SOIL SCIENCE ANNUAL
2022, 73(1), 147483

https://doi.org/10.37501/soilsa/147483

Features and assessment of decolorization of chernozems of Ukraine

Yaroslav Vitvitskyi[1]*, Volodymyr Haskevych[1], Stepan Pozniak[1], Ihor Kasiianyk[2]

[1] Ivan Franko National University of Lviv, Faculty of Geography, Department of Pedology and Geography of Soil, 41 Doroshenka St., Lviv, 79000, Ukraine

[2] Ivan Ohiienko National University of Kamianets-Podilskyi, Faculty of Natural Sciences and Economics, Department of Geography and Methods of Teaching, 14 Tatarska St., Kamianets-Podilskyi, 32302, Ukraine

* PhD students, Yaroslav Vitvitskyi, vitvickijaroslav690@gmail.com, ORCID iD: https://orcid.org/0000-0003-0530-644X

Received: 2021-12-29
Accepted: 2022-03-19
Published online: 2022-03-19
Associated editor: C. Kabała

Key words:

Soil color
Colorimetry
Decolorization
Erosional degradation
Typical chernozem

Abstract

The article presents the results of colorimetry and practical study of the processes of decolorization of chernozems by using a scanner as one of the effective and available methods for assessing soil color at the macromorphological level. The influence of moisture on the objectivity of the color parameters of typical chernozem samples in the color space of the CIE L*a*b* system is experimentally analyzed. Based on the parameters of brightness (L*), red (a*) and yellow (b*) color components, the color differences of typical chernozems of arable land and adjacent forest belts were established, and the horizontal color heterogeneity of the arable horizon of plain and slope areas was determined. The results of the study indicate that chernozems undergo an intense change in the natural color on slopes with a steepness of ≥ 4%. In soil samples, an increase in the range of the chromatic index b* indicates a low humus content and an increase in the role of loess loams in the pigmentation of the arable horizon. Compared to arable land, soil samples of typical chernozem taken under forest belts are characterized by low brightness (L*) and high levels of humus. The obtained results show the possibility of using this approach to assess the quality state of chernozems. In addition, a direct study of the color of chernozems will allow obtaining data regardless of weather conditions, the presence of vegetation, and soil cultivation technology. The minimized influence of the external environment on the process of fixing the color parameters of the soil will contribute to the objectivity of information, which can later be used as an addition to the results of remote sensing. The formation of a digital database of color data will allow localizing areas of manifestation of decolorization of chernozems and assessing the risks associated with the soil management system.

1. Introduction

Color is not a random feature, but a fundamental characteristic that reflects the quality state of the soil and is an identifying characteristic of soil horizons (Brown and O`Neal, 1923; Mieczyński, 1931). Many popular names of soils used in scientific classifications are formed precisely on the basis of color characteristics (Pozniak and Havrysh, 2019). Chernozems, famous for their agricultural potential, are a classic example. Historically, a stable stereotype of the identification of chernozems has long been formed in society, represented by a peculiar set of characteristics and properties: dark soil color→fertility→ chernozem. In scientific publications (Krupenikov, 1978), there is a symbolic comparison of the image of chernozems with the appearance of a crow's wing and an arabian horse, which emphasizes the aesthetic uniqueness of the color characteristics of these soils.

It is the typical chernozems that are the standard of biospheric fertility and the model of the image of chernozems. In the virgin state, the high humus content at the macromorphological level homogenizes and masks any color differences in the humus-accumulative horizon, and only with depth is a gradual change in color characteristics observed. The uniqueness of the reference color of chernozems at the landscape level is the result of long-term pedogenesis under meadow-steppe vegetation (Dokuchaev, 1949) with highly favorable conditions for the accumulation of organic matter.

Under the conditions of agricultural development, chernozems experienced almost the greatest anthropogenic pressure (Kravchenko, 2020). The modern landscape image of virgin areas has been replaced by spatially organized agricultural land with clear contour forms and a system of forest shelterbelts, which plays an important role in maintaining the quality state and fertility of the soil (Krupenikov, 2008; Novykh and Chendev, 2014). In addition, strip forest plantations affect the distribution of precipitation and heat, improve agronomic performance, and contribute to the accumulation of organic matter in the adjacent areas of arable land (Pardon et al., 2017).

