Studying the Condition of Soil Protection Agrolandscape in Ukraine Using Remote Sensing Methods

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Abstract: The article reviews the scientific approaches to monitoring of soil condition on the soil protection agrolandscape. In 1980s, the contour-meliorative soil protection system was established on the selected fields in Ukraine. The objective of the current research was to determine the capabilities of satellite survey to identify the changes of soil cover that had occurred on these fields during the past 25 years. Soil erosion processes are very dynamic, therefore it is essential to use time-series of operative satellite images to track those changes. Rills on the fields, caused by water erosion, are clearly identified on high-resolution satellite data. Erosion causes the decrease of humus content, which affects soil reflection values. This in turn leads to a corresponding change of color shade on satellite images. The research allowed to determine correlation between remote sensing data and soil organic carbon content and to acquire a mathematical model which describes this correlation. The condition of the agrolandscape soils was assessed using the regression model, which helped to evaluate erosion risk for different areas of the test polygon. The visual interpretation of satellite imagery led to a conclusion about a damaging effect of erosion on protective forest belts and accordingly on fields' soil cover and crops. Visual analysis results were approved by field research. Photos taken during the field research indicate an unsatisfactory status of forest belts and a devastating effect of eroding water flows. These are the results of irresponsible land use and constant violation of methodical principles of the contour-meliorative system organization. The article concludes that the use of time-series of high-resolution satellite imagery allows monitoring the condition of soil protection agrolandscape, in particular the forest belts' status, soil cover conditions and their change over time. The research results can be used as an informational basis for the soil protection agrolandscape monitoring system.

Key words: Soil cover, space imagery, remote sensing, anti-erosion agrolandscape, soil organic matter, monitoring, modeling.

1. Introduction

A prerequisite for sustainable agricultural development is the monitoring of current soil cover status and changes in major soil properties. Monitoring soil cover condition is considered as a significant challenge and has profound scientific and practical value, since the intensification of agricultural production often leads to increase of degradation in soils. A major problem for Ukrainian agriculture is water and wind erosion on soils. It has a devastating effect on national economy on arable lands. Therefore,

the monitoring issues of erosion processes stay relevant for state-of-the-art scientific studies. One of the corresponding research directions is to design agrolandscape which is intended to reduce erosion development rates. In Ukraine, such agrolandscapes were designed and created mainly in the late 80s of the 20th century. More than 25 years have passed since then, and therefore studying condition of these agrolandscapes is a major aspect of solving soil erosion problem. For efficient resolution of such problems, it is essential to use modern methods and means of obtaining, storing, processing and representing data, i.e., remote sensing methods and geographic information systems.

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The study of reflectance of eroded light-gray and gray forest soils showed that eroded soil is represented on space images by lighter tones than uneroded soil, because of lesser humus and silt particles content [1]. In this regard, it should be noted that monitoring of humus (soil organic carbon) content by the means of remote sensing is a widespread method, which was reviewed by many authors [2-4]. This gives an opportunity for interpretation of sheet erosion on tilled fields by direct signs. On the areas with dense vegetation cover, it is impossible to use direct signs of sheet soil erosion [5].

Linear erosion forms are clearly allocated on satellite images. Gully erosion forms (rills, gullies) are represented on high-resolution images as narrow clearly-delineated contours [6]. Indirect signs of soil erosion are related to studying the dynamics of vegetation changes. Increase of soil erosion rate leads to deterioration of plant growth conditions, since intensive water flow through a formed rill network damages crop shoots and plants root systems. Therefore, on eroded soils already on early phases of vegetation, there is a significant delay in plant growth, and the change of their phases lags behind by 3-5 d [7, 8]. As a result, crop productivity on eroded soils is reduced and the quality of production deteriorates.

Precise monitoring of such a dynamic global degradation process as soil erosion can be carried out only on the basis of operative remote sensing satellite systems. The need for combining satellite data of different spatial resolution for the study of the dynamics of agricultural landscapes and their changes was highlighted in many scientific papers [9, 10]. In particular, based on the analysis of multispectral data, the effectiveness of anti-erosion measures was evaluated for one of the regions of China, and a system of recommendations was developed for their improvement [11]. Therefore, the objective of the research was to identify the possibilities of using satellite imagery for anti-erosion agrolandscape status and functioning assessment, as well as forecasting of

their effectiveness.

