USE OF SPECTRAL SURFACE CHARACTERISTICS FOR MAPPING SOIL COVER STRUCTURE UNDER KRASNOYARSK FOREST-STEPPE CONDITIONS

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Abstract. The relations between the spectral surface characteristics of the elements of the soil cover structure and soil properties in the Krasnoyarsk forest-steppe of Central Siberia were investigated. It was revealed that the most informative parameters for field spectrometry are the content of humus, carbonate carbon dioxide and the prevailing particle-size fractions. A statistically significant relationship between the elements of the soil cover structure and the reflectivity of soils has been confirmed by means of multidimensional statistics. The wave lengths with the greatest coupling force are highlighted. Regression equations for remote study of soil cover structure have been obtained, which can be used if additional point studies are carried out in a wider range of test parameters. *Keywords: soil cover structure, spectral brightness coefficient, humus, particle-size distribution, multiple regression.*

Introduction

Sustainable and environmentally sound crop production requires consideration of all factors, including the heterogeneity of the soil cover or its structure (SCS) [1]. The most optimal method of accounting is digital mapping of the SCS with the subsequent use of a digital map in the adaptive landscape agriculture system [2]. Large-scale soil mapping is extremely economical and labor-intensive due to the specifics of the mapped object. The use of remote sensing data (RSD) greatly facilitates work, but requires a detailed methodological framework in a specific region.

Agricultural land on the territory of the Krasnoyarsk Region occupies about 5 million hectares, but at the moment the current soil and cartographic support of this area is extremely limited, point-wise. The development of methodological possibilities of using RSD for the recognition of soil heterogeneities is at the initial stage of development and is presented by single studies [3, 4]. The purpose of this work is to identify the relations

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between the spectral characteristics of the soil surface and its physicochemical parameters in the conditions of a pronounced microrelief of arable land of the Krasnoyarsk forest-steppe.

Objects and Methods

The study was carried out on a test site with an area of 10 hectares in the Minderlinskoye experimental-industrial farm of the Sukhobuzimsky district of the Krasnoyarsk Region (56˚25, 92˚53), on which a map of the SCS was previously drawn up.

A semi-closed intermountain basin, which is the Krasnoyarsk forest-steppe, stretches in a narrow strip along the left bank of the Yenisei with a hilly- ridged plain, the morphological structure of which is complicated to its periphery. From the east, the basin is bounded by the Yenisei Ridge, from the south by the spurs of the Eastern Sayan, from the southwest by the Kemchuga Highlands, and in the north and northwest it has no clear borders and merges with the taiga. In tectonic terms, this is a relatively stable section of the Kemchug depression [5, 6]. The territory is composed of sandstones and siltstones of the Jurassic system, covered by loess-shaped and deluvial loams and clays. The wavy denudation relief of the territory is represented by gentle (up to 15 °) slopes, the upper parts of which are formed under the influence of plane flushing, the middle ones - by the joint action of gravitational and fluvial processes. Long-term seasonal permafrost causes the formation of a pronounced microrelief - suffosion-subsidence on watersheds and extended on slopes.

The experimental field is located on the eastern slope of the watershed section between the Buzim-Minderla River. The absolute height difference is 10 meters (Fig. 2). The surface of the site is characterized by a pronounced hummocky-depression microrelief with open and semi-closed shallow stretches.

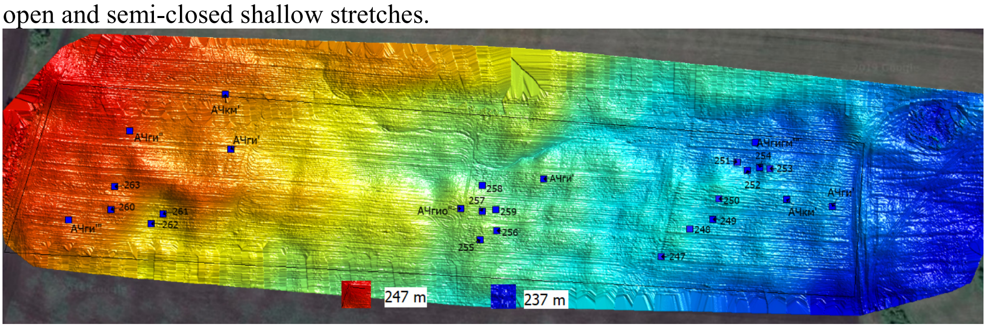

Fig. 1. Digital model of the experimental site

The climate of the Krasnoyarsk forest-steppe is characterized as very continental (continental coefficient calculated according to Ivanov - 220) and semi-humid . The relatively sharp continentality of the region is attributed to the great distance from the seas and the ocean and, as a result, a large temperature difference between the coldest (up to -49.4 ˚C) and the warmest (up to 36.1 ˚C) months of the year. Winters are long and cold, summers are short and hot, often dry. The sum of the active temperatures is 1886 ° C, the average annual air temperature is 0.4 ˚C. In spring, the temperature increases rapidly, in autumn it also drops rapidly. There is a significant risk of late spring frosts returning. The frost-free period ranges from 85-120 days. The duration of the active vegetation period is 108 days [7].

