MCA 4 and Tetracam ADC-micro cameras is based on the fact that the spectral range of camera fixation is in the range from 400 to 1150 nm. The spectral range of the HandHeld2 spectroradiometer is 325-1075 nm. That is, their ranges are quite comparable and their paired use is possible.

To obtain aerial photographs, a survey was made using a Tetracam camera in various spectral channels: green, red, NIR. A statistically significant relationship between soil parameters was revealed by the spectroradiometric component (Supercam-S350F) and ground sampling (data obtained with field instruments). Spectrograms of the selected polygons were obtained using a Handheld 2 spectroradiometer. With the help of UAV Supercam-S350F with multispectral cameras – spectral orthophoto of selected lands. Ground soil measurements were carried out in several ways: ground-based determination of characteristics (coordinates of selected points, soil acidity, spectrograms) and sampling carried out by the Chuvashsky agronomic laboratory with the determination of soil indicators (organic matter (humus), mobile organic phosphorus, total absorbed bases and mobile potassium). Examples of soil spectrograms obtained with the Handheld 2 spectroradiometer are shown in Fig. 1. This information was used to correct and update the original soil map in order to clarify the boundaries of elementary soil areas.

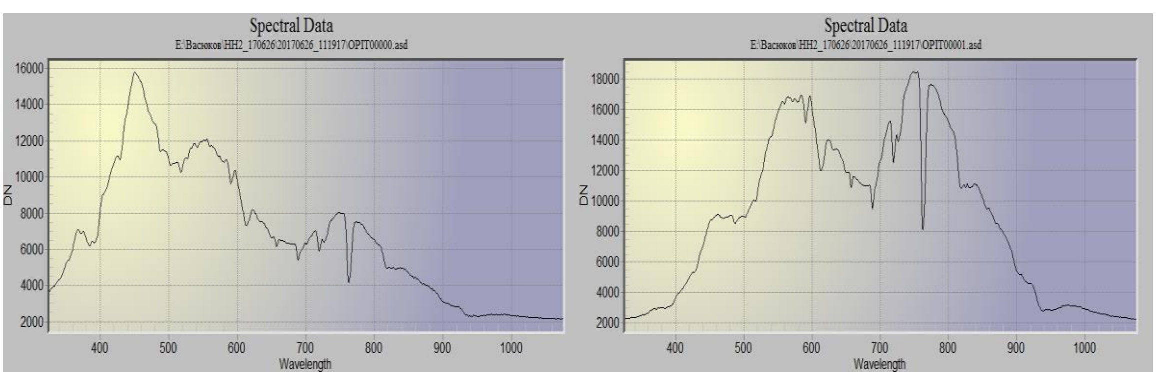

Figure 1. Examples of soil spectrograms obtained with Handheld 2

After receiving soil laboratory analyzes, they were compared with UAV spectroradiometric data in relation to each soil variety (Tables 1, 2).

Table 1. Laboratory analysis and spectrometric data of soils of the Komsomolsk site

Sample name	Organic substance (humus), %	Mobile phosphorus, mg/kg	Motile potassium, mg/kg	pH(H2O)	green	NDVI	NIR	red
soil №1	4.90	131	167	5.86	85.298	-0.3	117.019	62.014
soil №2	6.94	88	123	5.92	85.298	-0.3	117.019	62.014
soil №3	6.36	95	111	5.99	56.498	-0.3	73.18	46.507
soil №4	7.17	80	85	6.07	85.298	-0.3	94.035	62.014
soil №5	6.69	71	87	5.93	108.965	-0.3	117.019	62.014
soil №6	6.42	76	71	5.50	71.305	-0.3	73.18	46.507
soil №7	6.22	104	83	5.65	3.125	-0.3	2.269	0
soil №8	6.21	97	83	5.71	3.125	-0.3	2.269	24.491
soil №9	6.91	78	84	5.79	0	-0.3	187.961	0
soil №10	6.48	85	86	5.83	71.305	-0.3	94.035	62.014
soil №11	7.10	127	121	6.15	108.965	0.20	187.961	62.014
soil №12	6.28	159	116	6.23	3.125	-0.3	2.269	36.11
soil №13	6.52	125	106	6.20	56.498	-0.3	73.18	46.507
soil №14	7.38	51	105	6.00	71.305	-0.3	73.18	62.014
soil №15	7.14	244	91	5.91	56.498	0.69	117.019	0
soil №16	6.94	107	99	5.81	56.498	0.20	2.269	36.11
soil №17	7.08	81	81	5.89	3.125	0.20	2.269	36.11
soil №18	6.74	78	78	5.88	85.298	0.47	117.019	24.491
soil №19	7.17	85	85	5.87	71.305	0.20	94.035	62.014
soil №20	6.50	104	104	5.89	56.498	0.20	73.18	46.507
soil №21	6.68	89	89	5.55	56.498	0.31	94.035	36.11
soil №22	7.60	92	92	5.69	71.305	0.47	117.019	36.11

