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Color characteristics of the alluvial soils of the Desna River in the CIE – L*a* b * system depending on the content of C_{tot} and N_{tot}©2021

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We used a digital smartphone camera to read the color of soil samples. Determination of total carbon and nitrogen was carried out by conventional methods. A negative correlation was obtained for L* with C_{tot} and N_{tot} and a positive correlation between the indices a* and b*. It is shown that the equations of one-factor regression cannot adequately take into account the content of C_{tot} in the soil; for this purpose, it is more correct to use three-factor regression analysis.
Key words*: total carbon and nitrogen, color, correlation, regression, optical system*

1. Introduction

The color of the soil horizons is one of the key features in the field visual description of the profile, and allows the soil scientist to judge the classification of soils in the study area [1, 3, 10, 19].
The appearance of the soil is the result of the interaction of its various components with the incident light. Color and various other attributes of soil appearance are highly sensitive to the nature, proportions, size and morphology of the particles, as well as the spatial association of its mineral and organic components [23].
The main soil pigments are: humus, which stains the soil dark, calcite $CaCO_3$and other carbonates - white, hematite αFe_2O_3 - red, goethite αFeOOH - yellow. The presence of hematite and goethite in soils gives brown color of different shades [4, 5, 9].
Ultimately, the interpretation of color in terms of the ratio of the main pigments can make it possible to more correctly diagnose the classification position of soils when describing them in the field.
At the same time, the process of describing soil color to date, in many cases, is subjective, which excludes the possibility of statistical processing of this property [9, 23].
The transition from a verbal description of the color of soil horizons to a numerical one, represented in a particular optical system, is facilitated by the improvement of digital cameras and the development of software capable of "capturing" the color of the shooting object and presenting it in the required digital form [14, 15, 24].
The CIE–L*a*b* color system has been recognized for describing color. It is convenient because the value of the L* indicator (lightness) inversely depends on the content of dark pigment in the soil - humus. The a* (redness) index is directly proportional to the content of the red-colored hematite pigment αFe_2O_3in the soil. The b* value (yellowness) is directly proportional to the content of the yellow goethite pigment αFeOOH in the soil [9].
The purpose of this work is to analyze the relationship between the color characteristics of alluvial soils in the upper reaches of the Desna River with the content of total carbon and nitrogen.

2. Materials and methods

Soil samples were taken from the floodplain in the upper reaches of the Desna River in 2020 (Fig. 1). Soils at the sampling sites are mainly represented by alluvial underdeveloped layered and alluvial gray-humus soils [10], according to the World Soil Resources Base (WRB), they correspond to Fluvisols [19]. Samples were taken from the incision wall. A total of 64 samples were taken.
Samples were prepared for analyzes by conventional methods.
Total carbon was determined according to GOST 26213-91.
Total nitrogen was determined according to GOST R 58596-2019.

The color characteristics of the soil were determined on ground (0.25 mm), air-dry samples in the laboratory under natural light with a smartphone camera (camera characteristics: 13 MP, f / 2.2, 1.12 µm).

Color capture and presentation in the CIE – L*a*b* color system were performed using the Color Grab [30] program (www.loomatix.com/#colorgrab). Measurements were performed under controlled illumination. To ensure the correctness of the procedure, the white balance was periodically checked against the calibration plate. The use of this method is justified by the literature on the digital acquisition of soil color using smartphones [16]. and digital cameras [17, 18, 24].

Descriptive statistics, correlation and regression analysis of the obtained data were performed using MS Excel 2016 and STATISTICA.

3. Results and its discussion

Variation of parameters of soil color associated properties. Descriptive statistics of soil color parameters and related properties are listed in Table 1. In general, it can be noted that the values of the coefficients of variation (CV.%) for total carbon and total nitrogen are much higher than for the L* parameter, similar data were obtained by other authors [21].

At the same time, the grouping of samples along the horizons (humus separately from the rest) does not change the overall picture: the coefficient of variation L* is insignificant, for a*, b* C_{tot} and N_{tot} is significant. The data set on the content of total carbon is heterogeneous (CV> 33%). The performed two-sample t-test showed the presence of a significant difference in the L* parameter for the data arrays identified by the horizons.