2. Materials and Methods

The main territorial object of the research was the polygon Lisna Stinka (more 150 ha) located in Kupyansk district of Kharkiv region (Ukraine). This was because the area is classified as one of the highest levels of erosion risk zones in the region, and soil-protection agrolandscape system is implemented on the chosen territory. Test fields were situated in the Southern part of the forest-steppe zone with transition to steppe where widely-spread are chernozem-type soils with heavy loam and light clay composition: regraded and ordinary chernozems with different rates of erosion on loess and loess-like loams. Visual analysis of the satellite image of the test polygon allowed to determine surface areas with the highest erosion risk and to develop soil sampling system for field research. It should be noted that soil samples were obtained from all test fields with regard to topography specifics and based on the principle of maximizing description of different shades on the satellite image of soil cover (Fig. 1). To determine soil organic matter (SOM) content (humus) and granulometric content, 73 soil samples were collected from 0-10 cm layer during the field research using the instrumentality of GPS devises. Testing the remote sensing data capabilities for the study of soil erosion risk of this area was based on "Landsat-7" satellite images of air-dry bare soil surface, which was characterized by considerable complexity and contrast. The images were radiometrically calibrated and atmospherically corrected to obtain surface reflectance values. The research program included such tasks: analysis of the image; soil mapping and soil sampling systems; conducting a detailed field investigation and analytical studies of soil samples; the search of mathematical models to describe the relationship between optical characteristics of soil and its most stable genetic properties; creating soil properties maps on the basis of the obtained mathematical models and

Fig. 1 Satellite image of anti-erosion agrolandscape territory with soil sampling locations.

extrapolation procedures based on soil varieties obtained from spectral signatures interpretation. In order to accomplish these goals, the reflectance values (V_5 , V_7) were extracted from the satellite image in two spectral bands: SWIR-1 (1,550-1,750 nm) and SWIR-2 (2,090-2,350 nm), for each sampling point.

Agrophysical and agrochemical characteristics of the soil samples were identified for quantitative assessment of erosion risk within the agrolandscape and to determine the correlation of eroded soils' properties and space imagery data for interpreting current status and forecasting of the anti-erosion system functioning. For solving these tasks, the authors used statistical and geo-informational data processing methods. In particular, the authors used GIS for georeferencing space images, primary image processing, transformation, general statistical analysis and image classification. Variance, correlation and regression analysis of the whole quantitative information were conducted using Statistica package software [12].

3. Results and Discussion

The authors account the research polygon as a test field for observation of erosion processes within a system of soil-protection monitoring in Kharkiv region. Space images for several years were acquired alongside with archive maps of the region, and a digital elevation model was created for the studied territory using GIS spatial analysis tools. During field research, a preliminary assessment of state and functioning of the existing contour-meliorative system was done. On a pre-field stage, a dense network of erosion features was detected on satellite images. Field research only confirmed the fact of emerging rills and gullies on the test fields (Fig. 2). The design of such agrolandscape was based on the principle of using crop rotations on different parts of the field separated by forest belts. Unfortunately, in recent years, this principle was violated by land users, therefore during the field research all over the test fields' territory, there was only one crop raised. It was

Fig. 2 A photo of a narrow gully on the test field combined with corresponding linear forms on a satellite image.

identified that during intensive washout, soil-protective forest belts can't stand the pressure of water streams and sustain damage. Mainly in those parts of the fields where depressions are present, protective forest belts have significant gaps caused by intensive water flow during spring snowmelt period, as well as heavy rain periods of late spring and autumn when soil surface is poorly protected by vegetation. In such places, the forest belts are almost destroyed. Based on these observations, the authors have drawn a conclusion about an unsatisfactory state of soil-protective forest belts of the agrolandscape, which leads to deterioration of soil cover and agricultural vegetation conditions (Fig. 3). In gullies' locations, almost all vegetation cover is destroyed, and such gullies are clearly interpreted on high-resolution satellite imagery. Thus, during the research, it was confirmed that periodical satellite data can be used for monitoring of dense gully network development on

wide areas of arable slope lands, where anti-erosion agrolandscape systems have been created. This gives a perspective for further monitoring primarily of protective forest belts' condition, since the development of linear erosion forms on the fields is caused by gapes in forest belts.

