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Artículo

Análisis de la pertinencia de las plantaciones forestales en Oaxaca

Analysis of the pertinence of forest plantations in Oaxaca

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Resumen:

La evaluación de la cubierta vegetal a gran escala es una tarea complicada y costosa; sin embargo, la percepción remota ha facilitado el estudio de su dinámica y distribución espacial, a partir del estimador de biomasa, Índice de Vegetación de Diferencia Normalizada (NDVI). La necesidad de conocer el éxito de las plantaciones forestales establecidas en la región tropical y templada del sur de Oaxaca durante el periodo 2014 -2016, así como la complejidad y los altos costos implícitos en la evaluación tradicional de la cubierta vegetal a gran escala, motivaron el uso del NDVI y otras técnicas geomáticas para estimar la biomasa y determinar los factores ambientales que influyen en su desarrollo. Para ello, se obtuvo la biomasa procesando tres series de imágenes de satélites: dos del sensor *Landsat* 8 OLI y una del *Sentinel*-2. Mediante un análisis de correspondencia canónica se definieron las variables que incidieron sobre su dinámica. Y, a partir de un análisis con series temporales se determinó que las plantaciones de la zona tropical y templada presentan buen desarrollo, pero de comportamiento distinto entre ambas. Las variables ambientales que afectan su dinámica son la altitud, precipitación, temperatura, evapotranspiración, humedad y pH. Por ello, es importante considerar los factores ambientales y los requerimientos ecológicos de las especies antes de su establecimiento.

Palabras clave: Biomasa, factores ambientales, imágenes de satélite, índice de vegetación, sensores remotos, SIG.

Abstract:

The assessment of large-scale vegetation cover is a complicated and expensive task; however, remote sensing has facilitated the study of its dynamics and spatial distribution, based on the biomass estimator, Normalized Difference Vegetation Index (NDVI). The need to know the success of the forest plantations established in the tropical and temperate region of southern Oaxaca during the 2014-2016 period, as well as the complexity and high costs implicit in the traditional evaluation of large-scale vegetation cover, motivated the use of NDVI and other geomatic techniques to estimate biomass and determine the environmental factors that influence its development. For this, the biomass was obtained by processing three series of satellite images: two from the Landsat 8 OLI sensor and one from the Sentinel-2. Through a canonical correspondence analysis, the variables that affected its dynamics were defined. And, from an analysis with time series it was determined that the plantations of the tropical and temperate zones present good development, but of different behavior between both. The environmental variables that affect its dynamics are altitude, precipitation, temperature, evapotranspiration, humidity and pH. Therefore, it is important to consider the environmental factors and the ecological requirements of the species before their establishment.

Key words: Biomass, environmental factors, satellite images, vegetation index, remote sensing, GIS.

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Introduction

The supply of wood for industry based on the use of forests has been complemented with forest plantations to lower pressure and reduce natural ecosystems. This has resulted in the forest area of 29 countries increasing 6 % during the 2000-2010 period (FAO, 2016). At the global level, forest plantations covered an area of 264 million hectares in 2010, equivalent to 7 % of the world's forest area, from which, 30 % was concentrated in Asia, from native species, and most have been established for industrial purposes, with a minimum area for non-commercial purposes (FAO, 2010).

Species that are rapidly growing (70 %), such as *Pinus radiata* D.Don, *P. caribaea* Morelet, *P. taeda* L., *P. patula* Schiede ex Schltdl. & Cham., *P. elliottii*, *P. palustris* Mill., *P. oocarpa* Schiede ex Schltdl., *Eucalyptus grandis* W.Hill, *E. urophylla* S.T.Blake and *E. globulus* Labill. are often used for plantation projects in Mexico; while *Tectona grandis* L.f. covers 15 %, 12 % for hardwoods such as *Gmelina arborea* Roxb., *Acacia mangium* Willd. and *Albizia falcataria* (L.) Fosberg and other conifers, 3 % (Musálem, 2006; Velázquez *et al.*, 2013).