The C:N value is one of the basic parameters in the transformation of soil humus [6, 11, 13, 22], which ultimately affects its structure, and hence the color associated with it. Therefore, we have identified groups of samples according to the C:N ratio. A two-sample t-test showed a significant difference in the L* parameter for the selected groups. The values of the coefficient of variation for C_{tot} with such a grouping of samples decreases, but remains significant. The values of the coefficients of variation for the chromaticity indices also decrease, but not so significantly. The fact of a decrease in the coefficient of variation of N_{tot} to an insignificant level is interesting for a group of samples with a C:N ratio of 6.0-12.0 (zone of stable humification).

The relationship between soil color parameters and their associated properties. The correlation matrix between soil color parameters and associated properties are shown in Table 2. In all samples, a statistically significant close positive correlation was observed between the a* and b* indices. At the same time, the correlation with the parameter L* of these indicators is negative, depending on the sample, either statistically significant or not.

The L* value decreases linearly or curvilinearly as the organic matter content increases [20, 24, 31]. A number of researchers argue that the color parameters are not independent of each other, but they obtained positive correlations [21, 24], which may be associated with the different genesis of the considered soils.

Correlation of L* with C_{tot} and N_{tot} is negative for all the above options for ranking the data array. For C_{tot}, in general, the correlation coefficient is statistically significant, but the relationship is weak. The correlation with N_{tot} seems to be of an indirect nature, given its lower absolute value and its very close relationship with C_{tot}. Attention is drawn to the absence of statistically significant correlations between L* and other considered indicators in the data array at C:N from 6.0 to 12.0. The reason for this is unclear and requires further investigation.

In the various given samples, the value of the correlation coefficient between L* and C_{tot} varies, as noted [21]. Apparently, this is due to the heterogeneity of the qualitative composition of humus and the peculiarities of the synthesis of iron minerals. In [25, 29], it was noted that soil color is a first-order indicator for assessing soil organic carbon; As a rule, dark soils contain more soil organic matter than light soils. This darkening of soil with a higher organic matter content is caused by changes in the composition and amount of humic acid and soil moisture. Humates are much darker than fulvates [12]. As a result, 1% humate humus reduces the L value by more than 1% fulvate humus [26]. F.R. Seidelman [7, 8] notes that gleying not only decreases the brightness of the color tone, but also brightens the horizon. Yu.V. Vodyanitsky [2] associates the change in lightness (L*) in the gleyed horizons with the accumulation or loss of iron.

The results of calculating the regression equations of the one-factor dependence of L*, a* and b* on the content of the total are shown in table 3; they reflect the effect of organic matter on mineral pigments. However, it is necessary to take into account all three-color characteristics: the content of organic carbon affects not only the lightness L*, but also the redness a* and yellowness b* of soils. Most often, the effect of C_{tot} is taken into account using univariate regression analysis [21, 31]. Although the correlation coefficients C_{tot} ~ a* and C_{tot} ~ b* are lower than C_{tot} ~ L*, they can nevertheless sometimes reach significant levels [27, 28]. Thus, solving the problem of accurately calculating C_{tot} based on soil color requires simultaneous consideration of all three components of soil color: L*, a*, and b* [20, 27].

Sample "all samples". Separate dependences C_{tot} ~ L*, C_{tot} ~ a* and C_{tot} ~ b* showed that humus significantly increases the redness of the considered soils, neutralizing the action of green pigments. This is confirmed by the calculation of the redness a* according to the one-way regression equation. When C_{tot} = 0, the redness of the mineral matrix becomes negative. Apparently, organic matter increases the redness of soils by neutralizing the green pigment of soil minerals. In this case, the coefficient of determination of the dependences C_{tot} ~ a* and C_{tot} ~ b* is insignificant. The three-factor regression equation is written as: C = 10.795 - 0.173L + 0.185a - 0.115b. It insignificantly increases the coefficient of determination: from 0.42 for the dependence C_{tot} ~ L* to 0.48. The coefficients before a* and b* are significant. Thus, the dependence of the C_{tot} content on the color parameters for the total sample can be more accurately described by a three-factor dependence.

Sample "humus horizons". Separate dependences C_{tot} ~ L*, C_{tot} ~ a* and C_{tot} ~ b* are essentially similar to the total sample, but the coefficients of determination are insignificant. The three-factor regression equation is written as: C = 7.259 - 0.119L + 0.189a - 0.045b. It significantly increases the coefficient of determination: from 0.22 for the dependence C_{tot} ~ L* to 0.31; however, the coefficients before a* and b* are not significant.

