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Spectral Reflectivity as a Diagnostic Criteria of the Degree of Erosion of the Gray Forest Soils

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ABSTRACT

Spectral reflectivity of the eroded gray forest soils of the Central Russian Upland was studied. The following basic quantitative parameters were taken from the spectral curves: reflection coefficient at 750 nm - ρ_{750}, the angle of spectral curves $tan\alpha = \frac{\rho 750 - \rho 400}{750 - 400}$ and the magnitude of the bend $\Delta\rho = \rho_{620} - \rho_{470}$ It was found that upper soils horizons of the no eroded soils differ noticeably from the lower horizons which is caused by the differences in their composition (humus and nonsilicate iron compounds contents). As the result of erosion, originally lower soil horizons are exposed at the current surface and it is followed by the distinct change of the surface spectral parameters. The analysis of the variation ranges for the spectral indexes shows that both slightly and moderately eroded soils differ from noneroded soils by the ρ_{750}, tan α and Δρ values with a probability 0.95. The 60% mass share of the BE horizon to the composition of plow layer is a threshold limit under which all the spectral indexes (first of all the Δρ) are noticeably changed, and the soil should be classified as eroded.

INTRODUCTION

Soil erosion presents the greatest problem for cultivation in the forest-steppe zone. The erosion of gray forest soils with their relatively thin humus profile results in the appearance at the surface and involvement into the plow layer of deeper soil horizons often depleted of organic matter and having unfavorable physical properties.

The main methods for estimating the degree of erosion are based on morphological characteristics and information on the humus content in a soil profile (Zaslavskii, 1979, Classification and diagnostics of soils of USSR, 1977). For a more objective and quantitative estimation of the degree of erosion, some additional methods can be used. In particular, the spectral reflectance coefficients of (SRC) of electromagnetic oscillations by soils are suggested to be used as diagnostic indices (Lopuchina, 1983, Orlova, Fless, 1994, Shurikova, Makarova, 1981). Such an approach can be advised mainly for diagnosing the degree of erosion of the soils with a differentiated spectral profile, i.e., when the indices of spectral reflectivity (SR) of genetic horizons differ quantitatively.

OBJECTS AND MATERIAL

The possibility of using some quantitative spectral reflectivity indices (Orlov et al., 1995) of gray forest soils for the estimation of their erosion degree was studied taking the example of the gray forest soils of Yasnogorsk district, Tula region. The territory examined belongs to the Central Russian Upland and is characterized by well-manifested erosional relief. The slopes have slightly convex profiles; inclinations in the lower part of the slopes can reach 5°-6°, though the predominant gradients do not exceed 3°. Various signs of surface erosion are seen on the slopes.

The soil cover has been subjected to prolonged agrogenic impact (it has been plowed for more than four hundred years). The soil cover structure is characterized by slightly contrasting combinations of clay loamy gray and dark gray forest soils of various thickness, slightly and moderately eroded gray forest soils with the minor participation of gleyic modifications.

The SR of gray forest soils was determined in the samples of soil genetic horizons from four soil pits (23 samples); in addition, we analyzed more than 80 samples from surface horizons to study the ranges of natural variation in the reflection coefficients. Spectrums of reflection were plotted and basic quantitative parameters of reflectivity, developed by D.S. Orlov (Orlov et al., 1995) were calculated in order to estimate the optical features of the soil. In a number of samples, for detecting the influence of the main soil pigments on the reflection coefficients, the content of amorphous and crystallized forms of nonsilicate iron compounds was determined by the atomic adsorption method, and the gas analyzer AN7529 determined the content of organic carbon.

