

IMPROVING SOIL ORGANIC CARBON (SOC) PREDICTION BY FIELD SPECTROMETRY IN BARE CROPLAND BY REDUCING THE DISTURBING EFFECT OF SOIL ROUGHNESS

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ABSTRACT

The spatial estimation of Soil Organic Carbon (SOC) at large scale in outdoor condition is an important issue. It has been largely demonstrated that diffuse reflectance spectroscopic techniques, are efficient for SOC determination in field conditions. However these methods are influenced by disturbing factors such as soil water content, vegetation residues and surface roughness, the later being the object of this study. Our laboratory experiments showed that the accuracy of SOC prediction from shadowed soil samples with spectroscopy techniques decreases with increasing soil shadow.

In this study a new methodology using a digital camera for identifying and correcting the effect of soil shadow on field reflectance spectra measured with an Analytical Spectral Devices (ASD) during field campaign in bare crop lands has been elaborated and tested. Results showed that the proposed shadow correction method enables improving significantly SOC prediction accuracy and performs better than traditionally used methods consisting in automatic signal processing.

Keywords: Infrared, spectroscopy, soil, carbon, roughness

INTRODUCTION

The spatial estimation of Soil Organic Carbon (SOC) stocks at regional/national scales has been the object of a growing literature last decades due to their role in the conservation of soil fertility and in the global C cycle and their potential impact on global environmental changes through CO₂ fluxes between soils and the atmosphere [1].

Due to a slow temporal dynamic and a high spatial variability, SOC stocks changes are in general difficult to detect without using a high sampling density. At large scales conventional sampling techniques may be too expensive and time consuming to reach the amount of soil samples required.

Conversely, diffuse reflectance spectroscopic techniques, and in particular Visible and Near Infra Red (VNIR) spectroscopy (350 nm to 2500 nm), allows rapid sampling and instantaneous determination of SOC values, at field and regional levels (in remote sensing mode). This technique can provide in a cost effective way the large quantity of spatial data required in soil monitoring or modeling studies like the monitoring of decline of soil organic matter in the topsoil.

However spectroscopy techniques used for field campaigns in outdoor condition present still major constraints. In particular, spatial variation in surface soil properties induce a variability not directly related to the studied property and reduce the

accuracy of SOC prediction in the field. According to Atzberger (2000) [2], the main disturbing factors are soil water content, vegetation residues and surface roughness.

For the purpose of this study, field spectroscopic measurements were taken over bare and quite dry soils. In this context, soil roughness is considered to be the main disturbing factor and other influences will not be taken into consideration. Soil roughness is known to induce a variation in reflectance as a function of viewing and illumination angle. For the time being, these variations, known as BRDF (Bidirectional Reflectance Distribution Function) effects, have not been taken into account in the prediction of SOC. It has been shown that, the shadowing of soil aggregates or clods has a greater influence on reflectance than the scattering properties of a soil (Cierniewski and Verbrugghe, 1997) [3]. Therefore we will estimate the influence of roughness on soil reflectance through the study of its shadowing effects.

The purpose of this study is to identify and reduce the effect of soil Relative Shadow (RS, the percentage of shadowed soil of the studied surface) on the SOC prediction (SOCp) from VNIR field spectroscopic data.

First a methodology to measure RS and correct its impact on field reflectance measured with an Analytical Spectral Devices (ASD) spectroradiometer is proposed. Secondly the impact of RS on reflectance and SOCp accuracy is studied under laboratory conditions. Then SOC contents are predicted using uncorrected and corrected field reflectance values to evaluate the enhancement in SOC prediction achieved with this methodology. The proposed methodology is finally compared with other existing methods.

MATERIAL AND METHOD

A field campaign was realized in Grand-Duchy of Luxembourg on an area with different soil types and a large variation in SOC content. Ninety-nine soil plots were selected in 8 bare fields. For each plot, several measurements were carried out. Reflectance in the VNIR range of the electro-magnetic spectrum (350 nm to 2500 nm) was measured with a FieldSpec Pro spectroradiometer (Analytical Spectral Device ASD) with a Full Width Half Maximum of 3 nm for the 350-1000 nm region and 10 nm for the 1000-2500 nm region. Soil Relative Shadow (RS) was measured by the analysis of vertical digital photographs of the soil through a classical segmentation classification procedure with the image analysis software DEFINIENS DEVELOPPER (DEFINIENS Inc.) (Figure 1). Observed RS values ranged from 0.28 to 0.68. Finally soil samples were collected for analysis in laboratory among which SOC measurements with the method of dry combustion with a CN analyzer and spectral analysis with ASD.

