DETERMINATION OF ERODED CHERNOZEM SOILS OF THE RIGHT-BANK STEPPE OF UKRAINE USING THE "SOIL LINE"

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Abstract. This article evaluates the information content of the parameters of “soil lines,” which were built according to the data from remote multispectral images. Such a procedure is necessary for remote identification of the soil cover of the Right Bank Steppe of Ukraine and to map it for practical uses. We used images taken in the red (RED) and infrared (NIR) parts of the spectrum by the OLI scanner, which is on the US Landsat-8 satellite. The geographical information system QGIS was used for work with the data of multispectral images. Methods of graphical and statistical data analysis were also used. While processing the obtained satellite information for surfaces of agrolandscapes without vegetation, samples of brightness in the red (RED) and infrared (NIR) parts of the spectrum were formed for specific research sites with non-eroded and eroded ordinary and chernozem southern. On the basis of these data, “soil lines” were constructed and a statistical analysis was made of the samples and parameters of the equation NIR = f(RED). Soil lines built in the hyperspectral space can be used to identify and map various subtypes of chernozem and their eroded variants for the conditions of the Right Bank Steppe of Ukraine. The parameters of the soil line (β_1, β_0), as well as the magnitude of the coefficient of determination (r^2), are statistically significant, relative to the specific characteristics of the chemical composition of these soils, in particular with the content of humus, carbonates, and (for chernozem southern) the manifestation of solonetz soil properties. The uniqueness of the spectral characteristics of various subtypes of chernozem is shown by a statistical analysis of the brightness samples in the red and infrared parts of the spectrum.

Keywords: soil line; spectral brightness; ordinary chernozem; chernozem southern.

Introduction. The problem of mapping the soil cover of Ukraine is well–known and quite urgent. This is especially true for creating large maps for production purposes of scale 1:5000; 1:10000; and 1:25000. One opportunity to perform such mapping quickly and efficiently is through the use of satellite information, especially spectral images covering large areas. Satellite information has often been used in soil research. One of the most successful of these is the concept of the so-called "soil line." The soil line is the linear relationship between the values of red (RED) and near-infrared (NIR) spectra in the hyperspectral space obtained by a multi-spectral scan of the soil surface not occupied by vegetation. [1, 2, 3, 4, 5].

Such a line is described by the ordinary linear equation

$$NIR = RED \times \beta_0 + \beta_1. \tag{1}$$

where NIR is the value of brightness in the near-infrared part of the spectrum, RED is the value of brightness in the red part of the spectrum, β_0 is the tangent of the angle of inclination, β_0 is the distance along the y-axis from the point of intersection to the beginning of the axis.

The soil line was first described by Kaut and Thomas [1]. Gorey and Fox [5], who investigated the soils of the Midwestern United States and South Texas, argued that there were not unique soil lines for each soil type (subtype). However, a number of other authors [6, 7, 8] have proven that, most likely, each soil type (subtype) corresponds to its own soil line, with individual values for parameters β_1, β_0. In particular, Dematte and Marcos [9] have developed a technique for using multi-spectral remote sensing to obtain soil lines for soils in Sao Paulo, Brazil. Soil lines have been constructed for different soils, characterizing them depending on the content of clay < 0.01 mm, the properties of the parent rock, and the iron content. Recent work on soils of the Tula region of Russia confirms the prospect of using the soil line for their identification and mapping [10].

