This paper was peer-reviewed for scientific content.
Pages 217-222. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). 2001. Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Spectral Reflectance as a Tool to Study Soils in Semi-Arid Regions

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ABSTRACT

Remote sensing techniques were applied to study the possibilities of soils identification in the semi-arid environment, belonging to the territory of the Dzhizakskaya steppe of Uzbekistan (the former Soviet Union). Aerial photographs (scale 1:2 000) and multispectral space photographs (scale 1:500 000) were digitally scanned and used for the soil spectral classification. Moistening conditions (relative elevation of the place, ground water depth) and salinization level were the main factors determining the differences of the soil's spectral brightness. Aerial photographs allowed investigator to distinguish soils formed in the semihydromorphic conditions from the automorphic, and hydromorphic soils with the confidence level 0.90. Spectral classification of the color composite of satellite photographs (scale 1: 500 000) allowed the identification of five soil classes: two species of serosems, serosemic-meadow soils, meadow steppe soils, sulfate and gypsum solonchaks with average accuracy about 70%.

INTRODUCTION

Remote sensing methods are based on the measurements of the optical characteristics of the objects, i.e. their spectral reflectability. Each kind of object has its own specific spectral characteristics: type of the spectral curves and different values of the spectral reflectance coefficients in the different bands. These characteristics are determined by the physical-chemical properties of the objects. For soils the most important properties that influence the level of reflectance are: humus content, salinity, moisture, structure of the arable horizon and content of carbonates, ferric hydroxides and gypsum.

Different soils in arid regions vary widely in the chemical characteristics and their reflectance contributes significantly to the overall spectral response from the surface area when vegetation cover is below 25-35% (Vinogradov, 1984, Tueller, 1987). Our previous investigation, carried out in the laboratory, showed that different soil types in the semiarid zone of Uzbekistan have different levels of spectral reflectance. It has been found that the most informative for soil types identification are reflectance coefficients at 750 nm - ρ_{750}. These values measured for air-dried and sieved soil samples significantly correlated with soils composition (humus content, gypsum, iron oxides, water-soluble salts, carbonates) and also allowed to differentiate nine soil types at the local key area of Uzbekistan (Karavanova, 1990, 1991, Orlov, Karavanova, Pankova, 1992). These data let us suggest that remotely measured spectral characteristics also will be capable for soil mapping and studying their properties. Nevertheless i*n nature* soil spectral response is much more complicated and it is governed by inherent soil properties as well as conditions such as surface roughness and field moisture, orientation with respect to sensor, illumination situation, etc. So, the relationships observed in the laboratory conditions may differ from the natural regularities.

The present study aims to assess the possibility of using of aerial- and multi-spectral space photography for the discrimination of soils associations and mapping in semiarid environment.

OBJECTS AND MATERIALS

The area of investigation was the territory of Dzhizakskaya steppe of Uzbekistan (the former Soviet Union), which is located at the southern part of Golodnaya (Hungry) steppe plain. Golodnaya Steppe is a great triangle, comprising more than 1 million ha, and is bounded by the Syr-Daria River, the Turkestan's edge and the Kisil-Koom desert. Geographical coordinates of the area between 68-69º of eastern longitude and 40-41º of northern latitude. Dzhizakskaya steppe occupies the square 300 000 ha to the south from Southern Golodnaya steppe Channel (SGC). The area is located at the proluvial plain of the Turkestan's edge and has a continental subtropical climate, with cold winter and hot dry summer. The amount of annual rainfall is from 150 to 300 mm, most of the precipitation falls in spring and winter. The mean annual temperature is 14º C, summer maximum +43ºC, winter minimum -40º C in January. Soil parent material is represented by the proluvaial deposits removed by the small water streams from the Turkestan's Edge. Also loessy loams are present at the watersheds; paleosoian limestones, sandstones and slates are predominated at the foots of the Turkestan's Edge. The distribution of soil types depends on lithology, relief and ground water level. Soils are classified according to the classification and diagnostics of the soils of USSR (Fridland, 1977). The main soil types are: automorphic serosems, hydromorphic meadow serosemic, meadow, swampy-meadow soils (with different salinity levels) and different species of the solonchaks. Soils of the reclaimed areas are represented mainly by serosemic-meadow soils of the various degrees of salinization. The main field crop is cotton.

