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RESEARCH ARTICLE

Establishment of empirical relations between fuel moisture content and the normalised difference vegetation index

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Abstract

The object of the present research is to establish empirical relations between the Fuel Moisture Content (FMC) and the Normalised Difference Vegetation Index (NDVI) in pasture samples. The study area was the Carillanca Experimental Centre belonging to the Institute of Agriculture and Livestock Research (Instituto de Investigaciones Agropecuarias - INIA), Araucanía Region, Chile. The study period ran from November 2011 to January 2012, in order to determine the variation in vegetation moisture content from spring, when plant cover is most vigorous, to summer when it declines to a minimum due to the summer drought. The application of a linear adjustment model produced correlation coefficients higher than 0.6.

Keywords: Fuel content, normalized difference vegetation index, pasture

1. Introduction

Quantifying the humidity content is very important, as it is one of the key variables for the characterization of the earth’s floor and the knowledge it producesfor the improvement ofirrigation management in vegetation (Zhang *et al*., 2013; Shukla *et al*., 2013). More detailed knowledge in space and time of the moisture content of a crop under irrigation would enable farmers to manage water resources more effectively, supplying the crop with water when and where it was vitally needed. Furthermore, the prevention of natural disasters such as drought and forest fires (Cocero *et al*., 2000; Chuvieco *et al*., 2001; Yebra *et al*., 2005 ; Yebra *et al*., 2008a; Yebra *et al*., 2008b). in shrubby or herbaceous vegetation the moisture content is a key parameter for explaining the phenological evolution of plant formations, allowing deficit situations to be detected which might lead to critical deterioration in plant tissue (Sepulcre *et al*., 2006). Because the moisture content of plants is inversely related to their flammability and combustibility, it is very important for the prevention of natural disasters such as drought and forest fires (Cocero *et al*., 2000; Chuvieco *et al*., 2001; Yebra *et al*., 2005 ; Yebra *et al*., 2008a; Yebra *et al*., 2008b).

It can be estimated by gravimetric methods, or with models which use information from remote sensors on board satellite platforms as input (Yebra, 2008). The advantage of the latter is that they provide information on moisture content on a regional scale, while the former are of a more local nature. However for this type of estimation to be reliable, the effects of moisture on the reflectivity of the vegetation must be studied, in order to isolate the bands which are most sensitive in remote observation and determine critical effect levels (Vaughan, 2001).

In the context of research into correlations between biophysical variables to allow moisture content to be estimated from satellite platforms, the present contribution is oriented towards finding empirical relations between the moisture content and the normalised difference vegetation index.

2. Materials and Methods

2.1. Study area

The study area was the Carillanca Experimental Centre belonging to the Institute of Agriculture and Livestock Research (Instituto de InvestigacionesAgropecuarias–INIA), located between 38° and 39° south, 20 km north-east of Temuco, at kilometer 9.5 of the Cajón-Vilcún road. The experimental farm, located in the IX (Araucanía) Region of Chile, covers 530 hectares; it has irrigated flat land with volcanic ash soil, and dry rolling land with volcanic ash and transition soils, making it representative of a large part of the Region. The climate is characterised by an average annual temperature of 10° C, with average maximum in the hottest month (January) of 21.5° and average minimum in the coldest month (July) of 2.3° C. The average annual rainfall is 1394 mm, the wettest month being May with 236.6 mm. The annual pan evaporation is 921 mm, with a monthly maximum in January of 161 mm and minimum in July of 20 mm (Novoa and Villaseca, 1989).

A plot measuring 20m by 20m was established in the study area, from which samples of pasture (genus Festuca) were taken and subsequently stored in ziploc bags for transfer to the laboratory. The samples were taken between 12:00 and 16:00 hrs, over the period November 2011 to January 2012, in order to determine the variation in vegetation moisture content from spring, when plant cover is most vigorous, to summer when it declines to a minimum due to the summer drought.

2.2. Spectral reflectivity of samples

To record its reflectivity, each sample was placed inside a low reflectivity chamber, the sides of which were lined with high absorption black filter paper. This isolated the sample and prevented reflectivity interference from nearby objects.

The sample was illuminated with two 500 W halogen lights in parallel, at an angle of 45°, and kept lit for minimum 6 minutes, in order to stabilise the light source and diminish the effect of shadow. Reflectivity measurements were recorded for each sample using a PS-100 spectroradiometer, band-width 350 – 1000 nm and resolution 0.5 nm. The reflectivity measurements were taken vertically, and the reflectivity of a calibrated reference target (Spectralon) was taken before each measurement. Once the reflectivity records had been obtained, the moisture content and vegetation index were estimated.

