

Досліджено залежність характеристик спектрозональних растрових зображень Landsat 7 ETM+, зокрема відбивної здатності альbedo ρ та величин вегетаційних індексів від показників властивостей опідзолених гідроморфних ґрунтів перехідної частини Центрального Полісся України. Виявлено вплив способу виокремлення статистичної вибірки на результат кореляційно-регресійного аналізу з метою діагностування величин ґрунтових та агрохімічних показників

Ключові слова: зондування, властивості ґрунтів, екранованість, ρ альbedo, гідроморфність, кореляційний зв'язок, вегетаційний індекс

Исследована зависимость характеристик спектрозональных растровых изображений Landsat 7 ETM+, в частности отражающей способности альbedo ρ и величин некоторых вегетационных индексов от показателей оподзоленных гидроморфных почв переходной части Центрального Полесья Украины. Выведено влияние способа выделения статистической выборки на результат корреляционно-регрессионного анализа с целью диагностики величин почвенных и агрохимических показателей почв

Ключевые слова: зондирование, свойства почв, экранированность, ρ альbedo, гидроморфность, корреляционная связь, вегетационный индекс

THE USE OF SPECTRUM-ZONAL IMAGES BY LANDSAT 7 ETM+ FOR DIAGNOSING SOIL CHARACTERISTICS OF UKRAINIAN POLISSYA

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1. Introduction

It is generally known that the transformation of the world land resources as a result of anthropogenic influence and as a result of significant climate changes requires reliable information about the course of quantitative and qualitative changes in the indicators of soil fertility.

In this aspect, it is rather important for the researchers to be able to monitor changes in the individual indicators over the short and long-term perspectives. In addition, it appears interesting for the scientific community and state fiscal authorities to obtain access to information on the ways to control changing indicators of the agroecological condition of soils.

Important in this case is the timeliness of obtaining and the possibility to update remotely identified data. In the course of conducting monitoring studies of soil cover, the methods of Earth remote sensing (ERS) are considered to be quite effective at present, which are used under conditions of different soil-climatic zones of Ukraine.

With regard to the aforementioned, obtaining objective information about the condition, spatial distribution, efficient ways to use soils under conditions of strengthening

degradation processes, require further study. In this case, improvement and development of new effective and cheap methods for the remote diagnosis of soil cover acquire special importance.

In this aspect, an algorithm for remote identification of indicators of the properties of the podzolized soils in the transition zone of Central Polissya in Ukraine under conditions of complicated screening by vegetation needs further study and improvement. An examination of the peculiarities of remote sensing of soils, which undergo periodic excessive humectation and have, accordingly, attained a certain degree of hydromorphicity, appears to be particularly interesting.

Still not sufficiently explored up to now is the need and scale of the utilization of materials on massive soil surveys over previous years, which to a large degree are morally and physically obsolete, during current soil examination. Undoubtedly, conducting such a survey of the territory of Ukraine has to be implemented based on the new scientific and technical basis, which requires proper substantiation.

The approaches to the number and distribution of identification points for selecting soil samples, depending on the structure of soil cover and the type of common soils, have not been fully examined. The latter is especially important

in the context of a prospect for further interpolation and extrapolation.

In addition, the relevance of the conducted studies is in the need for development of technologies that combine using geoinformation technologies and methods for remote sensing of qualitative characteristics of soils. In this case, it is important to devise a complete algorithm for remote identification of qualitative parameters of soils, which should include establishing dependences, their assessment and the construction of schematic maps (maps). In this case, the role of effective tools in the form of functional software is hard to overestimate.

2. Literature review and problem statement

The issues of applying the multispectral satellite images for the purpose of determining the magnitudes of characteristics of soils were addressed by a number of scientists who in their research diagnosed their different qualitative attributes. Among the indicators of soil properties, the following ones were identified: xeromorphic coefficient [1], the content of physical clay, humus [2], the content of humus [3], a degree of gleization and erodibility of soils [4], granulometric composition and humus content [5], the content of iron, humus, granulometric composition [6], salinity [7] and many other indicators.

According to the assertions of some of them [1, 8], the established coefficients of correlation of the regression models cannot provide for determining qualitative characteristics of soils by the obtained models with the accuracy, which would equal traditional determining techniques. In their opinion, we can talk only about the accuracy of aligning the parameters of the examined sample with a certain existing interval of reliable values. According to [9, 10], soil as an object of modeling is a sophisticated multifunctional, dynamic, complex system that requires studying in the scale that enables observing permissible limits for finding an indicator of soil, which is diagnosed by means of ERS.

A limitation of using aerospace methods due to weather conditions and soil screening by vegetation is highlighted in papers [2, 3]. Authors, in this case, stress the need for the verification of the received data as a result of performing space remote sensing against the data obtained by using traditional methods.