Sample "Cg and G horizons". Separate dependencies C_{tot} ~ L*, C_{tot} ~ a* and C_{tot} ~ b* are essentially similar to the previous samples, the coefficients of determination are insignificant. The three-factor regression equation is written as: C = 8.913 - 0.133L

+ 0.169a - 0.131b. It significantly increases the coefficient of determination: from 0.28 for the dependence C_{tot} ~ L* to 0.42, the coefficient before a* is not significant.

Sample "only samples with a C:N ratio less than 6.0". Individual dependences C_{tot} ~ L*, C_{tot} ~ a* and C_{tot} ~ b* are similar to the previous samples, the coefficients of determination for the dependences C_{tot} ~ a* and C_{tot} ~ b* are insignificant. The three-factor regression equation is written as: C = 3.443 - 0.047L + 0.057a - 0.051b. It significantly increases the coefficient of determination: from 0.41 for the dependence C_{tot} ~ L* to 0.70, the coefficient before a* is not significant. In this case, the three-factor regression model gives a satisfactory description of the dependence of C_{tot} on the color characteristics of soils.

Sample "only samples with a C:N ratio from 6.0 to 12.0". The values of the coefficients of determination close to zero for all one-factor dependencies. The three-factor regression equation is written as: C = 3.938 - 0.034L + 0.123a - 0.102b. It significantly increases the coefficient of determination: from 0.08 for the dependence C_{tot} ~ L* to 0.23, but does not make it significant. The coefficients before L* and a* are not significant. The three-factor regression model in this case is as ineffective as the one-factor one.

Sample "only samples with a C:N ratio greater than 12.0". Insignificant coefficients of determination for the dependences C_{tot} ~ a* and C_{tot} ~ b*. The three-factor regression equation is written as: C = 12.119 - 0.171L + 0.219a - 0.149b. It significantly increases the coefficient of determination: from 0.39 for the dependence C_{tot} ~ L* to 0.50. However, the coefficients in the multiple regression equation are not significant, which casts doubt on the adequacy of the description of the phenomenon by this model.

In all of the above three-factor regression equations, attention is drawn to the lack of significance of the coefficients in front of the redness index (a*). Taking into account the negative value at C_{tot} = 0, there is an absence or an extremely insignificant amount of hematite in the studied soils. Yu.V. Vodyanitsky points out [1] that the general pathway for the synthesis of iron minerals in hydromorphic soils goes through the oxidation or hydrolysis of Fe (II). Oxidation and hydrolysis of Fe (II) lead to the formation of Fe $(OH)_3$. Unstable iron hydroxide is converted to either metastable ferrihydrite or stable goethite.

4. Conclusion

The coefficients of variation of the color characteristics of the studied alluvial soils are lower than the coefficients of variation of the content of C_{tot} and N_{tot}, which indicates that the observed color of the soil is a complex combination of mutually influencing pigments of the organic and mineral components.

A negative correlation dependence of L* with C_{tot} and N_{tot} was obtained for all the given options for ranking the data array, which coincides with the studies of other authors. In all samples, a statistically significant close positive correlation was observed between the a* and b* indices, apparently due to the peculiarities of the genesis of iron minerals in alluvial soils. This is also confirmed by the negative values of the a* index at C_{tot} = 0.

Based on the complexity of the color characteristics of soils, due to the nature of the phenomenon, the equations of one-factor regression cannot adequately take into account the content of C_{tot} in the soil. Three-factor regression analysis, which takes into account the influence of the three components of soil color: L*, a* and b*, is generally better at this task.

