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Spectral estimation of soil water content in visible and near infra-red range

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Abstract

Soils can be examined on the basis of spectral data, using such methods with which the reflected radiation can be divided into a large number of (several hundreds) small spectral channel (some nm). Based on the spectral characteristics of the soils, or the different index numbers calculated from hyperspectral data water content of soils can be well characterized. The examined soil samples were coming from different apple orchards of which soils had different physical characteristics (sandy loamy and clay). The goals of my experiments were the evaluation of spectral measurement method for soil content detection, and to carry out algorithms for fast field scale spectral evaluation of different soil water content. The spectral measuring was carried out by laboratory scale AvaSpec 2048 spectrometer at 400 – 1000 nm wavelength interval with 0.6 nm spectral resolutions and by ASD FieldSpec Junior at 350 – 2500 nm. After drying, dry soil samples were watered by 2.5 m/m% till maximal saturation, and each wetting was measured spectrally. Based on spectral properties, reflectances were decreased in the whole spectral range within the continuous wetting due to the high absorption characteristics of water. The most water sensitive spectral ranges were selected by principal component, and such algorithms were created, with which the water content can be detectable in the certain soil. The algorithms can facilitate farmers for irrigation scheduling of their orchards. These results can also be utilizable in precision water management, since it can be a basis for such integrated active sensors with LED or laser light source, measuring reflectance at the certain spectral range, which can facilitate real time water status assessment of orchards

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Introduction

It is a well-known that the crop production is closely related to soil conditions and soil moisture content of the agricultural area, so that accurate measurement of soil moisture is essential. Determination of soil moisture content is commonly required in agricultural water management and soil moisture control. The measurement of soil moisture content is important in irrigation because with the precise determination of water supply the irrigation scheduling water consumption of plants can be optimized. Naturally the moisture content of soils can be measured by several methods. The gravimetric method is one of the most simple and intensive way of it. However, more advanced technologies are widespread to detect water regime. For example tensiometers, which shows the matrix potential of soils based on the soil moisture content (Tóth, 1995). Another widespread method to determine of soil water content is the measurement of the propagation velocity of waves in soil. These techniques includes the "Time Domain Reflectometry" (TDR) method which is based on determination of the radio-frequency electromagnetic wave propagation velocity (Rajkai, 2004). The measurement of electrical resistance of soils is also includes in this methods.

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(Várallyay, 2002). These process are allowed point sample analysis. Calibrated spectral data enables the rapid detection of soil moisture content in laboratory or on field, in addition airborne or terrestrial systems allows to assess the spatial distribution of moisture content of the surface.

It is a well-known that the reflectance of soil generally increases with the wavelength. The rate of this is related to other physical and chemical properties of soil. Based on the earlier results, organic matter content, moisture content, parent material, the presence of colour chemical, soil texture, size of the soil particles and salt content are the most important factors which determine the reflectance. These factors are complex, changeable and thereare relationship among them. General observation that increase in organic matter and water content of the soil reduces the reflectance properties in the wavelength range of 0.4-2.5 microns. Humus is the major determinant of the reflectance, if the humus content of soil is more than 2%. The reflectance decrease in 1.3-1.5 and 1.75-1.95 micron intervals is the result of the absorption of water content in soil. The soil surface moisture content is one of most rapidly changing parameters, which is depending on physical, chemical and biological qualities of soils and environmental impacts (Csornai-Dalia, 1991). The main effect of moisture is observed on the middle infrared (MIR) range (Belényesi, 2008). The reflectance values (from soil reflectance curve) is mainly influenced by soil moisture and mineral composition. The higher is the moisture level of soils, the lower reflectance values are. Furthermore the reflectance increases within higher wavelengths. Precise spectral profile of a mineral can be determined only in laboratory. Nowadays, there are so called spectral libraries, where the typical spectral reference curves with absorption peaks and minimums of different minerals are stored (Belényesi, 2008). In this research, the impact of soil moisture content on the spectral properties of soils and their spectral calibration were analysed..