In the vast majority of articles it is indicated that the diagnostic attributes of soil quality reflect the brightness and image hue of spectrum-zonal images [11, 12], as well as their albedo-reflectivity [13, 14]. Especially pronounced are these relationships in red and near infrared ranges.

In this case, it is a generally known fact that informativeness of vegetation indexes, which are widely used to diagnose the state of grounds and to detect their characteristics, differs significantly and varies widely. The level of informativeness and reliability of vegetation indexes is affected by: season, type of soil, dominant type of plant cover, conditions of topography, type of landscape and agroecological soil condition at the time of research.

When diagnosing different types of soils, the most credible results were demonstrated at the following types: gray podzolized [4, 14] typical chernozems [12], ordinary chernozems, medium in humus, with differences in the degree of erodibility and soil-forming rocks [2, 5]. The data given in [4, 15]

evidence the most accurate diagnosis of sod-podzolic gleyey soils. The other types did not reveal reliable spectral image.

However, despite the constraints described, vegetation indexes are justifiably considered to be sufficiently informative comprehensive indexes for diagnosing parameters of soils. They demonstrate a considerable correlation with both a mineral component of soil – granulometric composition, and the content of organic matter and other indicators. They include: SAVI2 is the second soil vegetation index, NDVI is the normalized differential vegetation index [5, 16, 17], MSAVI – modified soil vegetation index [17–19], SFI is the index of soil fertility [20], NDSI is the normalized salinity index [7] and other indexes [21, 22]. According to scientists, using them may enable the identification of the following indicators of agroecological condition of soils: degree of erosion hazard, granulometric composition [6, 14], content of iron [6], content of humus [2, 3], alkalinity [7], type of soil and other characteristics. Identifying the indicated magnitudes is possible both through vegetation cover by zoned vegetation indicators and through soil's albedo indicator ρ at minimal amount of vegetation or its full absence.

In paper [13], researchers proposed an approach to predictive determining the content of organic carbon at a depth of 30 cm by calibrated reflectivity of the Landsat 7 ETM+ pixels. The results indicate an acceptable level of reliability at multiple correlation $R^2=0.67$ and 0.65 for calibrated data and validation data, respectively, for different types of soils in Africa. With the help of images, a significant correlation between characteristics of the images and the contents of physical sand, humidity and the content of organic carbon in soils was revealed.

However, despite a sufficient number of articles on remote sensing of soils, not fully studied as yet is the effectiveness of using available materials about terrestrial soil surveys in previous years. Here we mean the structure of soil cover for conducting ERS. It is clear that diagnosing the indicators of soils under conditions of variegated soil cover of Polissya in Ukraine compared, for example, with soils of the steppe zone, which are characterized by uniformity and spatial monolithic nature, will have substantial methodological differences and will differ by much more complexity. In addition, given the need for carrying out in Ukraine the next total soil survey, the question of feasibility and scalability of applying materials from massive soil surveys way back in 1957–1961, conducted in the territory of the former Soviet Union, gain a special importance.

In addition, it is necessary to note that while traditional use of vegetation indexes in vegetation period (season) of plants for diagnosing soil characteristics might be considered appropriate, then the question of their application beyond the vegetation season has remained insufficiently explored.

One should also consider as not examined well enough the peculiarities of using multispectral images for diagnosis of sod-podzolic, light gray and grey soils of transition zone in Polissya of Ukraine with attributes of hydromorphicity.

3. The aim and tasks of the study

The studies conducted set out to define methodological approaches to the remote identification of indicators of soil properties in the transition zone of the Central Polissya of Ukraine. The aim was to diagnose the magnitudes of indi-

cators of soil fertility under conditions of variegated soil cover with attributes of hydromorphicity and complicated screening of the Earth's surface by vegetation, using the Landsat 7 ETM+ spectrum-zonal imagery.

In the course of studies, the following tasks were set:

- to develop optimal approaches to diagnosing certain indicators of soil fertility with attributes of hydromorphicity and a high degree of diversity of soil habitats under conditions of transition zone in the Central Polissya of Ukraine;

- to develop an algorithm for remote diagnosis of characteristics of soils based on GIS technology, which implies the use of soil surveys materials for previous years and aims at minimizing the number of points where samples are taken;

- to establish the nature of interrelations between p albedo and the most wide-spread vegetation indexes based on multispectral images, on the one hand, and indicators of properties of soils, on the other hand, beyond the vegetation season of plants.

4. Materials and methods to study diagnosing of indicators of soil properties in the Ukrainian Polissya using the Landsat 7 ETM+ spectrum-zonal imagery

The study was conducted in 2015 in the territory of research field of Zhytomyr National Agroecological University, which is located in the zone of Central Polissya in Ukraine and is in in Chernyakhivsky district, Zhytomyr Region. Selection of soil samples was carried out at the levelling crops plots of research field.

