A TOOL FOR PREDICTING DIURNAL SOIL ALBEDO VARIATION IN POLAND AND ISRAEL

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ABSTRACT

Results of studies on the effects of soil surface roughness on the diurnal broadband blue-sky albedo variation of cultivated and uncultivated soils conducted so far in Poland and Israel indicated that the spectral reflectance behaviour of so genetically different soils such as those developed in these countries is similar enough to use the same procedure to predict the albedo's variation for all the soils together. This paper discusses this variation using data generated by equations describing the overall albedo level of these soils taking into account only the organic carbon and carbonates content and the slope of their diurnal albedo increase in the function of the solar zenith angle, disregarding other properties of the soils.

INTRODUCTION

Albedo integrates the surface reflectance over all view directions and is defined as the fraction of the incident solar reflective radiation in the range of 0.3-3 µm (1). Vegetation cover on light-coloured soils reduces the albedo, while on dark-coloured soils it increases the albedo (2). The brightness of soils is mostly determined by the content and quality of soil organic carbon (3). The albedo of bare soils changes dynamically, mainly as the consequence of their moisture and roughness. The spectral reflectance of bare soil increases with a decrease of soil aggregate and clod size (4). Matthias *et al.* (5) found that the albedo was 27, 18, 10, and 8% lower for dry rough-plough, disk, disk–disk, and seedbed treatments, respectively, as compared with the albedo of smooth soil. Monteith and Szeice (6) showed that broadband blue-sky albedo of bare-soils increased from 0.16 to 0.19 when the solar zenith angle (θ_s) increased from 30° to 70°. Kondratyev (7) mentioned that during the morning, when θ_s decreased from 60° to 10°, the albedo of dry rocky and loamy soils decreased from 0.22 to 0.14 and from 0.34 to 0.21, respectively. Cierniewski *et al.* (8,9), found that the diurnal albedo of deeply ploughed surfaces only rose slightly at θ_s values lower than 75°, while the albedo of smooth uncultivated surfaces clearly increased throughout the analysed θ_s ranges.

This paper reports studies conducted in Poland and Israel aimed at the effects of soil surface roughness on the diurnal variation of broadband blue-sky albedo of cultivated and uncultivated soils. The results obtained so far indicate that the spectral reflectance behaviour of so different soils such as those developed in Poland and Israel is similar enough to use the same equations to predict the diurnal broadband blue-sky albedo variation for all of the soils together. This paper focuses on the diurnal albedo's variation generated by the equations.

METHODS

These studies were conducted from April to September in 2011-2013 on 81 and 6 plots with cultivated soils in the Wielkopolska region in Poland and the Israeli Negev, respectively, as well as on 12 plots with uncultivated desert soil in the Negev. These cultivated soils were tested as formed by planters, ploughs, disk harrows, pulverizing harrows and smoothing harrows and some of the soils as modified by rainfall and sprinkler irrigation.

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The broadband blue-sky albedo (α) of the soils was measured with albedometers LP PYRA 06 in a spectral range of 0.335 – 2.8 μm under clear-sky conditions when the surfaces were air-dried. The roughness of the soil surfaces was investigated as revealed by stereo-photographs taken with a 12.2 MP Canon EOS 450D camera that was moved along the levelled construction above the ground. 3-D images of the plots were visualised by means of the PCI Geomatica Orthoengine 10.2 software, and their digital elevation models (DEMs) were created using the TNTmips 2012 software.

The textural composition of the soil surface material was analysed using a hydrometer, the organic carbon content by Walkley Black's method, the calcium carbonate equivalent by Piper's method, and the total "free" iron oxide by the CDB method described by Mehra and Jackson (10).

