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Correlations between moisture content and color spectrum of sandy soils

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ABSTRACT

It is a well-known phenomenon that the color of sand changes due to moisture. As the moisture content increases, the sand will typically become darker. In our research, we are looking for the answer to the exact function according to which this darkening process changes and what relationship there may be between the different, initial (dry) soil colors and how this relationship can influence the evolution of the darkening process. Using the suitably chosen range of the color spectrum, we created a color parameter to characterize the color of the measured sandy soil, and then, in addition to determining the moisture content, we also looked for other uses of the color spectrum for sandy soil. Thus, based on the color spectrum and other input parameters, not only the moisture content can be calculated, but in the case of two components, the grain composition can also be determined.

1. Introduction

Spectral remote sensing uses the entire or certain wavelength range of electromagnetic radiation for the non-destructive identification and characterization of various materials and surfaces. Electromagnetic waves leave the surface to be tested in different wavelength ranges and with reflectance values.

In most of the cases the reflectance curves of different materials are in the wavelength range of 380 and 2500 nm. Philpot, 2010 investigated wetted soils in this range. The curves take a characteristic shape depending on the surface from which the electromagnetic radiation is reflected, such as vegetation, water surface or soil (Siegmund and Menz, 2005). However, one must be careful with the measured data because the results are influenced, for example, by whether the water surface in the examined area is wavy or smooth (Körmöczi and Kiss, 2022).

Since different materials and surfaces and surface qualities reflect electromagnetic waves with different wavelengths in different ways, spectral remote sensing is used successfully in many areas, such as climate change monitoring, precision agriculture, geological systems research, and mapping the melting rate of glaciers, in pollution management and in many other areas as well. By knowing the color spectrum of the soil, we can infer the composition and properties of the soil, and so new possibilities open up to investigate changes in soil properties (Bedidi et al., 1992).

Spectral remote sensing is also used to detect leaks in plumbing systems. The change in soil moisture content can be clearly distinguished both in the visible (380–700 nm) and in the near-infrared range (750–1400 nm). Because there is a difference between the reflectance values, namely the drier soil has higher reflectance values. In this investigation the reflectance value of wet soil is usually 20–25 % lower than that of dry soil, and the maximum value of the difference is reached in the near-infrared wavelength range (Hadjimitsis et al., 2013). In this study, the surrounding, dry soil and the soil moistened by the leaking water pipe are separated from each other using the reflectance curves measured in the given area. We can also be observed that in the lower wavelength range (350–650 nm) and in the case of higher moisture contents, the curves approach each other and may overlap, while in the 600–700 nm range the curves are essentially parallel (Hadjimitsis et al., 2013).

In soil tests, when the color of soils is determined, an internationally accepted Munsell color scale is usually used, which can be used to identify the color of the soil. Maybe they describe the color with other color coordinates (X, Y, Z; L, a, b; etc.). The correlations between the physical properties of the soil, or the content of organic matter, and its color are created using these coordinates (Shield et al., 1968; Torrent, 1993). One of the disadvantages of this is the complexity of determining the color coordinates, and the fact that the measuring device itself calculates these characteristics.

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Fig. 1. Konica Minolta CM-700d color spectrophotometer

2. Material and method

A Konica Minolta CM-700d color spectrophotometer was used to record the color spectrum of the sandy soil. The device records both diffuse (SCE) and specular reflection (SCI) for each measurement. During the measurements, we worked with the results of diffuse reflection. The device can be used with both 3- and 8-mm diameter measuring heads. Reflectance range is 0–175 % and the wavelength range is 400–700 nm. We used the MAV: Ø8 mm setting for our measurements and the reflectance curves recorded by the instrument to further analyze the color of the sand. The device also calculates other color characteristics that we are not currently using (X, Y, Z or L, a, b) (Fig. 1).

A HE73 moisture meter was used to determine the moisture content of the sandy soil. The device contains a heating element and a scale with an accuracy of 1 mg. The tray containing the soil sample is placed on the scale, and after closing the lid of the device, the moisture content of the soil sample begins to be determined. During the measurement, the high temperature of the heating element (105 °C) continuously dries the soil, while the scale measures the mass change. The measurement continues until the difference between two mass measurements is sufficiently small. Then the soil sample is considered completely dry. From the masses before drying and after drying, the moisture content of the soil on a dry basis is displayed as a mass percentage.

