Relationship between semi-arid rangelands quality parameters and vegetation indexes

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Abstract
A large portion of the sheep production systems in the semi-arid zone of Central Chile base their feeding on the rangelands, adjusting both the production cycle and the use of supplementary feed to the natural supply of fodder. In this way, knowledge of the rangeland quantity and quality at the farm level emerges as an essential input for the decision-making of feed management. The objective of the study was to relate the herbage quality parameters of the semi-arid zone rangeland with Vegetation Indices (VI) and to determine which vegetation index report the best results. Vegetative indexes were obtained from aerial images multispectral captured by a drone. During the 2018 growing season (Oct to Dec), in three farms of the semi-arid zone of Central Chile, three plots of exclusion (per farm) of 100 m^2 each were installed and monitored. Samples were taken once a month to determine the contents of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of rangeland herbage. Regressions were developed between the rangeland herbage quality parameters and the calculated VI. Most of the regressions obtained were significant ($p < 0.05$). In DM, the index that presented the best R^2 (0.84) was Plant Senescence Reflectance Index (PSRI). In CP, the highest value of R^2 was only 0.38 for PSRI. For NDF, a maximum value of R^2 of 0.56 was obtained using Red Edge Chlorophyll Index (CI red edge). Finally, for ADF, the highest value of R^2 was 0.72 obtained in Green Normalized Difference Vegetation Index (GNDVI), Normalized Difference Vegetation Index (NDVI), Soil-Adjusted Vegetation Index (SAVI), and Green Chlorophyll Index (CI green).

Introduction
The vegetation indices (VI) obtained from multispectral images have been investigated for more than three decades to relate them to quantitative variables such as the height, availability, or covered area of arboreal and non-arboreal plant species (Fern et al., 2018, Lussem et al., 2019). However, the search investigating relationships between herbage quality parameters and wavelengths or VI is more recent (Posada-Asprilla, 2019, Barnetson et al., 2020). Some quality parameters such crude protein (CP), nitrogen, C:N ratio have already been related to wavelengths or VI (Beeri et al., 2007). Regarding the researches that make use of unmanned aerial systems (UASs) to capture multispectral images to estimate VIs, these are concentrated in the past decade (Poley and McDermid, 2020). In Chile, the information associated with the herbage quality of the rangeland and its temporal evolution has several decades; therefore, considering that climate change has reduced the length of the growing season of the rangelands, this information is outdated. Thus, the objective of this study was to relate the herbage quality parameters of the semi-arid zone rangeland with vegetative indexes and to determine which vegetation index report the best regression model to be used as a prediction tool.

Methods and Study Site

Study Site
The study was conducted in the O'Higgins Region, part of Central Chile, located between 33° and 35° 01′ S and between 70° 02′ W and the Pacific Ocean, specifically in the dried-fed areas of the region. The prevailing climate in the region is a temperate Mediterranean climate with variations according to the topography. The annual rainfall is irregular, with June and July as the wettest months, with a historical average between 100–300 mm per month (Pizarro, 2007). The annual average rainfall (1974-2019) ranges between 502 mm in the foothills to 533 mm in the Interior Central Valley (DGAC, 2020).

Methods

Sampling and take of multispectral imaging.

During the 2018 growing season (Oct to Dec), in three farms of the semi-arid zone of Central Chile, three 100 m^2 plots of exclusion (per farm) were installed. Once a month, in each of the exclusion plots, herbage rangeland samples were taken. The sample consisted of present herbage in an area of 0.75 m^2, considering a cutting height of 3 cm. The cutting place within the exclusion plot was obtained through the random cut of three 0.5 X 0.5 m squares per plot. The samples were weighed fresh to obtain the productivity per ha (kg fresh matter/ha) and later taken to the analysis laboratory of the Pontificia Universidad Católica de Chile to determine the content of Dry Matter (DM), Crude Protein (CP), Neutral Detergent Fiber (NDF), and Acid Detergent Fiber (ADF). The AOAC (2005) methods were used to estimate DM (method 2001.12) and CP (method 2001.11) concentrations. The NDF and ADF were determined using the Van Soest et al., (1991) method.

On the same days of sampling, multispectral images were captured in each of the three farms. An Inspire 2 drone, equipped with a Parrot Sequoia camera, was used to capture multispectral images. The Parrot Sequoia camera had five sensors, allowing the obtaining of spectral data in the following five bands: RGB, Green, Red, Red border and Near-Infrared. The images capture was carried out at the height of 100 meters, and 50 to 60 images were taken per farm and sampling.

Image processing and vegetation indexes estimation.

