LAND COVER DYNAMIC MONITORING IN THE REGION OF COQUIMBO (CHILE) BY THE ANALYSIS OF MULTITEMPORAL NOAA-AVHRR NDVI IMAGES

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ABSTRACT:

The current work presents a new method for the land cover dynamic monitoring based on the inter-annual variability of the NDVI obtained from multi-temporal NOAA-AVHRR time series. It consists in using the mean annual values of NDVI and its spatial variability in the study area. A matrix relating the statistics was designed in order to calculate the spatial homogeneity index (SHI), which is a good way to classify the variability of the NDVI. This classification permits the identification of areas with homogeneous behaviour in terms of inter-annual land cover dynamic. Moreover, with the aim to compare the aforementioned classification with the superficial Biomass, the potential yields of the natural prairies were modelled in the study area at the same spatial resolution of NOAA. A model based on simulation of the prairies growth and which integrates the main eco-physiologic processes and its climatic regulation and maturity, was developed. The last results together with the obtained classification permit a development of land cover cartography.

1. INTRODUCTION

In order to evaluate any process related to the vegetation dynamics from satellite data, it is necessary to take into account indicators that are related to the biophysical parameters which suitably describe the vegetation physiology. These parameters in the optical, thermal or the microwaves spectrum; can be used altogether or to be combined generating complex indices. This is sustained in the fact that all land cover changes, modify its spectral behaviour, in such way that this premise allows the monitoring of the vegetation dynamics in the land surface by the use of satellite data (Pearson and Miller, 1972; Rouse et al., 1976; Huete, 1988; Goward, 1989; Kaufman and Tanré, 1992; Liu and Huete, 1995). Among other parameters, the vegetation indices present a high correlation with some parameters related to the vegetation, such as the total biomass and the leaf area index (LAI), which makes it an efficient tool for vegetation studies (Curran, 1980; Jansen, 1983; Tucker and Sellers, 1986; Diallo et al., 1990; Price, 1992; Gong and Millar, 1995). In the field of the cartography of the spatial-temporal variability of the vegetation, numerous methods of analysis have been published, being based many of them on the normalised difference vegetation index (NDVI) (Tucker et al. 1985; Townshend et al. 1987; Loveland et al. 1991; Lambin & Strahler, 1994). In addition some investigations have introduced the land surface temperature (LST) as an analysis parameter for the study of the land cover changes (Lambin & Ehrlich, 1996; Raissouni & Sobrino, 1998; Sobrino & Raissouni, 2000). This last parameter is less used, owing fundamentally to the difficulty to obtain it. But, whatever it is the case, these analyses are based on the exhaustive knowledge of the biophysical relations between the used parameters and the ecological variables (Nemani & Running, 1989; Goward et al. 1985; Nemani ET to. 1993; The Friedl & Davis, 1994).

From these premises, we have developed a method for the monitoring of the land cover dynamics based on the inter-annual variability of the NDVI, obtained from a time series of NOAA-AVHRR images.

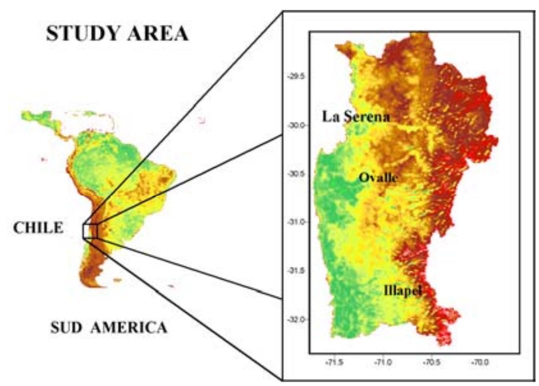

Figure 1.- Study area: Limarí province, which is located in the IVth region of Chile. This zone corresponds to a transition between the arid climate and the Mediterranean one known as a semi-arid zone.

