Journal of Quantitative Spectroscopy & Radiative Transfer 217 (2018) 213–223

Contents lists available at ScienceDirect

Journal of Quantitative Spectroscopy & Radiative Transfer

journal homepage: www.elsevier.com/locate/jqsrt

Estimating the diurnal blue-sky albedo of soils with given roughness using their laboratory reflectance spectra

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ARTICLE INFO

Article history:
Received 16 April 2018
Revised 4 June 2018
Accepted 4 June 2018
Available online 7 June 2018

Keywords:
Bare soil
Blue-sky albedo
Roughness
Hyperspectral reflectance

ABSTRACT

Various soil properties derived from soil reflectance spectra can effectively provide reliable data for soil monitoring, digital soil mapping, precision agriculture, and environmental modelling. This paper focuses on the improvement of the equations published in the previous paper predicting the diurnal blue-sky albedo of bare soils with given roughness using their reflectance spectra measured in laboratory conditions. The improved equations based on a 33% increase in the number of analysed soil samples and primarily on the quality expansion of the newly tested soil population. The albedo of the soils was measured when they were air-dried under clear sky conditions by albedometers working in a spectral range of 335–2800 nm. The roughness of the cultivated soils was measured using stereo-photographs taken with a digital camera and described by two roughness indices. The laboratory reflectance spectra of the soils were obtained using a spectroradiometer with a Hi-Brite Muglight receptor in the wavelength range of 350–2500 nm. The raw soil reflectance data and their transformations (linearization, normalization and filtering) were used in the equations mentioned above. Transforming spectra to the 2nd derivative using the Savitzky–Golay method gave the strongest accuracy of the prediction expressed by the coefficient of determination equals 0.91 and root mean square error 0.03.

1. Introduction

The broadband blue-sky albedo (α) level of bare soils depends mainly on their properties that remain almost unchanged, such as organic carbon (SOC), carbonates ($CaCO_3$), and iron oxide content [1]. The higher the content of SOC and iron oxides, and the lower the content of $CaCO_3$, the lower the α level. Cierniewski et al. [2] have also shown that the α level for many of the different soils in Poland and Israel, for values of the solar zenith angle (θ_s) below 75°, can be accurately enough described by their SOC and $CaCO_3$ content together with their roughness indices. The roughness of cultivated soils, as well as their moisture, are treated as the most dynamically changing properties of soil surfaces. Matthias et al. [3] reported how the α value of soils treated successively by a plough, a disk, and a seedbed, progressively increased. Raindrops and droplets created by sprinklers reduce the irregularity of the soil's surface, and after drying its α value increases [4,5]. Kondratyev and Fedchenko [6] found that the crust, which is formed around soil clods as a result of repetitive wetting and drying, caused an increase in the spectral reflectance of soils by a dozen or so percent. The irregularities in soil surfaces are the main cause of the diurnal variation in α values associated with changing θ_s. The α of soils under clear sky conditions increases with increasing θ_s, reaching its lowest value at local solar noontime, that is, at the lowest θ_s; meanwhile, the highest value, approximately 1, is reached at sunrise and sunset. Soils' α values at θ_s below 75° do not change significantly [7,8]. Cierniewski et al. [2], while analysing the diurnal α variation for bare cultivated soils in Poland and Israel under clear-sky conditions, found that the soil's roughness not only affected the overall level of α, but also the steepness of its rise from θ_s at local solar noon to about 75°. Deeply ploughed soils showed almost no rise in α values at θ_s lower than 75°, while the same soils, when smoothed out, exhibited a gradual increase in the value of α at these angles. Using 108 sets of the soil surface measurements of soils collected before 2016 in Poland and Israel, Cierniewski et al. [9] showed that the diurnal α variation of soils in a specific state of roughness can be predicted with a high accuracy by the proposed equations using data obtained from their transformed reflectance spectra in laboratory conditions and roughness indices predicted for the soils in field conditions. The authors of this paper intend to use similar equa-

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https://doi.org/10.1016/j.jqsrt.2018.06.003

tions, but improved adequately for usage in a procedure aimed at estimating the amount of short-wave radiation that could be reflected from bare soils within arable lands throughout the year on a global scale, based on the soil spectra that are commonly collected around the world and stored with other soil properties in soil databases such as the Global Soil Spectral Library [10] and the European LUCAS Soil Portal [11].

Therefore, the aim of the present research was to improve the equations presented in the aforementioned paper [9] that could be applied for calculation the α values of soils with specified roughness, depending on the θ_s for more diversified soils, using their laboratory reflectance spectra and their roughness indices in the field. This goal was achieved based on a 33% increase in the number of analysed soil samples compared to those used in the paper mentioned, and primarily on the quality expansion of the newly tested soil population, extended to include examples of soils collected additionally in southern France and the northern part of Israel. According to the principles of soil science, it was assumed that this additional soil group – developed in different soil-forming conditions than the previously collected soils – could verify, according to its specific properties, the form of the improved equations obtained using the same methods as in the previous paper.

