Prospects for Satellite Spectral Monitoring for Automation of Processes for Assessing Agricultural Soil Use

Natalia Pasichnyk[1], Sergey Shvorov[2], Yurii Gunchenko[3], Oleksandr Miroshkin[4], Elina Zakharchenko[5], Oleksiy Opryshko[6]

[1,2,6] *National University of Life and Environmental Sciences of Ukraine, Heroyiv Oborony st., 15, Kyiv, 03041, Ukraine*
[3] *Odessa I.I.Mechnikov National University, Dvoryanskaya str., 2, Odessa, 65082, Ukraine*
[4]*Communication and Information Centre Ulm University Ulm, Germany*
[5]*Sumy National Agrarian University, Herasyma Kondratieva Str., 160, Sumy 40021, Ukraine*

Abstract

Means of technical vision as innovative solutions have found wide use for automation of technological processes in agriculture in general and in crop production in particular. Their introduction becomes especially important when introducing the market of agricultural land in Ukraine when it is quite possible that it is misused by tenants or owners. The use of satellite monitoring may be an effective solution, as high and ultra-high resolution (resolution) satellite images have become available to farmers in recent years. The aim of the work was to assess the prospects of satellite spectral monitoring to automate the processes of assessing agricultural soil use. The research was conducted on the production fields NUBiP of Ukraine. During 2016-2021, the fields were occupied by different crops - winter and spring. Mostly cereals were grown, some fields were occupied by sunflowers, corn for grain and silage, perennial grasses. Archival data on multispectral images from a specialized Landsat 8 satellite were used for the research.

It is established that satellite spectral monitoring turned out to be suitable for automation of processes of technological soil erosion monitoring. Using a series of satellite images, it was possible to identify a field for which agricultural practices in crop production were carried out at a higher level and, accordingly, the soil has a higher fertility. To ensure one-year image accuracy, it is necessary to use images with a resolution suitable for precision atmospheric correction on terrestrial objects with stable and known spectral indices.

Keywords

Soil quality, satellite monitoring, automation

1. Actuality

Means of technical vision as innovative solutions have found wide use for automation of technological processes in agriculture in general and in crop production in particular. Their introduction becomes especially important when introducing the market of agricultural land in Ukraine when it is quite possible that it is misused by tenants or owners. The review article Hongkun Tian at al [1] (2020) on the prospects of technical vision shows that the specificity of agricultural production is the diversity and instability of the forms of the studied objects, when in addition to their geometry should be taken into account

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EMAIL: N.Pasichnyk@nubip.edu.ua (A. 1); sosdok@nubip.edu.ua (A. 2); gunchenko@onu.edu.ua (A. 3); miroshkinan@gmail.com (A.4); 7996445@gmail.com (A. 5); ozon.kiev@nubip.edu.ua (A. 6);
ORCID: 0000-0002-2120-1552 (A. 1); 0000-0003-3358-1297 (A. 2); 0000-0003-4423-8267 (A. 3); 0000-0002-9291-3389 (A. 5); 0000-0001-6433-3566 (A. 6)

spectral indicators. Certain technological operations with the use of technical vision devices have been successfully completed with the automation of agricultural production. What is an example of the identification of apples in the crown of trees, presented in the work of I. Smirnov at al [2] (2021), strawberries on the ridges, described in the work of D. Khort at al [3] (2020), tomatoes, considered in work I Korobiichuk et al [4] (2017). At the same time, the introduction of automation in agricultural practices is uneven, as evidenced in the analytical work Kirtan Jha at al [5] (2019), devoted to the prospects and needs of agricultural automation, which shows the need to strengthen developments to determine the state and especially soil fertility. The problem of soil fertility reproduction is extremely relevant not only on the scale of individual farms, but at the state level for European countries, which was covered in the article by Hakkı Emrah Erdogan at al [6] (2021). Ground-based devices such as the Dutch company SoilCares (https://www.soilcaresfoundation.com) and the experimental device described in Sérgio H.G. SILVA at al [7] (2021), intended for soil analysis, however, do not provide scalability of studies, as they require direct contact with the test sample. The use of satellite monitoring may be an effective solution, as high and ultra-high resolution (resolution) satellite images have become available to farmers in recent years.

The aim of the work was to assess the prospects of satellite spectral monitoring to automate the processes of assessing agricultural soil use.