Then for each soil sample, an individual correction factor "K_{RGB}" was computed by comparing the mean values of the three RGB spectral bands of the digital camera of non shadowed area ("Illuminated soil") with the ones of the whole soil photograph ("Whole soil") in the visible range according to the equation 1.

$$K_{RGB} = \frac{\text{Illuminated soil reflectance} - \text{Whole soil reflectance}}{\text{Whole soil reflectance}} \quad (1)$$

In order to determine the impact of shadow on reflectance and SOCp accuracy, ASD reflectance measurements of air dried soil samples collected during the field survey were realised for different RS levels under laboratory conditions. Grinded and 2 mm sieved soil samples were placed in big Petri dishes and exposed to a range of RS produced by the use of a sliding mate placed between the light source and the soil sample.

Our laboratory experiments showed that the influence of soil RS on reflectance does not affect all wavelengths in the same way. Consequently, a reference correction factor spectrum spreading in the whole spectral domain [350 - 2500 nm] was

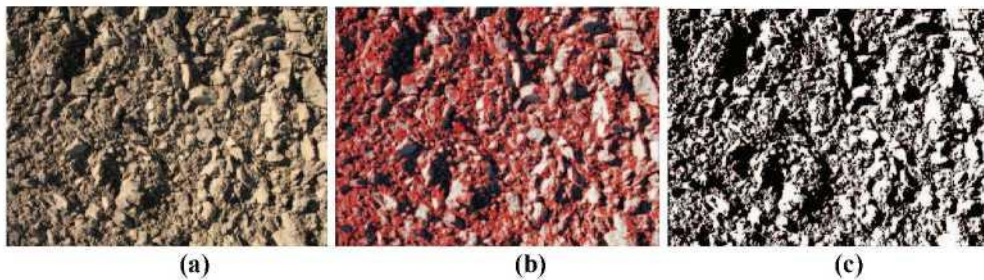
computed from ASD laboratory spectra measured under different shadow conditions in order to translate the general influence of RS for each wavelength in the range of RS observed in the field.

The methodology used to create this reference “ASD correction spectrum” consists in three steps:

1. Computing the ASD correction spectra (2151 values) from laboratory measurements for all plots for the RS values met in the field (KASD)
2. Computing the arithmetic mean of KASD spectra of all sampling plots to get a mean KASD shape (KASD_MEAN)
3. Scaling this KASD MEAN in order for the visible part to be equal to 1 (KASD_MEAN_SCA)

This reference correction spectrum was then used to extend the single KRGB values (visible) to the whole spectral domain [350 -2500 nm] by simple multiplication (KASD_MEAN_SCA * KRGB), which generated “KVNIR”.

Figure 1: (a) Vertical photograph of a bare crop field, (b) Segmented photograph, (c) Classified photograph in “Illuminated” and “Shadowed” objects.



Then the field ASD reflectance was corrected from soil relative shadow effect by applying the correction factors KRGB and KVNIR according to the equation 2.

$$\text{CorrectedReflectance} = \text{Field reflectance} * (1 + K) \quad (2)$$

Finally, for determining whether the corrected reflectance enhanced the SOC prediction, SOC prediction was realized with both raw field ASD reflectance and field ASD reflectance corrected using KRGB and KVNIR. The SOC prediction method consisted in a multivariate calibration technique (Partial Least Square Regression (PLSR)) under leave-one-out cross-validation. The performance of the prediction model was measured by the Root Mean Square Error of Prediction in Cross Validation (RMSECV) and by the Ratio of Performance to Deviation (RPD, ratio between standard deviation and RMSECV). According to Chang et al. (2001) [4] a calibration model with a RPD>2 can predict accurately the property under study.

The method described above was then compared with well-known methods that intend to decrease the noise of the spectral signal, enhance possible spectral features linked to the property studied and correct for light scattering effects. These methods (or “preprocessings”) are (i) conversion in absorbance (-logR), (ii) 1st and 2nd derivatives, (iii) 1st and 2nd gap derivatives (Norris and Williams, 1984) [5], (iv) Savitzky-Golay smoothing and derivatives (Savitzky and Golay 1964) [6], (v) Whittaker smoothing (Eilers, 2003) [7], (vi) detrending (Barnes et al., 1989) [8], (vii) Multiplicative Scatter Correction (MSC, Geladi et al., 1985) [9], (viii) a combination of the previous. All preprocessings were systematically tested. Only the best one, in terms of RPD values, was retained for comparison.

RESULTS

Impact of soil Relative Shadow (RS) on reflectance and Soil Organic Carbon prediction (SOCp) accuracy based on laboratory data.