In the state of *Oaxaca*, several plantations have been established in the temperate and tropical zone, mostly with native species, however, the current situation of their development is unknown, which makes good management of these resources impossible. The evaluation of large-scale plant cover is a costly, laborious and a demanding task of specialized technical skills, which forest producers can hardly face. This justifies the use of indirect techniques such as geomatics, which allow the integration of georeferenced bases on forest resources (García *et al.*, 2001; Olivas *et al.*, 2007; Castillo *et al.*, 2015). In addition, it facilitates the different activities of collection, capture, processing, analysis and interpretation of information. Its advantages include the ability to visually represent the data of electromagnetic radiation reflected by forest cover and other types of land surface cover, recorded with the help of remote sensors (Duarte *et al.*, 2016).

With the development of remote sensing, studies on productivity and vegetation biomass have been stimulated by the use of spectral indexes, the most common being

the Normalized Difference Vegetation Index (NDVI) that estimates the vegetation biomass of different ecosystems, is related to the growth of plants and helps characterize the structural aspects of forests (Torres *et al.*, 2014; Palestina *et al.*, 2015; Zhao *et al.*, 2015).

The aim of this investigation was to evaluate the commercial forest plantations of the tropical and temperate regions of the south of *Oaxaca* State, based on satellite images and acquired data of the environmental variables incorporated into a Geographic Information System (GIS).

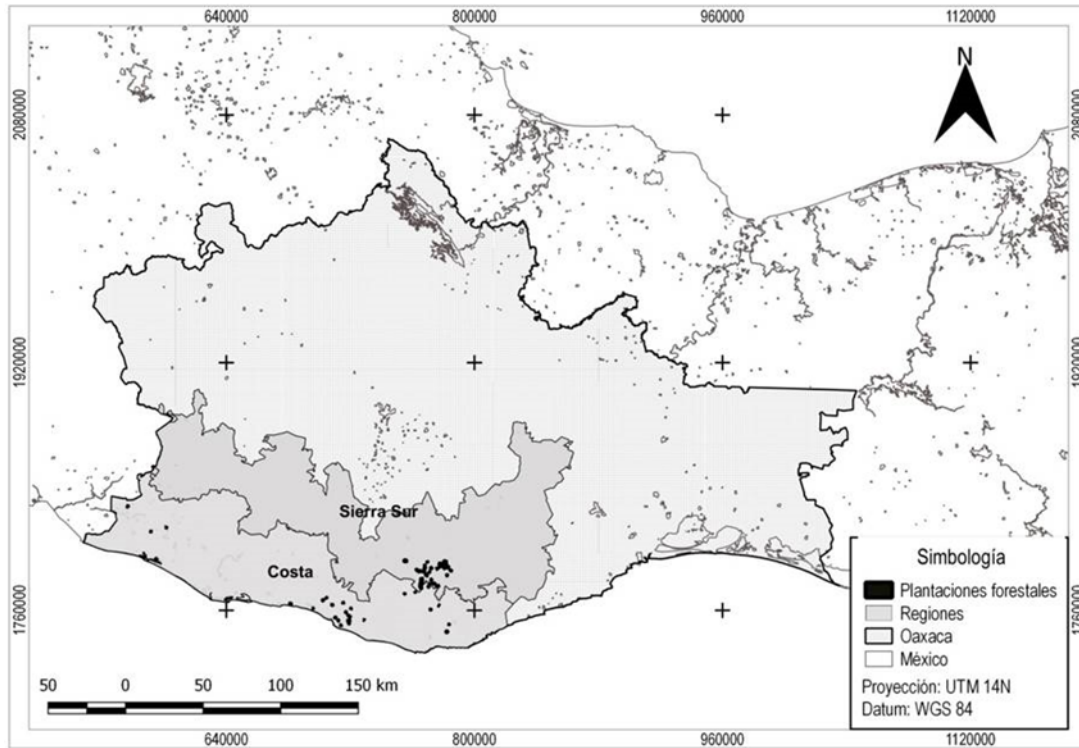
Materials and Methods

Study area

The study was developed in the southern zone of the state of *Oaxaca* (Figure 1); whose original vegetation cover in the *Costa* region (CR) corresponds to forest and in the *Sierra* region (SR) to temperate forest. Both types of cover currently include small areas for agriculture, livestock, deforested areas and forest plantations established on abandoned or degraded agricultural lands.