1.1. The state of the issue

The issue of spectral monitoring using satellite platforms is especially relevant for tropical regions, which in the context of growing global food shortages in the future may become additional agricultural land. The potential for successful use of satellite monitoring for soil science (Pedological assessment) was predicted in the work of José A.M. Demattê at al [8] (2014). Practical implementation was shown in the works of Wanderson de S. Mendes at al [9] (2019) and Raúl R. Poppiel at al [10] (2019). In staging articles, which showed both the presence of many methodological problems and promising ways to analyze not a single image, but the dynamics of changes in the characteristics of the images over time. One of the problems was the low resolution of existing Landsat-5 satellite images, but in recent years several new satellite platforms have been launched into orbit, such as Landsat-8, with higher image resolution, and, accordingly, new opportunities are emerging for researchers. . In the work of Nélida Elizabet Quiñonez Silvero at al [11] (2021) on the prediction of soil properties in Brazil, it was possible to determine the type of parent rock and to some extent the organic content. The authors were forced to work in conditions of significant shortage of open soil in the trails and changes in the humidity of the upper layer, so to assess the soil used the concept of "soil line", which led to the possibility of significant error even in numerous measurements. For similar climatic conditions in India, Kishan Singh Rawat at al [12] (2019) developed a modified water balance model (MWCM) based on spectral data from the LANDSAT-8 satellite. As in the previous work, the developed solution is based on the concept of the ground line, for the initial data uses the NDVI index. In the European part, soil monitoring of fields not occupied by vegetation can be carried out most often in spring and autumn. Moreover, the soil is mostly in the air-dry state, which contributes to the objectivity of its direct spectral evaluation. The open ground is characteristic of certain plantations, in particular perennials with keeping the rows unoccupied. Such objects, namely vineyards, were considered in the work of A. Brook at al [13] (2020), where the prospects of water erosion of the upper layer were successfully assessed. The authors compared the intensity of the color components compared data from satellites and UAVs, for the implementation of atmospheric correction as reflector panels used gravel roads. Considering the national specifics of Ukraine, the prospects of such standards in the production fields are currently insufficient. An alternative, as shown in the work of V. Lysenko at al [14] (2018), can be sections of dirt roads, the identification of which can be carried out according to the method described in the work of S.A.Shvorov at al [15] (2018).

In addition to traditional factors of soil erosion, such as wind and water, in intensive agriculture there is also technological erosion associated with changes in soil properties, primarily a decrease in organic matter content. According to the data covered in the work of Yawen Li at al [16] (2021), the issues of technological erosion are insufficiently studied. Thus, the authors found that for the garden erosion was higher than for industrial fields, which contradicts the results presented by Zhongwu Li at al [17] (2017).

The above analysis of the literature allows us to draw the following conclusions:

- satellite platforms can be used to assess the condition of soils, but ready-made solutions, especially regarding the nature of erosion, have not been identified;
- since the values of the intensity values of the color components are informative, for atmospheric correction it is possible to use as reflective panels of roads with artificial surface, as well as rolled soil;
- to determine the condition of the soil, it is advisable to consider the dynamics of changes in spectral indicators over time;

erosion of both traditional (wind, water) and technological nature is possible in the fields, which must be considered when organizing research.

2. Organization of the experiment

The research was carried out on the production fields of NUBiP (https://nubip.edu.ua/en) of Ukraine "Velykosnitynske training and research farm. OV Muzychenko "(Kyiv region; coordinates Lat: 50.09080, Lng: 30.02997). During 2016-2021, the fields were occupied by different crops - winter and spring. Mostly cereal grains were grown, some fields were occupied by sunflower, corn for grain and silage, perennial grasses (Table 1). The soil of the territory is podzolic chernozem.

Table 1
Alternating cultures grown in experimental fields

Year / years	Field 1	Field 2	Field 3
2020-2021	Winter barley	Sunflower	Winter wheat
2019-2020	Winter barley	Winter wheat	Corn / silage
2018-2019	Sunflower	Winter wheat	Winter wheat
2017-2018	Winter wheat	Corn silage	Spring barley
2016-2017	Perennial herbs / alfalfa	Spring barley	Corn for grain

To maintain soil fertility in some fields after harvesting the main crop sown green manure (leies). In field 3, organic fertilizers (manure from cattle) were applied.