Table 2. Laboratory analysis and spectrometric data of soils of the Tsivilsky site

Sample name	Organic substance (humus),%	Mobile phosphorus, mg/kg	Motile potassium, mg/kg	$pH_{(H2O)}$	green	NDVI	NIR	red
soil №1	5.92	124	87	5.34	3	0.33	0.89	0
soil №2	5.84	188	95	5.45	3	0.26	0.89	0
soil №3	5.33	188	94	5.42	57.427	0.26	78.702	39.05
soil №4	4.65	207	89	5.44	68.6	0.20	93.451	58.66
soil №5	4.82	277	162	5.55	79.72	0.20	93.451	58.66
soil №6	4.89	228	144	5.60	68.6	0.26	93.451	49.37
soil №7	6.10	243	114	5.62	68.6	0.20	93.451	58.66
soil №8	6.09	230	115	5.63	68.6	0.26	93.451	58.66
soil №9	5.20	218	109	5.65	57.427	0.20	78.702	49.37
soil №10	5.36	210	125	5.68	68.6	0.20	93.451	58.66
soil №382	5.91	263	184	5.80	3	0.20	78.702	39.05
soil №383	5.21	277	180	5.71	68.6	-0.19	78.702	49.37
soil №384	5.26	262	130	5.70	79.72	0.20	110.558	71.27
soil №385	4.89	284	161	5.71	107.473	0.47	163.555	71.27
soil №386	3.97	247	119	5.66	79.72	0.20	110.558	71.27
soil №387	5.90	260	111	5.59	3	0.20	0.89	0
soil №370	4.54	283	129	5.91	79.72	-0.197	110.558	71.27
soil №371	4.73	222	102	5.92	57.427	-0.19	78.702	58.66
soil №373	5.57	256	171	5.93	107.473	0.47	163.555	71.27
soil №372	5.70	262	148	5.91	57.427	-0.19	78.702	49.37

Data package obtained using remote and experimental methods was subjected to mathematical processing in order to determine dependencies and build regression equations for pairs of values that showed the maximum correlation.

3. RESULTS

For the sites of the Komsomolsk region, the following dependencies were obtained: green and humus, NIR and humus, NDVI and phosphorus, pH and mobile potassium, green and mobile potassium, red and mobile potassium, red and pH, red and green. For the polygons of the Tsivilsky district, the following dependences were obtained: red and humus, green and mobile phosphorus, NIR and mobile phosphorus, red and mobile phosphorus, red and mobile phosphorus, green and mobile potassium, NIR and mobile potassium, green and pH, NIR and pH , red and pH. Examples of regression equations and their graphs are shown in Fig. 2 and Fig. 3.

