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Changes in Vegetal Cover, Precipitations and Land Degradation in Puna Region, Argentina

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Abstract: The protection of the soil surface by the vegetation or rests of it is related with the decrease of the potential erosion. The Universal Soil Loss Equation (USLE) by the Soil Conservation Service (SCS) of the United States is the most used model for the estimation of water erosion. There are different methods to measure or estimate the vegetal cover or the C factor over the world. Mostly are available estimated data, meanwhile are scarce objective data of the vegetal cover in the Puna region and there is no baseline information that shows the temporal and spatial variation of the vegetation. The objective of this work is to obtain mathematical equations that allow predicting faster and economically the vegetation cover of the shrub steppes, being this one the most representative physiognomic type of the Puna. The best adjustments were found with a linear function and direct measurement data (R^2=0,57). A secondary objective was to compare the predicted vegetal cover through the functions obtained in this research with the precipitation recorded in the same geographical place.

Key words: vegetal cover, NDVI, precipitation, Puna

1. Introduction

The Puna region, in northwestern Argentina (NOA), is a high plateau that varies between 3,400 and 4,500 meters above sea level [1] (Fig. 1). The scarce precipitations and the low temperatures determine a deficient productivity and vegetal recovery, what is added the torrential character of the rain that causes erosion because of the low vegetation cover, fact aggravated remarkably in the last 30 years [2].

The study of land degradation requires the assessment of vegetal cover. There are several studies where natural vegetal cover in NOA region is measured or estimated *in situ*, with known geographic references (GPS) and date of sampling, through different methods. Some of them are based on obtaining data in a direct and objective way through Canfield lines [4] or Maras [5]. When it is not viable, is possible to use the visual

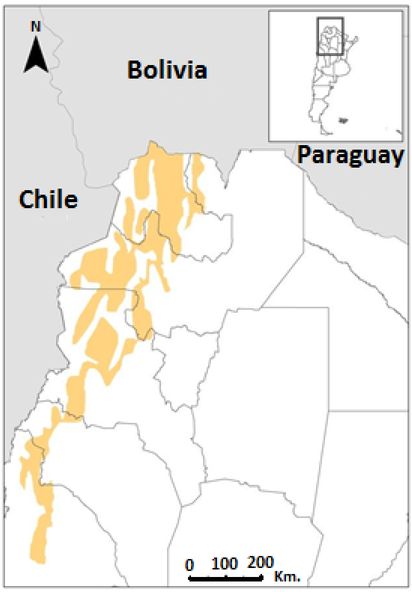

Fig. 1 Location of the Puna ecoregion [3].

estimation of vegetal cover in the field by the researcher. This methodology is expeditious, allows a greater number of samples and can be applied in large and difficult to access lands, but generating approximate and lower quality data; for example the

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protocols agreed by the National Observatory on Land Degradation and Desertification (ONDTyD) [6]. Another way faster and economically to estimate the coverage, is with information provided by remote sensing; since an attribute of the terrestrial surface is related to a determined spectral behaviour, with values of reflectance or emission of the terrestrial surface in different wavelengths [7]. The Normalized Difference Vegetation Index (NDVI) is the most used spectral index as an estimator of the presence and condition of vegetation [7]. One of the main advantages of NDVI is the possibility to calculate it through the information provided by the majority of the earth observation sensors and platforms and many of meteorological satellites [7]. In order to link the information generated by the satellites with the land measurement data, functions and algorithms are required.

In bibliography normally find equations that allow the estimation of vegetal cover in crops [8, 9], nevertheless in natural regions and specially the most remote, the information is scarce and it is specific for each region like the one elaborated by Gaitán et al. [10]. There is a strong relationship between vegetal cover and the NDVI and between both of them and the precipitations oscillations [11-13]. Maggi & Di Ferdinando [14] and Worcel & Maggi [15] showed the relationship between the NDVI and the precipitation in the Puna region. However, still not be obtained an equation that compares the NDVI index with the vegetal cover for this region, in order to include this one in the degradation land's models. In consequence, few objective data are available to estimate the vegetal cover of shrub steppes in the Puna region; furthermore there is no baseline information that shows the temporal and spatial variation of the vegetation. By better predicting soil cover better estimating of degradation would be obtained, and this in turn will allow predicting more accurately situations in the future from extreme climate changes.