RESULTS AND DISCUSSION

The reflective spectra of surface soil horizons are represented by typical smooth curves that gradually rise from the short-wave part of the spectrum (400 nm) to the long-wave one (750 nm). The reflection coefficients reach 15-20% in the 400 nm part (ρ_{400}) and 30-35% in the 750 nm one (ρ_{750}). The lower horizons are characterized by spectrums typical for ferruginous horizons with a greater reflection capacity (ρ_{750} 40-60%) and a rather distinct bend in the area of 470-620 nm wavelengths (the $\Delta\rho = \rho_{620} - \rho_{470}$ reach 23%).

The noticeable differentiation of spectral curves is

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caused by the distinctions in the composition of soils and individual horizons (Table 1). Changes in the spectral reflectance coefficients along the soil profile correlate with the distribution of iron compounds and humus in the soil. The reflection capacity (ρ_{750}), the angle of spectral curves ($\tan\alpha = \frac{\rho 750 - \rho 400}{750 - 400}$), and the magnitude of the bend ($\Delta\rho$) increase with the depth of soil horizons.

The reflection capacity and specifics of the spectra obtained from the surface horizons of gray forest soils depend on the degree of erosion and are conditioned by the content of humus. The ρ_{750} values directly correlate with the humus content (the correlation coefficient of the linearized relationship for a sample n = 135 is equal to 0.72 with 0.999 probability). The relationship has an exponential character and can be described by the equation:

$$\rho_{750} = \rho_{750,\,min} + A\ e^{-kH},$$

where $\rho_{750,\,min}$ = 30.0 is the reflection coefficient ρ_{750} of the soil with the maximum humus content (this value was empirically determined using the plot); A=34.8 and k = 0.92 are the regression coefficients; H is humus content in percent. The $\rho_{750,o}=\rho_{750,min}+A$=64.8%, which approximately corresponds to the spectral reflectivity of soil-forming rocks of the region (for a sample from the C horizon, the value of ρ_{750} equals 61 %).

Spectral reflectivity of lower soils horizons is mainly dictated by the presence of iron compounds. We have studied the relationships between the content of various compounds of nonsilicate iron and the character of a bend on spectral curves of soil reflection. The absolute value of the bend $\Delta\rho$, the length of the half-bend wave $\lambda_{1/2}$, and the bend height h (Orlov et al., 1995) were used as bend characteristics. Calculations have shown that the correlation coefficients of the relationship between the total content of nonsilicate iron (Fe ns) and all three bend indices have a tendency to be linear and are characterized by the certain correlation coefficients r = +0.60 (P = 0.999, n = 26), r = +0.43 (P = 0.95. n = 26), and r = +0.56 (P = 0.99, n = 22), respectively.. The relationship between the Fe ns content and a bend location on spectral curves of soils $\lambda_{1/2}$, points out that the increase in iron content is accompanied not only by a more distinct bend, but also by the shift of this bend toward the longer-wave diapason. In order to reveal more distinct correlation between iron content and soils spectral reflectivity the differences in humus content in the examined soil samples should be taken to the account. For this purpose the ratios Fe ns/ humus was calculated for each soil sample. As a result, a close correlation (r = +0.89 (for the linearized relation), P=0.999, n=25) between these ratios and $\Delta\rho$ values was obtained:

$$\Delta\rho = \Delta\rho_{max} - A\ e^{-k\,(Fe\ ns/H)}$$

where $\Delta\rho_{max}$ =24.5 is the $\Delta\rho$ value of the bend in the spectrum for the soil with the maximum content of Fe_{ns} per unit of humus content; A=15.9 and k= 0.9 are the regression coefficients.

All these data testify that humus and non-silicate iron compounds have a statistically significant effect on the reflection coefficients of genetic horizons of gray forest

Table 1. Content of humus and iron compounds and some characteristics of spectral reflectivity of the gray forest soils.

