MODELLING OF THE REFLECTANCE CONTRAST BETWEEN SOILS UNDER UNLIMITED SOIL MOISTURE, ROUGHNESS AND ILLUMINATION CONDITIONS

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INTRODUCTION

Spectral data of a given bare soil collected in field conditions, but at different moments, are not the same, because the soil reflectance changes dynamically. It was found that in the visible and near-infrared range it did not only depend on soil surface factors, such as the soil moisture and the roughness state, but also on illumination and viewing of the soil. For some soils the influence of these factors is clear, but for others, it may be insignificant. As a result of it, the spectral contrast between the soils changes unpredictably.

The aim of this work is to determine in what range of the illumination and moisture conditions the reflectance contrast in the interval of 0.32-1 μm between natural adjoining soils (of different roughness) reaches extreme values. The work was carried out on the example of typical soils of the Koscian diluvial plateau in Wielkopolska Lowland situated in western Poland.

METHODS

Two partial mathematical models, describing relations between the spectral response of bare soils in the range from 0.32 to 1 μm and: 1/ the soil-water potential, and 2/ the soil surface roughness were used in these studies.

ad.1/ Model (Cierniewski 1986) - was worked out on the basis of laboratory spectrophotometrical measurements of soil samples (from sand to sandy loam of organic matter content in the interval of 0.3-5.2%) brought to 12 following soil-water potential values: 0, 1, 1.5, 2, 2.5, 3, 4, 4.5, 5, 5.5, 6 and 7 pF. The relation between the relative spectral reflectance coefficient (βp), refered to defined wavelengths (λ), and the soil-water potential (p) was described by a square curve supplemented by a line parallel to the soil-water potential axis. The βp expresses the ratio of the soil reflectance at given soil-water potential ($R_{\lambda,p}$) to the reflectance of the same soil, but dry, i.e. at the higher potential than 5.2 pF ($R_{\lambda,p\geq 5.2}$). It practically enables to use this function (at a given wavelength) for describing textural different soils.

ad.2/ Model (Cierniewski 1987) is based on the assumption that the reflectance from anisotrropic rough soil surfaces is strongly correlated with the shadowed per unit area of soil fragments, which is called the shadowing coefficient of soil surface (SC_n). A rough soil surface is simulated by using equal -sized spheres lying in a net of squares on a freely sloping plane (γ). The roughness factor of this structure (RF_m) is defined as proportion of the sphere area from top view in a given unit of area whose side equals a distance between the spheres. The RF_m increases with the distance in relation to the spehres diameter increase with the distance in relation to the spheres diameter increase. This factor corresponds to a parameter of the state of soil roguhness in field conditions expressing a proportion of the aggregates' and clods' area in top view in a given soil surface area (RF_n). The modelled structure, forward or backward sloping to the sunbeams direction (sl) , is illuminated by the sunbeams projected ad an angle a to simulating the solar altitude. The total shadowed area, in a given area unit, in the horizontal projection, necessary for the determination of the shadowing coefficient of the modelled surface (SC_m), was found analitically by solving trigonometric equations. This model finally assumes that there is an exponential relationship between the SC_m and the reduction of the soil reflectance level (β_r) in relation to data for the same soil but in smooth and dry conditions.

The mentioned models, linked together in one, covert the bare soil reflectance data obtained for dry and smoot samples (d_λ) into data relating to any natural rough surface states (RF_n) under unlimited illumination and moisture conditions ($R_{\lambda,RF_n,\gamma,sl,p}$) defined by the solar altitude (α), the angle of slope (γ), the sloping of the soil surface relating to the sunbeams directions (sl) and the soil-water potential (p):

$$R_{\lambda,RFn,\gamma,sl,p} = d_\lambda \cdot \beta p_p \cdot \beta r_{RFn,\alpha,\gamma,sl}.$$

This composite model needs only five input spectral data (d_λ) corresponding to wavelengths (λ) of 440, 540, 640, 740 and 860 nm. The soil reflectance output data, concerned to the remaining wavelengths in range of 0.32-1 µm, were calculated at every 20 nm by the Condit's equations (Condit 1970).

This discussed model was used to simulating, by microcomputer, the reflectance contrast between chosen soils for the five wavelengths mentioned above.