4.1. Methods for fixing the points, selecting soil samples and determining the screening of the Earth surface

The points were laid down in the examined area with the most common soils at different grounds and their exact geocoding was accomplished (Tables 1, 2).

Table 1

Data of geodesic fixing of the points

Number of point	Latitude, B			Longitude, L			Mark, m
	degrees	minutes	seconds	degrees	minutes	seconds	
1	50	26	5,397	28	42	17,604	254,50
2	50	26	4,083	28	42	15,590	255,20
3	50	26	7,264	28	42	21,243	253,12
4	50	26	11,554	28	42	15,915	255,61
5	50	26	8,835	28	41	40,454	258,29
6	50	26	9,152	28	41	37,676	257,97
7	50	26	11,026	28	41	35,565	258,30
8	50	26	20,997	28	41	47,376	255,47
9	50	26	22,015	28	41	50,579	254,71
10	50	26	25,205	28	41	48,996	253,88
11	50	26	22,201	28	41	44,581	253,68
12	50	26	22,201	28	41	44,581	254,30
13	50	26	22,962	28	41	38,564	254,05
14	50	26	27,428	28	41	19,018	250,75
15	50	26	27,985	28	41	16,525	250,97

In order to control geodesic fixing of points, we used the device GPS Trimble R3, which is under mode of dynamic image-taking provides for differential accuracy WAAS/EGNOS<1 m. As a result, we obtained coordinates of points in the geographic coordinate system WGS 84 (UTM map projection – universal Mercator projection). As a cartographic basis for the research, we used map of soils with scale 1:2000. Soil survey of the research field of Zhytomyr Agricultural Institute (village Velyka Gorbasha, Ukraine) was conducted in 1982.

Table 2

Fixing the points of the study in terms of soils with the presence of vegetation on them

No.	Name of soil, agricultural crop	Quantity of monitoring points and their numbers
1	Sod middle podzolic gleyic sandy soil on waterborne and glacier sediments, Eutric Podzolvisols (PDe) (FAO), winter rye (<i>Secale cereale</i> L.)	2 – p. 5, p. 6
2	Sod middle podzolic gleyic sandy loam soil on waterborne and glacier sediments, Eutric Podzolvisols (PDe), (FAO), perennial cereal-leguminous grass mixtures (<i>Dactylis glomerata</i> L.) (<i>Bromus inermis</i> L.), (<i>Phleum pratense</i> L.), (<i>Lotus corniculatus</i> L.), (<i>Trifolium pratense</i> L.)	1 – p. 7
3	Eutric Podzolvisols (PDe) (FAO), perennial cereal-leguminous grass mixtures: (<i>Dactylis glomerata</i> L.) (<i>Bromus inermis</i> L.), (<i>Phleum pratense</i> L.), (<i>Lotus corniculatus</i> L.), (<i>Trifolium pratense</i> L.)	3 – p. 8, p. 9, p. 10
4	Eutric Podzolvisols (PDe) (FAO), winter spelta (<i>Triticum spelta</i> L.)	3 – p. 11, p. 12, p. 13
5	Grey podzolized gleyic sandy loam soil on forest sediments with waterborne and glacier sediments strewn under, Haplic Greyzems (GRh) (FAO), winter spelta (<i>Triticum spelta</i> L.)	2 – p. 14, p. 15
6	Dark gray podzolized gley sandy loam soils on loess loam underlaid from the depth of 1.0–1.5 meters of waterborne and glacier sediments, Haplic Greyzems (GRh), (FAO), cereals stubble	3 – p. 1, p. 4
7	Chernozemic-meadow calcareous, silty-loamy soils on loess loam, Eutric Planosols, (PLe), (FAO), cereals stubble	1 – p. 2
8	Peat-bog calcareous drained soil on waterborne and glacier sediments, bog vegetation, Terric Histosols (HSs), (FAO)	1 – p. 3

A selection of mixed soil samples was generated by the method of envelope (2×2 m) from a layer of 0–20 cm. Soil screening was determined based on digital images taken with a digital camera from a height of 1 m in a threefold sequence and subsequent calculation of the mean value. Screening in percentage was determined using electronic palette of the program Corel DrawX4 (Table 3).

