Modified Soil Adjusted Crop Residue Index (MSACRI): A new index for mapping crop residue

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Abstract -- In this study, we present a new index for mapping and estimating the crop residue cover fraction: the MSACRI (*Modified Soil Adjusted Crop Residue Index*). This index exploits the mid infrared channels: 1.55 µm to 1.75 µm and 2.10 µm to 2.35 µm. Compared to the visible, these channels are characterized by large transparence in relation to atmospheric constituents. In extreme atmospheric conditions, the MSACRI is subject to a slight reduction of approximately 4 %. It offers better discrimination of soils / residue and shows quite good dynamics in the presence of residue with average values close to ± 0.03 for bare soil and close to 0.70 for full cover residue.

INTRODUCTION

Dry vegetation and crop residue play an important role in the protection of the soil surface against water and wind erosion [1]. Their conservation on agricultural lands after harvesting is considered as an effective anti-erosion measure. Scientists [2] have demonstrated that a minimum residue cover of 20% reduces erosion and a team of scientists at the University of Guelph in Canada has found that a corn residue cover as low as 15 % can reduce erosion by 75 % in comparison to a bare soil [3]. Furthermore, information on the ground cover rate by senescent vegetation or crop residue is useful for hydrological models, for example, in the calculation of the "C" factor of the Universal Soil Loss Equation [4]. Due to the absence of contrast in the reflectance between the red and the near infrared in the case of dry vegetation, the classical vegetation indices are not well adapted for the detection of residue. In this sense, different indices for the detection of crop residue were developed such as: *Brightness Index* (BI) [5], *Cellulose Absorption Index* (CAI) [6], *Normalized Difference Index* (NDI) [7], *Soil Adjusted Corn Residue Index* (SACRI) [8] which improves the NDI with respect to the optical properties of soils and the *Crop Residue Index Multiband* (CRIM) [9]. In this study, we present a modified version of the SACRI, the MSACRI (*Modified Soil Adjusted Crop Residue Index*), which exploits the mid infrared spectral bands: 1.55 µm to 1.75 µm and 2.10 µm to 2.35 µm. The interest of these two bands resides in the fact that this region of the electromagnetic spectrum is identified as being favorable to the identification and the differentiation of rocks, soils and the dry components of vegetation and considerably less sensitive to variations of atmospheric conditions [10, 11]. We analyze the sensitivity of the MSACRI (equation 1) to crop residue, to the optical properties of the underlying bare soils and to atmospheric effects.

$$MSACRI = C^{ste}\left[\frac{a\left(r_{ETM5} - a\, r_{ETM7} - b\right)}{\left(a\, r_{ETM5} + r_{ETM7} - ab\right)}\right] \qquad (1)$$

with:
$\rho_{ETM\text{-}5}$: reflectance in the ETM-5 (or TM-5) band;
$\rho_{ETM\text{-}7}$: reflectance in the ETM-7 (or TM-7) band;
a : slope of the bare soil line in the ETM-5 / ETM-7 spectral space;
b : ordinate at the origin of the bare soil line in the ETM-5 / ETM-7 spectral space;
C^{ste} : multiplicative constant which is equal to 5.

MATERIAL AND METHOD

In this study, we have used spectroradiometric measurements acquired at the Agriculture and Agri-Food Canada research station, in Lennoxville (Quebec). The measurements were carried out with a portable GER-3700 spectroradiometer (350 to 2500 nm) over different types of crop residue (corn, soya, sunflower and wheat) for different cover rates and various bare soil types at different degrees of moisture and roughness. To take into account the bi-directional effect of the target reflectance, which depends both on the illumination angle and the viewing angle, we carried out measurements around the zenith hour following a vertical view direction.

The 6S [12] radiative transfer model was used for the atmospheric simulations. We set the observation zenithal angle at nadir while the illumination angle was equal to 35E with a relative azimuthal angle of 30E. The *Midlatitude Summer* atmospheric model and the *Continental aerosol* model where aerosol concentration is expressed in terms of horizontal visibility were retained. The visibilities under consideration are equal to 10, 20 and 50 km. Considering the atmosphere as being without diffusion, we varied the concentration of water vapor by 0.5, 3.0 and 6.0 gcm^{-2}, while for surface conditions, we took into consideration a soil free of residue and a soya cover at different cover rates.

ANALYSIS AND DISCUSSION

Since crop residue do not often constitute a complete cover, a good residue index must be independent from the optical properties of the underlying bare soils i.e. that its value for bare soils must be zero or close to zero. On Fig. 1, we show that the points relative to the MSACRI calculated solely over bare soils are not perfectly aligned along the theoretical soil line (null values), they are distributed randomly with a deviation capable of reaching ± 7 %. The error on this index is approximately 7 % when a soil is dry, light and brilliant in color, but if we consider all soils independently from their optical properties or their surface state, the root mean square caused by soils is approximately ± 0.03.