Material and Methods

The aim of this study to evaluate the soil moisture content based on reflectance, which availability of water to crops can measure quickly. Effect of moisture content of soil samples on spectral properties was carried out with laboratory spectrometers. The soil samples are from apple orchards, from certain parts of Hungary: Pallag, Nagykutas, Szepetnek and Siófok. The four orchards have different soils textures (Table 1). The soil is mainly clay loam in Szepetnek, there are sandy loam, clay loam and loam soils in Nagykutas loam and sandy loam in Siófok and sandy soils in Pallag. Soil texture was measured by the method of saturation percentage

Table 1. The texture of examined soils

Soils	Saturation percentage	Texture	Soils	Saturation percentage	Texture
Szepetnek 1	46	clay loam	Siófok 1	36	sandy loam
Szepetnek 2	41	loam	Siófok 2	37	sandy loam
Szepetnek 3	49	clay loam	Siófok 3	36	sandy loam
Szepetnek 4	42	loam	Siófok 4	40	loam
Szepetnek 5	48	clay loam	Siófok 5	41	loam
Kutas 1	37	sandy loam	Siófok 6	39	loam
Kutas 2	50	clay	Siófok 7	39	loam
Kutas 3	36	sandy loam	Siófok 8	37	sandy loam
Kutas 4	39	loam	Pallag 1	26	sand
Kutas 5	37	sandy loam	Pallag 2	27	sand
Kutas 6	45	clay loam	Pallag 3	27	sand
Kutas 7	43	clay loam	Pallag 4	27	sand
Kutas 8	73	heavy clay	Pallag 5	28	sand
			Pallag 6	28	sand
			Pallag 7	25	sand
			Pallag 8	28	sand

The spectral detectability of soil moisture contents were analyzed in laboratory conditions. The spectral profiles (reflectance) were measured by laboratory scale AvaSpec 2048 spectrometer at 400 – 1000 nm wavelength interval with 0.6 nm spectral resolution. The AvaSpec 2048 system consists of one spectrometer, AvaLight-HAL halogen light source which are joined by a fibre optic with 8 μm diameter. The halogen light source provides a constant emission of 400 – 1000 nm wavelength interval, which ensures a standard intensity of incoming energy in the whole range of measurement. However, laboratory measurements is disturbed by lot of factors such as the changeable lighting conditions, neon lights, due to the wavelength specific emissions of fluorescent lamps. To ensure accurate measurements, a self-innovated, special special sampling box were used to isolate samples in order to provide dark for measurements. The spectral profiles of the soil samples was measured at various moisture conditions. Soil samples were dried to constant weight at 105 ° C and 100g samples were saturated by 2.5 ml distilled water (2.5 percent of dry weight) until full saturation. In parallel, spectral profiles of wetted soil was regularly measured at all wetted stage, in three iteration (Figure 1).

Five soil samples with three different soil texture properties were also measured by ASD Field Spec Junior spectrometer in 350-2500 nm spectral range with 3 nm precision. The light source is a halogen bulb that, unlike the previous equipment, is joined with fiber optic detector. Thus the angle of the light is adjustable (the measurements were carried out at 45 ° angle of incidence). Two sandy two loam and one clay soil samples were measured. Samples were saturated by 5 percent distilled water (% of dry weight) and spectrally measured in three iteration in each wet conditions. Despite the fact that the measurement principle of the spectrometer is similar, the results of the two spectrometers were evaluated separately. This is due to that the soil sample illumination angle is different.