2.1. Initial data of spectral satellite monitoring

At present, there is free access to archival data of the results of spectral imaging from the Landsat 4-5 and 8 satellites (provided by NASA / USGS). The highest resolution is in the spectral systems of Landsat 8 and is 30 m (15 for the panchromatic band). The frequency of images is 16 days. According to the data presented in Hengbiao Zheng et al (2020) [18] regarding the identification of plantings, it was determined that the minimum possible size of the object for visual identification in the optical range is 13 × 13 pixels, respectively. Therefore, the use of local roads for atmospheric correction of dirt roads is not realized due to their small width. Therefore, the results of atmospheric correction directly from the image provider were used, namely, channels blue B2 (0.450–0.515 μm), green B3 (0.525–0.600 μm), red B4 (0.630–0.680 μm) and near infrared B5 (0.845–0.885 μm). . For ease of perception of information, consumers used not monochrome, but color images with an additive model of RGB color formation (channels 4, 3, 2) for the visible range of the spectrum and in false color composite (channels 5,4,3). The use of the infrared range is due to the need to assess the density and condition of plantations, as the analysis should be carried out for the top layer of soil. For research in the expert mode, images were selected where there are no clouds in the experimental fields and, accordingly, the shadow from them (Fig. 1).

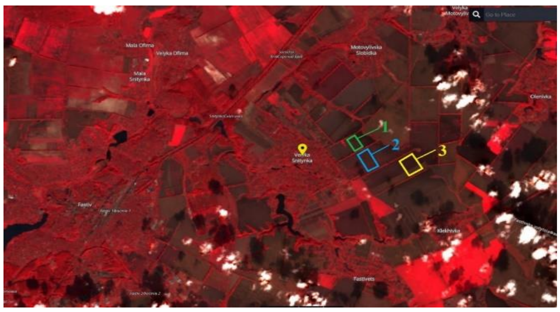

Figure 1: Image in false color from 2020.10.12 experimental fields 1-3, where part of the second and third fields are in the shadow of the clouds. Part of field 3 is sown with leies that are not growing at the time of shooting.

To take into account the possibility of the impact of water erosion of the soil at the choice of experimental sites, they were checked for the presence of stable puddles due to the terrain. An archive of high-resolution satellite images 0.5 m / pixel obtained (Fig. 2) from the archive data of the Google Earth Pro service (ver: 7.3.3.7786) was used for verification.

Figure 2: Visual identification of puddle locations on images from archival data from the Google Earth service for selection of research sites (date of shooting 2018.04.04).

2.2. Mathematical data processing

Processing of satellite images was performed using MathCad. Spectral monitoring data were saved in Jpeg format. For the data processing algorithm, two options were considered both directly for finding the average value and with the approximation of experimental data.

The first algorithm involved processing in two stages: the first determined the average intensity of the color component in the area, and the second to remove random objects removed pixels in which the intensity of the color components differed from the average by more than 10 units. If the area of the error plots exceeded 10%, a second algorithm based on the approximation of experimental data was used. For approximation, we used the Gaussian distribution according to the method described in N. Pasichnyk at al [19] (2021). The second approach makes it possible to estimate the presence of several objects at the same time in the experimental area, although it requires a multiple of larger computing power (Fig. 3).

Statistical processing showed that the data are described by the Gaussian distribution, the coefficient of determination was ≥0.95. Comparing the results obtained by the first algorithm, the data difference did not exceed 5%. Despite the presence of plantings in field 3, the value of the standard deviation w is virtually identical, respectively, when processing spectral data with a resolution of 30 m / pixel to assess the condition of the soil, the second algorithm will not have fundamental advantages.

Statistical data processing was performed using a specialized software product OriginPro Sp4 (Origin Lab Corporation).

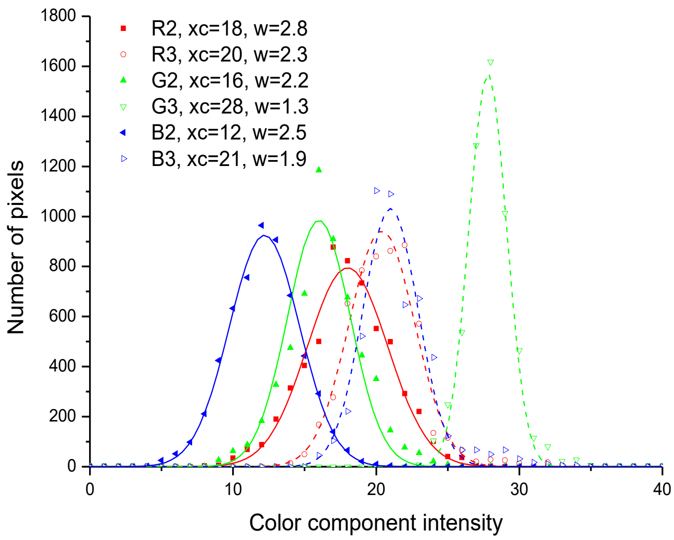

Figure 3: Intensity distribution of color components for the visible range of the spectrum for 2 and 3 fields (shooting date 2017.11.21; field 3 is occupied by leies.