The measurements were carried out on three different colored sandy soils that can be easily distinguished with the naked eye (Fig. 2). After collection, the sandy soils underwent pre-sieving, where the sieve pore size was 500 µm. Larger particle sizes and impurities were removed by pre-sieving. Based on the grain size classification, the tested soil is considered to be sand in the range of 2000–50 µm, so these correspond to fine-grained sandy soil and 90 % of the grains in the sample fall in this range of 500–50 µm. The remaining 10 % of the particles are smaller than 50 µm. After cleaning and setting the grain range, the samples were completely dried in a drying oven (24 h, 105 °C). Finally, they ended up in an airtight container.

3. Course of soil testing measurements

To explore the relationship between the moisture content and color spectrum of the investigated sandy soils, 20 g of sand is measured from the hermetically sealed container into a mixing vessel, to which we add the required amount of water based on the desired moisture content. The soil was mixed with water until homogeneous in a short time, and its color spectrum was immediately recorded by repeating it three times. Then half of the sample was placed in the moisture meter to determine the moisture content. The process was carried out in 1 % increments in the planned moisture content range of 0–20 %. Thus, in the case of the three soils, 60 experimental setups were created.

In the case of absolutely dry sand, we also performed an additional measurement, where the white and black soil were mixed together in different weight ratios, and then the color spectrum was measured. In addition, in the case of a mixing ratio of 50 % by mass, in addition to setting 9 different moisture contents, we also calculated the color parameter.

Fig. 3 shows the used measuring head with a quartz glass plate. After adjusting the moisture content of the sample, the measuring

Fig. 2. The examined sandy soils: black, yellow, and white.

head of the device was placed on the surface of the sand sample and pressed in by hand to such an extent that there was no gap between the head and the surface of the sand. There is also a measuring head without a glass plate. In addition to soiling the instrument, the disadvantage is that the surface of the soil entering the gap will take on an uncertain shape. It can bulge or crack, so the measuring surface of 50.3 mm^2 will change in a random way, which can have a significant impact on the measurement results. In the case of the glass flat measuring head, protrusion cannot occur. In this case the size of the pressure force will affect the distance between the grains, thus also can changing the size of the measured surface. There is also a measuring head with a diameter of 3 mm, which has a measuring surface of 7.1 mm^2. This means that compared to the 3 mm head, the 8 mm probe examines a surface 7 times larger. Thus, in the case of a sample, in the case of a head with a larger measuring surface, we will experience a smaller deviation between the measured values, since lighter and darker grains in the sample can be detected even with the naked eye.

4. Results

Fig. 4 shows some raw reflectance curves of the black sand soil. These are considered raw results because they directly show the measured values. The wavelength range of visible light between 380 and 700 nm is indicated on the horizontal axis. And on the vertical axis, the percentage of the light emitted by the spectrophotometer reflected from the tested surface. The measured results are in line with both literature data and our experience. As a result of wetting, the sand becomes darker, therefore the curve of soil with a higher moisture content is always lower in the row. A linear function can be fitted to the points whose correlation coefficient is over 98 %. In the lower wavelength range (380–550 nm), the measured values are closer to each other, and overlaps may also occur. In the upper wavelength range, on the other hand, the individual curves can be better separated and can essentially be considered parallel. Thus, in the future, we will continue to work with reflectance values belonging to the upper wavelength range (600–700 nm).

In Fig. 5, some results of the black, white, and yellow sand are compared in the upper wavelength range (600–700 nm). In Fig. 4, the moisture content of the black sand varies between 6 and 20 % by mass. Fig. 5 shows the first half of this moisture content range between 1 and 5 %. The values follow each other well, the reflectance range of the black sand soil varies between 2 and 15 % in the entire visible spectrum. Each value of the white sand with reflectance values between 15 and 35 % is located above this curve. Yellow sandy soil is closer to white, because the reflectance curve of yellow sandy soil with 0 % moisture content is approx. It is 2.5–3 % lower than that of white sand. The reflectance range (600–700 nm) that can be measured at a moisture content of 0 % to 20 % varies between 15 and 32 %. So, the values for yellow sand are within the range of white sand. For better clarity, these were not included in Fig. 5, because the curves for white and yellow sand would overlap in many places. The difference in color is thus only noticeable in the dry state, and the yellow and white sandy soil cannot be distinguished from each other in the wet state.

During the further analysis of Fig. 5, it can also be noticed that there is a greater distance between the reflectance values belonging to the lower moisture content than those belonging to the high moisture content. That is, because of wetting from 0 % to 5 %, the reflectance value changes more than when wetting the sand from 8 % to 13 %.