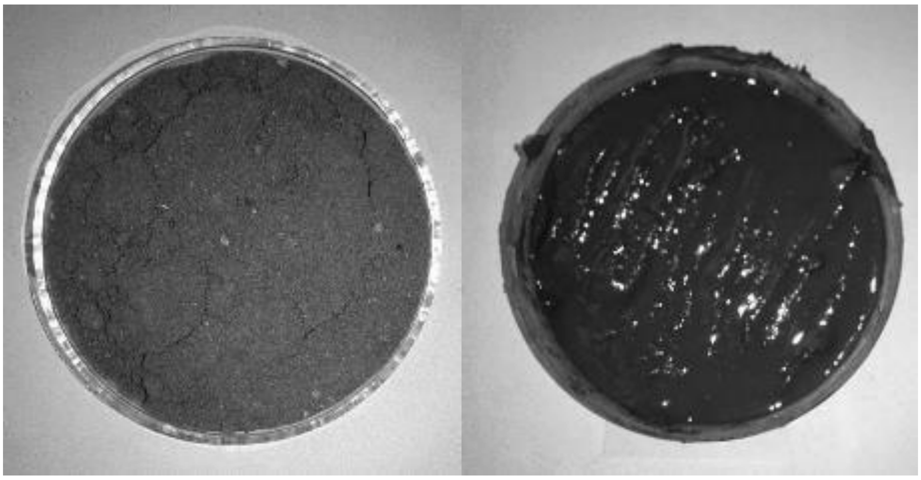

Figure 1. Dry and saturated sandy soil sample

First of all, spectral properties of the dry soil samples were measured. Using variance analysis the spectral identification of different soil textures were assessed with the analysis of the spectral differences in 400 and 1000 nm wavelength interval selecting certain wavelengths for the identification. Subsequently, the spectrally different soils were separated into different groups and the effect of moisture were studied on the spectral properties. The effect of moisture content on reflectance of specific wavelength was also evaluated by correlation analysis. Furthermore the applicability of spectral indices were also analysed for moisture detection. Identification of the wavelength ranges associated with the water content is performed by using principal component analysis. Different groups were made based on the soil moisture content categories. The strength of the soil moisture effect on the spectral properties was investigated by calculating standard deviation curves out of spectral curves of groups with different moisture content categories. Two kinds of grouping were made. In the first case, increasing moisture content limits were used to make the following groups: 0-5%, 0-10%, 0-15, 0%-saturated soil (percentage of dry weight). This provide the selection of wavelength range with the highest variation. In the second case different groups were made based on stepwise increase of moisture content and calculated the standard deviation curves: 0-5%, 5-10%, 10-15% etc. (percentage of dry weight). Based on the differences between groups ranges of moisture were selected, wherein the water has the largest effect on the spectral properties. In addition, Tukey's multiple-factor analysis of variance were used to elaborate the reflectance variations caused by the difference in moisture content, and to examine the differences in reflectance between the soils. In order to determine the soil moisture content, linear regression equations were set up, which was validated by T-test.

Results and Discussion

Impact of Soil texture and Moisture on the 1000-2450 nm Spectral Range by AvaSpec 2048. Based on the spectral characteristics of dried soil samples regardless of soil texture reflectance was low (8-14%) at the 400-420 nm range. Increase in reflectance was measured from mainly 480 nm, and reached its maximum at 980-1000 nm in NIR range. Different soil textures possess different spectral characteristics. The difference between the sand and sandy loam soil manifested mainly in the extent of reflectance. While reflectance curve of sand and sandy loam soil increases linearly with the wavelength, the gradual increase of the clay sample curves can be characterized as second and third-degree polynomial function. Besides, that loamy and clay soils reached their maxima at the NIR range, a local minimum value is observed in 900 nm also (Figure 2). There were no significant differences between spectral characteristics of loam, clay loam, clay and heavy clay soils.

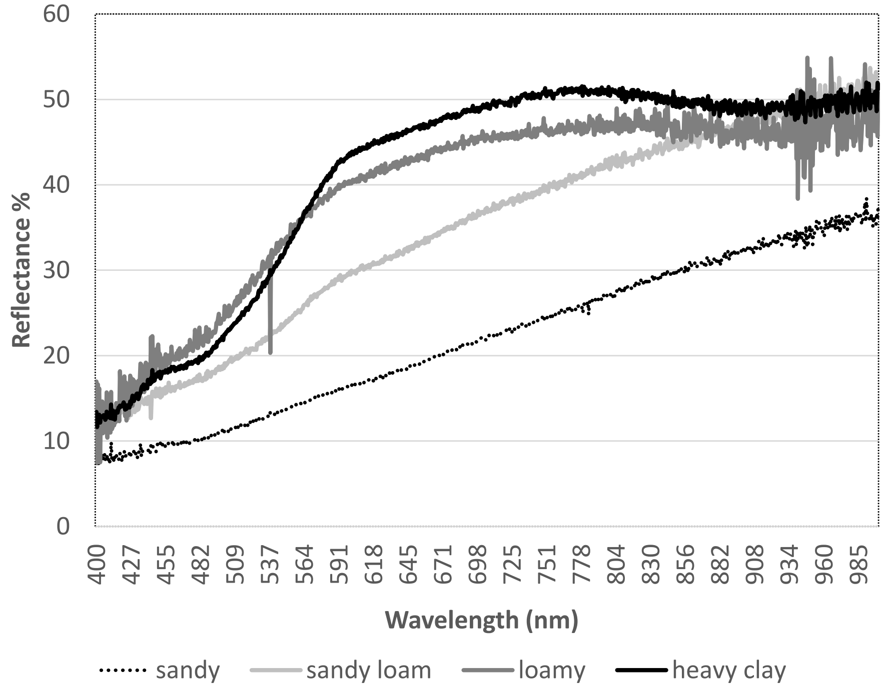

Figure 2. Spectral charachteristics of soils

In order to understand the relations between soil textures and spectral properties correlation and principal components analyses were carried out. Based on the statistical evaluation, soil texture was most sensitive to changes at 550 to 710 nm wavelength range (r^2> 0.6) (Figure 3.). In case of the Blue, Green and NIR range is not suitable for separation of soil texture.