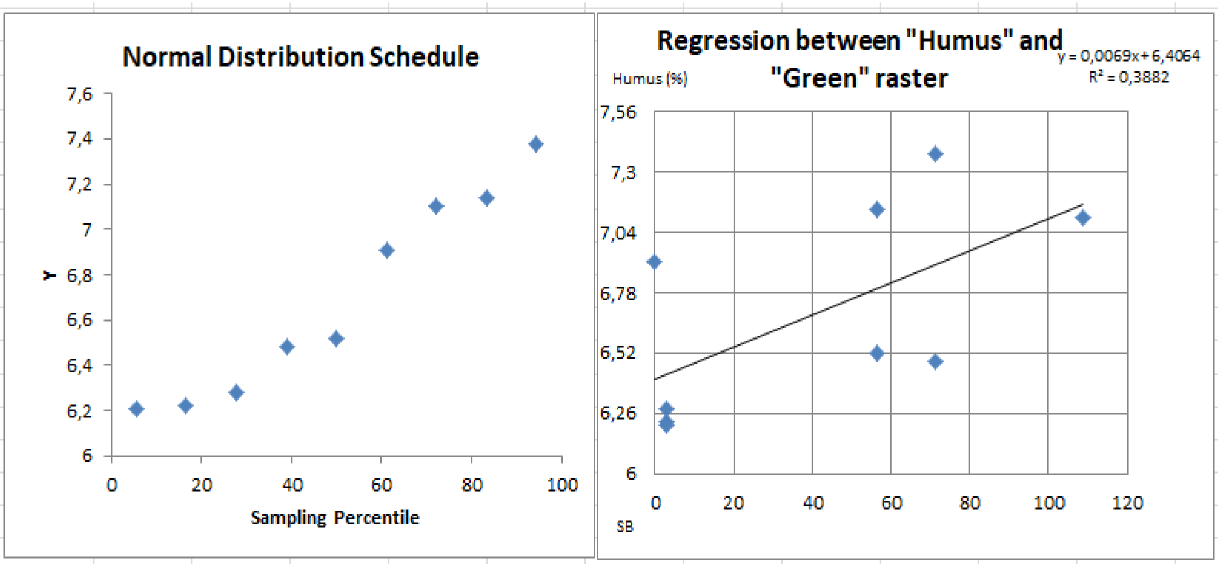

Figure 2. The relationship between the humus content and the "green" channel for leached chernozem (Komsomolsk site)

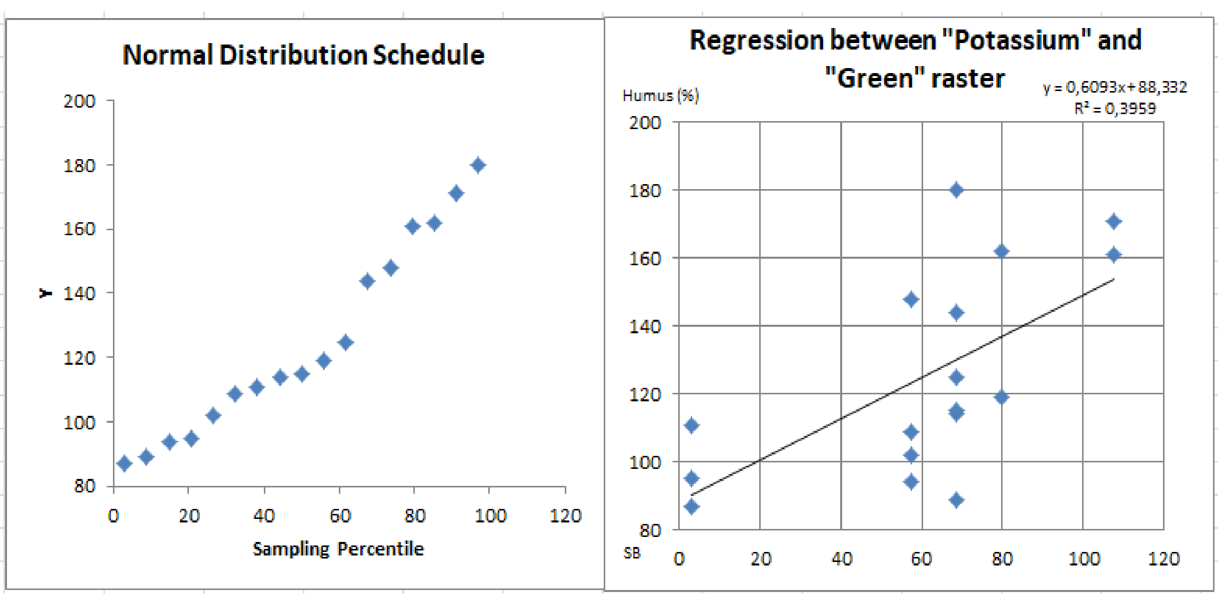

Figure 3. The relationship between the potassium content and the "green" channel for dark gray forest soils (Tsivilsky site)

In both plots, a positive linear relationship between soil parameters and the green channel can be noted. The resulting regression equations are shown in the upper right corner of the graphs.