Table 3
Distribution of soil screening with vegetation

Number of point	Screening degree, %			Free soil, %
	all types of vegetation	vegetation plants	dry vegetation	
1	57,5	55,5	2,0	42,5
2	93,0	32,0	61,0	7,0
3	97,0	12,0	85,0	3,0
4	51,0	18,0	33,0	49,0
5	25,0	23,0	2,0	75,0
6	24,0	21,0	3,0	76,0
7	90,5	34,5	56,0	9,5
8	93,0	23,6	69,4	7,0
9	92,0	28,7	63,3	8,0
10	92,0	30,0	62,0	8,0
11	53,0	38,0	15,0	47,0
12	48,5	30,0	18,0	52,0
13	33,0	27,0	6,0	67,0
14	80,0	32,0	48,0	20,0
15	72,0	35,0	37,0	28,0

Results of screening the soil cover indicate a complicated nature of vegetative cover in different parts of the examined territory.

4. 2. Methods of laboratory analyses of soil samples

In the selected samples, under laboratory conditions, we identified the following indicators: soil granulometric composition by Kaczynski (7 indicators), the humus content by Tyurin, carbon content of organic matter, nitrate nitrogen, ammonium nitrogen, water Ph, salt pH, exchange cations Ca²⁺, Mg²⁺, Na⁺, K⁺ (5 indicators), content of mobile phosphorus P₂O₅ and exchangeable potassium K₂O by Chyrikov, hydrolytic acidity, cation-anion composition of aqueous extract in the composition of HCO₃⁻, Cl⁻, SO₄²⁻, Ca²⁺, Mg²⁺, Na⁺, K⁺ (8 indicators), ash, % [23]. All in all, 30 indicators.

To achieve maximum synchronization of the dates for selecting soil samples (28.10. and 04.11.2015) with the moment of taking images of the Earth surface, from the archives of satellite data USGS EROS Data Center (USA Geological Service) we received a multispectral image taken by Landsat 7 ETM+. The date and time of taking the image is October 15, 2015; 08:14 a.m. Resolution is 28.5 m for VNIR/SWIR channels.

The raster image of the area with attached soils by results of the surveys in 1982, the multispectral photograph and the points for sampling were integrated into a single coordinate system in Quantum GIS – 2.18 (QGIS). Radiometric correction of DN values was carried out according to standard algorithms, recommended by researchers and producers of images [24–27]. Conversion of values of dimensionless DN magnitudes (numeric values), proportional to the intensity of radiation from the objects, which reaches sensor R into dimensionless absolute values of reflection – ρ albedo was performed in accordance with the Landsat 7 Science Data Users Handbook [24, 26]:

$$\rho = \frac{\pi \cdot R \cdot d^2}{E \cdot \sin \theta}, \tag{1}$$

where π – 3.14; R is the intensity of radiation that reaches the sensor in orbit; d is the distance between Earth and the Sun; E is the luminosity factor for each channel of a multichannel image, received in accordance with specifications of the sensor; θ is the height of the Sun above horizon at the time of taking an image.

Luminosity factors E were obtained from the reference to product Landsat-7 [26].

The Sun height above horizon θ was obtained from the image’s metadata file.

The intensity of radiation from the objects that reaches sensor R was calculated by formula:

$$R = M_R \cdot Q + A_R, \tag{2}$$

where M_R and A_R are the calibration coefficients for the image under discussion obtained from the service file of metadata that is delivered along with the pictures on the date of shooting.

d is the distance in astronomical units, calculated by approximate formula:

$$d = 1 - 0,01668 \cdot \cos\left(i \frac{2 \cdot \pi}{365}\right), \tag{3}$$

where i is the number of the day of the year, obtained from the metadata file.

Vegetation indexes were calculated by standard formulas obtained from the manual on using product Landsat 7 ETM+ [24].

Normalized Difference Vegetation Index (NDVI) was calculated by formula [16]:

$$NDVI = \frac{Band4 - Band3}{Band4 + Band3}, \tag{4}$$

where Band4 is the reflection in the near infrared range; Band3 is the reflection in the red region of the spectrum.

Normalized Difference Soil Index (NDSI) was calculated by formula [28]:

$$NDSI = \frac{Band5 - Band7}{Band5 + Band7}, \tag{5}$$

where Band5 is the reflection in infrared range 1550–1750 nm; Band7 is the reflection in infrared range 2080–2350 nm.

Soil Adjusted Vegetation Index (SAVI) was calculated by formula [22]:

$$SAVI = \frac{(Band4 - Band3)}{(Band4 + Band3 + L)} \cdot (1 + L), \tag{6}$$

where Band4 is the reflection in the near infrared range; Band3 is the reflection in the red region of the spectrum; L is index of reforestation, we used value 0.5.

Modified Soil Adjusted Vegetation Index (MSAVI) was calculated according to the formulas used in [18, 19]:

$$MSAVI = \frac{2 \cdot Band4 + 1 - \sqrt{(2 \cdot Band4 + 1)^2 - 8 \cdot (Band4 - Band3)}}{2}, \tag{7}$$

where Band4 is the reflection in the near infrared range, Band3 is the reflection in the red region of the spectrum.