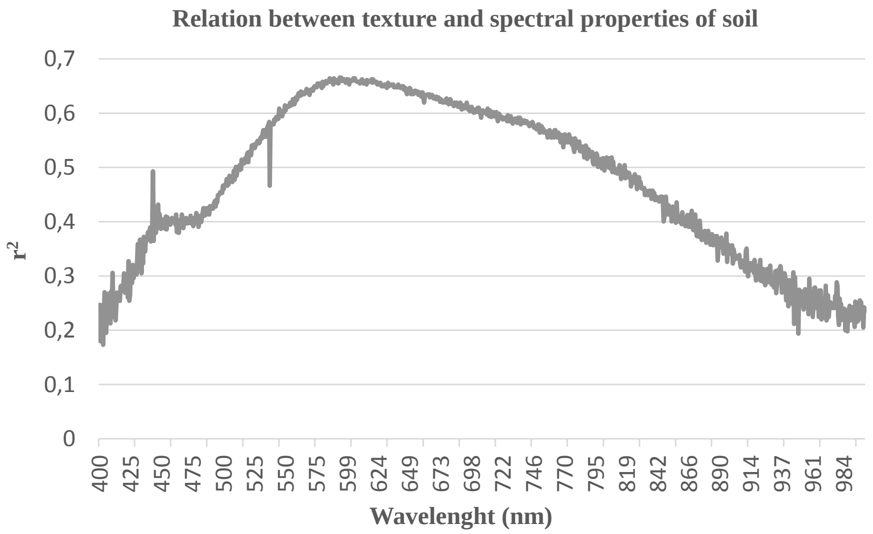

Figure 3. Relation between texture and spectral properties of soil

However, the correlation must be assessed in accordance with the fact that the spectral variability was low in loam, clay loam, clay and heavy clay soils. Additional correlation tests were made at 600 nm wavelength, which resulted the highest correlation among soil textures. The correlation between the all of the measured soil samples and the reflectance properties at 600 nm was strong r^2=0.66 (p = 0.002). On the other hand if loam, clay loam and clay soils were examined (sandy and sandy loam soils excluded from calculation) correlation is weak and not significant r^2=0.154 (p=0.342). In case of sandy, sandy loam and loamy soils significant strong correlation was found r^2=0.876 (p=0.000). The investigation resulted that 550 to 710 nm wavelength range may be suitable for separation of sand, sandy loam and loam soils. These findings were also confirmed by variance analysis between the reflectance data at 450 nm, 600 nm and 950 nm. The reflectance of sand, loam and sandy loam soil properties are significantly different at 600 nm, but only in case of sandy soil showed significant difference in reflectance at the NIR, Blue and Green range (Table 2).

Table 2. Differences between the different types of texture at specific wavelengths

	450 nm	600 nm	950 nm
Sand	8.38[a]	15.8[a]	32.6[a]
Sandy loam	15.9[b]	30.8[b]	46.9[b]
Loam	18.8[b]	41.4[c]	47.9[b]
Clay loam	19.6[b]	43.3[c]	49.1[b]

* there was no significant correlation between the data of the same letter index

However, soil samples were taken from different areas, so in addition to texture other different parameters of soil (humus content, clay mineral composition, lime content) can cause variations. These parameters and the limited number of samples can explain that there were no significant differences in reflectance in the case of high clay content. Based on the results, soils with spectrally different soil texture were evaluated in separate groups (sand, sandy loam and clay loam) for moisture analysis. Analysis of the impact of soil moisture on the spectral properties showed that regardless soil texture the increases of moisture affected the total reflectance curve between 400-1000 nm. In parallel with increasing moisture content, the reflectance showed trend like rising to higher wavelengths (Figure 4.). WBI index is not applicable in the case of soils since there were no substantial differences at the 900 and 970 nm reflectance.