For the purpose of investigation a sample area within the territory of Dzhizakskaya steppe, covering approximately 100 ha, was used as a key-site. This territory occupies the southern part of the Lomakinskaya plain. The elevation

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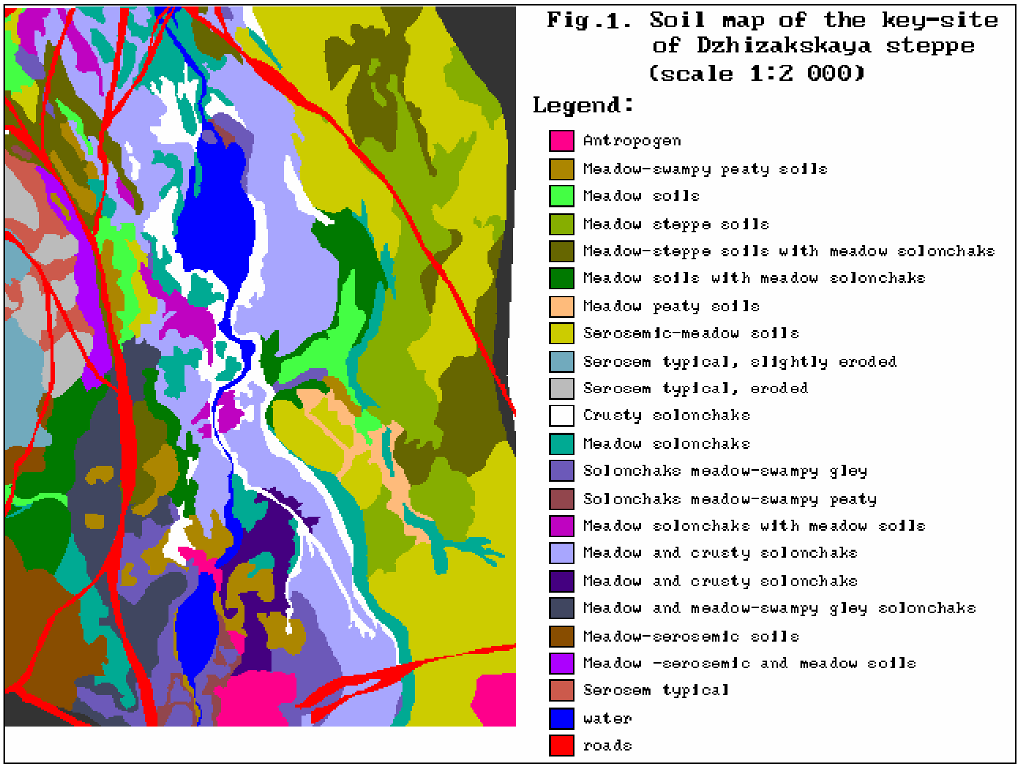

Fig.1. Soil map of the key-site of Dzhizakskaya steppe (scale 1:2 000)

varies from 398 to 410 m above sea level. Ground water level varies from 0.3 to 12 m. Projective power degree vary in average from 20 to 30 % in the study period. Soils are represented by serosems, serosemic-meadow, meadow-serosemic, meadow, swampy-meadow peat soils (with different salinity and gypsum contents) and solonchaks (meadow, swampy-meadow and crust species). Soil samples were collected from the surface (0-3 cm) horizons in September 1987 simultaneously with the aerial survey and soil mapping. Samples were used for the estimation of soils spectral characteristics.