Conflict of interest statement: no

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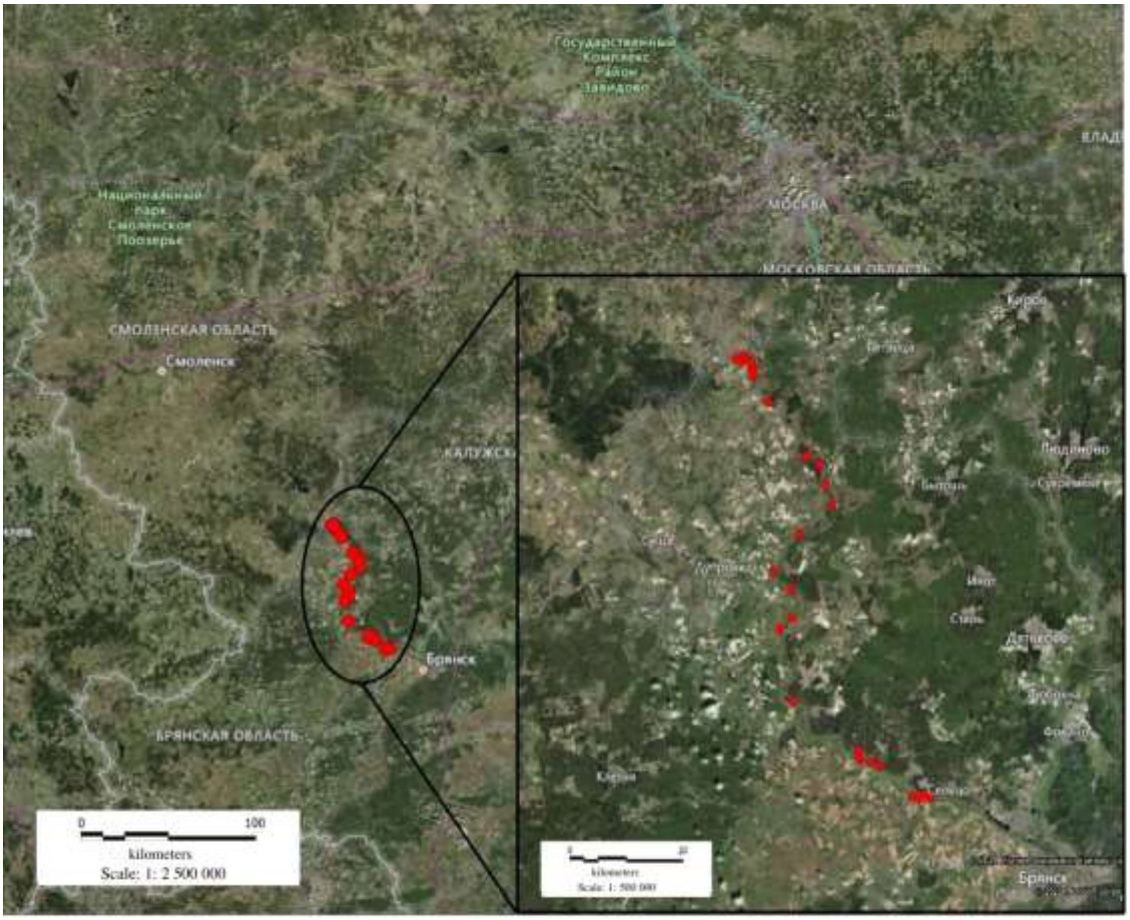

Figure 1. Points of soil sampling

Table 1. Descriptive statistics for soil color parameters, total carbon and nitrogen

Parameter	L*	a*	b*	C_{tot} (%)	(%)
All samples (n = 64)					
Average	49,4	10,2	19,1	1,9	0,2
Minimum	35,1	2,3	9,9	0,1	0,1
Maximum	59,1	20,8	32,7	7,4	0,4
CV (%)	9,9	27,4	22,5	77,5	33,4
Only humus horizons (n = 30)					
Average	46,5	10,1	18,4	2,8	0,2
Minimum	35,1	4,5	13,0	1,0	0,1
Maximum	59,1	20,8	32,7	7,4	0,4
CV (%)	10,2	30,3	23,3	52,9	24,0
Only Cg, G horizons (n = 34)					
Average	52,0	10,2	19,8	1,1	0,2
Minimum	42,3	2,3	9,9	0,1	0,1
Maximum	57,9	15,6	29,1	5,1	0,3
CV (%)	6,6	24,9	21,6	86,2	31,3
Only samples with a C:N ratio less than 6.0 (n = 16)					
Average	53,0	9,7	19,3	0,5	0,1
Minimum	43,3	7,3	14,1	0,1	0,1
Maximum	57,9	13,7	25,2	1,0	0,2
CV (%)	6,1	18,9	17,4	45,8	27,4
Only samples with a C:N ratio of 6.0 to 12.0 (n = 35)					
Average	49,9	9,9	18,6	1,6	49,9
Minimum	41,5	2,3	9,9	0,6	41,5
Maximum	59,1	14,1	29,1	3,7	59,1
CV (%)	8,7	23,5	22,2	42,1	8,7
Only samples with a C:N ratio greater than 12.0 (n = 16)					
Average	45,2	11,2	20,1	3,8	0,2
Minimum	35,1	4,5	14,2	1,7	0,1
Maximum	50,7	20,8	32,7	7,4	0,4
CV (%)	9,2	36,8	26,9	39,7	26,3

