# ASSESSING OF SOIL CRUSTING PROCESS IN A SEMIARID ENVIRONMENT, USING SOIL REFLECTANCE SPECTROSCOPY IN THE SWIR REGION

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## ABSTRACT

The structural crust, a thin layer that is formed on the soil surface after rainstorm events, has been spectrally studied across the SWIR region. The crust is the result of a physical segregation and rearrangement of soil particles in a form that affects some of the soil's physical properties, such as infiltration, runoff and soil erosion. In this study, a controlled spectral investigation of the structural crust across the SWIR spectral region was carried out, using clayey soils from Israel (Grumusol, typic chromoxerets). A subset of soil samples were treated in such a way that each sample was subjected to an increased level of cumulative energy from a simulated rainstorm. The result was a set of soil samples with increased levels of crusting and, respectively, with reduced infiltration rates. The spectral parameter of this set was studied in the laboratory across the SWIR region, using a Quantum 1200 spectrometer. Empirical relationships were found between infiltration rates and reflectance spectra properties and the suggestion to use the relationship as a tool for rapid, nondestructive, in situ crust assessment was raised.

## 1 INTRODUCTION

Loss of rain and irrigation water from cultivated fields is a matter of great concern, especially in arid and semiarid regions. The need for better water use efficiency in these regions is becoming more critical and more essential, because water resources are depleting and water quality is deteriorating. Even in many humid regions, water stress, associated with loss of yield, is commonly observed because of periodic drought conditions during flowering and the seed set of many crops. In addition to loss of water that could potentially be available to plants, runoff also results in soil erosion, decline in soil fertility and productivity and increased peak stream flow and associated floods. Controlling the deleterious effect of runoff, which causes major water losses in various climate regions, will contribute to more sustainable agriculture by reducing irrigation needs, enhancing dry land productivity and improving flood control. It may also alleviate to some extent the expected reduction of precipitation in arid and semiarid regions caused by global changes.

The main reasons for the runoff from rain and overhead irrigation water is the structural crust that develops over bare soils during rainfall or overhead irrigation events, and which greatly reduces the soils' infiltration rate. The hydraulic conductivity (HC) of this crust is a few orders of magnitude lower than that of the underlying soil (Morin and Benyamini, 1977). Whenever the HC of the crust is lower than the rainfall intensity, ponding, runoff and soil erosion will occur.

Two kinds of soil crusts and the mechanisms for their development have been identified. The first is depositional crust that is formed when sediment-laden water is deposited in furrows and on the soil surface as water infiltrates

(Shainberg and Singer, 1986). The second is the structural crust. Structural crust formation is the result of two complementary mechanisms (Agassi et al. 1981, 1985): Physical disintegration of surface soil aggregates, rearrangement and compaction of the disintegrated soil particles at the soil surface. Physicochemical dispersion of soil clays and migration of the fine particles into the soil with infiltrating water. Infiltration data are essential for predicting the amount of rainwater that percolates into the soil and for calculations of runoff rainwater. To date, infiltration during rainstorm has been measured in the laboratory and in small-scale field plots, using rainfall simulators (Agassi and Bradford, 1999). Consequently, the importance of mapping and the prediction of soil structural crust processes are of great interest to soil scientists and farmers. Apparently, there is no rapid and in situ method for monitoring, assessing and mapping crust status. Most of the available methods use disturbed soil samples that do not represent exact field conditions (Keren and Singer, 1991) or use simulation techniques that cannot mirror exact field conditions (Agassi and Bradford, 1999).

The remote-sensing field offers many capabilities for measuring, detecting and enhancing processes that occur on the soil's surface. In this regard, remote-sensing techniques, and especially hyperspectral technology, can be a perfect tool for assessing the condition of the soil crust and estimating related problems (e.g., infiltration rate and runoff potential). This is because the radiation that reflects from the surface is a product of the particle size distribution (physical effect) and the chemical composition (chemical effect) of the sensed matter. Apparently, to the best of our knowledge, this idea has never been studied and considered in both the remote-sensing and soil science fields. The ability to determine the soil crust status in the field by both imaging or point spectrometers is indeed challenging, since it could help to estimate the soil degradation stage on an almost real-time basis and could prevent possible misinterpretation of hyperspectral remote sensing data of soils. The purpose of this study is, therefore, to report the results of a controlled experiment that used a rain simulator and a sensitive spectrophotometer to examine the relationship between spectral and rain energy parameters.