Materials and Methods. The object of study was the soil lines of four study sites with ordinary chernozem and chernozem southern, together with their eroded slopes. All four sites are located in the Right-Bank Steppe of Ukraine (Tab. 1). In this region erosion has a severe impact on the structure of the soil cover and is the main reason for its high complexity. For example, in the Mykolaiv region alone, 814.8 thousand hectares (33.3% of the total area) of soils are considered eroded. Satellite images were obtained by an OLI (Operational Land Imager) scanner aboard the US LandSat-8 satellite. The images have a spatial resolution of 30 m per pixel for eight spectral channels. Only two spectral channels were needed to construct the soil lines - the fourth (red, RED, 0.64-0.67 μm) and the fifth (near infrared, NIR, 0.85-0.88 μm). QGIS 2.18 open source software was used to determine the spectral brightness of the studied agro-landscapes. The brightness is measured by QGIS 2.18 in unitless variable from 0 to 1. Before directly determining the magnitude of the spectral brightness of these parts of the spectrum on the basis of metadata, which were obtained together with satellite images, pre-processing of the images was performed. This included atmospheric and radiometric correction of the data, which was completed using the Semi-Automatic Classification Plug-in for QGIS 2.18. Using geographic data, satellite images were combined in QGIS 2.18 with data from sub-satellite, pre-field studies to identify soil erosion and determine the basic properties of soils in the study areas described above (Tab. 2). In addition to field research, archival materials of Zemproekt-Mikolaev LLC were also used to identify the soils of the study sites. As the technology of building soil lines is only possible in the absence of vegetation, the surfaces of the test plots were verified for all available cloudless images of the Landsat-8 satellite OLI scanner for 2015-2018. The estimation of the presence or absence of vegetation was determined using the vegetation Index NDVI [10]:

Table 1. Characteristics of the study sites

№ №	Soils	Coordinates of sites		Dates of the images used in the calculation’s	Number of selected pixels	
		Latitude(N)	Longitude (E)		Non-eroded soils	Eroded soils
1	Southern chernozem	46.905448	31.679024	04.04.17, 31.03. 18	94	140
2	Southern chernozem	46.892311	31.682028	04.04.17, 31.03.18	84	110
3	Southern chernozem	47.353425	32.874279	28.03.17, 13.04.17	148	314
4	Ordinary chernozem	47.826719	31.318726	29.10.17, 08.10.15	386	488

Table 2. Some properties of the topsoil of the study (numerator – watershed, denominator slope)

Parameters		Soils			
		Southern chernozem	Southern chernozem	Ordinary chernozem	Southern chernozem
Coordinates of sites	Latitude (N)	47,353425	46,892311	47,826719	46,905448
	Longitude (E)	32,874279	31,682028	31,318726	31,679024
Humus contens, %		2,44/2,28	3,30/3,20	4,31/4,03	3,21/2,86
Power of a soil horizon A+AB, см		52/49	52/45	56/50	55/44
The content of carbonates,%		3,33/7,28	0,20/0,13	0,28/0,62	0,20/0,42
Gratulometric composition, %	<0,01 мм	57,9/56,9	56,8/58,4	68,1/62,5	56,7/58,4
	<0,001 мм	31,4/30,5	31,6/32,1	41,1/43,7	31,6/32,2
The content of the absorbed cations	Ca^{2+}	18,07/16,81	24,50/25,75	29,64/31,72	23,40/22,60
	Mg^{2+}	4,92/3,44	6,25/4,00	4,68/2,60	5,24/3,39
	Na^{+}	0,02/0,08	0,10/0,17	0,07/0,13	0,12/0,18

$$NDVI = \frac{NIR - RED}{NIR + RED}. \qquad (2)$$

If the NDVI was in the range of 0-0.32, the soil surface was considered to either have no vegetation at all or to have virtually no effect on the reflective properties of the soil. Thus, six cloudless satellite images from 08.10.2015, 28.03.2017, 04.04.2017, 13.04.2017, 29.10.2017, 31.03.2018 were selected for the studies (Tab. 1). Soil lines were constructed using MS Excel 2010, and the data analysis package of the same software product was used for statistical estimation of the closeness and significance of the obtained regression equations NIR=f(RED) and parameters β_1, β_0.

In addition to directly studying the parameters of the soil line, a statistical analysis of the brightness of the red and infrared spectra of these satellite images were performed. As statistical indicators, the differences between the samples were used by several criteria - Fisher, Student, and Pearson, which were calculated using MS Excel 2010.