Panchromatic aerial photographs (scale 1:2000) of the sample area (key site) and multispectral space photographs (scale 1: 500000) of the whole territory of Dzhizakskaya steppe were available. Soil map of the key site at scales 1:2000 (fig.1) and soil map of the Dzhizakskaya steppe at scale 1:200 000 (fig.2), developed by the V.V. Dockuchaev Institute of Pedology, were digitized and attribute soil data were entered in the tabular database. The photographs were digitally scanned and converted into a format to be able to work in ILWIS, the Integrated Land and Water Information System, a GIS software package having capability to process remote sensing data.

Soils spectral reflectance curves in the visible part of spectrum were taken in the laboratory at the spectrophotometer SP-18 with the integer sphere (Zyrin, Orlov, 1980). Soil samples before measurements were air-dried, crushed and sieved through the 0.25-mm diameter sieve. Spectral reflectance coefficients at 750 nm ρ_{750} were used as the basic parameters of soil spectral reflectivity (Karavanova, 1990, 1991).

RESULTS AND DISCUSSION

The problem of working with hard copy remote sensing data is gray tone contrast variation in different photographs. In order to have the same gray tone contrast range in the adjacent photographs, histograms were computed from the overlapping parts of the digitized photographs. Because overlapping parts of the two images describe one and the same area, which is represented by one and the same set of objects, the parameters of the both resulting histograms (mean values and standard deviations) should be the same (if all the conditions are similar). Any deviations are assumed to be caused by differences during the development of the film and the printing of the photographs. These differences can be estimated by subtracting one of the overlapping fragments from another and computing of the relevant histogram. Average brightness value of the resulting histogram is one of the characteristics of the given SB-distribution and may be used as a criteria of the differences (Δ) in the gray tone contrast for the given pair of the photographs.

Then, in order to have the same contrast level in all the photographs, calculations were applied as followed: if photograph 1 is lighter than photograph 2 and the difference in brightness is Δ, then corrected photograph 1' = initial photograph 1 - Δ. The corrected photograph 1' has now the similar brightness of objects as in photograph 2. The objects in two photographs are now comparable. Such a procedure was applied in all the scanned aerophotographs. Corrected photographs were then geo-referenced and adjacent photographs were merged.

The geo-referenced, scanned photographs were overlaid on the soil map of the key-site area (fig.1) in order to know the distribution pattern of spectral reflectance values within each soil unit. Histograms were generated in the ILWIS statistics module and confidence limits (CLM) were calculated for each soil type:

$$CLM = M \pm \theta_p \sigma$$

where CLM - confidence limits of the variance, M = $\frac{\Sigma Xi}{n}$ - mean, $\theta_p = t_p \sqrt{\frac{n+1}{n}}$, t_p -Student-distribution coefficient (coefficient described normal distributed values, depends upon n, when n>120 tp=const) $\sigma = \sqrt{\frac{\Sigma(Xi-M)2}{n-1}}$ standard deviation, p - confidence level, n - number of the observations (>120). Confidence limits (CLM) describe those limits of the values variation where any accidental value will be hit on with the certain confidence level. Calculations can be used for the values, which are distributed normally (Student's distribution). Confidence limits of spectral brightness for the different soil types of the investigated area are given in the Table 1. According to these data several combinations of different soil can be separated (Table 2).

In general four soil groups can be delineated. The first group is represented by the semihydromorphic type (serosemic-meadow, meadow steppe and meadow steppe peat soils), which is located at valley sides where ground water table is at a depth of approximately 2 m. These soilsare characterized by the spectral brightness ranging from 154 to 275 and can be significantly (with the confidence level - 0.90) distinguished from the second (automorphic) group of soils consisting of the serosems and meadow-serosemic soils. These automorphic soils are located at the upper parts of slopes and at the tops of the hills where the ground water level is more then 2 m in depth. They have a spectral brightness range of 45 to 154 that is less than semihydromorphic type soils probably because of