RESULTS

The chosen soils belong, according to the Polish classifying system to: initial loose denudative soils (Id), typic brown podsolic sols (Bt), eroded (with Bt horizon on the surface) brown podsolic soils (Be), degraded black earths (Dd) and typic black earths (Dt). The description of these soils together with their approximate equivalents under the American soil classification system are listed in Table 1. Their spectral curves are shown in Figure 1.

The functioning of the model, only in the sphere of the soil roughness on the soil reflectance, is presented in Figure 1. and the soil illumination on soil curves examples of the initial denudative soils (Id) of low roughness (RF_n=0.05) and the eroded brown podsolic soils (Be) of the high one (RF_n=0.5) (Fig.2.). This first curves, as a result of the soil sloping in relation to the sunbeams direction, manifest a higher spectral differentiation for the low solar altitude than for the high sun level, but the next ones show the opposite relation. Each of the studied soils, in the analysed conditions for the solar altitude from 15 to 60^o, demonstrates the highest reflectance on the sun-facing slope, and the lowest spectral response on the backward slope.

Table 1. Description of the studied soils

Soil symbol	Order	Texture	Content (%) of sand	silt	clay	Dry soil wet color	OM (%)	RF_n
Id	Entisol	s	90	9	1	10YR 7/3 10YR 4/4	0.5	0.05
Bt	Alfisol	ls	78	20	2	10YR 6/3 10YR 4/4	1.5	0.25.
Be	Alfisol	sl	66	23	14	10YR 6/4 10YR 4/4	1.6	0.5
Dd	Mollisol	sl	70	27	3	10YR 3/2 10YR 2.5/1	3.0	0.4
Dt	Mollisol	sl	64	31	5	10YR 3/1 10YR 2/1	4.5	0:45

OM - organic matter content, RF_n - soil surface roughness factor, s - sand, ls - loamy sand, sl - sandy loam.

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Soils covering ridges and slopes of local elevation, i.e. Id, Bt and Be were analysed for two slope angles 0° and 10^o, but soils which occupy local depresions, i.e. Dd and Dt were only examined in horizontal position (Fig.3).

The results of the soil spectral simulation clearly demonstrate that the soil moisture has stronger influence on the soil reflectance contrast from among all the analysed soils. The highest influence is observed in dry soil conditions above 5.2 pF and the lowest influence in the soil moisture near field water capacity, i.e. about 2 pF.

On the one hand, if the reflectance contrast concernes soils of a very high roughness differentiation (such as between Id and Bt), it is practically the highest at the solar altitude near 30^o. This contrast is extreme high when one of the soils is on the backward slope and therefore it is completely shadowed. This situation, because of very low solar altitude, has no practical meaning. On the other hand, if the spectral contrast concernes soils of a low roughness differentiation (such as Bt-Be, Bt-Dd and Dd-Dt) near the solar altitude of 30^o it is the minimal in the most examined situation and it increases in the direction of the extreme solar altitude values.

This spectral simulation also demonstrates that the lowest contrast between the chosen soils is for wavelength of 440 nm, whereas the highest one is difficult to explicity define for all the examined soils (Fig.4.).

CONCLUSIONS

1. The simulation of the spectral contrast between the chosen soils clearly demonstrates that it is the highest one in dry soil conditions, i.e. in soil-water potential above 5.2 pF.

2. In natural range of the solar altitude, for studied soils ($\alpha \leq 60^{0}$), there is no common a value for which all the adjoining soils can reach the maximal spectral contrast. For similar soil cover, like the discussed example, the distribution of the lowest soil spectral contrast should decide about the choice of the most useful solar altitude for distinguishing soil units. According to this example, it is the sun elevation of 60^{0}.

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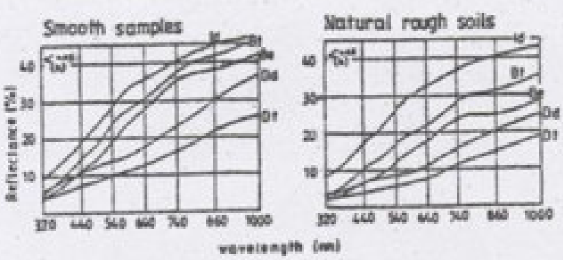


Figure 1. Reflectance curves of dry studied soils for horizontal position (h) and the solar altitude α of 45° in smooth and natural rough states

