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THE COLOR OF SOILS AS A BASIS FOR PROXIMAL SENSING OF THEIR COMPOSITION

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The color is one of the main morphological properties of soils, as it integrally reflects their material composition. Most of the macro-, micro- and nano-morphological methods in pedology are based on the analysis of soil reflectance characteristics within the visible spectrum (i.e., soils color). The evolution of soil color study methods and the features of modern instruments are described in the report. The main directions in the development of this field of soil science as well as the achievements and problems to be addressed in the study of soil color are demonstrated by specific examples.

Key words: spectral reflectance characteristics of soils, visible spectrum, remote sensing, proximal sensing.

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From the early days of pedology the color has been used as the main diagnostic property during soil observation in field. Indeed, the process of soil formation is accompanied by the change in the parent rock composition that can be visually assessed as the change in color of soil specific layers (horizons). For that reason, taxonomic identification of soils in many national classifications is based on their color. For example, in Russia there are Chernozem, Podzol, Brown and Grey Forest Soils, Chestnut Soils, etc. Moreover, the color is one of the first features specified during soil morphological description in field and it also serves as the main diagnostic property for distinguishing the genetic horizons of soils (Classification and Diagnostic System of Russian Soils, 2004).

The micro-morphological soil studies and its remote sensing techniques are also based on the analysis of the color just as the macro-morphological description of soil profiles and samples.

Regardless of technical progress, the human eye still remains the main analyzer of color in macro- and micro-morphological studies of soil profiles and samples. This is explained by the fact that existing devices for soil color identification are quite expensive. However, they are already being used in soil remote sensing. A human with a normal color vision can distinguish by comparison a great number of colors: by tone – about 150, by saturation – 25, by brightness – from 64 to 20 in light and dark conditions, respectively (Encyclopedia of Physics, 1998).

The practice of soil mapping from aerial photographs has shown that confident (accurate) visual identification of delineations can be done by only 8-10 shades of grey (Andronikov, 1990).

It should also be taken into account that every person has their own biological characteristics and, therefore, the precision of visual color perception is different for different people.

A human eye can perceive only a visible spectrum of wavelengths that range from approximately 300 to 750 nm. The visual perception of soil color is also confined to this range. Before the invention of special devices, soil scientists used (and still use) conventional soil color charts (Zakarov, 1927; Basic Charts …, 1982). The publication of Munsell Soil Color Charts (1992), which are based on numerical representation of colors, has been a great step forward in unifying soil color descriptions. Some researchers are still working on their improvement and refinement (Kirilova, 2015). The introduction of photography has become an important step in soil color studies. It resulted in the development of a new direction in pedology – remote sensing of soils by aerial photography and satellite imagery (Andronikov, 1990; Simakova and Savin, 1998), that is based on analyzing the color of soil images. Some scientists use photography for soil morphological analysis in field (Puzachenko et al., 2004; Bulygin et al., 2011).

The creation of spectrophotometers and spectroradiometers has allowed registering brightness of soil samples within visible spectrum and obtaining the brightness patterns that provide the most precise digital representation of soil color.

The availability of such information has opened the possibilities for the research into the relationship between soil color and soil composition. The most important factors influencing soil color have been found to be moisture (Bowers and Hanks, 1965; Sinha, 1986; Orlov, 2001; Lesaignoux et al., 2011), structure (Bowers and Hanks, 1965; Sinha, 1986; Coleman et al., 1993; Orlov, 2001; Daughtry and Bausch, 2003), particle-size distribution (Sinha, 1986; Barnes and Baker, 1999; Belinaso et al., 2010), bulk content of iron (Bowers and Hanks, 1965; Sinha, 1986; Coleman et al., 1993; Belinaso et al., 2010), organic matter content (Bowers and Hanks, 1965; Fedchenko and Kondrat'ev, 1981; Sinha, 1986; Coleman et al., 1993; Orlov, 2001; Fox and Sabbagh, 2002; Brown et al., 2006; Belinaso et al., 2010), the content of soiluble salts (Bowers and Hanks, 1965; Brown et al., 2006; Metternicht and Zinck, 2009), the content of calcium carbonate (Bowers and Hanks, 1965) and the mineralogical composition of soils (Bowers and Hanks, 1965; Orlov, 2001).

In most cases it is impossible to create a regression model describing the relationship of soil color and soil properties with a high coefficient of determination. This is connected with the spatial heterogeneity of soil properties resulting, to some extent, in generalization of reflected signals. The level of generalization grows from the micromorphological scale to the macromorphological and remote-sensing scales.

However, the relationship between many soil properties and its color is undoubted. A change in those properties is accompanied by the change in the color of soil, what can serve as a basis for their proximal sensing. The remote sensing techniques are widely applied in soil monitoring (Vinogradov, 1984; Pankova and Solov'ev, 1993; Savin, 1990). The main directions in the development of soil color assessment methods include the improvement of spatial resolution and the use of invisible part of electromagnetic radiation.

At the present time, the digital assessment of color heterogeneity in soil thin sections is only beginning to develop, while visual analysis of both quantitative and qualitative micromorphological features prevails (Lebedeva and Kust, 2015). However, the first results have demonstrated great possibilities of the application of digital assessment techniques in the quantitative micromorphological analysis of thin sections (Fig. 1).

Taking into account the growing use of high-magnification microscopes, the application of digital assessment techniques has a great potential.