## 2. MATERIALS AND METHODS

A clayey soil from Qedma, Central Israel, from an alluvial fan (52.9% clay; 25.4% silt; 21.7% sand) was selected for this study. The soil is termed *Grumusol,* according to a local Israeli classification system (Dan and Raz, 1970) and *typic Chromoxerets*, according to the USDA classification system. The soil samples were air-dried and passed through 4-mm sieves. The soils were identically packed into 30 50-cm perforated trays, 2 cm deep, over a layer of coarse sand**.** The boxes were placed on a carousel at 5% slope and were subjected to a simulated rainstorm, using distilled water (Morin et al., 1967).

The soils were subjected to several rainstorm stages of varying degrees of energy. The initial stage was a fog-type rain, which holds no energy, and a flux that approximated the initial infiltration rate of the soil. In this stage no crust is formed, and, thus, it is used as a baseline reference for further study. The fog storm lasted until the measured rate of percolation was similar to the intensity measured by the simulated rainstorm. Then, the rainfall was stopped and the five soil trays were gravimetrically drained. The "fog" soil tray was removed from the carousel. The next stage employed four steps of cumulative energy rainfall one for each of the remaining trays. The rainfall intensity approximated the initial infiltration rate of the soil, with energy of about 22.3 joule $mm^{-1}$ $m^{-2}$. The first step lasted until 6 mm of rainfall was accumulated (equal to ~ 134 joule $mm^{-1}$ $m^{-2)}$ , and the second, third and fourth steps lasted until 19, 25 and 93 mm of rainfall accumulated, respectively (equal to ~ 424, 558 and 2,074 joule, respectively).

The five soil boxes were oven-dried for 48 hours at $35^0$C. Five soil samples were carefuly taken from each box for spectral reflectance measurements. These measurements were done by using the Quantum 1200+ Spectrometer, optimized to the SWIR region (1.2–2.4 µm) and having a bandwidth of 1 nm. The reflectance of each soil sample was measured against HALON, and for each rainstorm (or tray) used, an average spectrum of the five samples taken from each tray was generated. In order to precisely study the spectral features as well as other possible (nonvisible) spectral changes, we employed a spectral ratio manipulation technique and first- and second-derivation techniques (Owen, 1986). Another means for investigating the spectral changes of the crusting process is to use peak intensities and positions along with the derivative technique (Owen, 1986).

## 3 RESULTS AND DISCUSSION

Figure 1 presents the spectral reflectance of the Grumusol soil under each rain energy treatment. A noticeable albedo sequence is observed going from the low energy level (low albedo) to the high energy (high albedo) levels. This albedo sequence is based on the fact that the forming crust is characterized by a finer particle size distribution than is found in the original soil. It is well known and documented that a finer grain size of a given material provides a greater reflectance (Ben-Dor et al., 1998). In this regard the higher spectral values obtained from the soil that was exposed to higher raindrop energy confirms the electron microscope observation that fine particles deposit on the soil surface and in fact form the crust. In order to find the best wavelengths, in terms of the albedo sequence, that clearly represent the infiltration rates, we applied an automatic correlation procedure to each of the spectral channels of the treated soils with the rainstorm energy values. In Figure 2, a correlation coefficient spectrum (termed *correlogram*) is presented.