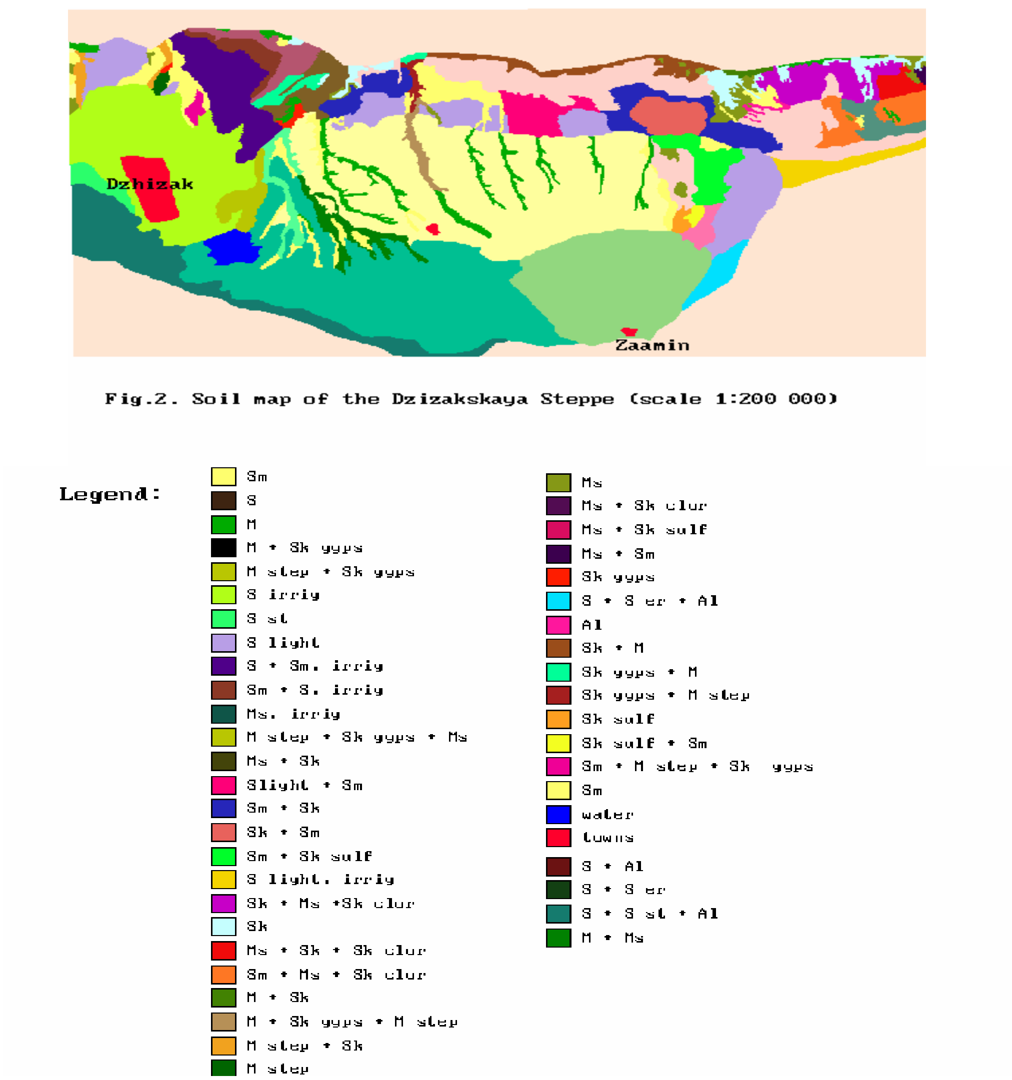

Figure 2. Soil map of the Dzizakskaya Steppe (scale 1:200,000).

Table 1. Mean, standard deviation and confidence limits of the spectral brightness (in DN-values) for different soil types.