An orthophoto was created from the multispectral images taken at each visit and for each farm using the Agisoft photoscan software. The orthophoto contained the information associated with each of the five spectral bands and a surface that made it possible to incorporate the three exclusion plots (Figure 1a). Subsequently, using the QGis software, the following vegetative indices were calculated: Simple Ratio Vegetation Index (RVI), Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Green Chlorophyll Index (CI green), Red Normalized Difference Vegetation Index (RNDVI), Red Edge Chlorophyll Index (CI red edge), Soil-Adjusted Vegetation Index (SAVI) and Plant Senescence Reflectance Index (PSRI). Subsequently, within the area corresponding to each exclusion plot, 100 measurement points were randomly selected (Figure 1b). For each point, the eight vegetation indices were obtained (Figure 1c), which were stored in a database that included the month, farm, and plot information.

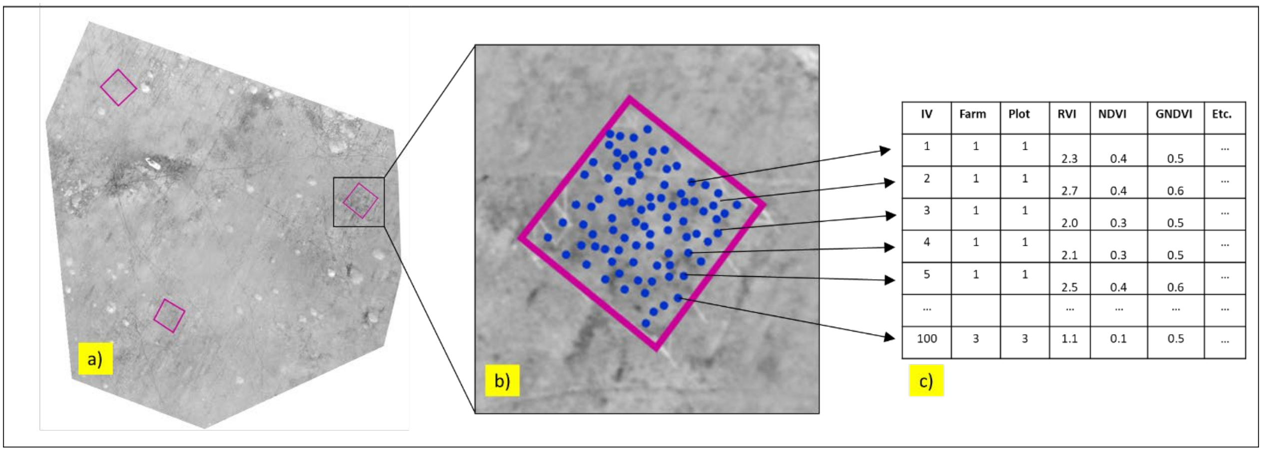

Figure 1. Stages for obtaining vegetation indexes.

Statistical analysis

For each vegetation index and quality parameter, the outline values were identified and eliminated. Then the mean and variance were obtained, and dispersion graphs were drawn. Analysis of variance were carried out to test the effect of month on quality parameter. Multiple comparisons of means were done by Duncan-test. Linear regression models were developed between vegetation indices and quality parameters (8 indices x 4 parameters) to determine which of the vegetation indices allows to predict the percentage content of DM, CP, NDF, and ADF with the least error. For the statistical analysis, R software (R Core Team, 2020) was used.

Results and Discussion

The percentages of DM and CP had significant changes in each month of the growing season (Table 1). For ADF, significant differences were observed only between October and November (Table 1). For NDF, despite increasing as the growing season progresses (Figure 2c), no significant differences were observed between the months studied.

Table 1. Rangelands herbage composition (Mean ±Standard deviation, %) during the growing season

Variables	October	November	December	P value
Dry Matter	28.7±8.6^{a}	66.4±24^{b}	95.4±1.9^{c}	<0.01
Crude protein	14.6±4^{c}	9.1±2.4^{b}	5.9±1.9^{a}	<0.01
Neutral Detergent Fiber	50.1±10.2	55.7±6.1	55.6±4.7	0.105
Acid Detergent Fiber	25.2±4.8^{a}	31±2.9^{b}	33.7±1.5^{b}	<0.01

The dispersion graphs, as well as the linear regression models that presented the best results for the parameters DM (%), CP (%), NDF (%) and ADF (%) are shown in Figure 2. In December, less variability was observed both in the vegetation indices and in the quality parameters of the rangelands due to the fact that the grass reach the state of senescence.