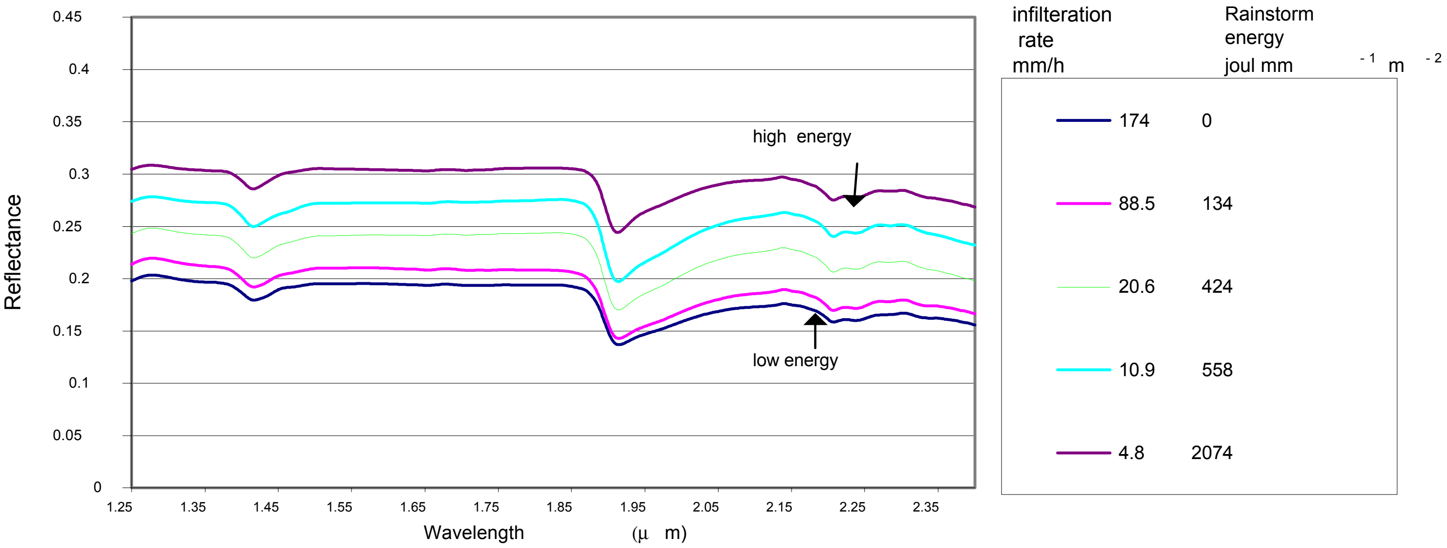

Figure 1. Reflectance spectra of the *Grumosol* soil after treated with different rain energy

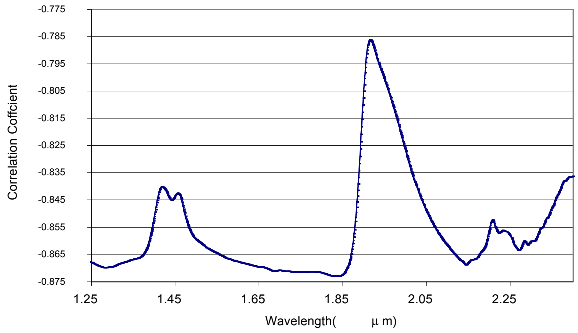

Figure 2: The correlogram between the reflectance values and infiltration rates

Two wavelengths (1.83 µm and 2.13 µm) were depicted by the analysis as holding the highest correlation between the spectroscopy and the raindrop energy. Calculating the rate of infiltration (as measured in the simulation) and using both wavelengths yielded a logarithmic curve (provided in Figure 3 that explains the overall capability of the reflectance data across the SWIR region to estimate raindrop energy and related properties such as rate of infiltration.. A similar analysis was applied to the first derivative values of the original reflectance data. The spectral derivation technique is a well-known tool for eliminating the albedo effects (Owen 1987). In this step we were actually looking for the absorption feature that best explains the raindrop energy and its related properties

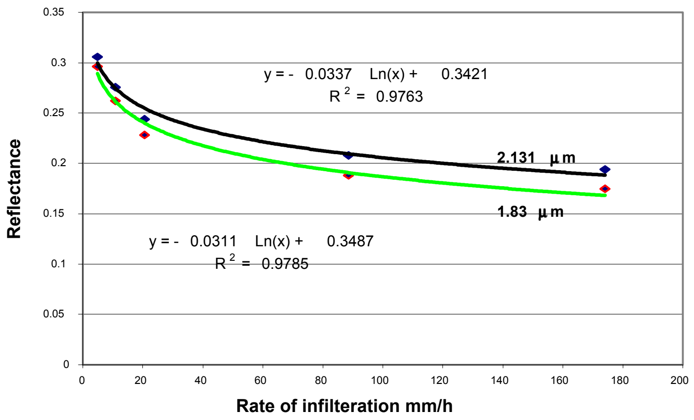

Figure 3. The relationship between soil reflectance values at 1.833 and 2.135 µm and the infiltration rate.