5. Results of research into an algorithm for remote identification of the fertility indicators of soils with attributes of hydromorphicity in the transition zone of Central Polissya in Ukraine

In the course of the studies, we identified, for most dependences, an average, relatively low, degree of correlation connection, regularly predetermined by different nature in the screening of soil cover and by the composition of integumentary vegetation in various points. In this case, a multi-component screening of the soil caused substantial obstacles for obtaining a more clear and informative spectral image (Tables 4, 5).

In the course of research, we established a correlation connection between the reflectivity – albedo ρ for pixels in the 4 and 5 channels of satellite image by Landsat 7 ETM+ and the content of exchange cations Ca^{2+} – in both cases, $r=-0.63$ (Table 4). The indicated image parameters correlate with the second fraction of sand (0.25–0.05 mm), $r=0.55$ and $r=0.52$ for channels 4 and 5, respectively. Parameters of channel 2 are associated with the contents of exchangeable potassium ($r=0.59$). The contents of cations K^+ affect the reflectivity of channel 2 ($r=0.65$), while the cation content of water extract Ca^{2+} is also correlated with values ρ of channel 7 (2080–2350 nm) at $r=-0.56$.

Given the lack of salinization processes in the given soils, any relation between characteristics of the Landsat 7 ETM+

images and indicators of content of salts was missing. Based on the research into correlation dependences between parameters of granulometric composition of soils and reflectivity ρ of different channels, depending on the type of mineral soils, their granulometric composition and the type of hydromorphicity, the indicators that are best diagnosed are the provision of soils with nutrients – phosphorus (P_2O_5) and potassium (K_2O). For 10 soils, a fraction of particles size of 0.25–0.05 mm is best correlated with channels 4 and 5 (760–900 and 1550–1750 nm) (Table 4), and for the whole sample of soils with channels 5 and 7 (1550–1750 and 2080–2350 nm) (Table 5), which proved to be the most informative.

The approach applied for compiling statistical sampling to conduct the correlation approach implied separating the soils with a podzolized type of ground formation. Typical for them, noticeably narrower (13.84–24.63) compared with the general sample of soils, a range of their physical clay content (13.84–28.35) (the sum of fractions with the soil particles size of <0,01 mm, %), allowed us to clearly diagnose dynamic agrochemical indicators of properties – movable phosphorus (P_2O_5) and exchangeable potassium (K_2O). In this case, it is generally known that the selected in the research factor for diagnostics of soils, which is limiting and accentuating, – their granulometric composition, constant over a long period, depends only on the soil-forming (maternal) rock and is inherent in every soil type. Given an urgent need to conduct continuous monitoring observations of agroecological condition of soils and the observation of dynamics of changes in agrochemical indicators in the long term, the latter peculiarity is without a doubt exceptionally important.

Table 4

Correlation coefficients of characteristics of images at reflectivity (ρ) with the indicators of sod-podzolic, light gray and gray soils $p<0.05$ $n=10$ (points 5, 6, 8–15), r

No. of entry, channel	Range, nm	Granulometric composition % (0,25–0,05 mm)	Content of exchange cations K^+	Movable phosphorus P_2O_5	Exchangeable potassium K_2O	Cation-anion composition of water extract, mmol/100 g of soil	
						Ca^{2+}	K^+
1	450–515	0,48	0,57	0,55	0,61	-0,42	0,52
2	525–605	–	0,59	0,65	0,74	-0,47	0,65
3	630–690	0,47	0,49	0,52	0,64	-0,57	0,56
4	760–900	0,55	0,46	0,58	0,65	-0,63	0,53
5	1550–1750	0,52	0,41	0,51	0,60	-0,63	0,45
7	2080–2350	0,50	0,49	0,57	0,65	-0,56	0,47

Note: “–” – low degree of correlation or its absence

Table 5

Correlation coefficients between reflectivity (ρ) and the indicators of properties of examined soils, at level $p<0,05$, $n=15$ (points 1–15), r

No. of channel	Range, nm	Granulometric composition, (0,25–0,05 mm)	Content of physical clay (sum of fractions<0,01)	pH_{HCl}	Exchangeable cations mmol /100 g of soil		Cation-anion composition, mass share, %		Cation-anion composition of water extract, mmol/100 g of soil	
					Ca^{2+}	Mg^{2+}	Na^+	K^+	Ca^{2+}	K^+
1	450–515	0,56	–	–	–	–	–	–	-0,39	–
2	525–605	0,46	–	–	–	–	–	0,46	-0,48	0,46
3	630–690	0,50	-0,47	-0,45	-0,40	–	-0,41	0,47	-0,63	0,48
4	760–900	0,53	-0,46	-0,47	-0,38	-0,42	–	0,41	-0,62	0,41
5	1550–1750	0,63	–	–	–	–	–	–	-0,47	–
7	2080–2350	0,61	–	–	–	–	–	–	-0,51	–