The climate of CR is warm sub-humid and semi-warm sub-humid, with a maximum temperature of 32 to 36 °C, an average of 24 to 28 °C; the average annual precipitation varies from 800 to 1 500 mm (Fernández *et al.*, 2012); and its soil units include regosoles, umbrisols, leptosols, luvisols and Phaeozem (Inegi, 2017). In the SR, the climate is temperate subhumid and semi-cold sub-humid, with an average temperature of 12 to 18 °C, and a precipitation of 1 000 to 1 500 mm (Fernández *et al.*, 2012); its main soil types are Cambisol, Leptosol, Luvisol and Umbrisol (Inegi, 2017).





Simbología = Symbology; *Plantaciones forestales* == Forest plantations;
Regiones = Regions.

Figure 1. Location points of the plantations where the study was carried out.

Methodology

In order to assess the commercial plantations, a selection was made among those established in 2000 to 2014 financed by Conafor. The vectorial data of its location and extension were provided by the management of Conafor in *Oaxaca*; farms with an area greater than or equal to 5 ha were considered, to facilitate the analysis using satellite images. In the RC the plantations correspond to broadleaved species: *Cedrela odorata* L., *Swietenia humilis* Zucc., *Tabebuia rosea* (Bertol.) Bertero ex A. DC. and *Swietenia macrophylla* King. In the RS, they are conifers: *Pinus pseudostrobus* Lindl., *P. greggii* Engelm., *P. patula* Schltdl. et Cham, *P. ayacahuite* Ehrenb. ex Schltdl., *P. douglasiana* Martínez, *P. maximinoi* H.E. Moore and *P. leiophylla* Schltdl. et Cham.

The plantations of the tropical region were developed under the following conditions: average evapotranspiration of 861 mm, average annual precipitation of 1 002 mm and at an altitude of 445 m above sea level; in the temperate region under the scenario described below: evapotranspiration of 636 mm, average precipitation of 1 340 mm and an altitude of 2 384 m.

Georeferenced environmental data were collected from the area of interest, corresponding to the average annual rainfall, average annual temperature, soil depth, soil pH, soil texture, altitude and slope of the land, on the websites of the Conabio, Inegi and of the *Inventario Nacional Forestal y de Suelos* (National Forestry and Soils Inventory) (Inegi, 2016; Inegi, 2017; Conabio, 2017; Conafor, 2017). Their projection systems were homogenized to UTM, in order to perform the analysis of the environmental conditions of the area where the plantations are located.

Scenes of satellite images of the year 2014, 2015 and 2016 were acquired, all from the same period (November-December). Those of 2014 and 2015 were from Landsat 8 OLI (Operational Land Imager) and the 2016 from Sentinel-2. All the images were obtained for free in the following links: [http:// earthexplorer.usgs.gov/\(Landsat 8\)](http://earthexplorer.usgs.gov/(Landsat%208)) and <https://scihub.copernicus.eu/dhus/#/home> (Sentinel-2).

Two types of corrections were carried out: the geometric one to adjust the location of the scenes of images among themselves, and the atmospheric one to correct anomalies of the images; in addition to converting the digital numbers of each of them to radiance values and then to reflectance by using the QGIS software.

In the analysis of the vegetation biomass, with the indirect technique based on the NDVI, a total of 78 forest plantations were included, 28 in the tropical zone and 50 in the temperate zone. Coniferous and hardwoods were analyzed separately, because both groups of species have different spectral responses.