The evolutionary chain of soil genesis under cultivated and silvicultural vegetation leads to spatial differences at the macromorphological level, which is also reflected in the color characteristics of the soil (Gorban et al., 2019). With the agrogenic transformation of chernozems, the dark color of the open surface is a key factor affecting microclimatic features, the course of photochemical reactions (Karavanova, 2003) and the biological activity of soils in general. The transformation of soil regimes, the formation of atypical technological horizons, and degradation processes led to evolutionary changes in the natural appearance (Nosko, 2006), among which black color plays a peculiar role of a physical indicator in reflecting the quality state of chernozems (Krupenikov, 2008). The change in tonality and the formation of variegated coloration of the arable layer indicate horizontal heterogeneity of soil formation, which is the result of irrational soil management (Haskevych, 2017).

Under the secondary forest areas of chernozems, which were previously cultivated, the ecology of soil genesis is changing (Pankova, 2020). The composition of the stand, the formation of an uncharacteristic layer of forest litter, and the transformation of soil regimes against the background of plowed areas determine spatial morphological differences. Visually, this is noticeable in the former areas of forest belts, which are illegally plowed up. Under conditions of post-agrogenic soil management, the color of the upper horizon of chernozems under forest belts does not directly affect physiological processes, but it is an important morphological indicator of the content of organic matter, the course of physiological processes, and soil degradation.

In the system of soil research, the issue of anthropogenesis of chernozems has been explored in sufficient detail, while the features of the transformation of color characteristics require further study. These studies are relevant and necessary, since soil color is a kind of mirror reflection of genetic relationships with other properties (Gunal, 2008) and morphological traits. In addition, the formation of a digital database of color parameters will make it possible to quickly assess the ecological stability of the soil under the influence of various stressors, identify the areas of active color transformations, and effectively diagnose the reproduction and rehabilitation of soils in a crisis state. The results of a specific study of the color characteristics of chernozems complement the remote sensing data. Due to the fact that the humus-accumulative horizon of chernozems is the most sensitive to the impact of the external environment and most actively undergoes the transformation of natural morphological features, the data of quantitative monitoring of color parameters will make it possible to form a clear system of risks and individually determine the "harmfulness" limit of existing soil management technologies. As world practice shows, the data are widely used for the needs of precision farming, the introduction of agroforestry technologies and an adaptive landscape-ecological system of farming, as promising areas of rational soil management in the fight against climate change. In addition, a clear and accessible methodology for assessing color characteristics will quickly determine the quality state of the soil cover, especially at the level of assessment of agricultural land of both large and small farms.

The aim of the research is to determine the influence of the anthropogenic factor on the transformation of the color characteristics of chernozems as the most productive soils for agriculture and to identify degradation processes.

2. Materials and methods

The study of the color characteristics of chernozems was carried out on the experimental sites "Ruda" (Rd) and "Basivka" (Bs) laid within the Prydnisterska upland. The structure of the experimental sites includes arable land and areas of adjacent forest belts (Fig. 1). The relief is of the same type, represented by upland soils with adjacent slopes. Experimental sites are a classic example of agrocenoses inherent in plowed areas of chernozems.

Soil sections are laid out in the form of a catena (Table 1). To determine the transformation of the color characteristics of chernozems under the influence of agrogenic degradation, samples were taken on arable land and under the adjacent forest belts. The tree stand of forest belts is represented by strip plantations of common oak (*Quercus robur L.*), aged 55–60 years.

The selection of soil samples was carried out in the last third of october.

Under laboratory conditions, pre-dried samples were ground and sieved through a sieve with a hole diameter of 1 mm. In glass boxes, soil samples were moistened to a paste-like state, mixed to obtain a homogeneous mass, which was filled into a plastic cup with a diameter of 30 mm (depth 10 mm). In beakers, the samples were dried to an air-dry state. Before being placed on the scanner glass, some of the samples were moistened to maximum saturation. This made it possible to obtain colorimetric data from dry and wet samples in a single scan (Kirillova et al., 2017).

Colorimetric analysis of the solid phase of soil samples was carried out on the basis of scanning. An office scanner (CanoScan LiDE 70) was used to unify the process of graphic reproduction and reduce the influence of external light sources with contact image sensor CIS (Contact Image Sensor) and light source 3-color (RGB) LED.