Pit no.	Horizon	Depth cm	Humus %	Iron compounds, % Nonsilicate	amor-phous	crystallized	Reflection indices ρ_{750}, %	tan α*, %/µm	$\Lambda_{1/2}$, nm	Δρ, %
4-95	Ap	0-10	2.86	0.64	0.15	0.49	32.4	50.3	nd**.	8.0
		10-20	2.24	0.60	0.14	0.46	33.0	51.4	-”-	8.5
	Ah	22-32	2.86	0.66	0.12	0.54	32.4	52.0	-”-	8.0
	EB	35-45	0.96	0.74	0.12	0.62	39.5	70.0	541	12.5
	B_t1	55-65	0.51	0.75	0.11	0.64	49.0	93.7	540	19.5
	B_t2	80-90	0.46	0.77	0.10	0.67	49.5	94.3	539	19.5
	BC	105-115	0.24	0.43	0.07	0.28	51.0	97.1	537	21.0
3-95. Plowland under	Ap	0-26	2.27	0.53	0.17	0.36	37.0	47.0	nd	7.0
	A1EB	26-52	2.00	0.57	0.13	0.44	37.0	50.0	540	8.1
	B_t1	52-70	0.60	0.75	0.11	0.64	51.0	88.6	544	18.0
	B_t2	70-95	0.56	0.80	0.11	0.69	55.2	97.7	544	20.6
50-95. Plowland under	Ap	0-29	2.72	0.57	0.15	0.42	36.0	54.0	nd	8.7
	A1E	29-32	2.24	0.62	0.16	0.46	40.0	62.9	nd	9.0
	EB	32-57	1.67	0.61	0.10	0.51	33.5	50.9	540	8.2
	B_t1	57-66	0.80	0.69	0.10	0.59	48.4	88.3	544	17.0
	B_t2	66-80	0.45	0.70	0.10	0.60	53.9	99.2	541	21.7
1-95. Forest	Al	0-6	6.62	0.64	0.15	0.49	41.7	62.0	nd	9.5
	A1E	6-16	1.81	0.60	0.14	0.46	54.0	84.6	532	14.2
	Ah	25-35	2.08	0.66	0.12	0.54	37.7	54.6	544	8.0
	Bh	45-55	1.51	0.74	0.12	0.62	43.8	72.0	545	11.9
	B_t1	65-75	0.52	0.75	0.11	0.64	57.5	95.7	544	22.0
	B_t2	90-100	0.39	0.77	0.10	0.67	61.0	97.3	543	23.5
	BC	103-112	0.21	0.43	0.07	0.28	57.1	95.1	543	21.9

*While calculating the tan α values, we expressed the $\lambda_2 - \lambda_1$ difference in micrometers in order to match it with the ρ_{750} values

** nd - is not determined.

soils. The fact that soil erosion leads to the involvement of All these data testify that humus and non-silicate iron compounds have a statistically significant effect on the reflection coefficients of genetic horizons of gray forest soils. The fact that soil erosion leads to the involvement of lower iron-rich horizons in the surface layer allows us to assume that the corresponding changes in the character of reflective capacity can be used as diagnostic indices of the degree of erosion. In our study, we tried to use the ρ_{750}, tan α, and Δρ indices for estimating the degree of erosion of gray forest soils.

The set of soil samples included non-eroded, slightly eroded, and moderately eroded soils distinguished on the basis of traditional approaches (Zaslavskii, 1979, Classification and diagnostics of soils of USSR, 1977) with due account for the specifics of the region. The morphological diagnostics of eroded gray forest soils is based on the analysis of a soil profile and thickness of the horizons. The non-eroded full-profile gray forest soil is composed of the following horizons: Al-AlE-(Ah)-EB (BE)-B_t-BC-C. The eroded soils have profiles in which one or several horizons are missing from this typical sequence. In our case, the lower boundary of the plow horizon ranged from 17 to 34 cm. Depending on the initial variation in the thickness of genetic horizons and the depth of plowing, the plow horizon can be composed of the A1, A1E (or Ah), and the upper part of the BE (EB) horizons, i.e., the sub plow layer of non-eroded soil should be represented by one of these horizons. In slightly eroded soils, the plow horizon can also be underlain by the BE horizon. However, when the B-horizon underlies the plow horizon, the soil is referred to as moderately erode. The criteria for the separation of non-eroded and slightly eroded gray forest soils are rather vague; therefore, in this study we used the earlier suggested statistical criterion (Sorokina, 1966). The statistical distribution of the total thickness of humus horizons (including the BE horizon, whose lower boundary corresponds to the mean humus content of 1%) was analyzed in the sample that included over 100 soil profiles described during the large-scale soil survey. It was found that slightly eroded and non-eroded soils may have partially intersecting intervals of the total thickness of the humus layer within the range of 34-40 cm; the most probable boundary between them can be set at the interval of 36-38 cm.