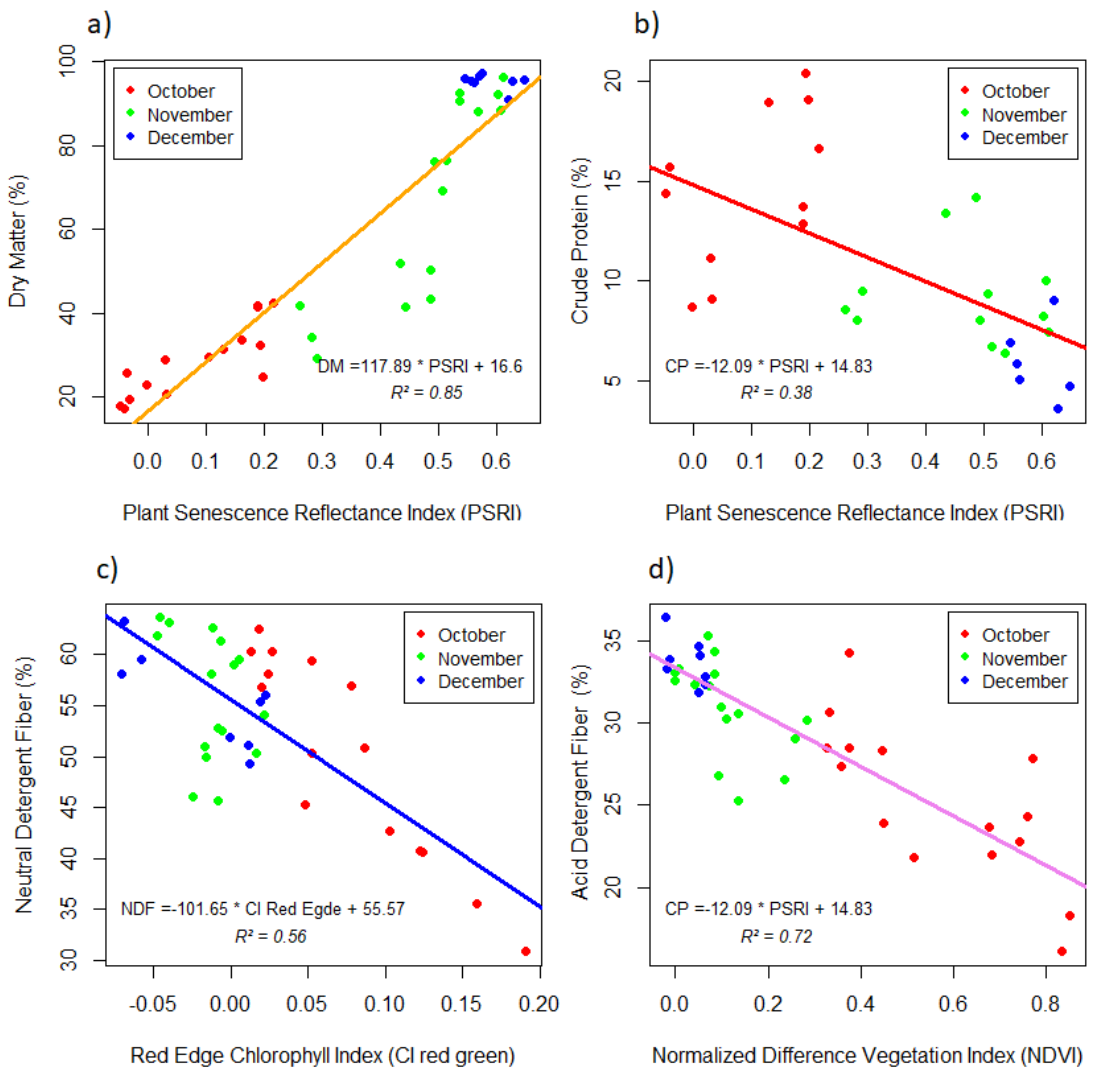

Figure 2. Selected linear regression models for DM, CP, NDF, and ADF

For both DM and ADF, the models were able to explain more than 70% of the variability of the data, which is considered acceptable. In the case for NDF and CP, despite obtaining significant models, the values of R^2 were low, 0.56 and 0.38, respectively. This result is explained by the variability of species that make up the semi-arid rangeland in the study area, within which a large number correspond to exotic species (Martín-Forés, 2012). The obtention of low coefficients R^2 has been addressed by authors such as Li et al. (2016) by incorporating factors related to land cover and the grassland type.

Conclusions/Implications

Despite obtaining significant models, the variability of species and edaphoclimatic conditions observed in the semi-arid rangelands of the O'Higgins region generate variability in the quality parameters that cannot be explained by univariate models. Thus, obtaining reliable regression models for estimating quality parameters from vegetation indices requires additional studies. These studies include the development of rangeland typologies and the generation of both linear and non-linear regression models that incorporate variables such as phenological status and the proportion of families of predominant species.

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