Results and Discussion. The concept of soil line, as an important attribute of soil diagnostics when using data from many spectral satellite probing of landscapes, means that the values of vegetation indices (such as, for example, NDVI (2)) that show the degree of saturation of the vegetation surface in the hyperspectral space with the NIR (Y-axis) and RED (X-axis) axes, will be at the top left of this graph. A boundary straight line, which roughly corresponds to the values of the vegetation indices when they are close to zero (i.e. in a state of very sparse vegetation or its absence), is the soil line. So, if the soil is an independent natural entity, as it is defined, then obviously it must have unique spectral characteristics that distinguish it from vegetation, snow cover, bodies of water, buildings, etc. Moreover, different soils must have different spectral parameters, which are related to the physical, chemical, and other properties of the surface layer. In this case, the quantitative parameters of the soil line (β_1, β_0) should carry information about these properties and can then be used to identify these soil properties, isolate individual soil contours during mapping, assess their degree of heterogeneity, etc.

An important point is the fact that, with the current acreage and cultivation technologies, it is very difficult to find soil surfaces without vegetation when using the concept of soil line. Our field studies show that both spring and autumn images of Landsat-8 are obtained at a time when there is no agricultural vegetation in the fields, but there is either a slight weediness or numerous crop residues. Satellite imaging of a surface with fresh-plowed soil without any vegetation and plant residues is an unlikely event, given the practices of surface tillage, widespread use of no till technology, frequency (once every 16 days) of surface photography by an OLI scanner and the presence of clouds. Therefore, under actual conditions, in the absence of any cultivated vegetation or in the presence of very sparse vegetation, NDVI values can reach 0.2-0.3. These somewhat higher "plant" criteria, compared to previous versions of images obtained by Landsat technology, are also associated with the fact that, for example, the image scanner EMI + (Landsat-7) has a red channel in the range of 0.63-0.69 microns and infrared 0.77-0.90 microns, and differs from the OLI scanner settings (Landsat-8). Narrower bands of red and infrared channels of OLI observations (Landsat-8) lead to relatively high NDVI values at low values of vegetation cover of soil surface or in its absence [11]. In general, the different bandwidths of the red and infrared channels of the various scanning devices used within the Landsat program make it practically impossible to broadly summarize the data obtained by the various satellites (Landsat-5, Landsat-7, Landsat-8).

A separate problem is the procedure for using the data and generalizing those OLI satellite images that are received at different times during the year. Despite the initial atmospheric and radiometric correction of the satellite data received, the generalization of the fourth and fifth channels of OLI images in the form of a soil line will obviously have errors, because different images were obtained at different altitudes of the sun and under different atmospheric conditions.

In summary, we can assume that, in fact, in the NIR=f(RED) graph, the data approximated by the soil line will have some variation, and therefore not only are the soil line parameters informative for soil problems (β_1, β_0), but also the coefficients of determination (r^2), which show the close relationship between the brightness of the red and infrared channels.

Table 3. Parameters of soil lines

№ №	Soils	Criterion Fisher (F)	Determination factor (R^2)	β_0			β_1		
				Value	Standard errors ($m_{\beta 0}$)	Students Criterion	Value	Standard errors ($m_{\beta 0}$)	Students Criterion
1.	Ordinary chornozem not eroded	102365	0,9963	1,8103	0,0056	319,94	0,0036	0,0004	10,15
2.	Ordinary chornozem eroded	74244	0,9935	1,7386	0,0064	272,48	0,0074	0,0005	15,71
3.	Southern chernozem not eroded	3090	0,9053	1,8812	0,0338	55,59	-0,0104	0,0022	4,71
4.	Southern chernozem eroded	2479	0,8149	1,6989	0,0341	49,79	0,0027	0,0021	2,29

The soil lines for the four test plots are shown in Figure 1 and their parameters are shown in Table 3. The calculated Fisher and Student's criteria indicate the statistical significance of the regression equations and parameters obtained β_1, β_0.

As can be seen from Figure 1 and Table 3, the original data are plotted in the form of a very elongated ellipse, and the line that approximates these data has different parameters β_1, β_0, and coefficients of determination (r^2) (Tab. 3). If for ordinary chernozems the connection is almost functional (r^2=0.99-1.00), both for eroded and for non-eroded soils, then for chernozem southern the coefficient of determination is somewhat lower. For non-eroded soils, it is 0.90, and for eroded ones, 0.81. A rational interpretation of these data should be made on the basis of those properties that determine the dependence NIR = f (RED).