Scanning process control is implemented based on CanoScan Toolbox 5.0.1.2a. in color mode with an optical resolution of 300 dpi. The color correction of the obtained images was performed in the target mode sRGB IEC61966-2.1. To determine the average RGB values, digital images were processed in the Irfan View graphic editor (Kirillova et al., 2018). This made it possible to obtain the initial quantitative data on the gradations of the RGB channels, which were later converted to the CIE (Internacionale Commission de l`éclairage) L*a*b* color system. The conversion of quantitative data from RGB to L*a*b* was carried out using the algorithm (Kirillova, 2018) available in the public domain in format (.xls). Determination of the color difference index ΔE_{2000} was carried out on the basis of the algorithm (Sharma et al., 2005) available in the public domain in format (.xls). The obtained parameters data L*, a* and b* were entered into corresponding cells, the calculations of the final results were carried out automatically.

In studies of the color characteristics of chernozems, the CIE L*a*b* system is convenient because the value of the achro-

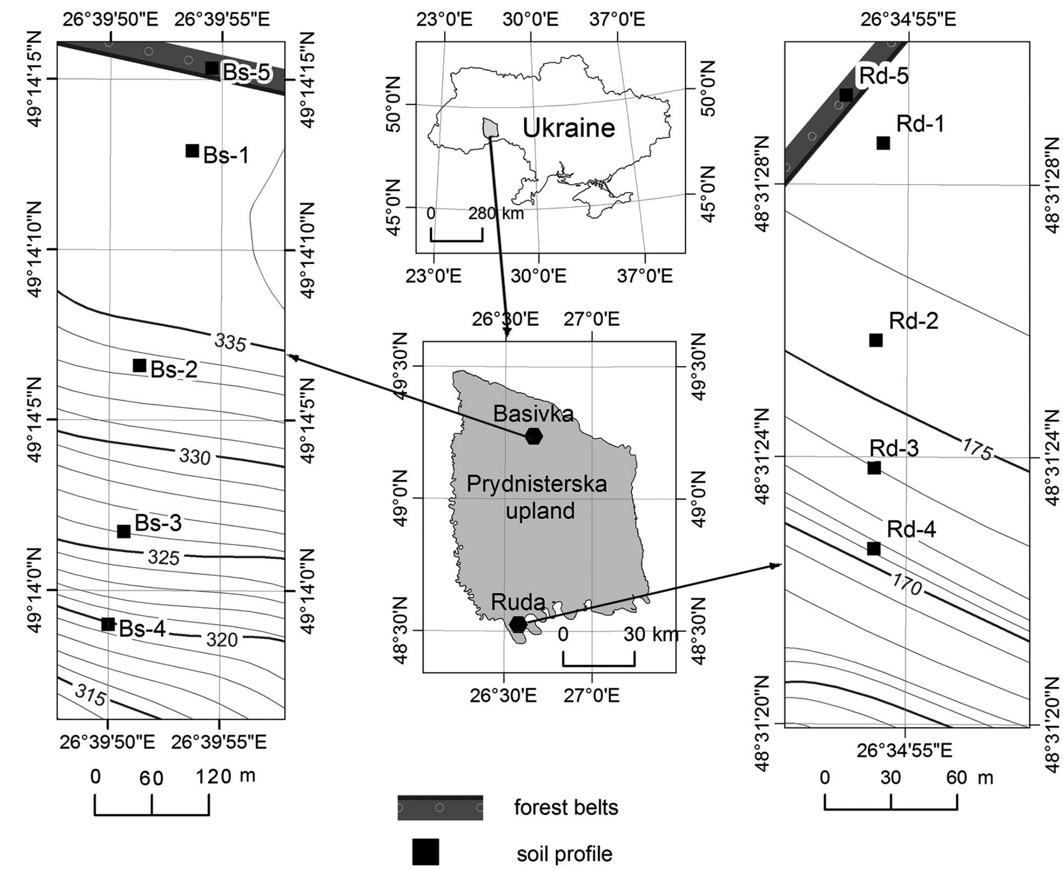

Fig. 1. Location of study area and sampling sites

Table 1
Characteristics of soil sampling sites

Experimental site	Soil profile	Landform	Slope (%)	Topography	Parent material	Land use	Soil name
	Bs-1	upland	0	nearly level areas	loess-like loam	arable field	
	Bs-2	slope	1	very gentle sloping	loess-like loam	arable field	
Basivka	Bs-3	slope	5	gentle sloping	loess-like loam	arable field	Typical chernozem
	Bs-4	slope	9	moderate sloping	loess-like loam	arable field	
	Bs-5	upland	0	nearly level areas	loess-like loam	forest belt	
	Rd-1	upland	0	nearly level areas	loess-like loam	arable field	
	Rd-2	slope	1	very gentle sloping	loess-like loam	arable field	
Ruda	Rd-3	slope	4	gentle sloping	loess-like loam	arable field	Typical chernozem
	Rd-4	slope	7	moderate sloping	loess-like loam	arable field	
	Rd-5	upland	0	nearly level areas	loess-like loam	forest belt	