2. Materials and method

2.1. Study area

This study is based on soil data sets collected in the Wielkopolska region of Poland and in the southern and central districts of Israel in the period 2008–2015 [9] and similar data sets collected in 2016 in the northern district of Israel and southern regions of France (Mid Pyrenees, Languedoc and Provence). A total of 32 soils (10, 13, and 9 located in Poland, Israel and France, respectively), divided into 153 samples (81, 30 and 42, in the same order as above) were examined (Table 1). They represent 22 soil units according to the World Reference Base (WRB) for Soil Resources (8, 9, and 5 units in Poland, Israel and France, respectively). These units belong to 10 WRB major reference groups [12]. The properties of all the units used to achieve the goal formulated above (the 15 soil units that were tested in the previously published paper [9] and the 7 units investigated in this study) are characterized together in this subsection, focusing on the properties significantly affecting their spectral brightness. The darkest-coloured of the soil units, with a low colour value of 4 in the Munsell Soil Colour system, belong to the following major WRB groups: (i) Phaeozems (Gleyic–Hg, Cambic–Hc, Calcic–Hx, Haplic–Hh) and (ii) Cambisols (Eutric–Be) developed from loamy sand (LS), (iii) Luvisols (Orthic–Lo) and (iv) Fluvisols (Eutric–Je) developed from loam (L) and (v) Vertisols (Chromic–Vc) developed from clay loam (CL), silty clay (SIC) or silty clay loam (SICL). These units are characterized by the content of SOC, $CaCO_3$ and Fe_2O_3 in the following ranges: 0.5%–2.5%, 0%–17% and 0.1%–1.4%, respectively. The soil units with higher colour values, 5–6, belong to the following major groups: (i) Arenosols (Brunic–Qb), (ii) Gleysols (G) and (iii) Xerosols (Haplic–Xh and Calcic–Xk) developed from sand (S), (iv) Luvisols (Vertic (Cutanic–Lc) developed from LS, (v) Vertisols (Chromic–Vc) developed from SIC or CL, (vi) Fluvisols (Eutric–Je and Calcaric–Jc) developed from L and CL, (vii) Cambisols (Eutric–Be, Calcaric–Ba and Chromic–Bc) developed from L, CL, and silty loam (SIL), respectively, and (viii) Leptosols (Rendzic–Eh) developed from CL or SL. The SOC, $CaCO_3$ and Fe_2O_3 contents of these soil units is within the following ranges: 0.3%–0.9%, 0%–39% and 0.1%–0.3%, respectively. The soil units with the highest colour value, 7, belong to two major WRB groups: (i) Calcisols (Siltic–Xs and Aridic–Xc) developed from L and SL, respectively, and (ii) Fluvisols (Calcaric–Jc) developed from SL. Their amounts of SOC, Fe_2O_3 and $CaCO_3$ are 0.3%–0.7%, 0.2%–0.4% and 18%–30%, respectively.

The fields selected for the measurements were selected in such a way as to eliminate potential shadows that could be cast by surrounding trees or other objects when the sun was close to setting and therefore low. All of the soil units characterized above were examined on selected plots formed by the following agricultural tools: a planter (Fp), ploughs (Pd), disk harrows (Hd), pulverizing harrows (Hp), and smoothing harrows (Hs). Some of these plots were additionally modified by droplets of rain or sprinkler irrigation, making them smoother and blurring their micro-irregularities; however, the surfaces were never artificially watered before the measurements. With the fields divided into distinct plots of varying surface roughness, the instruments were set up around the middle of each plot, so that they were focusing on a homogenous surface. The size of these plots varied greatly, depending on local conditions and the size of the field, but they were never smaller than 30 m by 30 m, easily covering the whole field of view of the instruments. The coordinates of the plots are listed in Table 2.

2.2. Field procedure

The diurnal  variation of the studied plots was measured in all cases from the local solar noon to sunset under clear sky conditions by an albedometer LP PYRA 06 when their soil surface were air-dried. The instrument working in a spectral range of 335–2800 nm, consists of one down-facing and one up-facing LP PYRA 03 pyranometer, observing shortwave radiation, reflected from plots and incident from sky (containing direct and diffused components), respectively, both in hemispherical space. The albedometers were calibrated by the manufacturer before the measurements were taken, and their appropriate calibration files were provided. For each soil surface, the diurnal albedo was measured once. The instruments were located in such a way that their downward-viewing sensors would take readings only from the measured surfaces, the surfaces being representative for soils treated by particular tools. With the albedometer sensing from a height of 1.5 m, the size of plots had to be at least 30 m by 30 m [13]. The moisture of the surfaces was not controlled before the measurements; it was assumed that the surfaces reached their air-dry state after at least a few days of sunny weather without rain or irrigation. The soil α was recorded in 1-min intervals by a Campbell Scientific 21x data logger or DaqPRO 5300 data loggers

The plots selected to estimate roughness were delimited from the aforementioned representative surfaces in view of the albedometers. The roughness of the soil plots was measured in two ways. Before 2015, a VIVID-910 laser scanner placed on a tripod that moved around the studied plots was used, and stereo-photographs were taken with a 12.2 MP Canon EOS 450D camera that moved along a levelled construction supported by two tripods [9]. The plots measured in this way covered an area of 1 m^2, and had a spatial resolution of 1 mm horizontally and vertically. After 2015, the roughness was measured using stereo-photographs taken with a 36.4-MP SONY α7 R camera with a fixed focal length of 35 mm from a height of about 2.5 m. The camera was attached to a 2.5 m long monopod that moved around 4 m^2 plots. Between 17 and 43 photos were taken from different angles (a greater number of angles on plots with higher roughness). These plots were square shaped, with a side length of 2 m, and their spatial resolution was 0.6 mm.

2.3. Laboratory procedure

The clay and silt content was determined using the hydrometer method [14] and the sand content was calculated as a com-