Spectral characteristics of soil and vegetation in saline wetlands, NE Spain

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ABSTRACT - Remote sensing is helpful to identify the changes of vegetation in wetlands and to assess their degradation. In this sense, it is crucial to establish a relationship between spectral data and vegetation cover, type, and phenological state. Mapping and estimating vegetation cover in arid environments is conditioned by the sparse vegetation and the influence of soil background reflectance. Moreover, the perennial plants adapted to saline environment include dry, senescent and green parts. Annual specimens are highly conditioned by local and seasonal variations.

The monitoring of the vegetation of the saline wetlands of Monegros, NE Spain, using remote sensing requires knowing the relationship between their spectral characteristics and the vegetation cover and soil conditions. For this purpose, we studied the spectral characteristics of soils and vegetation and we established the relationship between vegetation cover and spectral data collected using two spectrometers, based on discrete and continuous readings, respectively.

We conducted two field surveys in 11 wetlands. A total of 242 sites were sampled in 2007 and 2008 for their spectral study in the visible and infrared spectra. The resulting NDVI values were interpreted together with soil moisture and color data, allowing for their relationship with plant cover. The mixture of dry, senescent and green parts in the plant contribute to their spectral response. The NDVI and Brightness Index were the most suitable to discriminate vegetation and to separate soil classes. These results are essential to validate the reflectivity measured with remote sensors.

1 INTRODUCTION

A goal of European Habitats Directive is to protect the biodiversity through the conservation of habitats (Council Directive 92/43/EEC). This task requires data about the distribution of habitats and their conservation status. The Earth Observation Techniques can provide useful data for mapping habitats (Keramitsoglou et al., 2005; Boyd et al., 2006; Kobler et al., 2006) and assessing the vegetation cover (Wang et al., 2004; Xiao and Moody, 2005; Wang et al., 2007).

Mapping and estimating vegetation cover in arid areas could be difficult due to the characteristics of the vegetation and the reflectance of soil background (Huete et al., 1985; Huete and Jackson, 1987; Smith et al., 1990; Escadafal and Huete, 1991; Elmore et al., 2000). Todd and Hoffer (1998) studied the specific influence of soil background reflectance to estimate the vegetation cover. This is frequently overestimated because the high reflectivity of the soil (Xiao and Moody, 2005) masks the weak spectral response of sparse vegetation. Huete et al. (1985) and Elmore et al. (2000) analyzed the influence of soil brightness in the NDVI at low percent cover of vegetation. Montandon and Small (2008) showed that NDVI of soils is often underestimated in areas with sparse vegetation, resulting in overestimation of the vegetation fraction. These authors suggested local estimations of NDVI for soil and vegetation avoiding the use of global values.

The fraction of green cover could be estimated through satellite imagery, aerial photography or directly by field measures. Several efforts have been made to establish a relationship between vegetation cover, type, and phenological state with satellite data (Smith et al., 1990; Zhang et al., 2007). Several techniques are applied to determine the percent cover of green fraction, senescent vegetation, and bare soil from digital ground photographs (Jonckheere et al., 2005; Laliberte et al., 2007) to classify the vegetation cover of satellite images. In this sense, Maas (1998) studied the effect of the camera point of view on the
reflectance of the vegetation, observing a decrease in
reflectance as the shadow between plants increases.

The aim of this work is to study the spectral
characteristics of soils and vegetation and to establish
the relationship between green cover and spectral data
collected using proximal sensors.

2 STUDY AREA

Sebkha is a suitable term to designate some of the
saline wetlands of the south of Monegros, one of the
most arid regions in Europe (Herrero and Snyder,
1997). They are playa-lakes and close saline
depressions scattered in an agricultural landscape
(Figure 1) in an almost flat area in central Ebro basin
(NE Spain).

Saline wetlands or saladas undergo drought,
waterlogging, and high salinity, crucial factors in the
distribution of the vegetation. The percent cover of
vegetation is heterogeneous (maximum is 75%) and
includes patches of sparsely vegetated areas, densely
vegetated spots, and bare areas, which exhibit frequent
changes of soil surface appearance.

Figure 1. The saline wetlands studied in 2007 (blue striped filling), in 2008 (green striped filling), and in both years (red striped filling).