The color parameter “C” created to characterize the soil color or reflectance curve is based on the curves shown in Fig. 5, and the color parameter can be calculated using the following relationship:

$$C = \frac{1}{11} \cdot \left(\sum_{600}^{700} R_i \right) \tag{1}$$

Where “R_i” is the i-th reflectance value within the 600–700 nm wavelength range. Thus, “C” corresponds to the average value of the given reflectance curve. Fig. 6 shows the color parameters calculated for the three types of soil represented in a lin-log diagram.

In Fig. 6, two straight lines can be fitted to a set of points belonging to a sand type. In the case of black sand soil, one line can be fitted to points below 6 % moisture content, and another line can be fitted to points above 6 %. The breaking point of the curve (n_0, C_0) belonging to the given sandy soil creates a connection between the lines and equations belonging to low and high moisture contents. The coordinates of the breaking point for black sand are: (n_0 = 6; C_0 = 7.6). The curve that appears as a straight line in the lin-log diagram represents an exponential function relationship, as can be seen from the indicated equations.

It can be concluded that in the case of lower moisture contents, the color of the examined sandy soils is more sensitive to changes in moisture content than in the case of higher moisture contents after the mentioned breaking point. Furthermore, the slope of the curve before and after the breaking point, i.e., the color sensitivity, is essentially the same for all three sandy soils. There is a difference in the position of the break point. Moving towards lighter colors, the breaking point belongs to lower and lower moisture contents, 6 % for black soil, 4 % for yellow and white soil, and 5 % for a 50 % black, 50 % white mixture. The color parameter of the yellow sand soil is the same as that of white sand at higher moisture contents, at lower moisture contents (<8 %) the average reflectance values are slightly lower, but the position of its breaking point is the same as that of white sand.

The functional relationship between moisture content and color parameter shown in Fig. 6 can be written in the following form:

$$n = \frac{1}{b} \cdot \ln \left(\frac{C_0}{C} \right) + n_0 \tag{2}$$

Where,

n_0 – breaking point moisture content of the curve of the known soil [m%];
C_0 – breaking point color parameter of the curve of the known soil [%];
b – constant characteristic of color behavior [-];
n – the calculated surface soil moisture content [m%];
C – characteristic parameter [%] for the color calculated on the basis of the measured reflectance curve;

The surface moisture content of black sandy soil with unknown moisture content can be easily calculated using the color parameter “C” calculated from the measured color spectrum. For this soil, the coordinates of the breaking point are: n_0 = 6; C_0 = 7.6. Based on this, if “C” > “C_0'' then the value of ”b“ is 0.14, if ”C“ < ”C_0'' then the value of “b” is 0.02. Thus, the moisture content can be calculated using equation (2). The validity range of the equation on the horizontal axis is n_{min} = 0 %; n_{max} = 20 %, and on the vertical axis C_{min} = 5.5 %; C_{max} = 15 %. At moisture contents higher than 20 %, sandy soils can no longer retain water, their strength begins to decrease strongly, and water begins to precipitate on the surface. The reflectance values will approach the reflectance value of water. Thus, if C < C_{min}, the moisture content of the soil is greater than 20 %, i.e., the sandy soil is more like mud. Also, if C > C_{max} then it may not be the known sandy soil, but another one or one contaminated with other particles.

Fig. 6 also shows a 50–50 mass percent mixture of black and white sand. Here, fewer measurement points were enough to plot

Fig. 3. 8 mm measuring head with quartz plate.