2.3. The results and discussion

The results of spectral data processing are shown in table 2.

Table 2

Estimated average values for spectral channels

Date	Field 1				Field 2				Field 3			
	iR	R	G	B	iR	R	G	B	iR	R	G	B
02.04.2017	118,6	51	44	31	73	43,1	36,43	31,71	62	37,9	32,4	29,3
11.04.2017	168,8	40	41,5	25	83	46	37,13	31,6	74	43,1	36,1	31,5
27.04.2017	220,4	38	47,5	22	104	62,4	53,43	47	89	53,0	46,4	42,0
21.11.2017	32,1	14,7	14	10	36	18,4	16,6	12,5	96	18,0	26,2	19,0
14.04.2018	89,4	56	52	51	90	55	51	50,2	120	28,2	33,5	18,6
21.04.2018	89	50	42	34,7	88	51,2	43	36	160	25,0	30,5	19,3
30.04.2018	92	50	39,5	31,5	104	47	42,2	30,8	220	19,0	30,0	16,5
27.08.2018	89	44,3	37,3	29,3	78	40,4	34,9	28	155	34,2	35,5	9,7
12.09.2018	79	42	34,4	27,6	67	34,7	28,5	23,1	92	52,0	41,1	29,6
21.09.2018	71,7	41	36	33	85	46	39	35,3	93	54,1	45,0	36,2
07.10.2018	65,7	36,5	29	24	88	39,8	34,5	26,5	60	31,2	25,4	21,0
14.10.2018	63	35	28	23	93	34,2	32,8	24,5	56	31,0	25,3	21,0
08.11.2018	54,5	29	23	19	151	21,6	32,6	21	51	26,3	21,7	17,2
07.03.2019	58,1	32,5	26,6	12,5	131	36,1	34,5	14,7	49	27,3	22,3	6,8
23.03.2019	67	35,4	27,2	21,5	117	28,3	30	19,6	60	32,0	25,0	20,2
01.04.2019	80	44	35	29,4	144	30,8	35,4	23,6	70	38,0	31,0	26,5
24.04.2019	86	48,5	42,1	37	187	18,5	27,4	12,6	77	43,7	39,3	35,6
08.09.2019	93,3	53	46,7	41,8	125	73	61,4	52,7	237	102,7	67,5	39,8
24.09.2019	81,8	46,3	28	32,7	101	55,4	43,7	36,3	109	63,0	48,3	38,7
17.10.2019	91	52	44	36,2	95	43,4	39	30,8	88	54,9	44,8	37,0
16.08.2020	83	44,2	35,4	26,8	88	46,4	36,7	27,7	242	24,9	38,5	8,2
01.09.2020	116,3	64,5	53	41,5	126	69,3	56,5	43,8	149	57,5	50,5	32,7
10.09.2020	119,9	65,5	54,3	45	127	70,4	57,4	46,8	75	40,0	33,6	28,8
26.09.2020	123	68	59	50,5	130	73	62,1	52,8	85	49,0	43,0	38,6
12.10.2020	58,2	35	31,3	22,8	72	34	32	22,2	60	27,7	28,1	17,6
06.12.2020	96,3	42,7	38	24,2	41	14	10	4	19	5,3	5,2	2,1

2.4. Selection of suitable data

Remote detection and assessment of the degree of erosion of a technological nature can be done for soil that is in an air-dry state, because the color of dry chernozem corresponds to gray gradations, and moist soil is close to black, which is difficult to interpret. The available satellite image processing programs estimate cloudiness and temperature, not humidity. According to the authors, some of the pictures, namely from 11/21/2017 and 12/20/202020, were taken when the soil was in a wet state, as evidenced by the low values of the intensity of the color components (in Table 1, these items are highlighted in gray). At higher image resolutions, it will be possible to reliably assess the moisture content of the topsoil by assessing the color of dirt roads. For further calculations, data were used in which the value of any color component was more than 10 units for the 8-bit color model.

2.5. Evaluation of the quality of atmospheric correction of spectral data

Based on the data given in Table 2, in the period 27.08 - 08.11.2018 there were favorable weather conditions for satellite monitoring, so we managed to take a series of images for the fields, the results of which are shown in Figure 4.