The vegetation includes endemic species and
habitats protected by European laws. The most
prominent halophytes are Arthrocnemum
macrostachyum and Suaeda vera. Gypso-halophytic
vegetation (Lygeum spartum) occupies high
topographic positions, in the escarpments of the
depressions, whereas halo-nitrophilous vegetation
(Salsola vermiculata) can appear in the bottom.
Annual halophytes such as Halopeplis amplexicaulis
frequently pioneer the bottoms. The plants appearance
depends on their phenological state and the previous
rains; their greenness is always darker than that of
surrounding crops, such as maize or alfalfa.

The soil surface is prone to frequent changes due
to the occurrence of water, algal mats, efflorescence
and salt crust.

3 MATERIAL AND METHODS

3.1 Sites selection and sampling

We conducted two field surveys, in the summer season
of 2007 and 2008, based on the georeferenced
database of vegetation (Domínguez et al., 2006) which
fits the CORINE biotopes standard (European
Commission, 1991) adapted to our region (Bento,
2010). A Quickbird image acquired in 2007 helped for
the selection of sampling points in 2008.
We surveyed 11 wetlands in 2007 and 6 in 2008; 4 of them sampled in both years. Reflectivity of pure samples of soil or vegetation was recorded in the 2007 campaign, at 144 points (4 to 34 points at each salada) with CropScan MSR16R multispectral radiometer (16 bands, 450-1750 nm).

A continuum spectrum (200-1100 nm) was recorded in 2008 with Ocean Optics HR2000CG-UV-NIR Spectroradiometer, along 18 transects (2 to 5 transects in each salada). From 5 to 10 points were collected in each transect, totaling 98 sampling points. We sampled points deemed as representative of soils with different moisture and efflorescence conditions, and representative plants with different percent cover, following both the ecological and the remotely sensed approach. The readings were calibrated with a 50% (grey) Spectralon reflectance standard panel (Labsphere, Inc.). The measures were systematically collected from 11 a.m. to 15 p.m. and out of solar noon to avoid the shadows as much as possible.

3.2 Ground photographs processing and auxiliary field data.

A photograph of the ground was taken simultaneously to each spectral measure, an oblique photography in 2007, and a vertical photograph with similar field of view than the spectrometer in 2008.

The percentage of each component of our photographs was derived with Can-Eye free software developed by INRA (http://147.100.66.194/can_eye/), often used to characterize the structure of crops (Baret et al., 2004). Five classes resulted from photographs (Figure 2): green vegetation, senescent vegetation, trunks, bare soil, and mixed (i.e., shadows and pixels not included in the previous classes). Visual estimation of plant cover, Munsell soil color, and gravimetric moisture from soil surface (< 2 cm) were also recorded.

3.3 Spectral data processing

The reflectance of CropScan channels was directly analyzed. Row data from Ocean Optics were pre-processed using SAMS software (Spectral Analysis Management System, http://www.cstars.ucdavis.edu/software-sams.htm) developed by CSTARS (Center for Spatial Technologies and Remote Sensing, Davis, California).

The NDVI was calculated and verified according to the field data. The fCover (Kallel et al., 2007) or percent cover of vegetation (included yellow-green senescent parts) from photographs was related to the NDVI.

Figure 2. (a): Photograph of a sampled point (field of vision adjusted). (b): CanEye classification in five classes.

4 RESULTS

4.1 Dominant spectral features of bare soil.

The bare soil reflectivity (Figure 3) changes even in short distances, associated to the soil color and moisture and the occurrence of efflorescence, salt crust, sapropellic soil, and shadows.

Wet soil, darker than dry soil, causes a radiance absorption masking other soil characteristics. Dry soil and efflorescences dramatically increased the soil brightness.

The continuous increasing of reflectance from VIS to MIR is the spectral feature of dry soils without efflorescence. Its magnitude depends on soil color, which in turn varies with the soil composition. The high content in calcium carbonate and gypsum contributes to the bright color of the soil. The desiccation polygons decrease the reflectance due to the shadows between cracks and the dark color of the underlying soil.

Figure 3. Reflectance of soil and vegetation (different density cover) under dry and moist conditions.

The efflorescence is a dominant factor maintaining the VIS and NIR reflectance of soils above that of other type of soils, except if saturated. In moist conditions, even a thin efflorescence increases the reflectance (overall magnitude) and dimmed the decreasing of MIR reflectance.
Salt crusts yield a relatively high reflectance, rising from the visible (VIS) to the near infrared (NIR), with a strong decrease in the middle infrared (MIR) related to the occurrence of hygroscopic salts. A sapropelic layer of millimetric thickness resulting from accumulation and decomposition of organic matter under anaerobic conditions was a dominant feature producing a much lower reflectance at VIS, NIR, and MIR than any type of soil. Sapropelic soil has a distinctive spectrum of low and flat-shaped reflectance, especially between green and red (Zhang et al., 2007). The occurrence of sapropel caused a decrease of soil reflectance to the half, independently of moisture, similar to shadows effect.