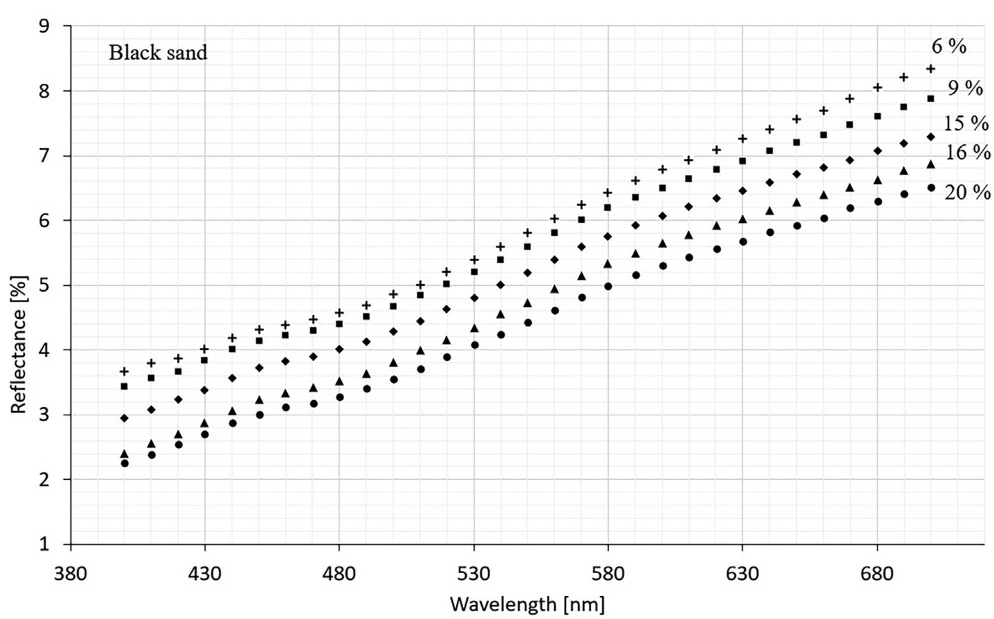

Fig. 4. Some raw reflectance curves of black sand at different moisture contents.

the curves and determine the breaking point. It can be concluded that the slope of the curved sections is the same as that of black and white sand, and its breaking point is located between the aforementioned two. Another important finding is that the average value of the reflectance is approximately it differs by 26 %.

In addition to the mixture with a mass ratio of 0.5, we also measured the color parameters of different mixing ratios with a moisture content of 0 %. The horizontal axis of Fig. 7 shows the mass ratio of white sand in the mixture. Where "m_W" is the mass of the white soil, "m_M" is the total mass of the mixture. The vertical

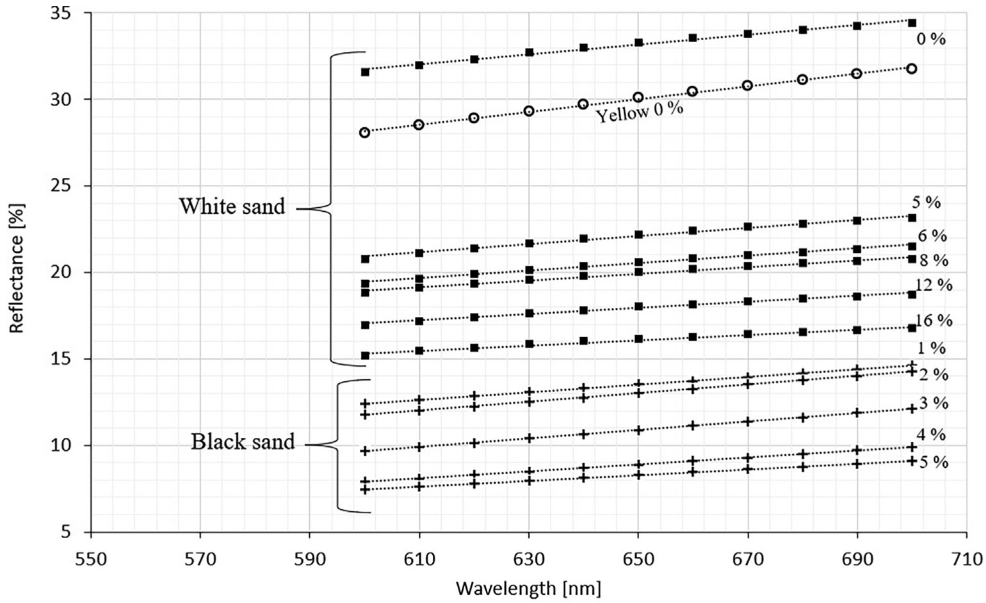

Fig. 5. Some raw reflectance curves of black and white sand in the 600–700 nm range.