The possibility of diagnosing the degree of soil erosion by the character of the surface horizon is based on correlative relationships between the humus profile thickness, the humus content, and the color of the plow horizon. There is a direct relationship ($r = 0.68$) between the humus content in the plow horizon and the depth of the upper boundary of the Bt horizon. The most identifiable are the moderately eroded soils in which the upper boundary of the Bt horizon coincides with the lower boundary of the plow horizon at a depth of 28 cm. A humus content in the plow horizon of these soils is always below 2.2% (2.0 ± 0.2, coefficient of variation V = 16%). A humus content above 2.8% can only be observed in the Ap horizon of non-eroded soils in which the depth of the Bt horizon exceeds 40 cm.

At the same time, there is no unambiguous correspondence between the humus content in the plow Ap horizon and the total thickness of the humus profile. The humus content in the plow horizons of non-eroded soils constitutes 2.8 ± 0.8 *(V*= 27%); in slightly eroded soils, it is somewhat lower (2.3 ±0.4, V = 16%); however, a considerable overlap is observed. This means that the humus content in slightly eroded soils can be the same as in the non-eroded ones. Indeed, when the thickness of the humus layer reaches 30-60 cm, the humus content in the plow horizon varies from 2.2 to 2.8% in both slightly eroded and non-eroded soils. Wide ranges of variation in humus content in the surface horizon of differently eroded soils are caused not only by the impact of erosion, but also by some other factors, e.g., the initial spatial variation and the differences in the degree of de-humification. Therefore, it is sometimes difficult to judge the degree of soil erosion based on purely morphological criteria. Often, we need some additional diagnostic indices, including those that can be provided by the study of soil reflection capacity.

The analysis of variation ranges for spectral parameters ρ_{750}, tan α, and Δρ (Table 2) shows that reflection coefficients for differently eroded soils are less variable than the content of humus in these soils. Similar data were earlier obtained for many other zonal soil types. Thus, the soil reflection indices are more stable than the humus content and are more informative than the latter ones for diagnosing the degree of soil erosion. From the data given in Table 2, it is seen that both slightly and moderately eroded soils differ from non-eroded soils by the ρ_{750}, tan α, and Δρ with a probability of 0.95. However, the confidence intervals of reflection coefficients for slightly and moderately eroded soil overlap. The relatively wide variation in the reflection capacity of eroded soils is caused, among other reasons, by the different degree of involvement of the lower soil horizons in the plow layer. According to the literature (Shurikova, Makarova, 1981), the hhomogeneity of the plow layer mainly composed of one genetic horizon (the humus-accumulative or the alluvial one) ensures the possibility of using the reflection indices for diagnosing non-eroded or strongly eroded soils, respectively.