The aim of this work is to obtain mathematical equations that allow predicting faster and economically the vegetation cover of the shrub steppes, being this one the most representative physiognomic type of the Puna region. Besides, to know the reliability of the estimation methods in relation to the observational and/or measurable methods of the vegetation cover. As a secondary objective, compare the predicted vegetal cover through the functions obtained in this research with the precipitation recorded in the same geographical place.

2. Materials and Methods

The data from the same date and place has been related, of NDVI provided by MODIS images and of the vegetal cover obtained from visual estimations or measured with Canfield lines [4] or Maras [5] in shrub steppes of Laguna de los Pozuelos and Miraflores river basin with its GPS point. The images of the MODIS sensor on board the Terra satellite were used, of 250 m of spatial resolution per pixel, corresponding to the product MOD13Q1. A depuration of the NDVI data was done, verifying how heterogeneous each pixel was through the MODIS Subsets website [16]. Some data were discarded since it was observed that an important road crossed the diagonal of the pixel, the pixel covered part of the Laguna de los Pozuelos or bare soil; as it was considered that the NDVI value was underestimating the vegetal coverage that really was in that pixel.

The percent vegetation cover and NDVI value from 139 data of shrub steppes were recorded, of which 23 are direct measurement and the rest visual estimation. Direct measurement data were provided by different projects of the ONDTyD [6] and UBACyT (The University of Buenos Aires Science and Technology), Faculty of Agronomy; corresponding to the months of March 2007, September 2009 and October 2014. While visual estimation data were provided by other projects of the ONDTyD and UBACyT, corresponding to the months of March and May 2016, and also data estimated in the field by Baldassini P. [17] between

January and August 2008. All these data were identified by GPS.

The coefficient of determination R^2 was used to evaluate the reliability of the methods that measure vegetal cover. To observe if there were significant differences between the linear functions found for the two methods, an analysis of variance was performed for a regression with categorical variables where the hypothesis of parallelism and coincidence were tested using alpha 0.05 and 0.1.

$$COB_i = \beta_0 + \beta_1 \times NDVI_i + \beta_2 \times Z_i + \beta_3 \times NDVI_i \times Z_i + \varepsilon_i$$

Where:

COB_i: the vegetal cover in the i-th measurement.

Z_i: the methodology used in the i-th measurement.

Z_i=0, visual estimation; Z_i=1, direct measurement.

β_0: the intercept with the y-axis of the visual estimation methodology, when the NDVI is zero.

β_1: the average change on vegetal cover for each unitary increase of the NDVI value with the visual estimation methodology.

β_2: the average difference in the percent vegetation cover with the direct measurement methodology with respect to the visual estimation.

β_3: the average difference in the average change of the vegetal cover measured directly in the field with respect to visual estimation when unitary change occurs in the NDVI value.

$NDVI_i$: the NDVI index value in the i-th measurement.

ε_i: the random, independent error, with normal distribution with zero mean and variance σ^2.

In order to test the best adjustment proposed by the different equations to predict vegetal cover, years with strong difference in rainfall were compared. According to what was demonstrated by Barrera & Maggi [18], the months between October to April 2004-2005 correspond to a dry period in the Puna region, warm phase of the ENSO (El Niño Southern Oscillation); meanwhile the same months in 2008-2009 correspond to a wet period, cold phase of the ENSO. Being the monthly precipitation data obtained from the estimates made by the Global Precipitation Climatology Centre (GPCC), organized in a grid with a spatial resolution of 0.5º×0.5º [19]. Therefore, it was compared the average of predicted monthly vegetal cover, with the function obtained from direct measurement data, of two pixels of MODIS from two locations (22º45'39.4''S, 65º54'39.7''O; 22º22'12''S, 65º39'18''O) included in one pixel of GPCC, with centre in 22º 45'S and 65º 45'O, between October and April 2004-2005 vs. 2008-2009.