Table 2. Correlation matrix between soil color parameters and related properties

	L*	a*	b*	C_{tot} (%)	N_{tot} (%)
All samples (n = 64)					
L*	1,00				
a*	***-0,33***	1,00			
b*	-0,10	***0,75***	1,00		
C_{tot} (%)	***-0,65***	***0,28***	-0,02	1,00	
N_{tot} (%)	***-0,56***	***0,26***	-0,20	***0,87***	1,00
Only humus horizons (n = 30)					
L*	1,00				
a*	-0,29	1,00			
b*	-0,16	***0,77***	1,00		
C_{tot} (%)	***-0,47***	***0,40***	0,24	1,00	
N_{tot} (%)	-0,34	***0,44***	0,08	***0,83***	1,00
Only Cg, G horizons (n = 34)					
L*	1,00				
a*	***-0,59***	1,00			
b*	***-0,34***	***0,75***	1,00		
C_{tot} (%)	***-0,53***	0,29	-0,08	1,00	
N_{tot} (%)	***-0,36***	0,20	-0,33	***0,80***	1,00
Only samples with a C:N ratio less than 6.0 (n = 16)					
L*	1,00				
a*	-0,34	1,00			
b*	-0,21	***0,65***	1,00		
C_{tot} (%)	***-0,64***	0,20	-0,29	1,00	
N_{tot} (%)	-0,29	0,20	-0,39	***0,69***	1,00

Only samples with a C:N ratio of 6.0 to 12.0 (n = 35)					
L*	1,00				
a*	-0,27	1,00			
b*	-0,07	***0,76***	1,00		
C_{tot} (%)	-0,28	0,01	-0,28	1,00	
N_{tot} (%)	-0,24	0,06	***-0,35***	***0,90***	1,00
Only samples with a C:N ratio greater than 12.0 (n = 16)					
L*	1,00				
a*	-0,29	1,00			
b*	-0,03	***0,79***	1,00		
C_{tot} (%)	***-0,63***	0,31	-0,05	1,00	
N_{tot} (%)	***-0,58***	0,35	-0,11	***0,91***	1,00

* Statistically significant values of the correlation coefficient for given n are italicized

Table 3. One-factor and three-factor regression equations for the relationship between the content of C_{tot} and soil color parameters in the CIE–L*a*b*system

Parameter	$C_{tot} = f(L)$	$C_{tot} = f(a)$	$C_{tot} = f(b)$	$C_{tot} = f(L, a, b)$
All samples (n = 64)				
The equation	C = 11,688-0,198L	C = 0,371+0,153a	C = 2,041-0,006b	C = 10,795-0,173L+0,185a-0,115b
R^2	0,42	0,08	0,0003	0,48
Only humus horizons (n = 30)				
The equation	C = 9,697-0,148L	C = 0,838+0,195a	C = 1,307+0,082b	C = 7,259-0,119L+0,189a-0,045b
R^2	0,22	0,16	0,06	0,31
Only Cg, G horizons (n = 34)				
The equation	C = 9,007-0,151L	C = 0,014+0,111a	C = 1,525-0,019b	C = 8,913-0,133L+0,169a-0,131b
R^2	0,28	0,08	0,007	0,42
Only samples with a C:N ratio less than 6.0 (n = 16)				
The equation	C = 3,022-0,047L	C = 0,275+0,026a	C = 0,921-0,021b	C = 3,443-0,047L+0,057a-0,051b
R^2	0,41	0,04	0,08	0,70
Only samples with a C:N ratio of 6.0 to 12.0 (n = 35)				
The equation	C = 3,827-0,045L	C = 1,563+0,003a	C = 2,448-0,046b	C = 3,938-0,034L+0,123a-0,102b
R^2	0,08	0,00	0,08	0,23
Only samples with a C:N ratio greater than 12.0 (n = 16)				
The equation	C = 14,165-0,229L	C = 2,557+0,114a	C = 4,110-0,014b	C = 12,119-0,171L+0,219a-0,149b
R^2	0,39	0,10	0,003	0,50

* Significance level p = 0.05