The effect of the involvement of lower horizons in the plow layer on the spectral characteristics of the latter was proved by the model experiment. We used mixed samples with different mass ratios of genetic horizons to simulate various degrees of erosion and studied the reflection of light from these samples. The most notable changes in spectral characteristics arise from the involvement of the BE horizon in the plow layer. When the mass of the material from this horizon reaches 40% of the mass of the mixed sample, the bend on the spectral curve is manifested in the area of 470-620 nm; the Δρ value increases by 2-3.5% and reaches 9-9.5%; the tan α increases by 5%. With the further increase in the share of the BE material by every 20%, the tan α values increase by 3-6%. The increase in the ρ_{750} values is not so pronounced, and equals 4-5% when the share of the BE material in the mixed sample reaches 60%. Thus, the 60% mass contribution of the BE horizon to the composition of the plow layer can be considered the threshold limit under which all the spectral indices considerably change. The brown coloring of the soil surface that is visually observed in the field and serves as one of the morphological indications of the degree of erosion of gray forest soils also appears at this threshold.

The analysis of quantitative characteristics of soil spectral reflectivity and their relationships with the diagnostic properties of the soils studied allows us to suggest additional criteria for soil diagnostics. Let us consider a diagnostically controversial group of soils with the humus horizon of 34-40 cm and the humus content of 1.8-2.8%. According to traditional criteria, these soils can be attributed to the groups of both eroded and non-eroded soils.

The $\Delta\rho$ index for the plow horizon of these soils varies from 7 to 12. It is reasonable to suggest that if a decrease in humus content (below 2.5%) is accompanied by relatively high $\Delta\rho$ (>9.5%), then we are dealing with the involvement of the BE horizon in the plow layer, i.e., the soil should be referred to the slightly eroded group. If the same decrease in humus content is accompanied by low Ap values $\Delta\rho \leq 8.5$), then it cannot be caused by the involvement of the BE horizon in the plow layer, but by the processes of de-humification. The thicker the humus profile and the lower the humus content in the plow horizon, the more probable the latter interpretation. For example, the Ap horizon in one of the soil pits contained just 1.9% of humus, though the total thickness of the humus layer reached 44 cm; the $\Delta\rho$ value for this horizon was equal to 7.5. In this case, we can definitely state that the low humus content in the Ap was not due to erosion, but due to de-humification. In a similar way, we can distinguish between strongly eroded and non-eroded, but initially shallow soils. The latter ones are characterized by a relatively high humus content in the Ap horizon (>2.5%), low $\Delta\rho$ values (about 8). and a total thickness of the humus layer of about 30-36 cm. Thus, the use of spectral characteristics in diagnosing eroded gray forest soils can increase the validity of our judgments While calculating the tan α values, we expressed the λ_1-λ_2 difference in micrometers in order to match it with the ρ_{750} values.

CONCLUSIONS

1. Spectral reflectivity of the gray forest soils of Tula oblast are controlled by humus and nonsilicate iron compounds contents.
2. The limits of natural variation in the spectral reflectance of soils make it possible to separate non-eroded soils from the slightly and moderately eroded ones judging by ρ_{750}, tan α, and $\Delta\rho$ indices.
3. Values of $\Delta\rho$ may be used as additional criteria for discrimination between erosion and dehumification as well as between slightly eroded and noneroded but initially shallow soils.

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Table 2. Characterization of spectral reflectivity of surface horizons of gray forest soils with different degrees of erosion.

Degree of erosion	n	Mean M, %	Standard deviation S	Variation coefficient V, %	Confidence limits of the mean (P=0.95)
For the ρ_{750} value, %					
Noneroded	30	34.6	3.0	8.7	33.5-35.7
Slightly eroded	26	37.8	4.8	12.7	35.9-39.7
Moderately	17	41.2	6.1	14.8	38.1-44.3
For the tan α * value %/µm					
Noneroded	30	52.6	5.9	11.3	50.4 - 54.8
Slightly eroded	26	59.8	9.8	16.3	55.8-63.8
Moderately eroded	17	66.5	12.4	18.7	60.0-72.9
For the $\Delta\rho$ value, %					
Noneroded	30	8.4	1.3	15.9	7.9-8.9
Slightly eroded	26	9.8	2.1	21.1	9.0-10.7
Moderately eroded	17	11.2	2.7	24.1	9.8-12.6