Note: “–” – low degree of correlation or its absence

Thus, it should be stated that under conditions of a variegated soil cover of Polissya in Ukraine with multicomponent screening by ground vegetation, the basis for diagnosing the agrochemical indicators is the technique for filtering analytical correlation sample of soils according to the type of soil-formation and close granulometric composition. As a result of excluding from the sample the soils with a high content of physical clay, we managed to considerably extend the magnitudes of correlation coefficients between the agrochemical indicators and ρ albedo.

As a result of establishing peculiarities in the dependence between the indicated indicators of soils and the albedo magnitudes, we discovered a polynomial nature of the connection (Fig. 1).

The most reliable is the dependence of exchangeable potassium content on the reflectivity ρ albedo of channel 2 (8).

$$y = -130325x^2 + 34746x - 2175,7 \quad (8)$$

where y is the content of exchangeable potassium in soils, x is the number of units of albedo ρ .

When calculating vegetation indexes, the largest correlation between the vegetation indexes values and the indicators of soils was demonstrated by index NDSI – normalized index of salinity. The correlation coefficient of the content of exchangeable potassium and the index value is equal to $r = -0.67$. For the case of calculation in a wide list of the types of soils, NDSI correlates with the second fraction of granulometric composition (0.25–0.05 mm), $r = -0.55$ (Table 6).

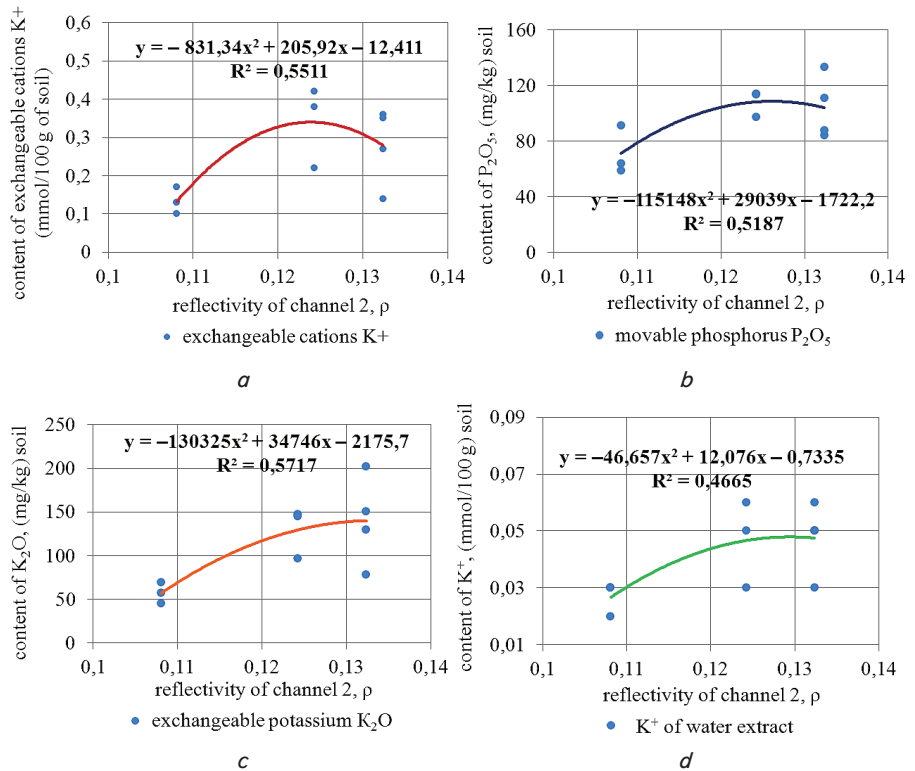


Fig. 1. Functional dependences of the content of nutrient elements of soils with reflectivity of channel 2: *a* – with exchangeable cations K^+ , *b* – with movable phosphorus, *c* – with exchangeable potassium, *d* – with cations K^+ of water extract

Results of the conducted construction of surface by the albedo ρ magnitude on the soil cover of research field, based on the classification of equal intervals, Fig. 2.

Based on the obtained equation of dependence between the albedo values and the content of movable potassium in soils (Fig. 1, c), we performed in the QGIS environment, using the methods for interpolation and extrapolation, a recalculation of the magnitudes ρ of raster model for the soil surface into the magnitudes of K_2O content (Fig. 3).