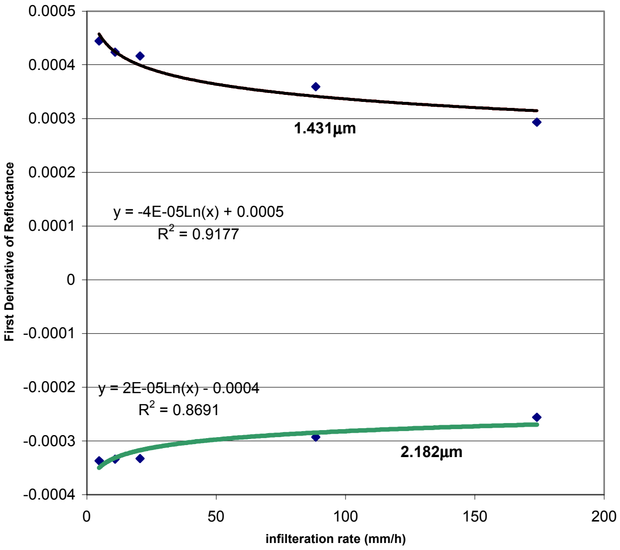

Figure 4. The relationship between first derivative of soil reflectance values at 1.49 and 1.88µm and the infiltration rate

In this regard, two wavelengths--at 1.49 µm and 1.88 µm--were found to carry the highest correlation between the spectral parameter and raindrop energy. Using both wavelengths it was found that a logarithmic relationship occurred between the spectral parameters and the rate of infiltration (Figure 4).

The different wavelengths that were found for the different spectral manipulations (neither reflectance nor its derivatives) resulted because each manipulation accounts for a different mechanism. Whereas the original reflectance spectrum provides albedo sequences governed by the particle size distribution, the derivation spectrum mimics absorption features that are governed by the existence of chromophors. In the albedo mechanism the two wavelengths were selected at spectral regions without known specific absorption, whereas in the absorption mechanism the wavelengths were selected at regions where significant absorption of OH in hygroscopic water were present.

Because during the crust formation process, clay fractions are concentrated on the soil surface, its fine grain size (<0.002 mm) is responsible for the albedo sequence, whereas its high specific surface area (800 m2/g) is responsible for the OH absorption sequence.  Based on this relationship, we estimated the infiltration rate by averaging the two mentioned mechanisms to provide a 1:1 prediction equation as seen in Figures 5. It can be seen from the figures that it is possible to estimate the infiltration rate only from the spectral reflectance data. However, as expected, this estimation can be improved by increasing the rain energy provided during the simulator experience.  In this regard, it is strongly expected that such an estimation can yield a better tool for improving decision making under a real-time mode.

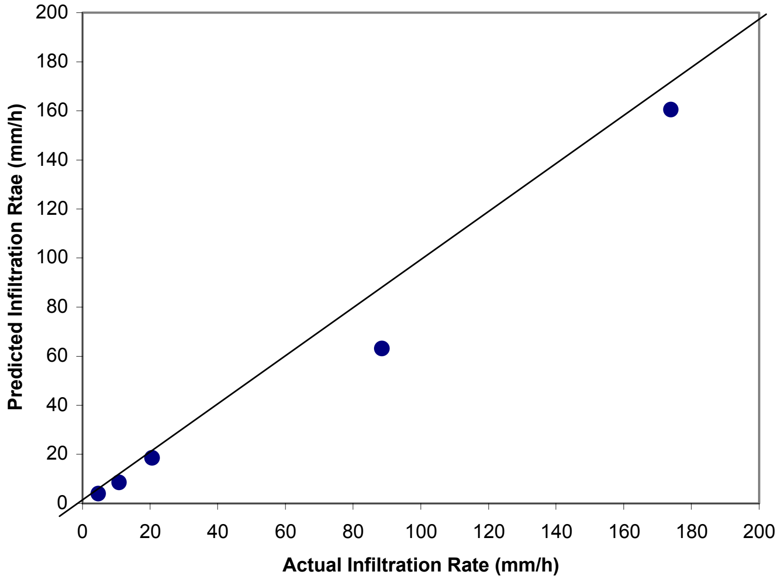

Figure 5. Prediction of the infiltration rate using spectral information as extracted based on Figure 3 and 4 results. The Y axis represents predicted infiltration rate (from the spectroscopy) and X axis actual infiltration rate (from the simulator).

## 4 CONCLUSIONS

This research addresses an important problem related to the soil degradation issue that arises from structural crust formation during rainstorm events. It was shown that the structural crust status on clayey soil (Grumusol) could be assessed using spectral reflectance in the SWIR region. Both the albedo and specific absorption features were found to be correlated with the raindrop energy (and thus with associated problems such as: soil infiltration, water run-off and soil erosion). It can be concluded that the ability to estimate the crusting level via spectral reflectance measurements could open up a new frontier in monitoring soil degradation processes via hyperspectral remote-sensing means. Another important conclusion that can be drawn from this study is that precaution must be taken while analyzing optical remote sensing data of soils after rain events. Sandy soils might be classified as clayey soils because of the surface particle segregation driven by the raindrop energy.

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