Soil	Mean spectral brightness, M	Standard deviation, σ	Confidence limits of M, CLM 1
Automorphic type			
Serosem (S)	93.2	29.5	45-142 55-131
Meadow-serosemic (Sm)	104.6	27.7	51-150 65-144
Semihydromorphic type			
Serosemic-meadow (Ms)	213.2	36.3	154-273 167-260
Meadow steppe (Mst)	217.4	29.5	169-265 180-255
Meadow steppe peaty (Mstp)	232.9	25.8	191-275 200-266
Hydromorphic type			
Meadow swampy peaty (Swp)	78.2	39.5	13-143 28-129
Solonchak meadow swampy gley (Skmsg)	88.4	44.5	15-162 31-145
Solonchak meadow swampy peaty (Skmsp)	95.6	49.6	14-177 32-150
Meadow (M) and their complexes	106.6	37.2	46-168 59-154

[1]Numerator - at CL=0.9, denominator - at CL=0.8)

Table 2 . Statistical significance of the soils spectral brightness differences.

Soil	S	Ms	M	Mst	Mstp	Swp	Skmsg	Sm	Skmsp
S		0.80	-	0.9	0.9	-	-	-	-
Ms	0.80		0.8	0.9	-	0.9	0.8	-	0.8
M	-	0.80		0.9	0.9	-	-	-	-
Mst	0.90	0.90	0.9		-	0.9	0.9	0.9	0.8
Mstp	0.90	-	0.9	-		0.9	0.9	0.9	0.9
Swp	-	0.90	-	0.9	0.9		-	-	-
Skmsg	-	0.80	-	0.9	0.9	-		-	-
Sm	-	-	-	0.9	0.9	-	-		-
Skmsp	-	0.80	-	0.8	0.9	-	-	-	

the erosion processes. The third group of the soils (hydromorphic type) is represented by the dark colored soils rich of organic matter. These soils are typically located at the lowest part of the valley, where the ground water level is less then 2 m (in the most cases less than 1-1.5 m). This group includes from the one-hand meadow swampy peaty soils with the different level of salinity (including solonchaks). Salinization processes are accompanied by the processes of gley and peat formation and such soils have a lower spectral brightness range. On the other hand, this group of soils contained less dark meadow soils (with different degree of salinity) and their complexes with meadow solonchaks, that have the spectral brightness varying in the wide range. Most of the hydromorphic soils can be distinguished from the semihydromorphic soils (with CL=0.9 or 0.8).

In comparing the variation of soils spectral brightness estimated from air photographs spectral response with the variation parameters received in the lab (Karavanova, 1990) for the same soils in the standard conditions (air dried, crushed and sieved samples) one can comes to the conclusion that in nature soils have greater variation of their spectral reflectance. So the diagnostics of the individual genetical types of soils by using air photographs in many cases becomes impossible. In nature spectral brightness parameters of the investigated soils depend first of all on the water regime (and therefore - upon the relative elevation of their location). In arid and semiarid regions soils water regime is of a greatest importance for the formation of the properties of the soils: salts, gypsum and organic matter contents depend on the water regime (water dynamics, accessibility etc.). Spectral differences between the semihydromorphic group of soils (at the slopes of the valley) and automorphic serosem soils can be caused also by the erosion processes and humus losses from the soils at the slopes, as was mentioned before. Remotely measured values of the spectral reflectance, expressed as a phototone density of the panchromatic aerophotographs allow the identification of the semihydromorphic soils from automorphic and hydromorphic (with the confidence level 0.90 and 0.8). As far as soils of the last two groups have the overlaid ranges of the spectral brightness, topography-map and map of the ground water level should be taken to the account at classification. At the investigated area the elevation varies from 398 to 410 m above sea level, and ground water level (measured in spring, 1987) varies from 0.3 to 12 m. Soils of the automorphic group are located at the elevation higher than 400 m where ground water level was lower than 2 m (in the most of the studied soil profiles - more than 5 m); hydromorphic soils occupies lower elevation positions with ground water level 0.3-2 m. Thus, the elevation and ground water level allow the identification between automorphic and hydromorphic soils