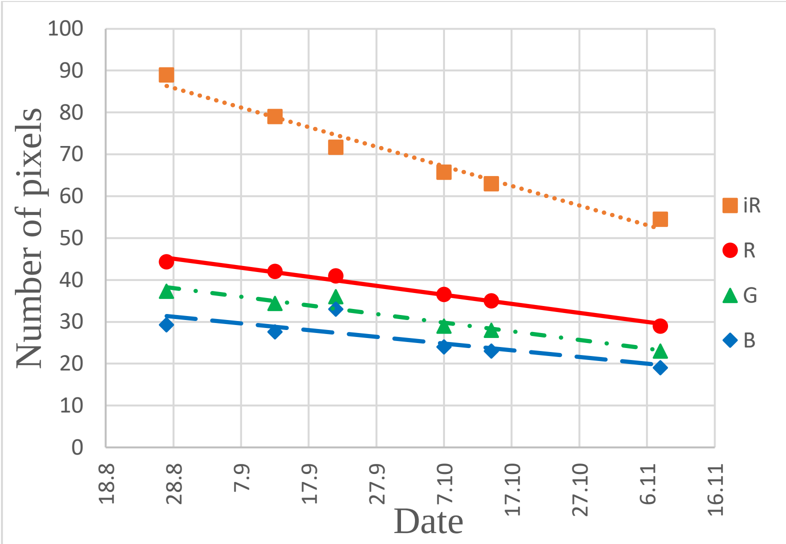

Figure 4: Graphs of dependence of intensity of components of color of soil on date of shooting

As can be seen from the above data, for the visible range there is a trend to reduce the intensity of the color components, which could be explained by the gradual moistening of the soil and, accordingly, its darkening. However, in the case of soil moisture, for the infrared channel, according to the results of A. J. Richardson at al [20] (1977), there should be an increase, but a declining trend. According to the authors, the explanation for this is the imperfect atmospheric correction, which must be carried out using artificial ground or natural reflector panels. Because this is not always easy to implement, especially for low-resolution images such as Landsat 8, it may be appropriate to focus on a series of images over several years.

2.6. The results of statistical data processing

Different types and subtypes of soils can have different values of color intensity of color components, so setting a limit value that corresponds to soil without plants is a debatable issue. In addition, different crops during the growing season have different indicators of the intensity of the color component in both the optical and infrared ranges. Therefore, to determine the soil parameters, data was filtered based on the value in the infrared channel. The results are shown in Figure 5.

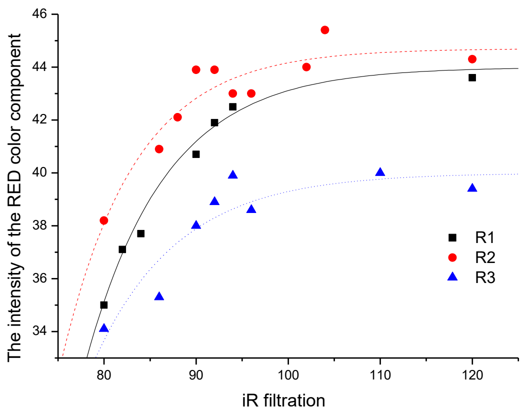

Figure 5: The dependence of the mean value of the intensity of the red color component, calculated for the condition of the mean value for pixels if the value of the iR pixel ≤iR filtration

First-order Exponential Decay equations were used to approximate the experimental data. For the green and blue components of color, dependences of a similar nature were obtained.

The analysis of the obtained data showed that for the third field the color is significantly darker, which is obviously a consequence of more organic matter in the soil.

2.7. Direction of further research

In addition to the Landsat v5-8 agricultural satellites, there are alternative solutions, such as Sentinel-2 with higher image resolution, for which it is easier to choose acceptable optical templates.

Establishing the state of moisture of the upper soil layer will be of fundamental importance for the automated determination of the state of soil erosion based on the results of spectral monitoring. It is necessary to develop a mathematical algorithm that can assess the suitability of the data.

Agricultural satellites are shooting in automatic mode, not taking into account the state of clouds. The systems provide an assessment of the state of clouds throughout the photograph, but there is a high probability that for the experimental area the state of clouds may not correspond to the average value. According to the authors, research on the introduction of machine learning to assess the suitability of images for cloud parameters in the experimental areas is promising.

3. Conclusions

1. Satellite spectral monitoring proved to be suitable for automation of processes of technological soil erosion monitoring.
2. Using a series of satellite images, it was possible to identify a field for which agricultural practices in crop production were carried out at the highest level and, accordingly, the soil has a higher fertility.
3. To ensure the accuracy of one-year images, it is necessary to use images with a resolution suitable for precision atmospheric correction on terrestrial objects with stable and known spectral indices.

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