On the basis of the graphs, maps of the distribution of agrochemical indicators were built according to UAV images in various spectral channels. These maps were built in the QGIS software using the "raster calculator" tool. Maps reflecting the distribution of humus (%) in the Green and NIR spectral channels in the Komsomolsk region are shown in Figure. 4. Maps showing the distribution of exchangeable potassium (mg/kg) in the Green and NIR spectral channels in the Tsivilsky district are shown in Figure 5.

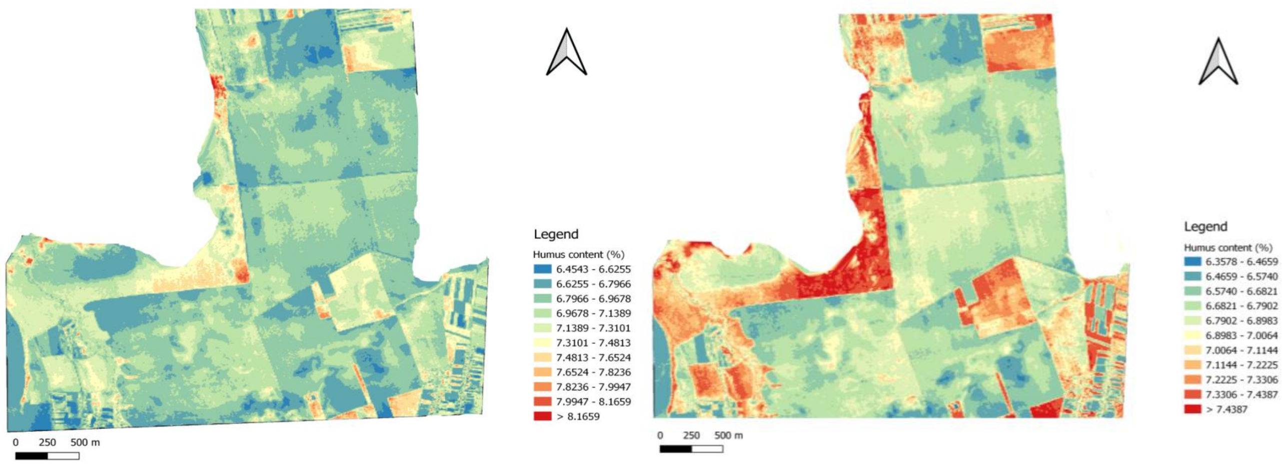

Figure 4. Map of humus distribution of the Komsomolsky site, built on the basis of the mathematical dependence of the humus content and the data of the spectral channels Green (left) and NIR (right)