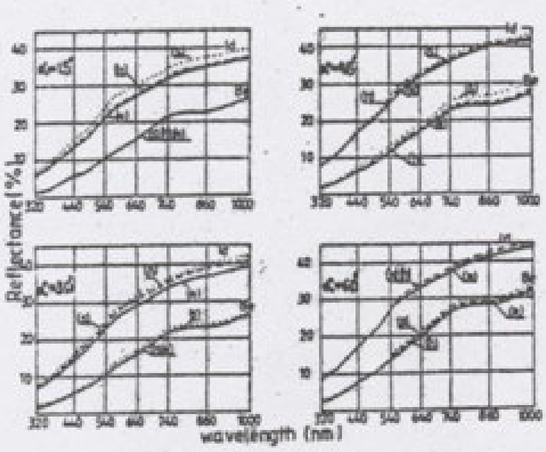


Figure 2. Spectral curves of the initial loose denudative soils (Id) and the eroded brown podsolic soils (Be) under different solar altitude (α) for the horizontal position (h) and the sun-facing slope (S)or the back slope (N) at the slope angle of 10°

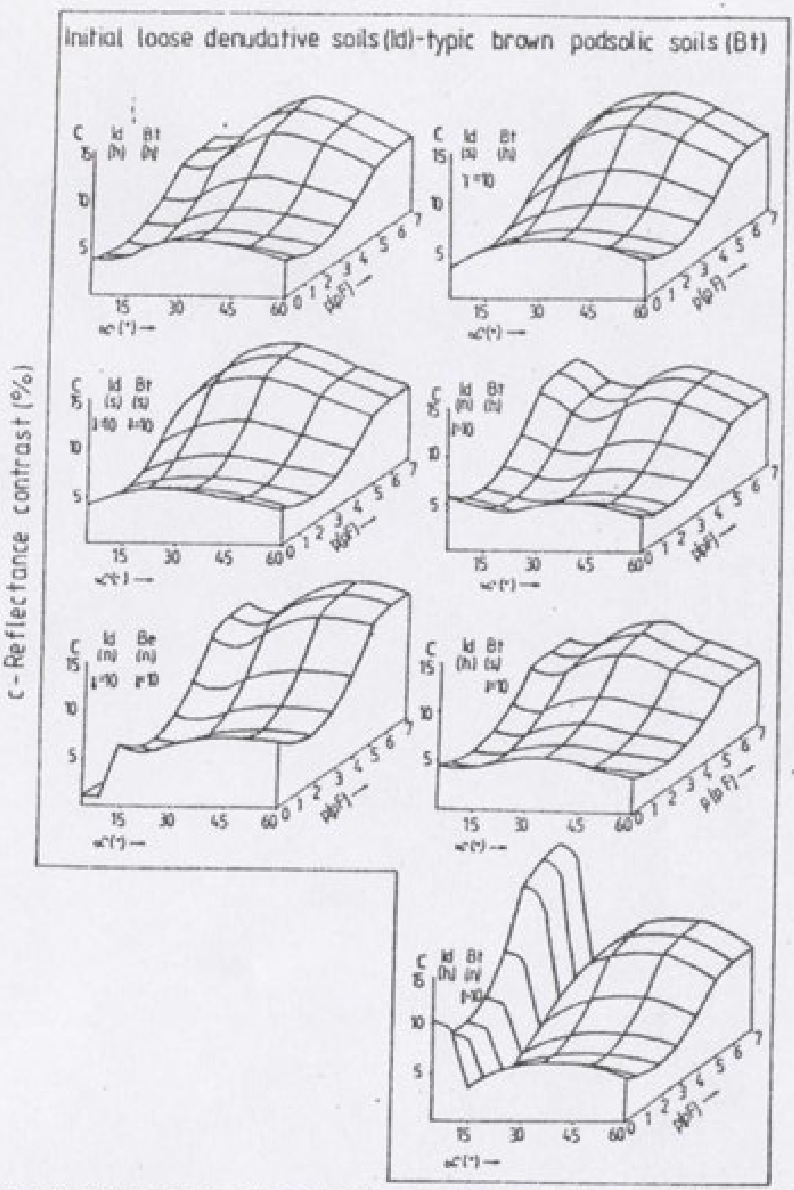
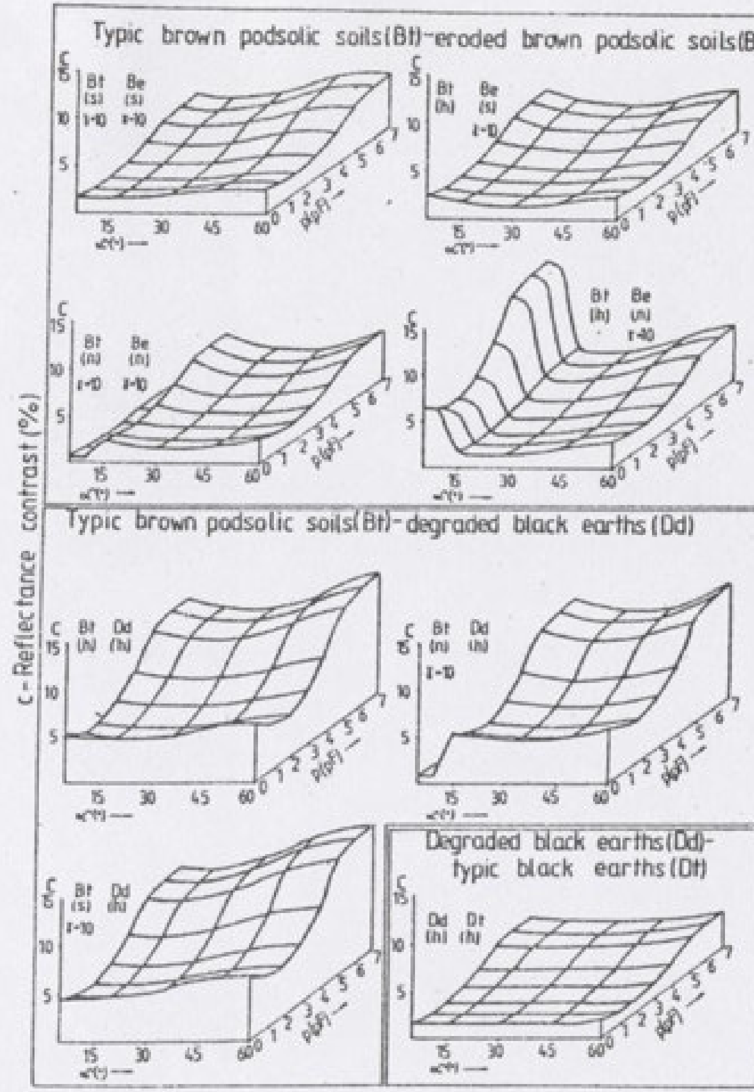