4.2 Spectral characteristics of vegetation

A relative low spectral signal (reflectivity > 35%) is obtained from vegetation due to the (1) darkness of halophyte green, (2) absorption of the pigments in succulent stems (Salisbury et al. 1992), (3) variable density cover, and (4) soil moisture. VIS reflectance is < 10%, and NIR reflectance, > 10%.

The reflectance of control samples with known percent cover (0%, 25%, 50%, and 100%) confirms that the reflectance of vegetation (1) increases with the decreasing of vegetation density, though the shape of the spectral signature remains; and (2) decreases with the increasing of soil moisture, especially for low-density covers.

For different plants sampled, VIS reflectance increases with the decrease of the density cover, from 100% to 30%, producing similar spectra than bare soil. The plants sampled show a 20% difference between VIS and NIR reflectance, excepting for Juncus maritimus. Hypersaline plants such as Salicornia have a high variability of NIR and MIR reflectance because of the occurrence of efflorescence patches.

Despite the differences in color, morphology, and density cover, L. spartum, Microcnemum coralloides, and Salsola kali have similar spectra. The high proportion of dry and senescent vegetation for S. vera results in a short difference between NIR and MIR reflectance. The occurrence of moisture and organic matter in the soil, or a thin sheet of water covering the vegetation, make difficult the interpretation of the spectra.

Moisture masks the occurrence of sparse vegetation. Decaying and dry vegetation have greater influence on soil spectra than green vegetation; dead vegetation can be spectrally confused with soil because of the flat signature and the increase from VIS to MIR.

4.3 Spectral indexes and surface characteristics

4.3.1 NDVI versus green cover fraction (jCover)

Different fCover values were extracted with CanEye (Figure 4) by computing: (1) the pure green vegetation of control samples with known percent cover; (2) the green fraction of sampled points; (3) the green and yellow-green fractional coverage of sampled points, which includes dry and dead vegetation, largely represented in our sampling points.

The first approach provides the stronger correlation between fCover values and NDVI ($R^2 = 0.91$), followed by that derived from the sum or green and yellow-green parts of the plant ($R^2 = 0.90$).

Spectrometer measures overestimate NDVI due to the contribution of the soil background, with a high reflectance in NIR. Ground photograph classification underestimates the fCover, even if computed as also the yellow-green fraction, due to (1) the masking effect of shadows, and (2) the difficulty of classifying the wide range of green and yellow-green hues in the photographs.

4.3.2 Indexes to separate vegetation and soils

The field spectral measures used to quantify the fCover were strongly affected by soil brightness, and for a given density of vegetation, dark soil gives lower NDVI values (Huete et al., 1985). Redness Index (Escadafal, 1993) is better adapted to arid lands, and its relationship with NDVI indicates the influence of the type of plant or the dominance of the vegetation against the soil.
S. vera and L. spartum differ in the range, while A. macrostachyum and S. vera clearly differ from non halophytes. Their low chlorophyll concentration decreases the VIS reflectance absorption and the RED boundary value resulting in BI < 30%, except if efflorescence occurs. BI is very high for L. spartum, similar to the soil.

The proportion of shadows produced by branches and intertwines stems is an additional factor influencing BI values. L. spartum is less affected.

To improve separation of plant species we related BI with color index (Houssa et al., 1996). Bare soils have a wide range of BI (20%-100%) and low values of CI (< 0.15), corresponding to the Munsell colors 10YR and 2.5Y.

RI, BI, and CI indexes allow studying the influence of the type of vegetation or its dominance, and are suitable to separate soil and vegetation and to distinguish halophytes from non-halophytes. However, they are not useful to differentiate species of halophytes.

5 CONCLUSIONS

Vegetation has low reflectance < 30%, depending on the vegetation density, plant species community, phenological state, and shadows. In sparsely vegetated areas, the efflorescences and the sapropelic layer increase and decrease the reflectance, respectively.

The classification of ground photographs shows (1) the spectral confusion of dry and died vegetation with soil, and (2) the contribution of green and yellow green parts of the plant to the fraction cover and NDVI.

Field data about spectral characteristics of soil and vegetation are essential in the validation and classification of satellite images.

6 REFERENCES


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