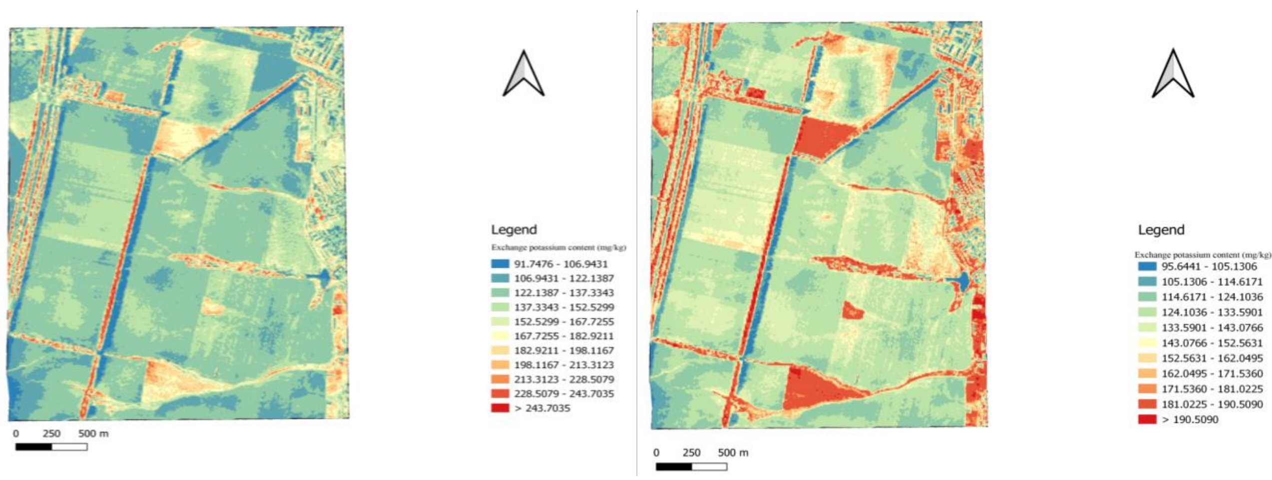

Figure 5. Map of humus distribution of the Tsivilsky site, built on the basis of the mathematical dependence of the potassum content and the data of the spectral channels Green (left) and NIR (right)

As we can see from the figures, the use of this technology makes it possible to determine the relationship between the content of agrochemical elements in the soil and the indicators of various spectral ranges (for example, the Green and NIR channels). In the future, it is planned to carry out additional work on soil sampling for the final verification of the created maps. According to a similar principle, it is also possible to construct maps based on the dependence of the following indicators and spectral channels: mobile potassium – green, mobile potassium – red, humus – red, phosphorus – green, phosphorus – NIR, phosphorus – red. It is also possible to find dependencies between Ph and NDVI and spectral channels, as well as dependencies of other indicators.

4. CONCLUSION

The applied technology makes it possible, using the data obtained from the UAV, to prepare a basis, also in cartographic form, for the determination of critically important agrochemicals for agricultural lands. This allows, with a certain degree of optimism, to say that with the accumulation of relevant data on specific soils, it will be possible to automate this process. Based on the results of the work, it became reasonable to write a software package and create an expert system for monitoring the state of soils, to form a database of agrochemical parameters of the studied soils and determine the relationship between spectral channels[23]. When filling this system with data on new soils, it becomes possible to use it for any region of the Russian Federation.

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REFERENCES

[1] Jkimovich, D. N., Sirotkin, V.V. and Vasyukov, S.V., "Experimental application of basic hydrophysical characteristic of soils in order to optimize their qualitative characteristics and agricultural soil quality evaluation criteria," Revista Publicando 4(13), 214-226 (2017).

[2] "On Approval of Criteria for Significant Reduction of Fertility of Agricultural Lands," Decree of the government of the Russian Federation, 22.07.2011 № 612 (2011). (in Russian)

[3] Egorov, V.V., Friedland, V.M., Ivanova, E.N. and Rozov, N.N., "Classification and diagnosis of soils of the USSR," Kolos, Moscow, 221 (1977). (in Russian)

[4] "Federal instruction on soil surveys and large-scale soil land use maps," Ed. T.A.Ishhenko, Kolos, Moscow, 75 (1973). (in Russian)

[5] Vasyukov, S. and Sirotkin, V., "An aerodynamic approach in soil hydraulic conductivity estimation for investigating soil erosion degree," Proc. IAHS 367, 66-71, (2015). https://doi.org/10.5194/piahs-367-66-2015

[6] Sirotkin, V., Vasyukov, S. and Usmanov, B., "The possibility of using spectrographic data to assess soils fertility," International Multidisciplinary Scientific Geo Conference Surveying Geology and Mining Ecology Management, SGEM 17(32), 639-646 (2017). DOI: 10.5593/sgem2017/32/S13.083

[7] Sirotkin, V., Vasyukov, S. and Usmanov, B., "Spectrographic characteristics of Chuvash Republic zonal soils with different erosion degrees," Proc.Water resources, forest, marine and ocean ecosystems conference proceedings, SGEM 2016 3(II), 357-362 (2016). DOI:10.5593/SGEM2016/B32/S13.047

[8] Vasyukov, S.V, Sirotkin, V.V. and Usmanov, B.M, "Spectroscopic methods for determining of zonal soils erosion (Chuvash Republic, Russia)," Proc.IOP Conference Series: Earth and Environmental Science 107, 012024 (2018). doi :10.1088/1755-1315/107/1/012024

[9] Cecillon, L., Barthes, B.G., Gomez, C., Ertlen, D., Genot, V., Hedde, M., Stevens, A. and Brun, J.J., "Assessment and monitoring of soil quality using near infrared reflectance spectroscopy (NIRS)," Eur J Soil Sci 60, 770-784 (2009).