2. STUDY AREA AND SATELLITE DATA

The total of the population in 1992 was of 504 387 inhabitants (INE, 1992). In average, 30% of the total number of inhabitants of the IVth Region live in rural areas. Some of the communes are typically rural like: La Higuera, Hurtado river & Paihuano, where 100% of the population live in rural areas, but also Vicuña, Patria Mount, Combarbalá, Punitaqui and Canela have more than 2/3 of the population living in rural areas. In the communes who have cities or towns, like Serena and Coquimbo, most of the population live in urban areas. The climate of the study area can be classified as sub-desert, and it is characterized fundamentally by a strong anticyclone influence that governs the radiative, thermal and hydric regimes. Nevertheless, the space variability of these regimes is due to its physiographic state, composed by four unities, such as the coastal strip, the cross-sectional valleys, the pre-mountain range and the mountain range of the Andes. The region fundamentally presents an important hydric deficit during the months of summer, which is due mainly to an atmospheric demand of elevated water, and low precipitations. These last ones have an annual rank between 100 and 500 mm, nevertheless present a noticeable space variability, growing in the west and east directions. The combination of both previous elements together with the incidence of a strong solar radiation due to the presence of an atmosphere is transparent and with very low cloudiness. The thermal regime is characterized by the thermal amplitude caused by the high diurnal temperatures and moderate nocturnal temperatures. The region presents a coastal strip where the climate becomes considerably fresher as a result of the oceanic regulation of the thermal regime. The sea is something colder than what it should be in this latitude, due to the presence of the cold current of Humboldt (Santibáñez, 1986). The study area is dominated preferably by natural prairies, which constitute the main resource to feed for the cattle mass of the region. If the precipitations are sufficient, there will be pastes from March to November, which gives an appreciable inter-annual variability viewed by satellite images. Nevertheless, unpredictable rains and the increase of the degradation of the prairies, contribute to a diminution of the availability of vegetation apt for pasturing. In addition, the fact that the precipitations have diminished in the last century between a 10% and 30 %, with a decreasing rate of approximately 0.7 mm/year (Morales, 2003). This situation could be due to cycles in the climate, or to a possible climatic change. However, in any case a monitoring of the dynamics of the vegetation would contribute as an antecedent of management and decision making.

3. SPATIAL HOMOGENEITY INDEX

To analyze the vegetation spatial dynamics is necessary to express its behaviour based on homogenous areas. Based on this fact, we propose an index that expresses the inter-annual variability of the vegetation as a relation between the average values and their coefficient of variation, in the interior of a series of time. In order to do this, we was used a series of time of seven years of satellite images NOAA (National Oceanic and Atmospheric Administration)-AVHRR(Advanced Very High Resolution Radiometer). This series of images was acquired by an antenna pertaining to the University of Chile, corresponding to the period 1986-1992, and geo-referenced and corrected from the atmospheric effects (Chávez, 1996). From them, we calculated the NDVI using the relation where ρ_{nir} corresponds to the reflectivity in the near infrared band and ρ_{red} the reflectivity in the red band. From this series, monthly average images from weekly average images were calculated, because they are divided in three daily images, from which the maximum values were extracted, with the purpose of eliminating the effect of the cloudiness. Later, the monthly average values for every year were calculated, using the same previous method. Considering that the amount and the seasonality of the biomass production depend on the type and state of the vegetation, an index was elaborated that combines both aspects. For this, a matrix of two entrances was constructed and combines the maximum NDVI considered for each one of the seven years and the coefficient of variation respectively. It was divided in three intervals and within each one of them three states were considered (low, medium and high), so that 9 combinations were generated that represent the different behaviours of the vegetation (Figure 2).

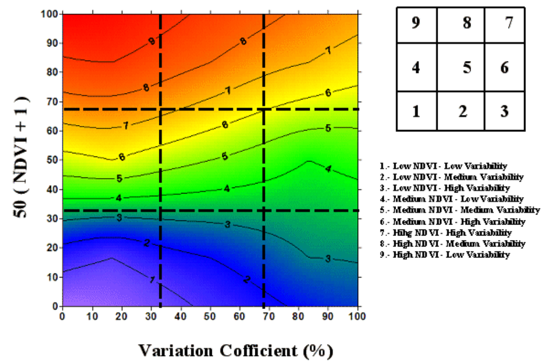

Figure 2.- Proposed relation for the study area classification. It is based on the variability among the time series, and its absolute maximum values. This corresponds to the used classification matrice.