Table 6

Correlation coefficients between different vegetation indexes and the indicators of soil properties, at level $p < 0,05$, r

No. of entry	Indicators of soil properties									
	granulometric composition (0,25–0,05 mm)	salt pH	exchangeable cations K^+	movable phosphorus, P_2O_5	exchangeable potassium, K_2O	cation-anion composition of water extract, mmol/100 g of soil		cation-anion composition of water extract, mass share, %		
						Ca^{2+}	Mg^{2+}	K^+	Mg^{2+}	Na^+
for sod-podzolic, light grey and grey soils, (n=10)										
NDVI	–	0,37	–0,44	–	–0,47	–	–	–0,51	–0,39	0,38
NDSI	–	–	–	–	–0,67	–	–	–	–	–
SAVI	0,34	–	–	–	–	–	–	–	–	–
MSAVI	0,43	–	–	0,37	–	–0,38	–	–	–	–
for all types of soils in the examined territory, (n=15)										
NDVI	–	0,38	–	–	–	–	–	–	–0,34	–
NDSI	–0,55	–	–	–	–	0,42	–	–	–	–
SAVI	–	–	–	–	–	–	–0,44	–	–	–
MSAVI	–	–	–	–	–	–	–0,43	–	–	–

Note: “–” – low degree of correlation or its absence

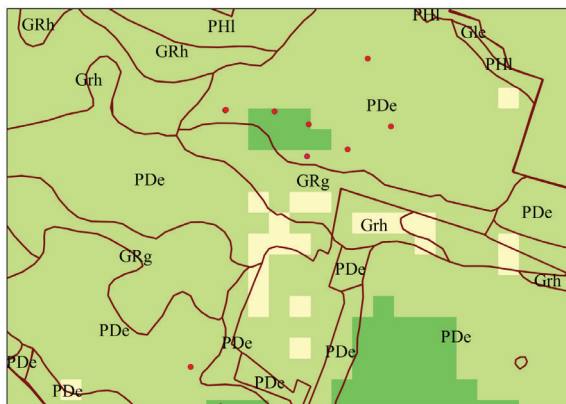


Fig. 2. Raster image of reflectivity of soil cover, computed in the QGIS environment by the albedo ρ magnitude (1)
 Note: codes of soils in the schematic map are in line with the FAO classification (1997) and in accordance with Table 2

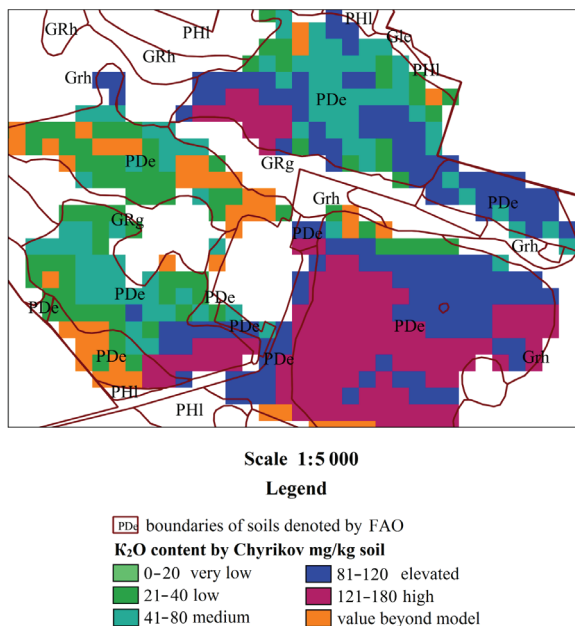


Fig. 3. Schematic map of the content of movable potassium (K₂O) in podzolized gleyey soils, computed in the QGIS environment by albedo ρ (8)
 Note: codes of soils in the schematic map are in line with the FAO classification (1997) and in accordance with Table 2

By orange color in the schematic map we, under automated mode, outlined parts of the soil cover with a very low K₂O content, which is beyond the range defined by the equation. This is partly due to the fact that the selection of soil samples was carried out locally, without covering the entire examined territory with podzolized soils, widespread over it, with a regular network. This approach, however, allowed us to minimize the costs associated with the necessity of selecting and running laboratorial analysis of larger number of soil samples. Given the fact that the K₂O magnitudes, calculated for the indicated pixels, have taken negative values, a proba-

ble location of true magnitudes of potassium content is in the range 0–40 mg/kg of soil.

In the south-eastern part of schematic map demonstrating the provision of soils with movable potassium are the light gray sandy loam gleyey soils with elevated and high content of K₂O (Fig. 3). A high content of movable potassium in the specified territory is naturally predetermined by temporary (one-year) research fields located over it, where the systematic introduction of organic and mineral fertilizers is carried out.