[10] McCarty, G.W. and Reeves, J.B.,"Comparison of NFAR infrared and mid infrared diffuse reflectance spectroscopy for field-scale measurement of soil fertility parameters," Soil Science 171(2), 94-102 (2006).

[11] Mouazen, A. M., Karoui, R., Deckers, J., De Baerdemaeker, J. and Ramon, H., "Potential of Visible And Near-Infrared Spectroscopy To Derive Color Groups Utilizing The Munsell Soil Color Charts,"Biosystems Engineering 97(2), 131-143 (2007).

[12] Viscarra-Rossel, R.A., Walvoort, D.J.J., McBratney, A.B., Janik, L.J. and Skjemstad, J.O., "Visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties," Geoderma 131, 59-75 (2006).

[13] Linker, R., Kenny, A., Shaviv, A., Singher, L. and Shmulevich, I., "Fourier Transform Infrared–Attenuated Total Reflection Nitrate Determination of Soil Pastes Using Principal Component Regression, Partial Least Squares, and Cross Correlation," Applied Spectroscopy 58(5), 516-520 (2004).

[14] Borenstein, A., Linker, R., Shmulevich, I. and Shaviv, A., "Determination of soil nitrate and water content using attenuated total reflectance spectroscopy," Applied Spectroscopy 60(11), 1267-1272 (2006).

[15] Jahn, B.R., Linker, R., Upadhyaya, S.K., Shaviv, A., Slaughter, D.C. and Shmulevich, I. "Midinfrared spectroscopic determination of soil nitrate content," Biosystems Engineering 94(4), 505-515 (2006).
[16] Bertrand, I., Janik, L.J., Holloway, R.E., Armstrong, R.D. and McLaughlin, M.J. "The rapid assessment of concentrations and solid phase associations of macro- and micronutrients in alkaline soils by mid-infrared diffuse reflectance spectroscopy," Australian Journal of Soil Research 40(8), 1339-1356 (2002).
[17] Du, C.W., Zhou, J.M., Wang, H.Y., Mang, J.B. and Zhu, A.N., "Study on the soil mid-infrared photoacoustic spectroscopy," Spectroscopy and Spectral Analysis 28(6), 1242-1245 (2008).
[18] Reeves, J.B. and Smith, D.B., "The potential of mid- and near-infrared diffuse reflectance spectroscopy for determining major- and trace-element concentrations in soils from a geochemical survey of North America," Applied Geochemistry 24,(8), 1472-1481 (2009).
[19] Janik, L.J., Forrester, S.T. and Rawson, A., "The prediction of soil chemical and physical properties from mid-infrared spectroscopy and combined partial least-squares regression and neural networks (PLS-NN) analysis," Chemometrics and Intelligent Laboratory Systems 97(2), 179-188 (2009).
[20] Du, C.W., Zhou, J.M., Wang, H.Y., Chen, X.Q., Zhu, A.N. and Zhang, J.B., "Determination of soil properties using Fourier transform mid-infrared photoacoustic spectroscopy," Vibrational Spectroscopy 49(1), 32-37 (2009).
[21] Masserschmidt, I., Cuelbas, C.J., Poppi, R.J., De Andrade, J.C., De Abreu, C.A. and Davanzo, C.U., "Determination of organic matter in soils by FTIR/diffuse reflectance and multivariate calibration," Journal of Chemometrics 13, 265-273 (1999).
[22] Canasveras, J.C., Barron, V., del Campillo, M.C., Torrent, J. and Gomez, J.A., "Estimation of aggregate stability indices in Mediterranean soils by diffuse reflectance spectroscopy," Geoderma 158(1-2), 78-84 (2010).
[23] Vasyukov, S.V., Markelova, E.A. and Toguzov, S.A., " Software for soil monitoring using UAVs," Computer Program State Registration Certificate № 2020613066 (in Russian)