matic brightness parameter (L*) depends on the humus content and moisture content, the chromatic parameters of redness (a*) and yellowness (b*) indicate the concentration of mineral component (Viscarra Rossel et al., 2006; Vodyanitskii and Kirillova, 2016). In addition, the ranges of color differences are adapted to the visual assessment of observers, which facilitates the interpretation of color perception (Mokrzycki and Tatol, 2012). In view of this, we used the data of the parameters L*, a* and b* as baseline data for general quantitative comparisons and establishing the index of color difference (ΔE_{2000}) of soil samples.

For a comprehensive understanding of the problem of loss of natural color by chernozems, data on the content of humus are given (Table 2). The analysis of the humus content in the studied samples was carried out in accordance with the standards of Ukraine (National standards of Ukraine, 2004). The method consists in oxidation of soil organic matter with chromium mixture during heating in a thermostat at a temperature of 150°C. Accurately, 0.2 g of soil sample was added in a 50 mL flask, ahd 4.0 mL of $K_2Cr_2O_7$. The resulting solutions were carefully poured into a cuvette with a translucent layer thickness of 10 mm and its optical density was measured on a spectrophotometer at a wavelength of 590 nm. According to the found values of the optical density of the solution and the known proportion of carbon determined the humus content in the soil.

Table 2
Humus content in soil samples

Experimental site	Soil profile	Genetic horizon	Depth, cm	Soil sample	Humus content (%)
Basivka	Bs-1	Har	0–15	Bs-1a	3.47
	Bs-2	Har	0–15	Bs-2a	3.21
	Bs-3	Har	0–15	Bs-3a	2.42
	Bs-4	Har	0–15	Bs-4a	1.83
	Bs-5	H	0–15	Bs-5a	4.24
Ruda	Rd-1	Har	0–15	Rd-1a	3.63
	Rd-2	Har	0–15	Rd-2a	3.32
	Rd-3	Har	0–15	Rd-3a	2.58
	Rd-4	Har	0–15	Rd-4a	2.05
	Rd-5	H	0–15	Rd-5a	4.35

3. Results and discussion

Under laboratory conditions, visual analysis did not confirm color differences for all soil samples dry. The samples taken under forest belts and on slopes with a steepness of ≥ 4% contrasted most with each other. However, it should be noted that in the moistened state, the color differences of the mentioned soil samples somewhat decrease, but do not disappear. In the case of the visual comparison of moistened soil samples taken on arable land and under adjacent forest belts, almost no color differences are observed.

Within the color space of the CIE L*a*b* system, most dry samples of are represented by the achromatic component of color, dominated by a dark tone. The exceptions are samples Bs-4a and Rd-4a, in which the maximum increase in the influence of the chromatic color components a* and b* is observed.

On the background of dry samples changes in the color parameters of the solid phase due to the light-absorbing properties of water form sharp contrasts. In particular, the color difference index data (ΔE_{2000}) quantitatively confirm the clear difference in the parameters L*, a* and b* in the CIE L* a* b* color space (Table 3). Digital images of wet and dry samples are perceived as the dominance of two different colors. An increase in the parameter L* of dry samples indicates the absence of masking effect of water and the objective color parameters of the solid phase. Due to the decrease in humidity, the samples brighten and the pigmenting effect of the mineral component increases. We assume, that the range of the b* index indicates the key role of loess loams in the pigmentation of typical chernozems on slopes with a steepness of ≥ 4%.

Given the scale and history of agricultural development of typical chernozems, the anthropogenic factor is key in changing the natural color. First of all, the destruction of the natural phytocenosis affected the balance of the intake of organic matter, and the constant mechanical impact and the manifestation of degradation processes enhance the spatial heterogeneity of color characteristics. In this context, we carried out a comprehensive analysis of the transformation of the color characteristics of typical chernozems in two stages:

1. The first stage included the analysis of color differences in samples taken in an area with homogeneous geomorphological conditions, but with different characteristics of soil management and phytocenoses.
2. The second stage – with homogeneous features of soil management and phytocenosis, but with different hypsometric indicators of the surface.