It is obvious that the spatial and temporal changes in soil properties should be reflected in changes in the spectral characteristics of the soil. When it comes to the visible part of the spectrum, including its red component (RED) and near-infrared (NIR), there are two groups of soil properties that are responsible for such changes [7].

The first group includes soil moisture, structure, and particle size distribution. As these soil parameters change, the energy distribution across the spectrum does not change, and therefore the brightness values in the red and near infrared spectra

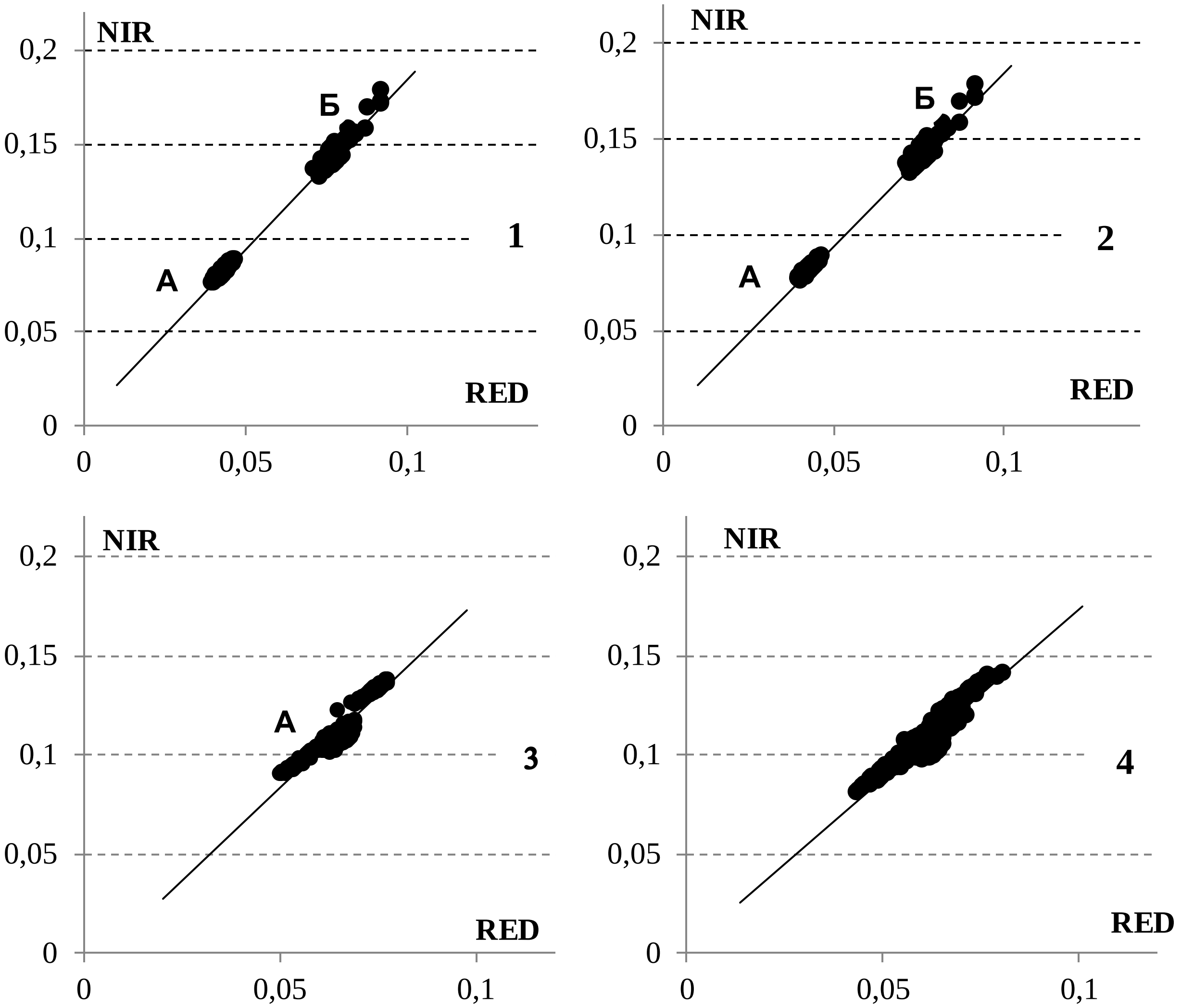

Figure 1. Soil lines (1 - chernozem ordinary non-eroded; 2 - chernozem ordinary eroded; 3 - chernozem southern non-eroded; 4 - chernozem southern eroded.