RESULTS

The World Reference Base for Soil Resources 2007 (11) was used to classify the studied soils. The lowest colour value, 4, in the soil Munsell colour system of the dark-coloured soils studied in Poland (developed from loamy sand (LS)) classified as *Phaeozem* of the WRB major reference group, mainly results from their relatively high soil organic carbon (*SOC*) content, the absence of $CaCO_3$. The colour value, 5 - 6, of the remaining soils studied in Poland, belonging to the *Arenosol* and *Gleysol* major groups (developed from sand (S)) and the *Luvisol* group (developed from LS and the sandy loam (SL)), contain less of the *SOC* by an average of about 1% and, on average, quite similar quantities of Fe_2O_3 of about 0.2%. The colour value of the soils investigated in Israel, developed from loam (L) and SL and classified as *Calcisol* and *Regosol*, respectively, reaches even up to 7. They contain a similar amount of the *SOC*, but more than 20-30% of the $CaCO_3$ found in the light-coloured soils tested in Poland.

The shape of all the tested plots was computed from their DEMs using two roughness indices, *HSD* and T_{3D}. The *HSD* expresses the height standard deviation of a soil surface area within its delineated basic DEM unit, while the T_{3D} is the ratio of the real surface area within the DEM unit to the flat horizontal area of the unit. The plots that were freshly formed by a plough (Pd) were described by the T_{3D} as the most irregular with a number of 1.5, higher by about 20% compared to the surfaces shaped by a planter (Fp). A stormy rainfall significantly reduced the irregularities of the plots formed by the Fp located on the *Arenosols* developed from S. Their average T_{3D} dropped by about 20%. The natural desert rough (Dr) and smooth (Ds) soil surfaces were characterized by the average T_{3D} index similar to the cultivated surfaces shaped by a smoothing harrow (Hs) and treated by those tools modified by rain.

All datasets of the diurnal variation of α were analysed as the function of θ_s. They demonstrated a very slight or gradual increase of the soil α between the θ_s (at the local noon) and about 75°-80° of the θ_s. Above these θ_s values, the α increase was rapid, reaching 1 near sunset. The relation between the α and θ_s of the datasets from the local noon to sunset was quantitatively described by:

$$\alpha(\theta_s) = \exp\left[\left(a + c\theta_s\right)/\left(1 + b\theta_s + d\theta_s^2\right)\right], \quad (1)$$

where *a*, *b*, *c*, and *d* are parameters. To allow a comparison of the diurnal variation of the α in different datasets, α values were calculated with respect to the α at the $\theta_s = 0°$, denoted hereafter as α_o. Examples of the half diurnal α datasets referring to the *Phaeozem* and *Calcisol* collected in Poland and Israel (Figure 1) show that their α_o depends not only on the colour value of the soils, but also on their surface roughness caused by a specific farming practice and the modification caused by water. The α_o of the dark-coloured *Phaeozem,* treated by the Pd, as compared to the same soil formed by the Hs is 15% lower, and the α_o of the light-coloured *Calcisol* Pd, as compared to the same uncultivated (Ds) soil, is 45% lower. The roughness indices are variables that precisely determine only the α_o of soils with the same colour value, such as those studied in Israel. If the contents of *SOC* and $CaCO_3$ were treated as the dominant variables, combined with the T_{3D}, these three variables together significantly described the α_o of all the soil surfaces studied in Poland and Israel, using the following formula:

$$\alpha_o = 0.301 - 0.042\,SOC + 0.007\,\mathrm{CaCO_3} - 0.088\,T_{3D} \quad (2)$$

Soil roughness not only affects the overall level of the diurnal variation of the albedo, but also affects the intensity of the diurnal increase from the θ_s at the local noon to about 75°-80°. This intensity (s_α) was determined by the slope of the α increase as a function of θ_s:

$$s_\alpha = \left(\alpha_{\theta_s=50^\circ} - \alpha_{sm}\right)/\left(50^\circ - \theta_{sm}\right) \quad (3)$$

The high ratio of performance to deviation (RPD), higher than 2, calculated for the relations expressed by Eqs. (2) and (3) confirmed their statistical precision (9). The minimally rising values of the α at the specific θ_s range were clearly related to the plots freshly formed by the Fp and Pd, as well as shaped by those tools and modified by rain or sprinkler irrigation. It was found that the *HSD* variable, like T_{3D}, is sufficient to accurately describe the slope of the albedo's increase of all the soil plots investigated in Poland and Israel, disregarding other soil properties.