On Fig. 2, we show the evolution of the MSACRI in relation to the cover rate of soya, corn, sunflower and wheat residue. We can observe that independently from the residue type, the value of MSACRI increases progressively and in a relatively linear way as the percentage of residue increases. The level of correlation between this index and the residue cover rate is relatively high. As a matter of fact, we obtain on the average a correlation coefficient of 0.97 for all residue considered in this study. However, for all the residue that present full cover, saturation of the signal occurs and, consequently the value of MSACRI does not surpass 0.70. This saturation can be caused by signal attenuation because of the presence of multiple layers of residue and also by the shadow characteristic of residue. It is very important to specify that in this study, we evaluated the performance of the MSACRI by considering only fresh (non degraded) and dry residue.

Apart from the absorption by water vapor, the mid infrared is characterized by high transparence in relation to atmospheric constituents. As opposed to the visible, in this region of the spectrum, diffusion by molecules and aerosols is quite limited and the contribution of the target to the signal received at the sensor dominates the contribution of atmospheric diffusion. With less residue cover, atmospheric effects, diffusion and absorption, are negligible in the mid infrared channels. On the other hand, when residue cover is complete, reflectance decreases by 1 % and 2.5 % respectively in the ETM-7 and ETM-5 channels in the case of low atmospheric visibility (10 km). In addition, a high concentration of water vapor in the atmosphere (6.0 g/cm^2) causes a decrease in reflectance of 2.1 % and 3.3 % in the ETM-7 and ETM-5 channels respectively. In extreme atmospheric conditions, diffusion and absorption, we observe that the ETM-7 channel is less influenced by atmospheric effects than the ETM-5 channel and that the MSACRI is subject to a slight decrease of approximately 4 %. We can see that this error is nearly in the same size range as the one caused by soils. Due to the fact that the MSACRI offers better discrimination between soils and residue and since in remote sensing we always use images acquired in favorable atmospheric conditions where images are corrected for atmospheric effects, we can hence say that the MSACRI is a good tool for mapping crop residue.

CONCLUSION

The objective of this study is to evaluate the performance of the MSACRI for mapping crop residue independently from soil effects and atmospheric variations. The index shows quite good dynamics in the presence of residue independently from underlying bare soils with average values close to ±0.03 for bare soil and close to 0.70 for residue that present full cover. Compared to the visible, the mid-infrared channels (ETM-5 and ETM-7) used in the calculation of the MSACRI are characterized by large transparence in relation to atmospheric constituents. According to this study based on simulations, the MSACRI is a good index for mapping crop residue. However, further tests are required over other residue types with different moisture levels and under different degrees of degradation, and with image data.

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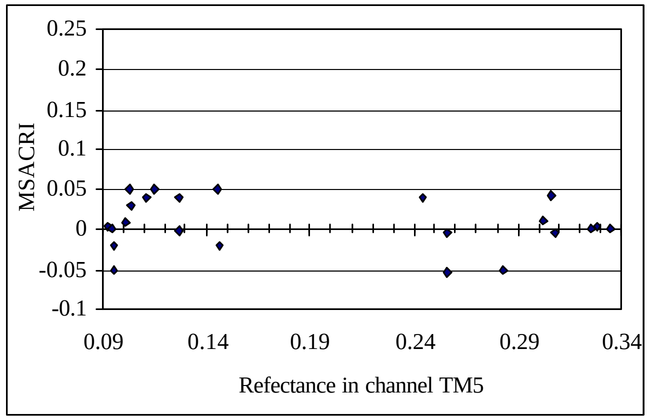

Fig. 1 Discrimination power of the MSACRI in relation to underlying bare soils

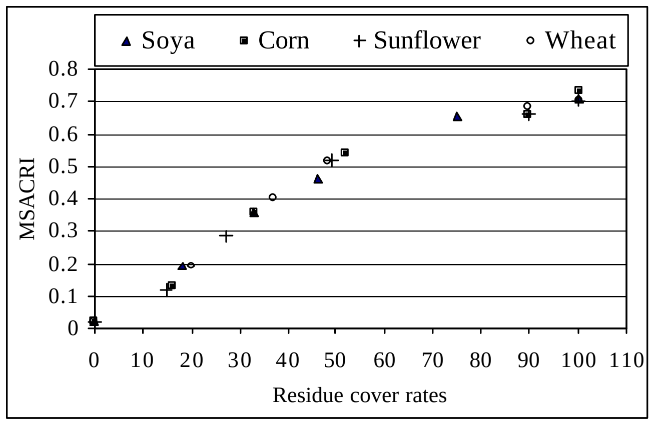

Fig. 2 Sensitivity of the MSACRI to soya, corn, sunflower and wheat residue for different cover rates