6. Discussion of results of exploring diagnosis of indicators of soil properties in the Ukrainian Polissya using the Landsat 7 ETM+ spectrum-zonal imagery

Results of the conducted studies on remote sensing of indicators of soil properties in the transition zone of Polissya in Ukraine beyond the limits of vegetation season of plants indicate a mostly average reliability of diagnosis in the majority of parameters. The obtained data allow us to draw a conclusion about the significant impact of ground vegetation on the qualitative characteristics of the received spectrum-zonal images. Under conditions of a variegated soil cover, characteristic of the transition zone of Polissya in Ukraine, an important factor in the quality of diagnosis of soil fertility magnitudes is an optimal approach towards the formation of statistical sampling. Grouping of soils according to the principle of uniformity of the type of soil formation and by the granulometric composition allowed us to identify their content of nutrients – movable phosphorus and exchangeable potassium. In this case, the number of selected soil samples is minimal, which affected insignificantly the quality of building a schematic map demonstrating the provision of soils with exchangeable potassium.

An integration of cartographic base with results of soil surveys in 1982 allowed us to take samples within the soil habitats, obtained by the results of ground-based surveys. In this case, the availability of detailed information about the history of agro loads on the research field has contributed to a better interpretation of the results of building a schematic map demonstrating the provision of podzolized soils with potassium by interpolation.

Given the desperate need for carrying out next soil survey in the territory of Ukraine, remote identification of agrochemical soil indicators, along with traditional methods of diagnosis, will reduce the time of image taking and significantly decrease its cost. A described technology of remote sensing might be used to provide agricultural enterprises with information on the availability of basic nutrients in soils.

In this case, increasing the level of reliability of correlation connection between characteristics of spectrum-zonal images and the magnitudes of soil properties should be a priority for further research.

Improving the quality of the proposed algorithm for remote sensing of soils should provide for the principle of homogeneity when compiling analytical sample of correlation relationship between the indicators of properties and characteristics of satellite images. It consists in the fact that not only the optimal formation of statistical sampling but the selection of soil samples itself should be consistent with the materials of massive soil surveys in previous years. Here we mean a prospect of taking into account a territorial enlargement of selected soil habitats. But given the possibility of low quality of the materials of terrestrial soil surveys, their application should be maximally weighted.

In the absence of cartographic materials, a clearer identifier that underlies remote diagnosing of certain agrochemical indicators of soils is their granulometric composition, namely, the content of physical clay. It should be noted that the formation of statistical sampling for a correlation analysis of the relationship between the indicators of soil properties and characteristics of images, as well as a range of their content of physical clay, must take into account the structure of existing soil cover. In our case, given the exceptional diversity of soil cover, quite informative was the range of physical clay content at 10.79 %. In the case of homogeneity of the soil cover, such a range will be naturally narrower.

Undoubtedly, not a less potential to increase the tightness of connection between parameters of reflectivity of images and vegetation indexes by qualitative characteristics of soils is in the provision of principle of uniformity when selecting the indicated similar research on the Earth surface. At best, such studies are necessary to carry out after the main cultivation of soils and their preparation for planting the crops or directly after planting (in autumn). In this case, there will be provided a short-term absence of vegetation on the Earth surface and, to some extent, the appropriate uniformity. Not a less potential to improve the quality of diagnosing the soils is demonstrated by remote phytoindication. In this case, the principle of uniformity will be provided through full or partial coverage of the Earth surface with agricultural plants. High identification capacity of basic quality properties of soils might be ensured through spectral characteristics of the agricultural crops [21].

7. Conclusions

1. It is established that the grouping of soils based on the principle of uniformity according to the type of soil formation and granulometric composition when compiling statistical sampling contributed to increasing the level of informativeness of spectrum-zonal images by ρ albedo reflectivity and vegetation index NDSI.

2. It was proven that in the case of adding to analytical sample the soils with narrow content of physical clay (from 13.84 to 24.63 %), by the channel of image with wave length (525–605 nm) by ρ , indicators of nutrients content are better diagnosed – movable phosphorus P_2O_5 ($r=0.65$), exchangeable potassium K_2O ($r=0.74$). In the case of statistical processing of data with a wide range of contents of physical clay (from 13.84 to 28.35 %), by channel 5 of image with wave length (1550–1750 nm) by ρ , the contents of medium sand are better identified (0.25–0.05 mm) ($r=0.63$). And by channel 3 of the image (630–690 nm) – the cations of calcium ($r=-0.63$).

3. The most informative among vegetation indexes is NDSI – correlation coefficient with the contents of exchangeable potassium K_2O ($r=0.67$).

4. A polynomial nature of connection is established between the values of ρ albedo of channel 2 (525–605), on one hand, and magnitudes of movable phosphorus (P_2O_5), exchangeable potassium (K_2O), exchangeable cations K^+ , as well as cations K^+ of water extract of podzolized hydro-morphic soils, respectively, on the other hand.

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