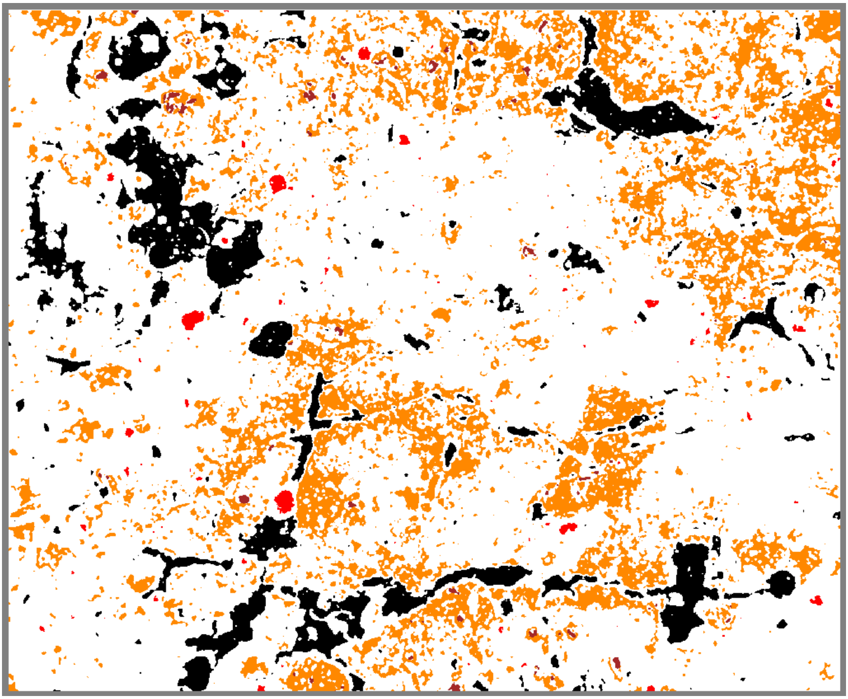

Fig. 1. The output of automated analysis of thin section of soil. Color code: black – pores and voids (7.27% of the total area and thin section), red – large mineral grains (0.38%), brown – ferruginous concretions (0.28%), orange – ferruginized areas (15.38%) and white – background (76.68%)

In macro-morphological description of soils, apparently, in the nearest time there will be a transition to quantitative determination of soil color using spectroradiometers (Fig. 2).

The most promising research area in remote sensing of soils is the use of information acquired in narrow spectral bands and microwave part of spectrum (Fig. 3).

Generally, at all the scales of soil color analysis, there is a tendency for transition from the regression analysis of color dependence on soil properties to the modeling of color characteristics depending on soil properties.

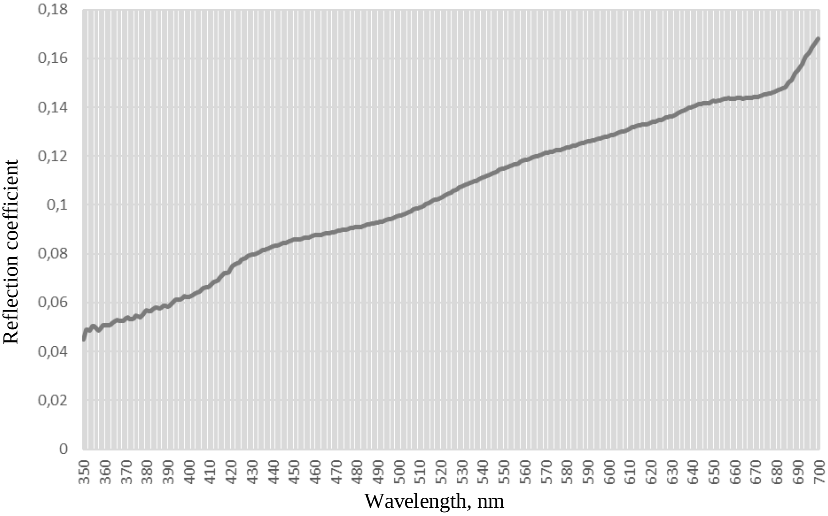

Fig. 2. An example of quantitative determination of soil color by a spectral reflectance curve.

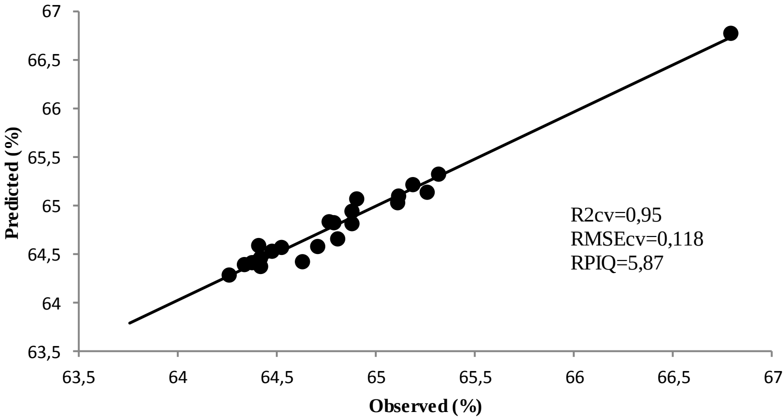

Fig. 3. An example of regression relationship between the spectral reflectance characteristics of soils and the content of SiO_2 (Podzolized Chernozems, Tula region, Russia).

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