The results received for the key-site, have been checked out for the whole territory of the Dzhizakskaya steppe (for non-reclaimed area) -square near 300 000 ha. This area was represented at the multispectral space photographs, scale 1: 500 000 (fig.3). According to the soil map (scale 1:200 000), soil cover of the Dzhizakskaya steppe are characterized by the great complexity, it is represented by more than 10 soil types and more than 30 variants of their combinations. All these soils at the previously digitized soil map were combined into 6 groups:

1. Serosemic soils,
2. Complexes of the meadow-serosemic soil and solonchaks,
3. Complexes of the meadow soils with solonchaks,
4. Sulfate solonchaks,
5. Chloride and sulfate-chloride solonchaks (and their complexes with meadow and serosemic-meadow soils).

Then this “generalized ”soil map has been overlaid with the images, and values of spectral brightness corresponding to the different soil groups were calculated (Table 3).

The values of the soils spectral brightness in the near infrared and - especially - red bands are characterized by a greater variation as compared with the green band (in the red band standard deviation within one soil type and even within groups of soils (mentioned before) - is 35-60%), so the photographs in the green band were used for the soils identification (table 3). According to Table 3, only sulfate and gypsum solonchaks can be easily distinguished from the serosems (with the confidence level 0.80, i.e. in 80% occasions from 100). Also sulfate and gypsum solonchaks differ from complexes of the meadow soils with solonchaks , and serosems can be separated from the complexes of serosemic- meadow soils with solonchaks — both with the confidence level 0.7.

Spectral classifications have been done for a color composite (made from the photographs in the green, red and infrared bands) of the whole investigated area, excluding reclaimed lands, which have been separated by using green vegetation index map (constructed in ILWIS.). In the classification, the nearest neighborhood alghoritm (threshold 25) and 1-time post classification smoothing (majority filter) had been applied.

- Final map contained 6 classes:
- meadow steppe soils,
- serosemic-meadow soils,
- typical serosems,
- serosems with alluvial deposits,
- solonchaks sulfate and gypsum,
- green vegetation.

To check out the results of the classification we compared them with the soil map (scale 1:200 000); final conclusions can be made only after the additional examination in the field. It was revealed that for the area