The NDVI was used to monitor the establishment of the plantations for 2014, 2015 and 2016. This index described the dynamics of soil-vegetation mix, as well as the quantity, quality, development and vigor of the plantations (Torres *et al.*, 2014; Escribano *et al.*, 2015; Muñoz *et al.*, 2016). The NDVI was calculated using the

spectral values corresponding to the region of red visible light (R) (0.6-0.7 µm) and near infrared light (IRC) (0.7-1.3 µm):

$$NDVI = \frac{IRC - R}{IRC + R}$$

Prior to the evaluation of the NDVI time series, the extraction of the area corresponding to the plantations was carried out, for which the limits of each area were used. The product was a portion per image, for which the statistics were estimated considering the values of the pixels (mean, standard deviation, minimum and maximum value). After obtaining a significant deviation ($p < 0.05$) of the data towards a non-normal distribution, a comparison of means with the Friedman test was applied to determine if there are significant changes in the three planting dates. In the classification of the NDVI values, those between 0 and 0.4 were assigned for low or sparse vegetation; from 0.5, 0.6 to 0.8, for developing vegetation; and from 0.8 to 1, for healthy, vigorous and dense vegetation (Merg *et al.*, 2011; Meneses, 2012; López *et al.*, 2015) (Table 1).

Table 1. Classification of the NDVI values.

Classification	Value
Clouds and water	<0.01
Soil without vegetation	0.01-0.1
Light vegetation	0.1-0.2

Medium vegetation	0.2-0.4
High vegetation	>0.4

Finally, a multivariate analysis of canonical correspondence (CCA) was done with the R Studio program 1.1.4 version (RStudio Team, 2016) to determine the environmental variables (annual average precipitation, annual average temperature, altitude, slope, pH and soil depth) that affect the dynamics of plantations. The CCA consisted of determining the degree of association of all environmental variables with respect to the NDVI of 2014, 2015 and 2016.

Results and Discussion

Plantations dynamics from NDVI

All the plantations of the tropical zone in their three assessments corresponded to a medium to high and vigorous vegetation, according to the classification of the NDVI by Merg *et al.* (2011), López *et al.* (2015) and Meneses (2012). The NDVI trend was similar in the three annual periods analyzed; however, their values were lower for 2016, due to a better resolution of the images used (Figure 2). The results of the Friedman test indicate that there are important differences in the three time series of NDVI for the tropical zone (ANOVA Chi square = 33.429 $p < 0.000$), which show an increase with the passage of years.