The diurnal α variation of the soils studied in Poland and Israel, shown by the diagrams in Figure 2, were generated as the function of θ_s using Eqs. (2) and (3) for θ_s lower than 75°, and Eq. (1) for θ_s between 75 and 90°, assuming that α reaches 1 at θ_s of 90°. The diagrams relate to light and dark-coloured soils with a *SOC* content varying between 0 and 3%. These graphs characterise soils with the $CaCO_3$ content of 0, 15, and 30% in changing states of roughness expressed by the T_{3D} index. The T_{3D} values between

- 1.025 and 1.1 describe the Ds and Dr desert soils, as well as cultivated soils formed by the Hs and that tool modified by rain;
- and 1.2 relate to soils formed by a pulverising harrow (Hp), disk harrow (Hd) and those devices modified by rain and sprinkler irrigation (Hd+w);
- and 1.6 represent soils shaped by a plough (Pd), planter (Fp) and formed by those tools and then modified by rain or sprinkler irrigation.

The α data generated in such a way allow us to state that a higher *SOC* content of 1% reduces instantaneous α values by about 0.04, while a 15% higher carbonate content results in an increase of instantaneous α values by about 0.1. Reduction of the soil roughness, expressed by the T_{3D}, results in increasing α at θ_s of 75° with varying intensity. If T_{3D} decreases from 1.6 through 1.2, 1.1, to 1.05, the α at this θ_s value approximately increases by the same value of about 0.02, although the index value successively decreases less intensively.

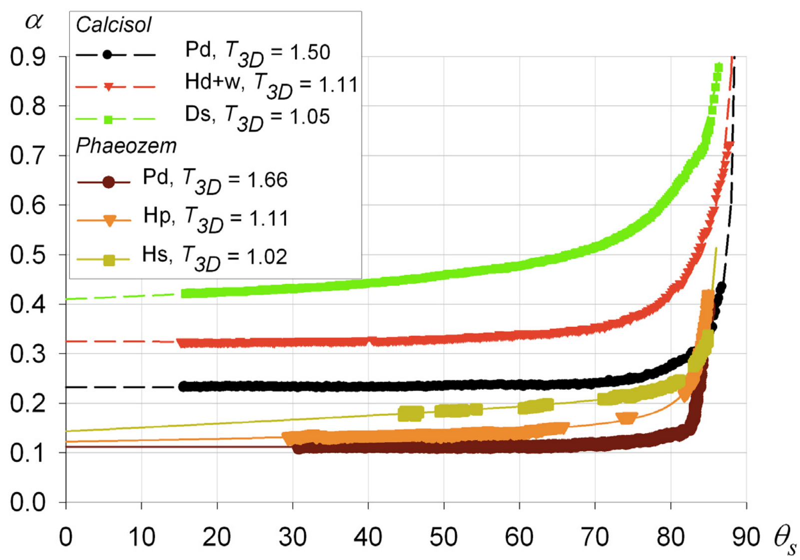

Figure 1: Variation of half diurnal albedo for different treatments: the dark-coloured Phaeozem formed by the plough (Pd), disk harrow (Hd), smoothing harrow (Hs), and the light-colour Calcisol, natural, uncultivated (Ds) and formed by the Pd, Hd and Hs the Hd modified by irrigation (Hd+w).