In the first stage, samples were taken under forest belts and in the adjacent plowed areas. The quantitative data of the parameters (L*, a* and b*) of soil samples (Bs-5a and Rd-5a) taken as the standard. In order to avoid the impact of erosion processes, sampling was carried out on leveled upland areas of the relief. For a quantitative comparison of colorimetric data, defined the smallest color differences (ΔE_{2000}) (Table 4).

The obtained results indicate color differences that can only be recorded using hardware, because the color difference index is $0 < \Delta E_{2000} < 2.2$. In view of the quantitative data of the brightness parameter (L*) we can assert that even within homogeneous geomorphological conditions, in the absence of the influence of erosion, the agrogenic degradation of chernozems reflected in the color characteristics. In particular, this is observed when comparing the colorimetric data of dry samples. Similar

Table 3
Colorimetric data of dry and wet chernozem samples

Experimental site	Soil sample	Wet samples			Dry samples			ΔE_{2000}
		L*	a*	b*	L*	a*	b*	
Basivka	Bs-1a	19.3	10.1	–0.2	36	11	1.7	12.67
	Bs-2a	19.9	10.5	–0.1	36.6	11.3	1.8	12.75
	Bs-3a	21.6	11.2	0.6	39	12	3.1	13.65
	Bs-4a	23.8	11.5	0.5	41.3	11.7	4.3	14.26
	Bs-5a	18.5	9.8	–0.1	33.7	10.8	1.9	11.38
Ruda	Rd-1a	18.6	10.1	–0.2	34.4	10.8	0.8	11.78
	Rd-2a	19.2	10.3	–0.1	34.9	10.9	1.4	11.80
	Rd-3a	20.7	11.2	0.7	36.8	10.8	2.3	12.34
	Rd-4a	22.6	11.7	1.1	38.7	12	3.8	12.72
	Rd-5a	17.3	10.0	–0.1	31.9	10.7	1	10.67

results were obtained in studies (Gorban et al., 2019) in which a corresponding trend is also observed.

In the second stage, sampling was carried out only within the arable land. The quantitative data of the parameters (L*, a* and b*) of soil samples (Bs-1a and Rd-1a) taken as the standard. To establish the color difference, the reference samples were alternately equated to the corresponding indicators of the samples taken on the slopes (Table 5).

The results of colorimetry indicate a clear spatial heterogeneity of the color characteristics of the arable horizon (0–15 cm). Against the background of standard color indicators of the flat areas, slope areas are distinguished by a dynamic process of loss of natural color. We assume that these changes are due to a decrease in humus content. In general, for all studied samples, a close inverse relationship between the total humus content and the brightness parameter (L*) was proved (Fig. 2).

An increase in the brightness index (L*) indicates a decrease in the content of the main pigmenting substance – humus, which stains chernozems in dark colors.

It should be noted that the maximum content of total humus was recorded precisely in the selected samples under forest belts, which, in turn, are characterized by the lowest brightness index (L*). The opposite effect is observed for slopes with steepness ≥ 4%. With decreasing slope steepness, the color differences in the samples decrease and content humus growing.

Howeve r, in the general assessment of the variability of the color parameters of soil samples taken on the slopes, the influence of humidity should be taken into account.

In particular, when the corresponding samples are moistened, the color difference index decreases due to the masking effect of water to the minimum values correlated with the total humus content. Quite the opposite effect is observed as a result of comparison of dry and wet samples, the maximum index of color difference of which increases to 68–74%.