2.3. Estimation of moisture content

The samples were weighed (humid weight) in a scale accurate to 0.01 gr. They were then placed in an oven at 60º C for 48 hrs for dessication (higher temperatures lead to a loss of biomass). The sample was then weighed again (dry weight). With this information, the moisture content was calculated in the form of the FMC (Fuel Moisture Content) index, defined as:

$$FMC = \frac{(W_h - W_d)}{W_d} \; x\; 100 \qquad 1$$

W_h is the humid weight and W_d the dry weight, i.e. that obtained after dessication of the sample. The result is expressed as a percentage of the dry weight.

2.4. Estimation of the vegetation index

The vegetation index is calculated from the reflectivity values at different wavelengths. It is used for extracting information on the vegetation while minimising the influence of other external factors such as the optical properties of the soil, solar irradiance, etc. (Sobrino, 2000).

More than twenty vegetation indices can be found in the literature, however the most commonly used, due to its mathematical simplicity and ease of use, is the Normalized Difference Vegetation Index (Rouse *et al.*, 1974):

$$NDVI = \frac{\rho_{nir} - \rho_v}{\rho_v + \rho_{nir}} \qquad 2$$

P_v and P_{nir} are the reflectivities in the visible and near infra-red regions. NDVI takes values in the range -1.0 to 1.0; negative values indicate surfaces free of vegetation, such as water, snow or cloud, and increasing positive values indicate increasing levels of vegetation.

Integrated reflectivity values were used to obtain vegetation indices.

$$\rho_{\Delta\lambda} = \int_{\lambda_1}^{\lambda_2} \rho(\lambda)\, d\lambda \qquad 3$$

The spectral ranges selected were matched with those found in the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and MODIS (Moderate-Resolution Imaging Spectroradiometer) sensors on board the TERRA satellite platform. Both sensors have band-widths in the visible and near infra-red regions: ASTER (v: 520-690 nm; nir: 760-860 nm), MODIS (v: 620-670 nm; nir: 841-876 nm).

3. Results

3.1. Reflectivity records

Figure 1 shows the spectral signature corresponding to the typical behaviour of a sample of pasture, derived from the reflectivity records obtained.

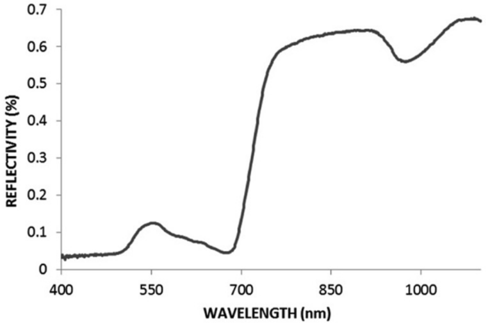

Figure 1. Spectral signature of a pasture sample

As can be seen from the figure, the reflectivity varies widely with the wavelength, with minimum values in the visible spectrum (400-700 nm) corresponding to blue (436 – 495 nm) and red (627-770 nm), related to the chlorophyll in the vegetation. The lowest reflectivity values in fact coincide with the maximum absorption values, corresponding in these intervals to chlorophyll. Among the maximum absorption values is a relative maximum in the reflectivity, around 550 nm, corresponding to the green (495-566 nm) of the vegetation. Reflectivity is high towards the near infra-red region (700-1100 nm), associated with the vigorous state of the vegetation, the proportion of green cover and the healthy leaves.

3.2. Moisture content

Figure 2 shows the evolution over time of the moisture content. There is a clear contrast between spring (value close to 400 %) and summer (around 40%), which agrees with the reduced precipitation and the higher temperatures.

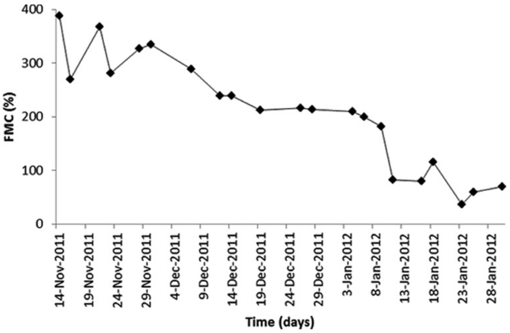

Figure 2. Evolution over time of the moisture content (%)

3.3. Ratios between the moisture content and the normalised difference vegetation index

Figure 3 shows the graphs for FMC (%) as a function of NDVI for the ASTER and MODIS sensors, with the straight line for linear fit, linear regression model and correlation coefficient.