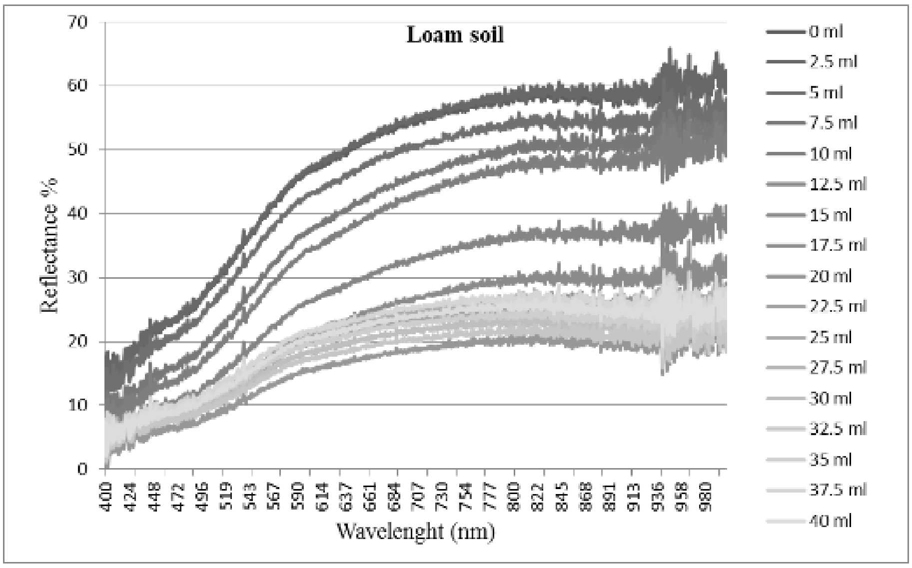

Figure 4. Reflectance of loam soils with different moisture condition

Regardless soil texture, variability between reflectance curves of groups with different soil moisture content (0-5%, 0-10%, 0-15% ... 0%-saturated soil) were not significant on the 400 nm, but reached its maximum at 900 nm. Because of great reflectance variability near infrared (NIR) wavelength range seemed to be sensitive to moisture changes. Based on the standard deviation curves of stepwise group categories (0-5%, 5-10%, 10-15% etc) it can be stated, that the increase of moisture content did not result linear changes in reflectance. The relationship is more parabolic-like, since, e.g. in sand soils very small variances were found in the case of the minimum moisture content category group (0-5%) and the variance was the highest in moderately wet condition groups, in the case of 5-20 % moisture change, whereas significant changes could not also be detected on saturated soil (20-25%) (Figure 5.). This phenomenon is likely due to the effect of wetting on the changing structure of the soil samples. Small amount of water caused better aggregation to dry soil, while too much moisture caused slurrification of soil sample.

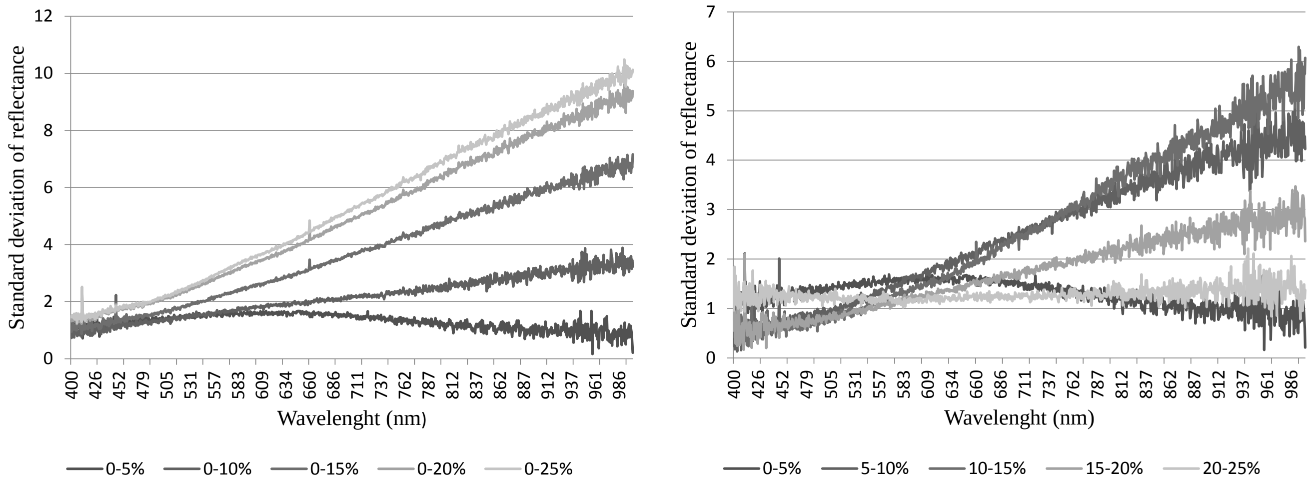

Figure 5. Variation curves of different moisture groups (sandy soil)

The reflectance variability of different moisture groups was confirmed by the results of principal component analyses. The factor weight of reflectance are growing towards the NIR range, which emphasize the importance of NIR range in moisture detection. The relationship between soil moisture and reflectance curves of the three soil texture groups (sand, sandy loam, as well as loam-clay) were also the highest in the NIR range (Figure 6.), although the differences between each soils types were also observed. In case of sandy soil the highest correlation was found at the near-infrared range, while it was the lowest in the visible range. In case of sandy loam and clay loam soils correlation differences were smaller than sandy soil in the VIS and NIR ranges.