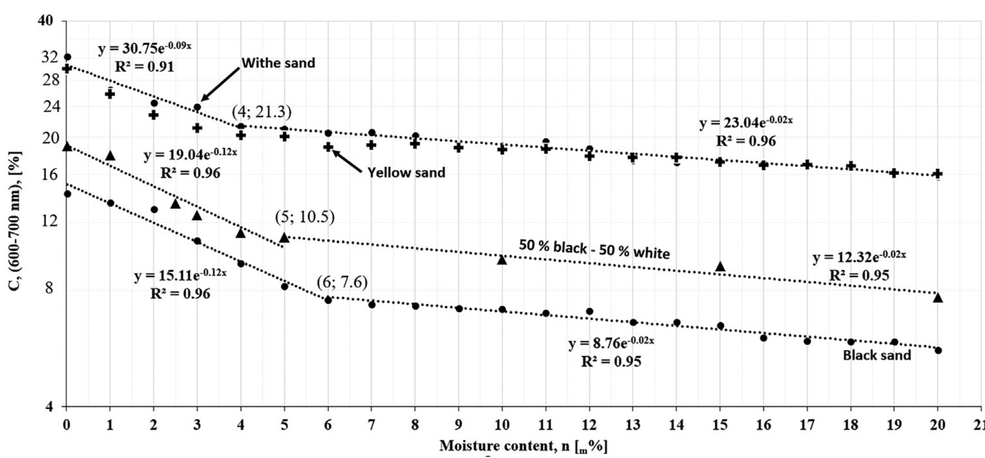

Fig. 6. Relationship between reflectance and moisture content.

axis shows the difference in the color parameter compared to black sand. Thus, when the mass ratio of the white soil is zero, the difference compared to the black sand is also 0 %, since in this case the mixture consists of pure black sand. During the preparation of the mixture, it became clear that it was not possible to mix the two types of sand completely homogeneously. This means that black and white areas remained on the surface of the sample despite persistent stirring. Thus, the positioning of the sensor head with a diameter of 8 mm affects the measured spectrum. On the other hand, power functions can be fitted to the measured points, and it can be established that even before the breaking point, the black soil became lighter by only 26 % with a half-half mixing ratio. However, from a proportion of white sand exceeding 0.5, the mixture starts to react more sensitively to the presence of white sand.

According to Fig. 6, the curves of the black, white and 50–50 % mixtures are essentially parallel to each other in the tested moisture content range, it can be stated that the relationship revealed in Fig. 7 also applies between other mixing ratios and moisture contents for the tested sandy soils, thus, the relationship between the mass ratios and the color change of the sand is described by the following equation:

$$C_{dev} = C_{d0} \cdot \left(\frac{m_{M0}}{M_{W0}} \cdot \frac{m_W}{m_M} \right)^t \tag{3}$$

Where,

C_{dev} - color deviation from black (lightening) [-].

C_{d0} – the vertical coordinate of the breaking point [-].

m_{M0}/m_{W0} – the reciprocal of the mass ratio of the white soil at the breaking point [-].

t – characteristic constant for the color behavior of the mixture [-].

The value of "t" for this sandy soil mixture is 1.26 for $m_W/m_M < 0.5$ and 1.99 for $m_W/m_M > 0.5$. Thus, if we mix 70 g of black and 30 g of white sand soil with a moisture content of 15 %, we get a mixture with a mass ratio of $m_W/m_M = 0.3$. According to equation (2), the color parameter of black sand soil with 15 % moisture content is C = 6.7 %, and according to equation (3), $C_{dev} = 0.09$, then the color parameter of the mixture is $C_{mix} = C + C \cdot C_{dev} = 6.7 + 6\ 0.7 \cdot 0.\ 09 = 7.3$ %.

By rearranging and supplementing equation (3), the composition of the mixture of particles can also be determined:

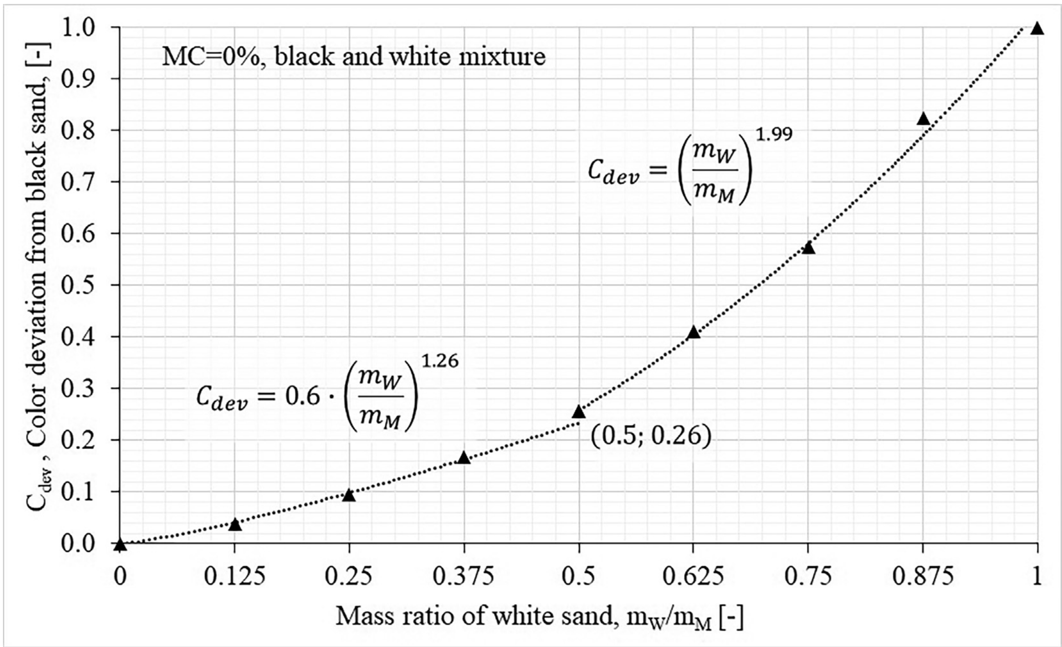

Fig. 7. The mass ratio of white sand in the mixture and the color parameter deviation compared to black sand, in the case of 0 % moisture content.

$$\frac{m_W}{m_M} = \frac{M_{W0}}{m_{M0}} \cdot \sqrt[t]{\frac{C_{mix}}{C \cdot C_{d0}} - \frac{1}{C_{d0}}} \tag{4}$$

$m_{W0}/m_{M0} = 0.5$, $C_{d0} = 0.25$ for the investigated particle set mixture. To determine the mixing ratio, it is necessary to measure the color spectrum of the mixture and determine the color parameter "C_{mix}", and also to know the color parameter "C" of one set of particles, in this case black. We can determine the exponent by knowing C_{d0}: if $C_{dev} < C_{d0}$, then t = 1.26, if $C_{dev} > C_{d0}$, then t = 1.99.

5. Conclusions and recommendations

Based on the theoretical and experimental studies, the following main conclusions can be drawn:

- The measured reflection curve is valid for the surface of the soil. The moisture content determined by equation (2) from the reflection curve is also valid for the soil surface. The term "surface" is still to be clarified. The question is whether we mean the surface of the uppermost grain row or a certain soil thickness, since the upper grain row does not close perfectly, the light is the second, third, etc. it is also reflected from the row, so a certain sand thickness determines the reflectance. Another problem is that with compaction, the grains become closer to each other, so the initial state of compaction also affects the reflectance. The spectrophotometer's own weight compresses the sample under itself, thus modifying the measurement result. If the measuring head is not pressed into the ground, light can escape through the gap formed between the sensor head and the ground, which also reduces the proportion of reflected light. If a sheet of glass is placed on the sample in order to avoid the compression that occurs during the measurement, the glass, depending on its thickness, also conducts the light, thus reducing the reflectance.
- The measured and calculated values for the color are only valid at the time of measurement, or for a short period of time from this time, depending on the environmental conditions, as the surface moisture content of the soil changes rapidly. The surface of the soil is in direct contact with the air, where it is exposed to constantly changing solar radiation, humidity, wind, and air pressure. All of these can change the surface moisture content of the soil, so the surface moisture content can continuously change and fluctuate over time.
- In the determined relations (2) and (3), there are also constants "b" and "t" which are constant only in a certain range, and we cannot justify the position of the breakpoints (Figs. 6 and 7). The next step in this research area is the exploration of the physical phenomena affecting the constants in the equations and the position of the breakpoints.
- Equation (4) can be used to test a mixture of two-component granular materials for quality control purposes. The constants of the equation can be determined based on the color spectrum of the two components recorded in advance, and then the actual particle composition can be calculated using the color spectrum of the sample taken from the mixture.

6. Summary

In this study, we investigated the change in the color of three different colored sandy soils with a similar grain fraction distribution as a function of moisture content. To quantify the color of sandy soils with different moisture contents, we created a color parameter based on the recorded color spectral sign. With the help of this, it became possible to illustrate the change in the color of the sand and its nature. In a given range, the surface moisture content of the known sandy soil can now be calculated based on the color spectrum sign. Finally, we developed a relationship to determine the composition of two different colored sand grains based on the color spectrum sign.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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