Figure 2 shows reflectance decrease on the whole spectrum with increasing RS. Table 1 presents the impact of RS on SOCp accuracy and shows in particular that the range of RS measured during field campaign, as modeled in laboratory, decreases SOCp accuracy significantly. Generally increasing soil RS decreases SOCp accuracy.

Results in terms of SOCp accuracy enhancement for corrected field reflectance

Results presented in table 2 shows that all K-correction methods improve significantly both RPD and RMSECV values. In particular, SOCp enhancement is 10 % RMSECV with KRGB and 27 % RMSECV with KVNIR which is the best correcting factor.

Table 3 shows that, when using the K-correction method in addition to preprocessings, the “K-correction methods” proposed still allows to increase the accuracy of SOCp by 3 and 5 % RMSECV with KRGB and KVNIR respectively. However the fact that SOCp enhancement is significantly smaller when the K-correction method is combined with preprocessings suggests that an important part of the shadow disturbing effect is corrected by both methods.

However the best K-correction on raw (non-preprocessed) reflectance gives better SOCp than the best preprocessing on uncorrected reflectance which suggests that the proposed method is relevant. Compared to raw uncorrected reflectance, total improvement in the accuracy (K- correction + preprocessings) reaches 29 % RMSECV for KVNIR. The best SOCp is always achieved using K-corrected and preprocessed reflectance.

Figure 2: Reflectance spectra of a soil sample for 13 Relative Shadow levels measured under laboratory condition. RS level equal to 0 for the highest spectrum and equal to 1 for the lowest one

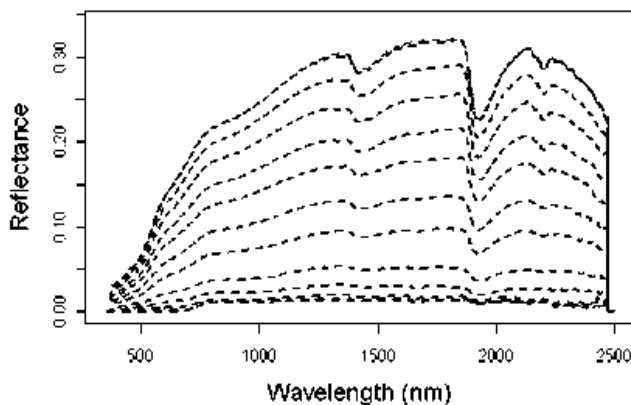


Table 1: SOCp based on laboratory data for different RS conditions. "Field value" is the range of values measured during the field survey. N is the number of soil sample used.

Relative Shadow	RMSECV (gC/kg)	RP D	N
0	3.12	3.07	52
0.20	3.26	2.94	52
0.50	3.53	2.72	52
0.88	4.19	2.28	52
1	5.35	1.79	52
Field value [0.28, 0.68]	3.75	2.56	52

Table 2: SOC prediction results with non-preprocessed uncorrected and corrected reflectance.

Treatment	RPD	RMSECV (gC/kg dry soil)	R ²	N	SD	SOCp enhancement (% of RMSEP)
Reflectance uncorrected	2.51	4.42	0.77	96	11.08	/
Reflectance corrected with KRGB	2.81	3.96	0.83	96	11.13	10
Reflectance corrected with KVNIR	3.4	3.24	0.89	96	11.04	27

Table 3: SOC prediction results with preprocessed uncorrected and corrected reflectance.

Treatment	RPD	RMSECV (gC/kg dry soil)	R ²	N	SD	SOCp enhancement (% of RMSEP) (compared to preprocessed uncorrected reflectance)	Total SOCp enhancement (% of RMSEP) (compared to non-preprocessed uncorrected reflectance)
Reflectance preprocessed and uncorrected	3.33	3.31	0.89	96	11.04	/	25
Reflectance preprocessed and corrected with KRGB	3.45	3.21	0.90	96	11.08	3	27
Reflectance preprocessed and corrected with KVNIR	3.56	3.13	0.91	96	11.04	5	29

CONCLUSION

Laboratory experiments showed that SOCp accuracy decreases when soil RS increases on soil sample. A methodology for identifying and correcting the effect of soil RS on field reflectance spectra measured with an ASD during a field campaign was elaborated and tested. Results showed that the RS correction method proposed allows improving significantly SOC

prediction by correcting the effect of soil relative shadow on spectral data. The fact that this method enhances SOCp even on pre-processed reflectance suggests that it enables to assess a part of the shadow disturbing effect that existing preprocessing techniques can not take into account. Considering soil shadow could represent a step forward in order to use spectral techniques in the field where soil surface conditions are not always optimal and cannot be controlled.

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