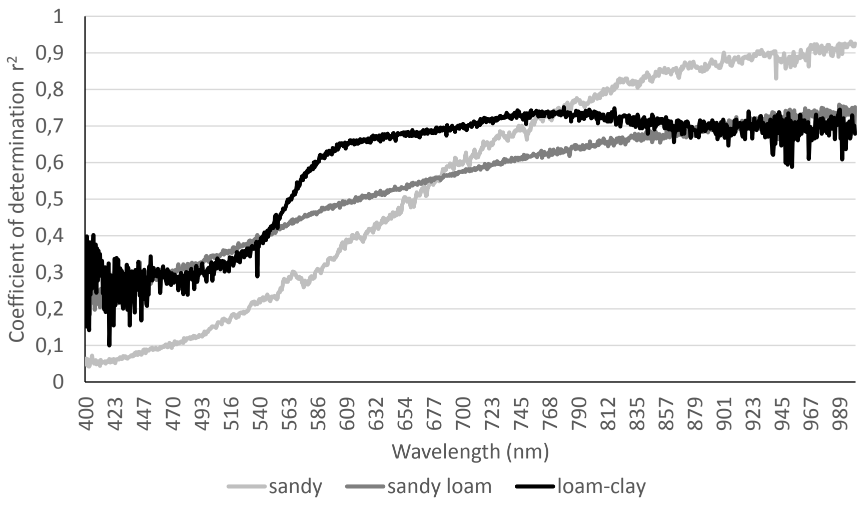

Figure 6. Correlations between the moisture content and spectral properties

Since the highest correlation and spectral variability were observed at the NIR range (and vice versa in the VIS range), ratio calculations out of the two reflectance values in the VIS and NIR wavelengths can be the solution to spectral monitoring of soil moisture. Simple ratio and difference indices were calculated based on the reflectance value at 950 nm and 450 nm. Application of the simple ratio index for moisture detection is not recommended, because there were no significant correlation between the index and moisture content of soils. The reason for this is that the moisture content affects to the total reflectance curve, and the proportion of decrease are similar in NIR and VIS ranges (Figure 7). However, the difference index showed strong negative correlation with the moisture content.

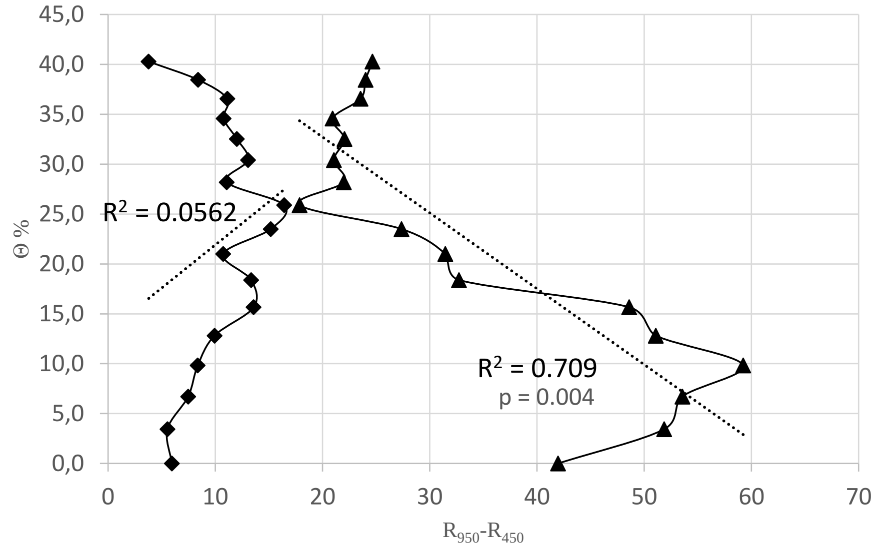

Figure 7. Simple ratio and difference indices depending on the moisture content in case of loamy soil samples (n_{tf}% is the volumetric water content)

Since the increase of moisture content did not result linear changes in reflectance, the difference index did not show significant difference over 25-30 % and below 5 % volumetric water content of moisture content. Analysing the moisture profiles of soils with different textures types, moderate and strong correlation was observed especially in the case of sandy soil. Nevertheless, this index can measure moisture content reliably only at 5-30 vol%. Concerning this fact, based on difference index, equations for moisture content estimation were set up separately for sand, sandy loam and loamy soils (Table 3). The equations were validated by Student-t-test; whereas no significant difference was detected between the measured and evaluated moisture values, these equations are valid to apply for measurement of soil moisture.