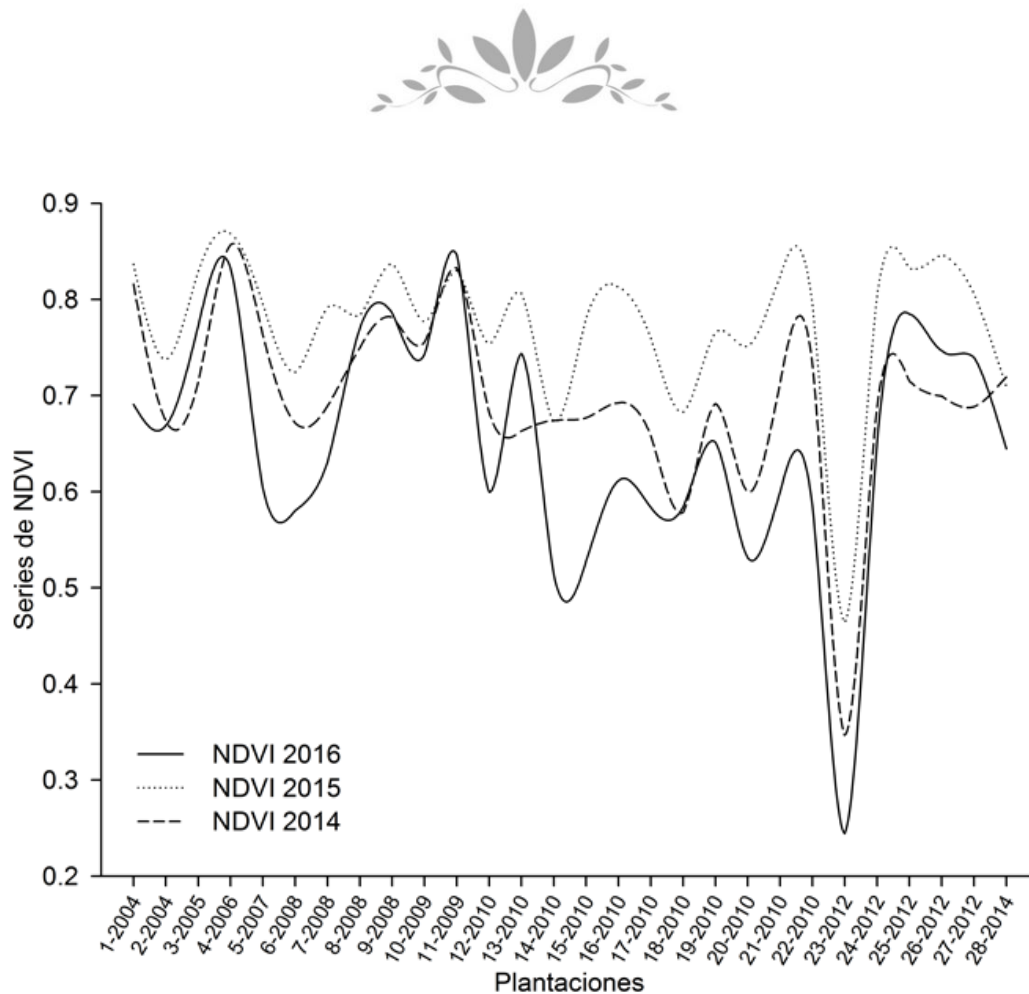


Figure 2. NDVI values for the biomass of the plantations in the tropical zone 2014 - 2016.

In the temperate zone it was determined that all areas correspond to tall and developing vegetation. The biomass figures represented by the NDVI showed an increasing trend between 2014 and 2015 (Figure 3); this is consistent with that described by Vicente *et al.* (2004) for forests and well-developed vegetation. The values recorded for the plantations established in recent years were the only ones low for the amount of biomass, which is probably due to the short time elapsed between establishment and evaluation (Figure 3). When using the Friedman test, it

was found that there are significant differences between plantations (ANOVA Chi square = 50.520 $p < 0.000$).