Figure 3. Spectral contrast between the adjoining soils under their extreme position in relation to the sunbeams direction in the function of the solar altitude (α) and the soil-water potential (p) for wavelength of 640 nm



Continuation of Figure 3

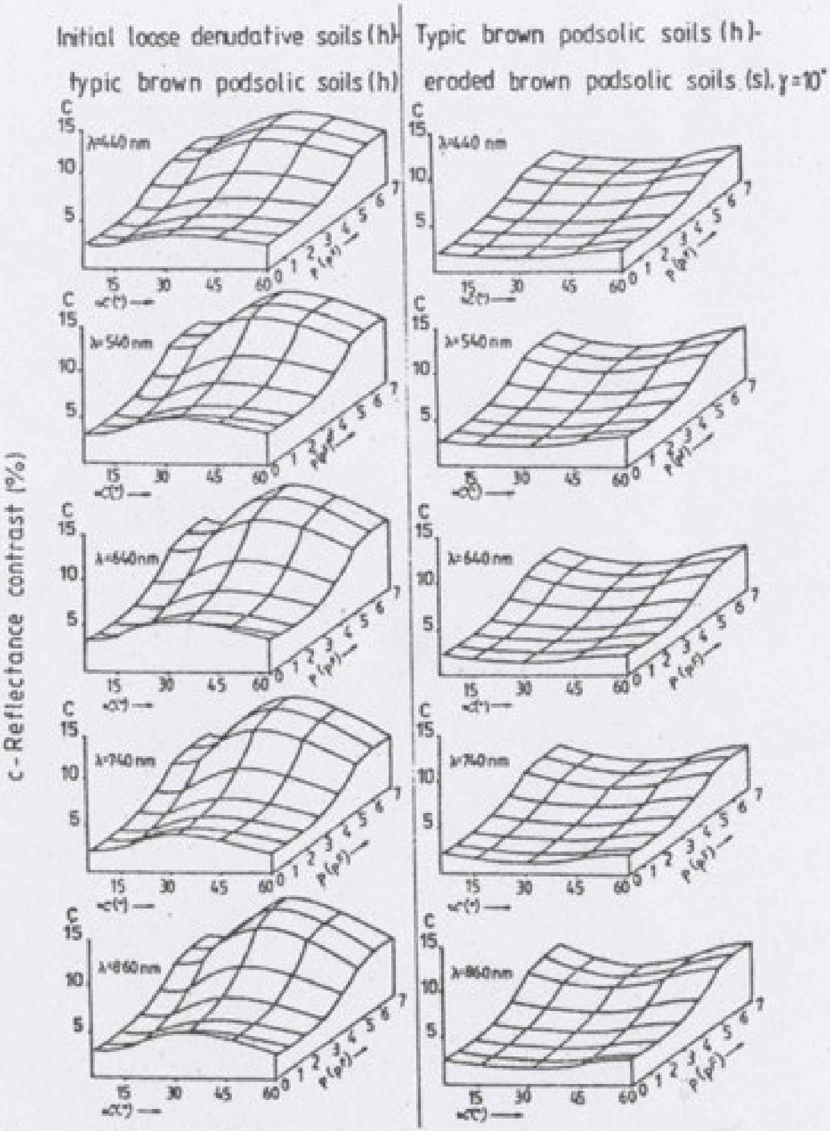
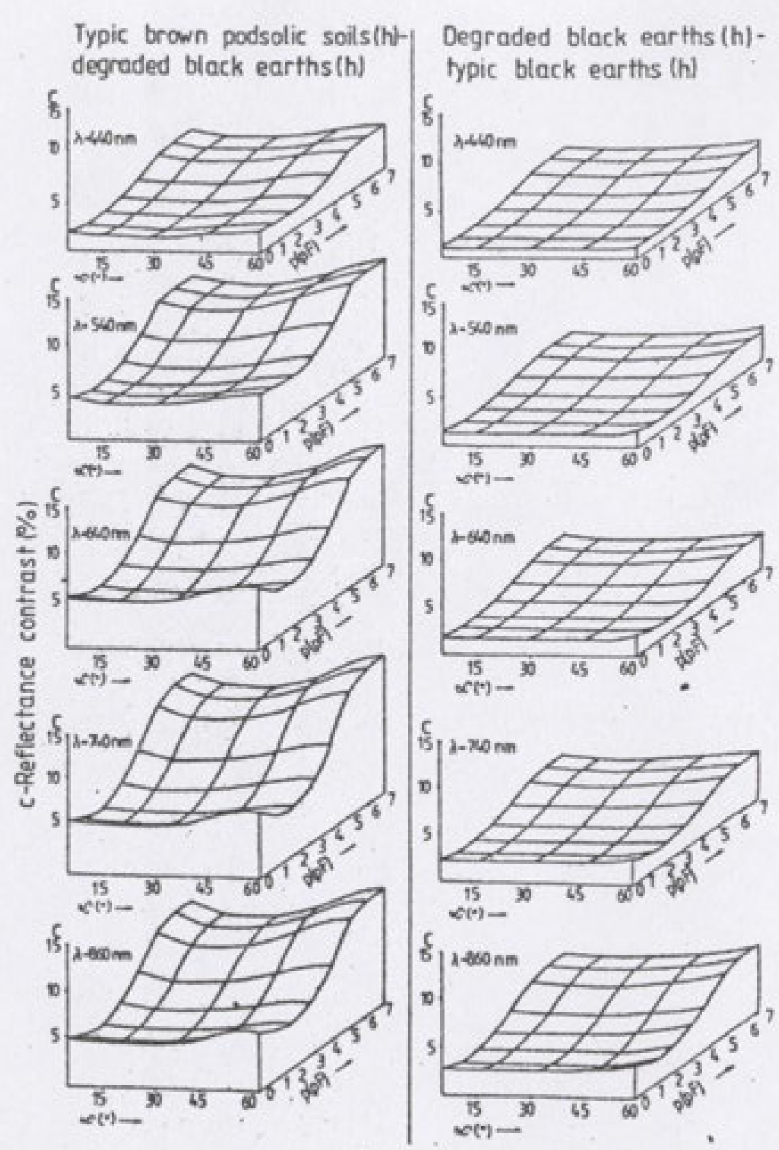


Figure 4. Spectral contrast between the adjoining soils under their horizontal position (h) or the sun-facing slope at the slope angle (γ) of 10° in the function of the solar altitude (α) and the soil-water potential (p) for different wavelengths (λ)



Continuation of Figure 4