Analytical determination of soil properties was conducted after the field research stage. The results of analytical testing of the samples made up a database for this region and were subjected to statistical processing. On the first stage of the statistical analysis, the authors determined the correlation between the reflectance values and soil parameters, including the total humus content (SOM) and physical clay content (soil particles less than 0.01 mm). Acquired data are presented in Table 1 for eroded and uneroded soils.

The negative correlation was determined between reflectance values in the infrared bands and the total humus content. The correlation coefficient was

Fig. 3 Photos of critical state of forest belts, soil cover and crops on the test field.

Table 1 Statistical data on soil indicators and optical parameters of eroded and uneroded soils.

Soil	Mean	SE ($\pm$)	Median	Min	Max	Lower quartile	Upper quartile	SD	CV
Eroded soil									
SOM	1.81	0.08	1.80	0.95	2.33	1.59	2.22	0.38	21.00
V_5	0.27	0.002	0.26	0.25	0.29	0.26	0.27	0.01	3.89
V_7	0.26	0.002	0.26	0.25	0.29	0.26	0.27	0.01	3.86
PhCl	41.06	1.03	41.04	33.93	50.07	36.00	44.52	4.93	12.00
Uneroded soils									
SOM	2.85	0.10	2.65	2.33	3.71	2.60	3.18	0.39	13.80
V_5	0.21	0.002	0.21	0.20	0.22	0.21	0.22	0.01	3.35
V_7	0.21	0.002	0.22	0.20	0.23	0.21	0.22	0.01	3.22
PhCl	58.19	1.64	59.88	42.60	67.13	55.11	62.17	6.54	11.25

SE: standard error of mean; SD: standard deviation; CV: coefficient of variation; SOM: soil organic matter (humus), %; PhCl: physical clay content (soil particles less than 0.01 mm), %; V_5 and V_7 mean the reflectance value of space imagery in SWIR-5 and SWIR-7 band, respectively.

Table 2 Regression summary for dependent variable—soil organic matter (SOM).

Multiple R	Multiple R^2	Adjusted R^2	F	P	SE of estimate
0.82	0.67	0.65	48.28	3.23	0.35

R : coefficient of multiple correlation; R^2 : coefficient of multiple determination; F : F -test of the relationship between the dependent variable and the set in independent variables; P : P -value used to test the hypothesis that the intercept is equal to 0; SE: standard error of mean.

$r = -0.78$. The selection of an approximating function was used during the regression analysis. The mathematical model in Eq. (1) describes the

dependence of humus content on reflectance values in two spectral bands:

$$\text{SOM} = 7.16 - 4.6 \times V_5 - 15.81 \times V_7 \quad (1)$$

This model was statistically significant, according to the parameters shown in Table 2.

The use of this statistical model allowed to build a cartogram of total humus content for the test polygon and to make conclusions about soil conditions of different areas of the agrolandscape.

4. Conclusions

Based on the foregoing, satellite observations data of large territories with contour-meliorative structure provide an objective assessment of their condition and appear to be a reliable informational basis for soil monitoring system. The research results allowed to draw the following conclusions:

(1) Joint use of remote sensing data of different temporal and spatial resolution was proved to be an effective methodical approach for status assessment of a soil-protection agrolandscape.

(2) Spatial modeling of total humus content in the soils of the agrolandscape based on Landsat data allowed determining areas with high erosion risk.

(3) Space imagery data show that on the fields with contour-meliorative territory structure, comparatively wide gullies are located where there are gaps or damaged forest belts. For 25 years of their existence, forest belts were in despair which led to intensive growth of erosion network.

(4) Using periodical satellite imagery data, it is possible not only to assess current status of agrolandscape, but also to forecast their unfavorable change in case of lack of sustaining measures.

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