Table 3. Moisture estimating equations in case of sand, sandy loam and loamy soils

	0% - water saturation		5-30 n_{tf}%*		
soil texture	R^2	P	R^2	P	estimator equations
sand	0.796	0.002	0.819	0.001	$y = -0.7874x + 32.753$
sandy loam	0.681	0.012	0.774	0.007	$y = -0.4483x + 34.144$
loamy	0.584	0.044	0.827	0.001	$y = -0.66x + 38.528$

*n_{tf}% is the volumetric water content

Impact of Soil Moisture on the 1000-2450 nm Spectral Range by Field Spec Junior

The spectral properties of the soils are different in the 350-830 nm range from the measured ones with the previous instrument and other studies (Bowers et al. 1965, Nagy et al., 2009). While in other studies a continuous increase is described in reflectance at the 350-830 nm region, in this case the initial rapid increase at 450 nm followed by a significant valley with minimum value at 590-610 nm, and then a significant increase was detected (Figure 8). Possible reason for this phenomenon is that in the case of Field Spec Junior laboratory sampling box could not be used, so reflectance was highly influenced by the environment. Due to this high reflectance uncertainty the values of the spectral curves below 1000 nm had to be ignored in further examinations. On the basis of spectral profiles - measured with the Field Spec Junior spectrometer –, there were also differences between sand and loam soils, but differences between the loam and clay soils was found only at wavelengths above 1700 nm. Due to the described uncertainties and the low number of samples, there is a need further examination to identify differences between clay containing soil types.

Concerning the reliability of our results, the effect of moisture content on spectral properties were analyzed at the wavelength range between 1000 and 2450 nm. The 1450-1460 nm and 1920-1930 nm wavelength range were the most sensitive to moisture. Similarly to each wavelength, the moisture content decreases the reflectance of the sensitive ranges as well, but the rate of decrease was nearly triple (Figure 9).