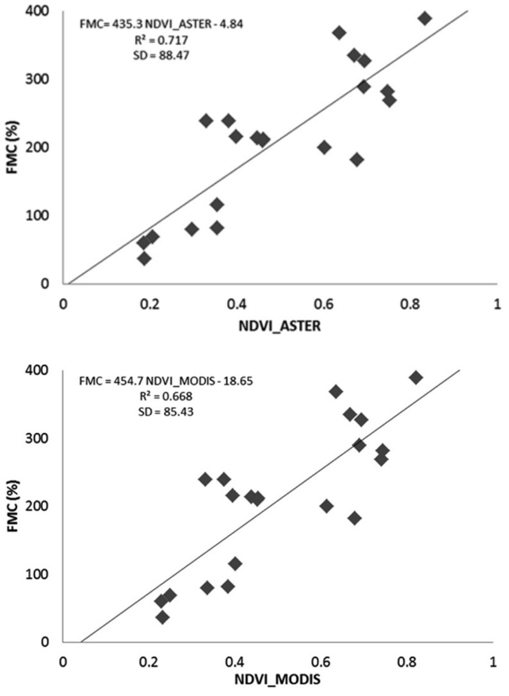

Figure 3. Variability of FMC (%) as a function of NDVI for the ASTER and MODIS sensors

The correlation signs are consistent with expectations. The NDVI measures the vigour of the vegetation (principally its chlorophyll content); therefore when the moisture content increases, other physiological processes of the vegetation do likewise, implying an increase in NDVI. A summary of the statistical analysis is given in Table 1.

Table 1. Statistical analysis of FMC (%) as a function of NDVI for the ASTER and MODIS sensors a

$$BIAS = \sum_{i=1}^{n} \frac{(FMC\ observed - FMC\ estimated)}{n}$$

b

$$RMSD = \left[\sum_{i=1}^{n} \frac{(FMC\ observed - FMC\ estimated)^2}{n}\right]^{0.5}$$

[c]Slope of linear fit; [d] intercept of linear fit; [e] correlation coefficient.

FMC	BIAS[a] (%)	RMSD[b] (%)	a[c]	b[d] (%)	R^2[e]
ASTER	-0.00019	54.21	435.3	-4.84	0.71
MODIS	-0.00169	58.69	454.7	-18.65	0.66

The FMC values observed and estimated, together with the linear trend lines 1:1, for the ASTER and MODIS sensors are shown in Figure 4.

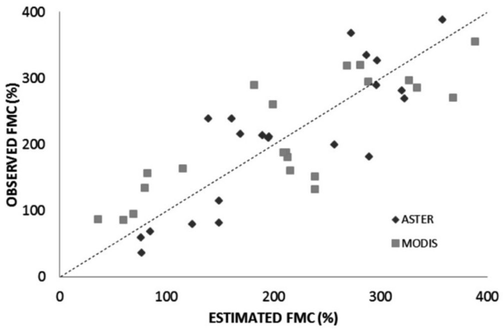

Figure 4. Observed FMC values contrasted with estimated FMC values for the ASTER and MODIS sensors. The straight line of the linear trend 1:1 is indicated.

4. Conclusions

The results of this study indicate that the reflectivity records for the different samples vary widely with the wavelength; the spectral reflectivity curves show maximum and minimum values associated with absorption bands. Minimum values appear in the visible spectrum region which correspond to maximum chlorophyll absorption, while the near infra-red region presents an increase in reflectivity, associated with the vigour of the vegetation, the proportion of green cover and the health of the leaves.

The evolution over time of the moisture content of the pasture shows marked variations between spring (close to 400 %) and summer (around 40 %), resulting from reduced precipitations and higher temperatures. When the FMC index is correlated statistically with the NDVI, as estimated for spectral bands located in the visible and near infra-red spectrum in the ASTER and MODIS sensors, linear correlation coefficients higher than 0.6 are obtained. This means that it is possible to estimate the moisture content based on information provided by satellite platforms at a spatial resolution suitable for agronomy and forestry studies.

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