3. Results and Discussion

It was found that the linear function, between values of vegetal cover and NDVI of direct measurement, is the one that best explains this relation (Fig. 2). It is defined by the function $y = 201.9x+3.7$ $R^2 = 0.57$, where x is NDVI value and y is percent vegetation cover predicted by the model. When estimating the vegetation cover in the field it is easier to make mistakes due to overestimation or underestimation, increasing the coefficient of variation. This methodology is better adjusted to a logarithmic function where is an asymptote to avoid coverage from exceeding 100% with high NDVI values (Table 1). The advantage is to obtain many records with low cost in regions where access is difficult.

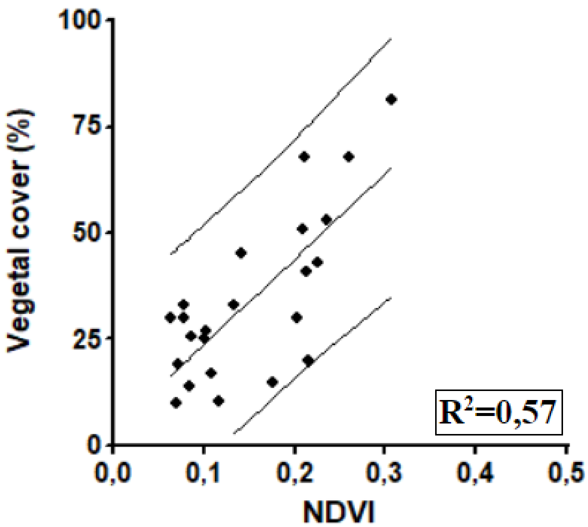

Fig. 2 Linear function with 95% prediction bands between vegetal cover (%) and NDVI for direct measurement data.

Table 1 Linear and logarithmic functions obtained from the relationship between vegetal cover (*y*) and NDVI (*x*) according to the methodology used.

Method	Type	Function	R^2
Both methods	linear	y = 181.7x+18.2	0.29
	ln	y = 27.7lnx+100	0.30
Direct measurement	linear	y = 201.9x+3.7	0.57
	ln	y = 26.9lnx+88.3	0.47
Visual estimation	linear	y = 176.9x+21.2	0.26
	ln	y = 27.4lnx+101.5	0.28

Most of the works that estimate vegetation cover with NDVI use linear functions, both natural vegetation [12, 20, 21] and crops [8, 9, 22]. In this work, the usefulness of this function is also recognized. After an analysis of variance for a regression with categorical variables differentiating the linear functions that represent the two methods to record data on the field, it is not rejected the parallelism hypothesis (p-value = 0.6405) but it is rejected the coincidence hypothesis (p-value = 0.048). Therefore, both models present the same slope of the line but they differ since the visual estimation method presents a higher intercept with the *y* axis, overestimating the real values of vegetal cover.

The direct measurement methodology presents better adjustments than the visual estimation method (Table 1). This results are similar to those found by Gaitán et al. [10] in the arid and dry sub-humid region of Patagonia, Argentina; where the NDVI explains 40% of the basal coverage measured with transects, through a linear regression with coefficients a = 154.31±14.42 and b = 1.88±1.34. Although, contrasted to this work, they considered every physiognomic type present in Patagonia. It must be taken into account that direct measurement data are available in a smaller quantity, which may cause the R^2 to increase. Consequently, the visual estimation method presents more recorded data; hence it has greater influence on the adjustment of the percent vegetation cover and the NDVI when total data is considered.

The importance of obtaining this function (Fig. 2) remains in the fact that one of the possible applications of it is to obtain maps of percent vegetation cover that are thematic layers and input of the GIS developed for the study of land degradation, based on thematic images such as the NDVI. To this extent, it was compared the average of predicted monthly vegetal cover with the precipitation recorded in each month from a wet period respect to a dry period (Fig. 3). Moreover, it was found R^2 adjustments of 0.76 and 0.83 respectively, between the average of predicted monthly vegetal cover and the accumulated precipitation predicted by GPCC (Fig. 4a). Additionally, the importance of the distribution of precipitation in response of vegetation cover was observed. Even though the ENSO is the most important factor to explain the oscillations of rainfall in the NOA [18], they do not depend totally on this phenomenon. On the other hand, precipitation shows spatial variation, which is why even comparing the same years for contrasting phases two pixels can show different behaviours between the phases (Fig. 3a, b and 4a, b).