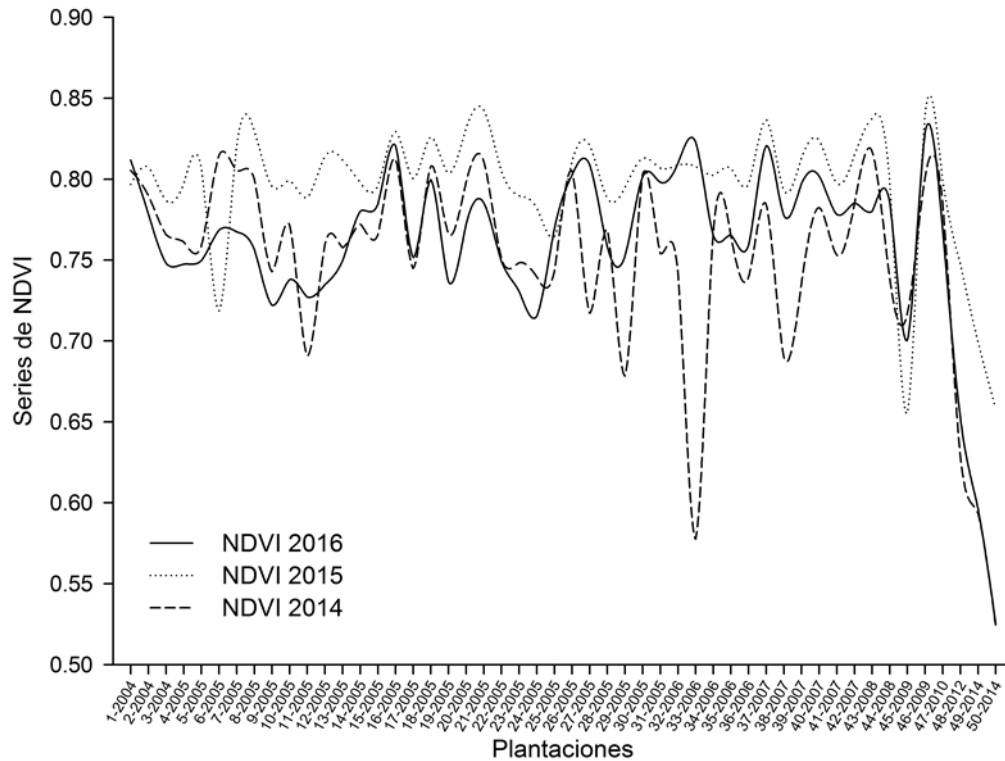


Figure 3. NDVI values for the biomass of the plantations in the temperate zone 2014 - 2016.

Environmental factors associated with the NDVI

Based on the multivariate analysis of canonical correspondence (CCA), with time series of biomass and environmental variables, it was determined that for the tropical region, evapotranspiration, precipitation and altitude are factors that influence the biomass dynamics of the plantations (Figure 4). While, in the temperate region: altitude, pH, temperature, evapotranspiration and precipitation were the determining variables (Figure 5). Therefore, it is important to consider the environmental variables and the characteristics of the site (biotic and abiotic factors), to have a greater productivity of future plantings and fewer failures.

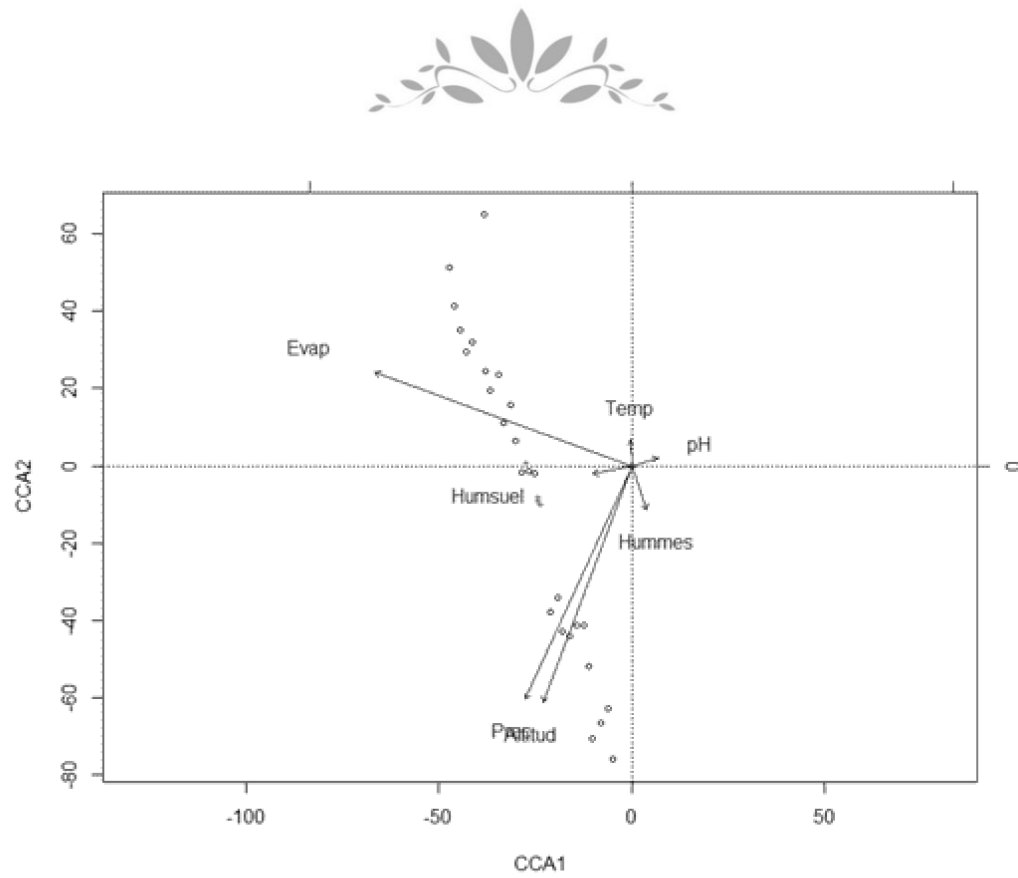


Figure 4. CCA: NDVI series of tropical species vs environmental variables.