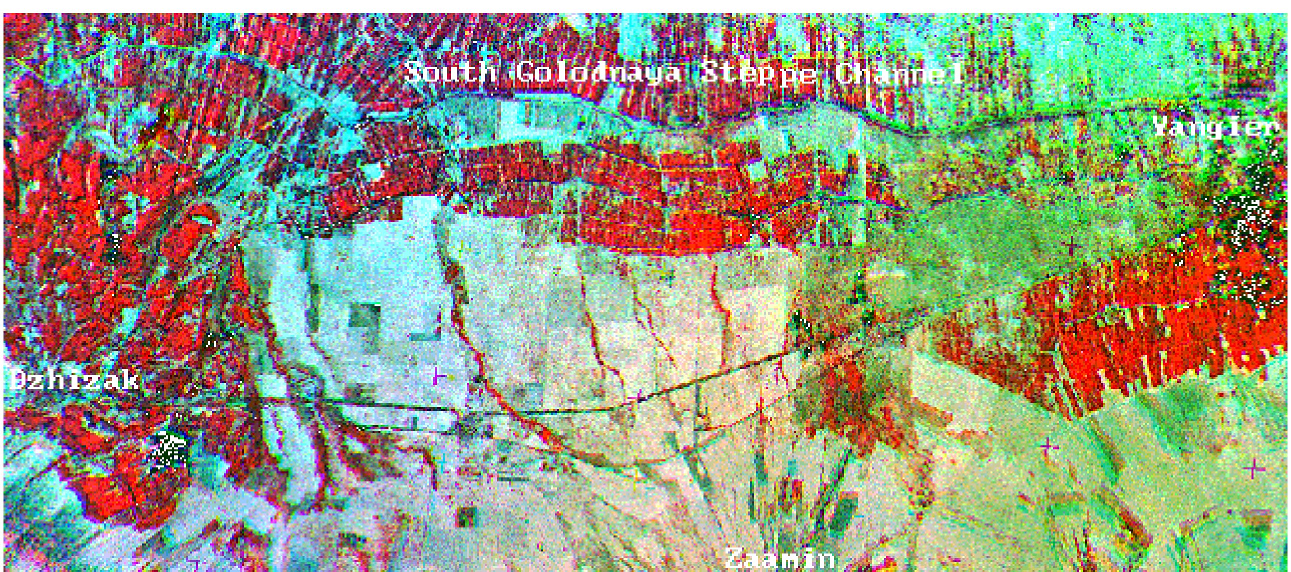

Figure 3. False color composite of the Dzhizakskaya Steppe.

Table 3. The values of spectral brightness of the satellite images (green band) for different soil groups.

Soil groups	Mean spectral brightness, M	Standard deviation of the spectral brightness within group, σ	Confidence limits, CLM
Serosem	144.2	22.0	116-172.4* 122.2-166.2**
Meadow-serosemic +solonchaks	101.2	37.0	53.8-148.6 64.2-138.2
Serosemic-meadow + solonchaks	87.0	28.9	50.0-124.0 58.1-115.9
Meadow + solonchaks	122.8	41.7	70.5-177.3 81.1-164.5
Solonchaks sulphate and gypsum	65.5	15.6	45.9-85.9 50.3-81.1
Solonchaks sulphate-chloride and chloride	106.8	37.1	59.3-154.3 69.7-143.9

*-numerator - at the confidence level 0.8; **- at the confidence level -0.7

represented (according to the soil map) by the typical serosems 69,9% of all the pixels at the classified map also are represented by typical serosem and 13.4% - by the serosems with alluvial deposits. Thus the accuracy of the classification for this type of soils is near 83.3%. Serosemic-meadow, meadow-steppe soils and solonchaks also are present at this territory (17.7%), but that is quite possible, because of the great complexity of the soil cover at the investigated area, which can not be completely represented at the map of 1:200 000 scale. Sulfate solonchaks and their complexes with meadow-serosemic soils are classified correctly in 73.4% cases; gypsum solonchaks and their complexes with meadow and meadow steppe soils in 65.7% cases. These preliminary results allow us to conclude that differences in the spectral reflectance of these soils (with different hydromorphic extent and salinity) are sufficient for the spectral classification with the average accuracy near 70%).

CONCLUSIONS

1. In the arid environment differences in the soils salinity and hydromorphic level provide the most significant differences in their spectral reflectance.
2. Semihydromorphic soils can be distinguished from the soils of hydromorphic and automorphic type by their spectral brightness, expressed in the values of phototone density on the black-and-white panchromatic aerophotographs (scale 1:2000) with the accuracy near 90% (confidence level CL=0.9). The demarcation between two last groups can be made by using the relative elevation of the place and the ground water level, so these factors must be taken to the account, as an obligatory components of the geographic informational system.
3. Satellite photos (scale 1: 500 000) in the green band allow to separate sulfate and gypsum solonchaks from the serosems with the confidence level 0.80; sulfate and gypsum solonchaks can be distinguished from complexes of the meadow soils with solonchaks. and serosems - from the complexes of serosemic- meadow soils plus solonchaks with the confidence level 0.7.
4. Spectral classification of the color composite of satellite photographs in the green, red and near-infrared bands allows to distinguish two species of serosems, serosemic-meadow soils, meadow steppe soils, sulfate and gypsum solonchaks with the average accuracy near 70%.

ACKNOWLEDGMENT

This investigation was financed by the Dutch scientific organization (NWO) and Russian Foundation for Basic Researches (RFBR) - project N 00-15-97856 - for which the author is very grateful. Author also is very grateful to Dr. E.I. Pankova and Dr. D.A. Soloviev for their kind attitude, help during the fieldwork and assistance in providing with the necessary cartographic material.

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