The average annual rainfall is 400 mm, most of which falls on the period of active vegetation. The average height of the snow cover is 21.5 cm. The hydrothermal coefficient is 1.2. The humidification coefficient (0.81) characterizes the test zone as semi-humid with a periodically flushing type of water regime. The soils of the Krasnoyarsk forest-steppe belong to the cold (long-term-seasonally freezing) type.

The soil cover of the study site is represented by spotting of typical clay-illuvial agrochernozems, podzolic and hydro-metamorphised with a humus horizon thickness from low to high and low-power cryogenic-micellar agrochernozems.

In May 2019 (during this period, the soil surface was open), 153 point samples were taken from the arable soil horizon of the site with a parallel spectral survey of the soil surface by a field spectrometric complex consisting of a Spectral Evolution PSR-1100F spectrometer with the possibility of internal data storage and a calibration reflective element. Remote data collection and analysis was carried out using the DARWin SP Data Acquisition Package joint software. The height of the survey is100 cm above the soil surface, the area is 50 cm2. The shooting was carried out in clear weather from 11:00 to 15:00. The position of the spectrometer was installed vertically above the surface of the shooting area (in nadir). Particle-size analysis was carried out in the selected samples, the content of humus and carbonate carbon dioxide [8] was determined. Mathematical processing of the results was carried out with the combined use of the programs Microsoft Excel and StatSoft Statistica 8.0.

Results and discussion

The humus content in the analysis of point-like samples ranged from 11 to 5%, which is estimated as very high, high and medium. The humus horizon, despite its small power, is very fertile and highly humus. In some areas, a reduced content of humus is observed, due to the manifestation of erosion processes. The calcium carbonate content is small and does not exceed 0.8%.

The particle-size distribution of point samples is heavy: from heavy loamy to medium loamy,, measured in every third sample. The predominant fractions are coarse dust and silt. There is a significant depletion of the sand fraction.

Spectral brightness coefficients were obtained in the range from 320 to 1100 nm. For convenience of work, the available spectral range by means of factor analysis of multidimensional statistics was reduced to one generalized index (factor) in 11 categories on the basis of division of spectrum of electromagnetic radiation into groups [9]. With the help of discriminant analysis, only those in which the soil parameters differ significantly in the spectral brightness set were identified from the selected areas (Table 1). To group the data, the variable "Шифр - Code" is selected, which means the grouping of points by contours in the structure of the soil cover.

Table 1. Discriminant Analysis Results.

Range wave lengths	Lambda Wilks	Private lambda	Value F-criterion	P-levels
320-380	0,511696	0,793567	7,387798	0,0000035
451-480	0,564171	0,719755	11,0579	0,0000052
481-510	0,51822	0,783576	7,844115	0,0000015
621-700	0,482611	0,841391	5,353615	0,000154
701-770	0,472976	0,858531	4,679756	0,000551
771-820	0,456788	0,888957	3,547559	0,004716

Using the same factor analysis within each range, we identified specific wave lengths according to the value of the correlation coefficient with the highest binding strength: 360, 465, 495, 660, 733 and 800 nm, and then to establish the relationship between soil parameters and spectral properties of soils used the coefficients of spectral brightness in the given lengths.

The dependence of reflectivity on the studied soil parameters was established by multiple regression analysis (Table 2).

Table 2. Multiple Regression Analysis Results

Soil parameter, %	Multiple R	P-levels	Wave length, nanometer	Regression coefficient
Sludge fraction	0,5737	0,000279	360	35,733
			46.5	-160,425
			495	123,651
Coarse dust fraction	0,5373	0,001043	360	-38,0765
			465	133,4074
			495	-99,1852
Physical clay	0,6333	0,000021	360	46,041
			465	-169,569
			495	126,365
Humus	0,5294	0,000001	360	10,9312
			465	-33,8066
			495	24,5224
$CaCO_3$	0,5891	0,000001	465	2,20776
			495	-2,67923
			660	0,94665
			800	0,35709

A statistically significant relationship of particle size distribution exists only in the predominant fractions: coarse dust, slit and physical clay with wave lengths of 360, 465 and 495 nm in the ultraviolet, blue and blue parts of the spectrum, respectively. The relationship between humus and spectral brightness coefficients is observed in the same ranges (360, 465 and 495 nm). Carbonates of calcium show bonds with the light blue, blue, red and near infrared areas of a range in lengths of 465, 495, 660 and 800 nanometers, respectively.