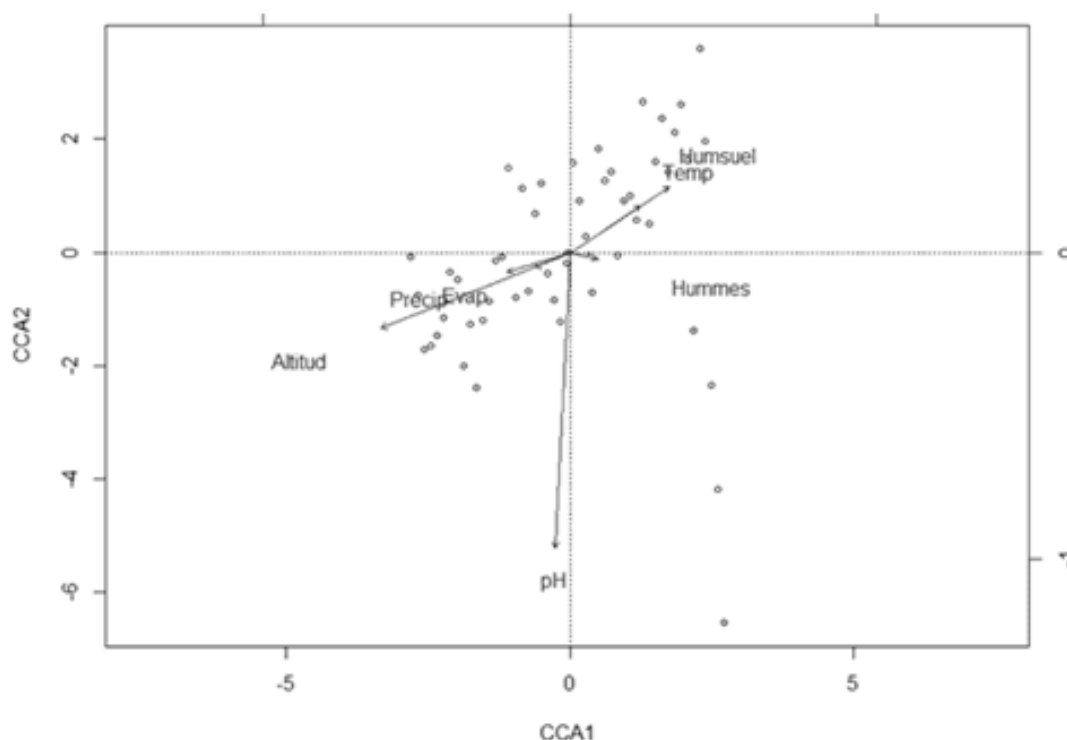


Figure 5. CCA: conifer NDVI series vs environmental variables.

The interaction of climatic, soil and topographic variables determine the place where forest species can grow, how quickly, and how well they do it; however, internal factors such as the quality of the plants should be considered when they are established in the field (Schlatter and Gerding, 2014). It is necessary to make a good selection of the sites before establishing the forest species, in order to obtain good timber productivity (Jofré *et al.*, 2013).

Conclusions

Plantations in the tropical and temperate regions of southern *Oaxaca* show a favorable development. The vegetation of each date in both regions is present in the first evaluation and shows an increase over the years. The plantations established two years before the evaluation lack an increase in their biomass; so it is clear that a reasonable amount of time is required to use this indirect method of evaluation.

The development of the biomass of the plantations in both types of ecosystems depends on environmental factors, which should be considered when modeling ideal areas to execute projects related to the plantations in tropical and temperate zones.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Prudencia Caballero Cruz: planning of the study, data collecting and analysis, writing of the manuscript; Eduardo J. Treviño Garza: planning of the study, data analysis, writing and review of the manuscript.

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