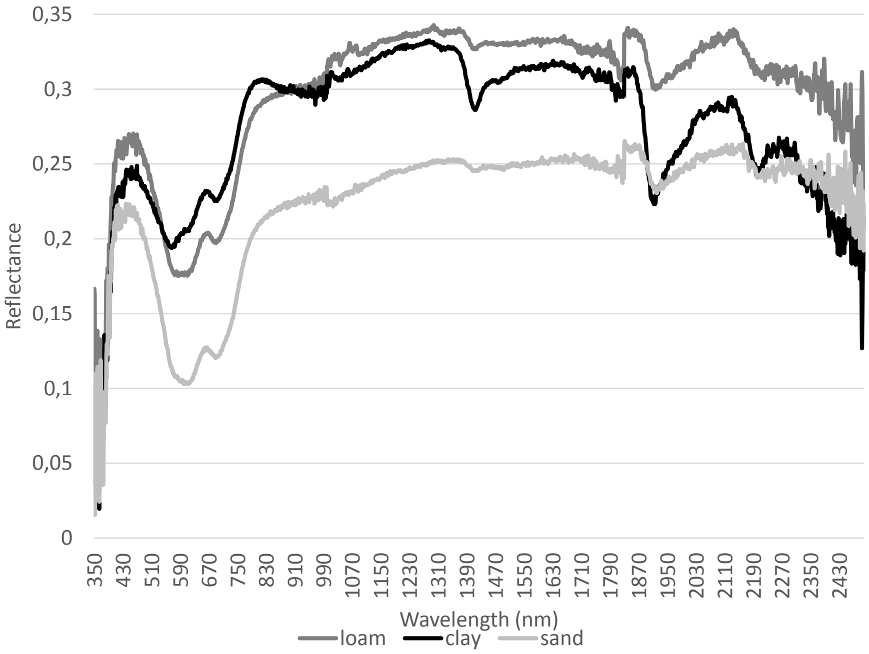

Figure 8. Soil spectra measured by Field Spec Junior

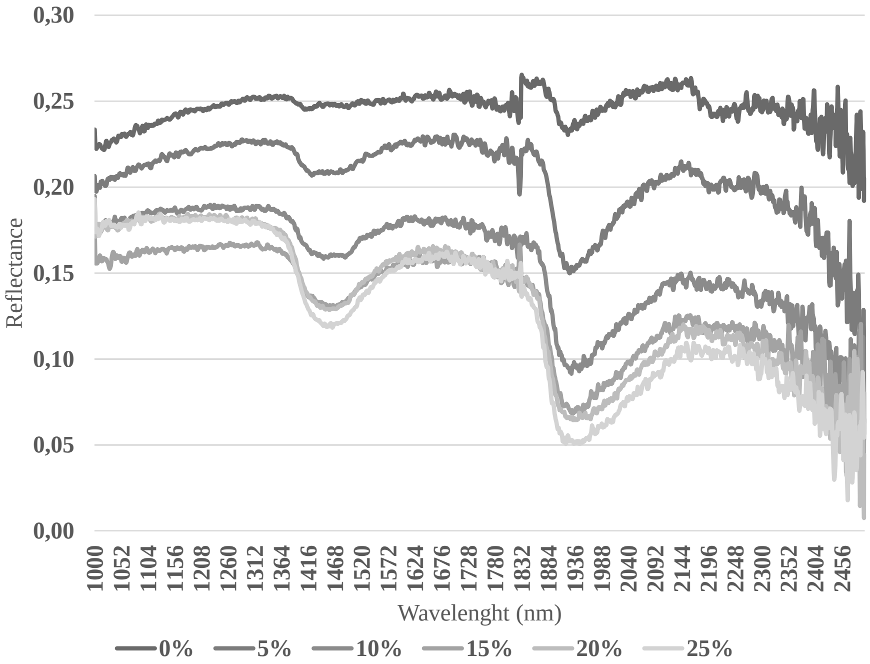

Figure 9. Reflectance of sandy soil (1000-2500 nm) in different moisture conditions

Moisture content indexes were created by the quotient of the moisture sensitive spectral ranges. The local minimum of spectral range and the closest local maxima were used to calculate the following simple ratio indices R1350/R1460 and R1860/R1925.

In this case due to the small sample size, soil textures were not separated from each other. The separation was not necessary, because despite there are significant differences among soil textures of dry samples, indices are calculated from the ratio of two reflectance values which are independent from soil texture, and not affected by any other parameters but moisture. Correlation and linear regression analysis showed that there is a strong relationship between the values of moisture content and the indices. Out of the two indices, the index R1350/R1460 seems to give more reliable result in moisture detection since the effect of soil texture in the range above 25% moisture content were more significant in the case of R1860/R1925 index (Figure 10.). Based on the validation, the R1350/R1460 is s recommended for moisture monitoring and measuring.

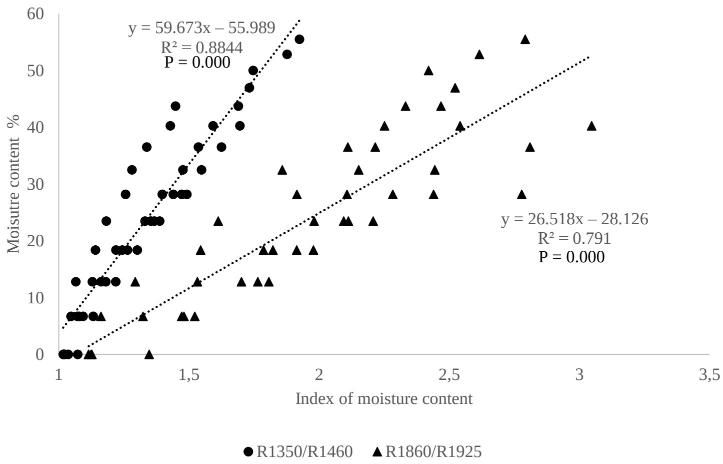

Figure 10. The correlation between soil moisture content and index of t

Conclusion

Based on the results of AvaSpec 2048 spectrometer, moisture content the increase of moisture content did not result linear changes in reflectance. Based on the spectral properties difference index (R950-R450) was calculated with a well-defined measurement range. There is no significant correlations between spectral features and soil moisture over 25-30 % and less than 5% of moisture content. Concerning this fact, based on difference index, equations for moisture content estimation were set up separately for sand, sandy loam and loamy soils. Using the difference index and the calculated equation water content can be calculated till full saturation in the case of sandy soil and near full saturation (at PF1) in case of sandy loam. In the case of loamy soils water content can be calculated till the field capacity of loam (at pF 2.5). From irrigation scheduling point of view it is optimal, since the total available water content can be measured in the case of sandy, sandy loam and loam soils. The clay has 46 % of field capacity and 33 % water at wilting point (Filep, 1999), so that this measurement method is not applicable in the case of clay soils.

As a results of the Field Spec Junior measurements between 1000-2450 nm range 1450-1460 nm and 1920-1930 nm wavelength range were found to be the most sensitive to moisture and based on these sensitive wavelengths moisture-sensitive indices and estimating equations were created. Based on the results of the use of R1350/R1460 index is recommended for soil moisture calculation, since the soil texture differences has only slight effects on the index. The method of measuring soil moisture by spectral properties and using the developed spectral indices provides the fast determination of water content of a certain soil. As a result, such up to date information can be obtained on water supply, which is essential for irrigation, and from agro technical point of view. Additionally, it is suitable for the calibration of airborne hyperspectral images.

Acknowledgements

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