increase or decrease, but their ratio does not change, thus the parameters of the soil line are not affected. In this context, it is necessary to pay attention to two groups of points in graphs 1 and 2 with normal chernozems (Fig. 1). The group of points B in each graph is the data from Figure 8.10.2015, when the soil was dry. According to the nearest weather stations (Pervomaisk and Voznesensk), only 15-27 mm of precipitation fell in August and September. The second group of points (A) is data from an image obtained on October 29, 2017, when, during the prior two months, 50 to 65 mm of precipitation had fallen, according to the observations of the same weather stations. The group of points A reflects more moisture and darker soil in the visible part with minimal brightness values in comparison with the points B, but all of them are on the same soil line, whose parameters (β_1, β_0) do not change.

The second group of properties (the chemical and mineralogical composition of the soil) changes the character (shape) of the spectral curve [7], and changing these properties will significantly affect the parameters of the soil line. In our case, the most obvious chemical properties that will determine the parameters of the soil line on the background of uniform granulometric composition (heavy loam and light clay) are the content of humus and, for eroded differences, the content of carbonates. It is known from the literature, as well as confirmed by our field studies (Tab. 2), that the highest content of organic matter is observed in non-eroded ordinary chernozems, less in eroded ones, and even less in the chernozem southern watersheds and in slope eroded variants. Another chemical property that will affect, in our opinion, the nature of the spectral curve is the appearance of low-sodium natural salinity, especially the southernmost analogues of the chernozem southern (soil 2 and 3 of Table 1). It is perhaps the solubility that enhances the spread of points in Figure 3 and leads to a decrease in the coefficients of determination (Tab. 2). Visually, in graphs 3 (especially) and 4, the point cloud breaks down into two separate sets, one of which (A, with smaller NIR and RED values) characterizes the soil line of the saline chernozem southern.

Based on the above, it is evident that the linear function NIR = f (RED) for all the cases under consideration will have different parameters (β_1, β_0), which are statistically significant but still related to the peculiarities of the chemical composition of these soils. The parameters of the soil line (β_1, β_0) thus obtained (Tab. 2) can be used as diagnostic features for soil mapping in the Right-Bank Steppe of Ukraine.

Indirect confirmation of the effectiveness of the soil diagnostic method in the Right-Bank Steppe of Ukraine through their soil line is a paired statistical analysis of the brightness samples of non-eroded and eroded ordinary and chernozem southern in the red (RED) and infrared (NIR) spectrum. All three criteria used for the analysis – Student's t test (for arithmetic averages), Fisher (for variances), and χ^2 (to assess the degree of compliance) − indicate the complete independence of these samples at the lowest levels of significance (Tab. 3 and 4). That is, these samples characterize individual soil varieties with unique reflective spectral characteristics.

Conclusions. Linear functions NIR=f(RED) (or “soil line”) constructed in hyperspectral space, based on data obtained from multi-spectral scanning of vegetation landscapes not occupied by vegetation, by an OLI scanner aboard the US Landsat satellite 8, can be used for identification and future mapping of different subtypes of chernozem and their eroded variants of the Right-Bank Steppe of Ukraine. The parameters of the soil line (β_1, β_0), as well as the magnitude of the determination coefficient (r^2), which indicates the close relationship between the NIR and RED samples, are statistically significant and are related to the chemical composition of these soils, in particular the content of humus, carbonates, and (for chernozems southern) low-sodium salinity. A statistical analysis of the brightness samples in the red and infrared parts of the spectrum demonstrates the uniqueness of the spectral characteristics of different subtypes of chernozems and their eroded variants.

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