Based on statistical data and visual analysis of digital images, it can be argued that an increase in the heterogeneity of color parameters leads to an increase in the contrast of the arable horizon in the horizontal direction. With an increase in the color

Table 4
Comparison of colorimetric data of soil samples of forest belts and arable land

Experimental site	Soil sample	Wet samples				Dry samples			
		L*	a*	b*	ΔE_{2000}	L*	a*	b*	ΔE_{2000}
Basivka	Bs-5a	18.5	9.8	–0.1	0	33.7	10.8	1.9	0
	Bs-1a	19.3	10.1	–0.2	0.61	36	11	1.7	1.90
Ruda	Rd-5a	17.3	10.0	–0.1	0	31.9	10.7	1	0
	Rd-1a	18.6	10.1	–0.2	0.89	34.4	10.8	0.8	2.02

Table 5
Comparison of colorimetric data of soil samples of arable land in flat and slope areas

Experimental site	Soil sample	Wet samples				Dry samples			
		L*	a*	b*	ΔE_{2000}	L*	a*	b*	ΔE_{2000}
Basivka	Bs-1a	19.3	10.1	–0.2	0	36	11	1.7	0
	Bs-2a	19.9	10.5	–0.1	0.55	36.6	11.3	1.8	0.57
	Bs-3a	21.6	11.2	0.6	1.96	39	12	3.1	2.86
	Bs-4a	23.8	11.5	0.5	3.43	41.3	11.7	4.3	5
Ruda	Rd-1a	18.6	10.1	–0.2	0	34.4	10.8	0.8	0
	Rd-2a	19.2	10.3	–0.1	0.45	34.9	10.9	1.1	0.62
	Rd-3a	20.7	11.2	0.7	1.86	36.8	10.8	2.3	2.30
	Rd-4a	22.6	11.7	1.1	3.25	38.7	12	3.8	4.35

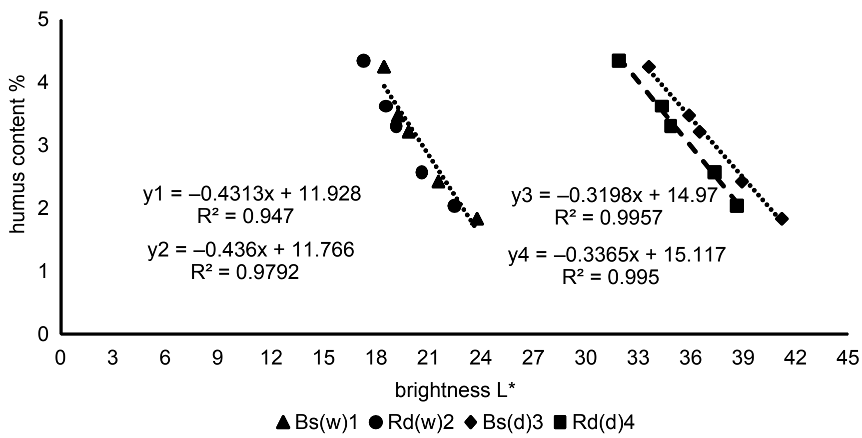

Fig. 2. Correlation between the brightness parameter (L*) and the humus content (%) in soil samples (w – in the wet state; d – in the dry state)

difference index of samples in a dry state $2 < \Delta E_{2000} < 3.5$, the heterogeneity of color characteristics is visually traced, which can be recorded by a non-specialist. The content of humus indicates that these areas are in an intermediate pre-crisis state, where degradation has not yet exceeded the "harmfulness limit". However, with a color difference index of $3.5 < \Delta E_{2000} < 5$, the color characteristics of the samples clearly differ in dissimilar achromatic and chromatic indicators, indicating the crisis state of the slopes and the active manifestation of the decolorization of chernozems.

5. Conclusions

The conducted studies experimentally confirmed the effect of moisture and humus content on the change in the color characteristics of chernozems (in the 0–15 cm layer). In the case of maximum moistening of soil samples, the color difference index indicates a decrease in the objectivity of the colorimetry results, which is associated with the masking effect of water. The identifying feature of the manifestation of decolorization of chernozems is a change in the achromatic component of color, which are fixed due to an increase in the brightness index.

Analysis of the colorimetric data showed that the increase in the brightness index is observed not only in the soil samples taken on the slopes, but also in the samples taken on the uplands. This refutes our idea that chernozems undergo decolorization only on slopes, but the change in the natural color of upland chernozems is much smaller. The demonstrated correlation between the brightness index and the humus content indicates the possibility of using colorimetric data to assess the humus content at the macromorphological level.

The study of the color features of chernozems by direct scanning of soil samples using an office scanner makes it possible to identify the problem of their decolorization with a minimum expenditure of resources and time. The value of this method is enhanced by the qualitative assessment of chernozems in: plowed areas with a heterogeneous topography, areas covered with woody vegetation, protected areas with undisturbed grass cover, where soil color is hidden from remote sensing.

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