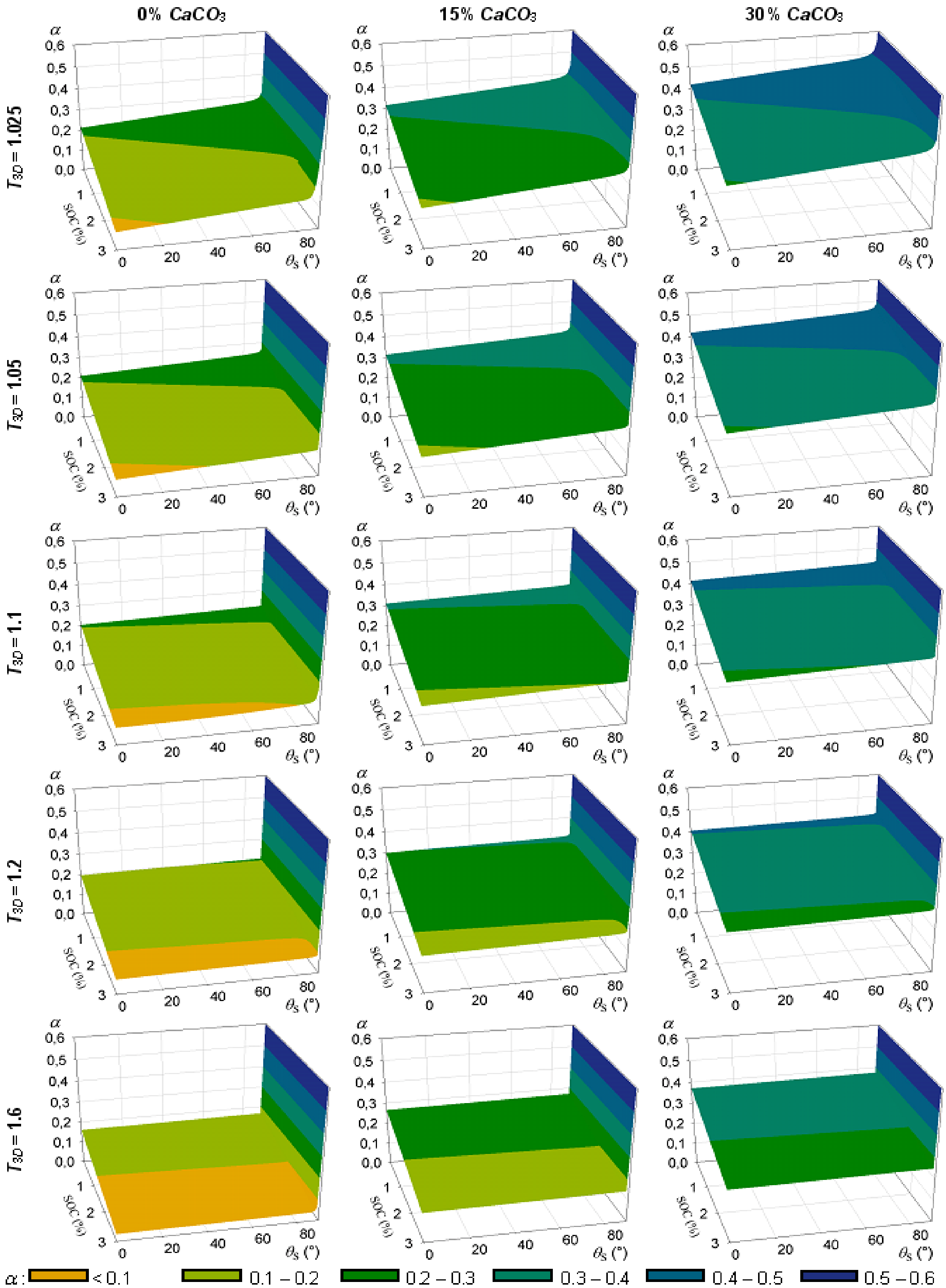

Figure 2: Diurnal albedo variation of the studied soils generated taking into account their soil organic carbon (SOC) and carbonates ($CaCO_3$) content and the roughness index (T_{3D}).

CONCLUSIONS

These quantitative dependencies between soil surface roughness and the diurnal variation of the broadband blue-sky albedo require further studies on other examples of soils.

Knowing that the albedo varies during the day, it seems that attention should be focused on the time of the satellite's acquisition of the albedo, which would correspond to its average diurnal value. Cierniewski *et al.* (8), using the preliminary results of these studies related to the moderately rough soils, calculated the optimal time for their average diurnal albedo observation using satellites on the sun-synchronous orbits, and also assessed the usefulness of some of the satellites for this purpose with errors lower than ±2%.

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