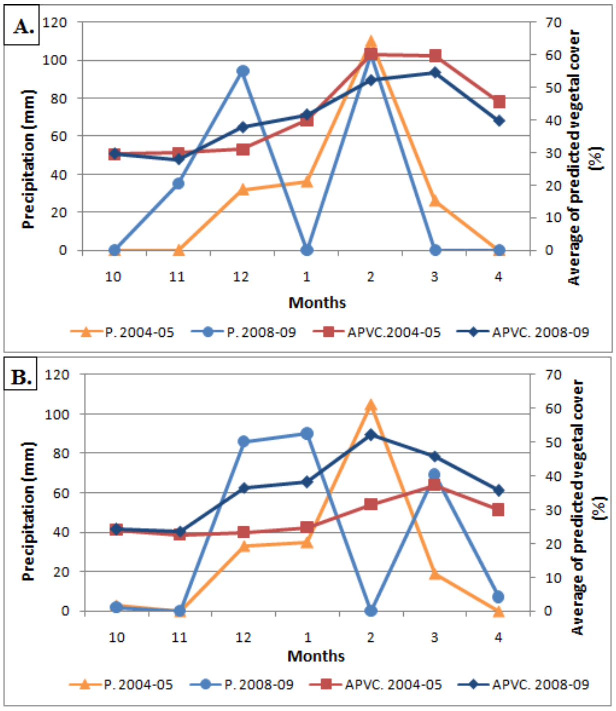

Fig. 3 Precipitation and average of predicted monthly vegetal cover for the period between October and April 2004-2005 vs. 2008-2009: (A) Pixel with centre in 22°45'39.4''S, 65°54'39.7''O. (B) Pixel with centre in 22°22'12''S, 65°39'18''O.

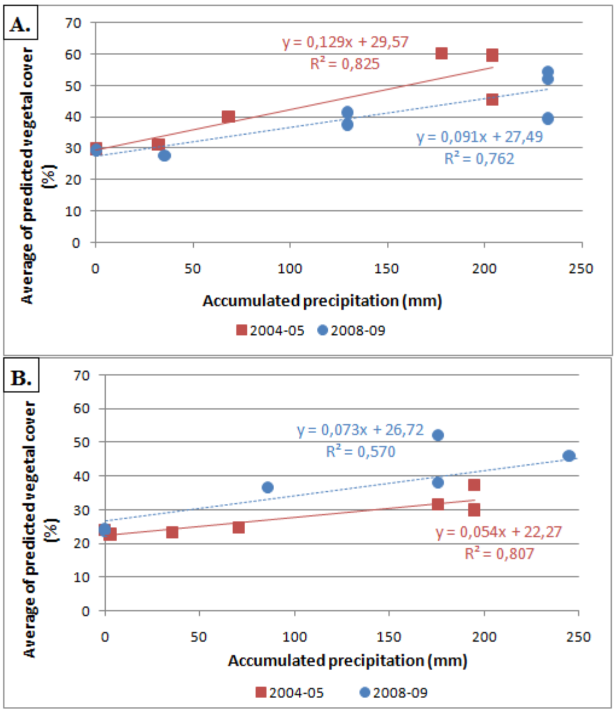

Fig. 4 Relation between the average of predicted monthly vegetal cover and the accumulated precipitation: (A) Pixel with centre in 22º45'39.4''S, 65º54'39.7''O. (B) Pixel with centre in 22º22'12''S, 65º39'18''O.

4. Conclusions

It was possible to obtain mathematical functions that allow the prediction of vegetation cover in shrub steppes of the Puna, using NDVI data provided by MODIS images. These can be related with spatio-temporal variations of precipitations and land degradation. In addition it was demonstrated that measurable methods of vegetation cover presents more reliable results than the estimation methods, as they present better adjustments and significant differences in the functions found for each method. Even though measurable methods are more precise when estimated data are included in the functions, which are faster and economics, then these one can be used at a regional scale.

The average of predicted vegetation coverage is related to the accumulated precipitation, independently of the ENSO phase considered.

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