The regression coefficients are statistically significant for all soil parameters, but their regression equations cannot be applied in practice due to the large error of the results (Figure). In the case of calcium carbonates and humus, such an error is minimal, with a particle size distribution of maximum.

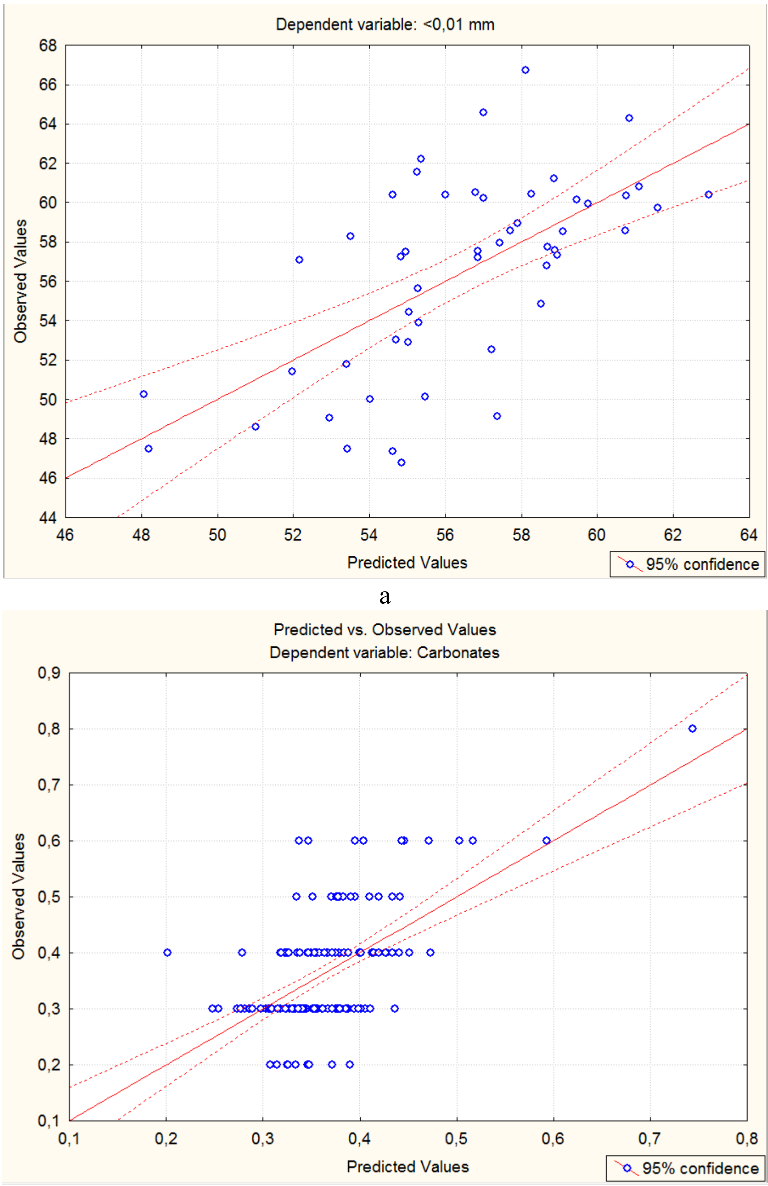

Fig. 2. Predicted and observed values of soil parameters when formulated in the regression equation,%: a - calcium carbonates, b - physical clay

Almost all points lie outside the confidence interval. The reasons for the error may be unaccounted for factors: soil moisture, the number of crop residues on the surface, etc. Undoubtedly, expanding the range of test parameters by involving additional off-field testing points will have a positive effect on multiple regression results.

Despite the significant variation in values, the straightforward relationship between the actual values and the predicted values is clearly visible. The possibility of using these characteristics is confirmed by the reliable coefficients of multiple correlation (Table 2), however, in order to improve the accuracy of the forecast, it is necessary to develop the data analysis methods.

Conclusion

Thus, the most informative of the studied parameters for field spectrometry are the content of humus, calcium carbonates, physical clay and the predominant particle-size fractions. A statistically significant relationship between the elements of the soil cover structure and the reflectivity of soils has been confirmed by means of multidimensional statistics. Spectra with a wave length of 360, 465, 495, 660, 733 and 800 nm have the greatest strength of connection..

The obtained regression equations can be used for remote research of the SCS of the Krasnoyarsk forest-steppe, subject to additional point studies carried out in a wider range of test parameters.

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