In this sense, we refer by the NDVI to the biomass, because it was found, for the zone of study, a linear relationship between both variables (Morales, 1998). High biomass in combination with a low variability indicates the presence of an ecosystem in good conditions, with a participation discharge of shrubs or arboreal perennial species. On the contrary, low biomasses, with low variability indicates; that it is an ecosystem in desertification end, incapable to respond as opposed to the variations of the climate. As a general rule, increases in the biomass means better quality of the ecosystem, and increases in the variability is interpreted as an increase of the instability of the ecosystem which is typical of annual vegetal covers with little perennial vegetation. Figure 3 shows the space distribution of the inter-annual variability of the vegetation, stratified in the biological patrons defined by the SHI. This last is obtained thanks to the cross of the information about average values and the coefficient of variation in agreement with the matrix of relation shown in Figure 2. The original image has been reclassified to show a simpler vision at the time of interpreting the vegetational zones. Figure 4 shows the temporary variability of the NDVI for all the time series. However, Figure 5 shows the maximum mean monthly values, both for each one of the reclassified zones of SHI. In Figure 5, it is possible to observe that the vegetation shows two important tips, associated to the shrubs vegetation and the prairies. Nevertheless, classes 7 and 8 correspond to the zones of irrigated land, fundamentally grapes for export, which is out of the present work analysis. Figure 6 shows the accumulated NDVI, that presents a logistic form approximately and has the same structure of the curve of biomass accumulation of a prairie during their interval of growth.

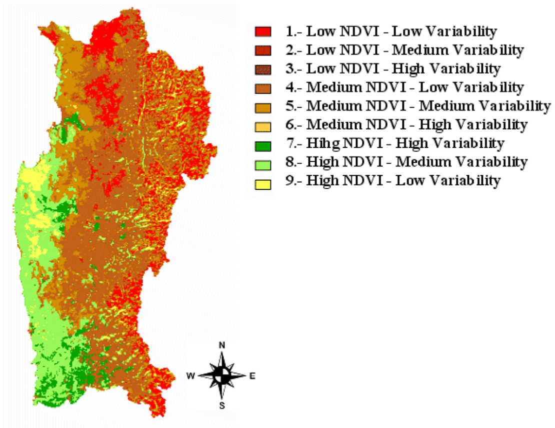

Figure 3.- Spatial homogeneity index (SHI) which relates the mean maximum values and the variation coefficient. As a general norm, increased NDVI means better ecosystem quality, and increased variability means an increase in the ecosystem instability.

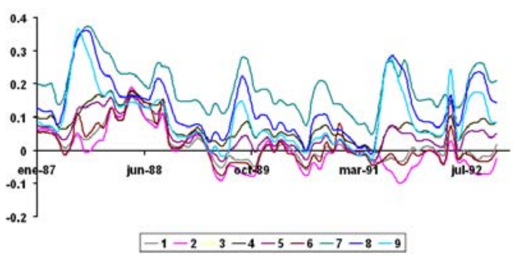

Figure 4.- Monthly evolution of the NDVI for each class of the SHI in the time series of NOAA-AVHRR images.

4. VEGETATION DYNAMICS

In the study area a great ground diversity exists such as those of alluvial type of fine and heavy textures, “depresionals”, “graníticos of lomajes” and hills (mountain range of the coast), alluvial of marine terraces, “pumicíticos” and “trumaos granítico”s (Honorato, 2000). In this atmosphere, the most important forages resources are the spinal ones. This vegetal formation is defined as a pseudo-savannah (Ovalle et al., 1990), in which two layers are clearly distinguished: one of shrubs type, dominated Acacia digs Mol. (hawthorn) and a herbaceous layer, composed by “Poáceas” (gramíneas) mainly of annual winter growth. Among these last ones, species pertaining to the sorts Oats, Aira, Bromus, Hordeum, Vulpia and Lolium are emphasised. They are common in the herbaceous layer, species of the Composite family, in special of the Hypochoeris sorts, Cynara and Chartamus, in addition to species of the Fabaceae family (leguminosas) Papilionoideae subfamily, pertaining to the Medicago sorts and Trifolium, mainly (Castellaro et al., 1994; Ovalle and Squella, 1996).

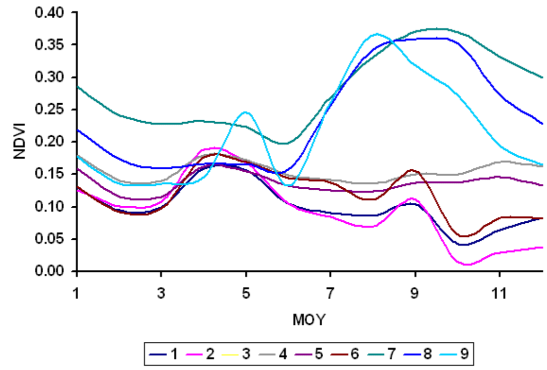

Figure 5.- Mean monthly evolution of the NDVI for each SHI class

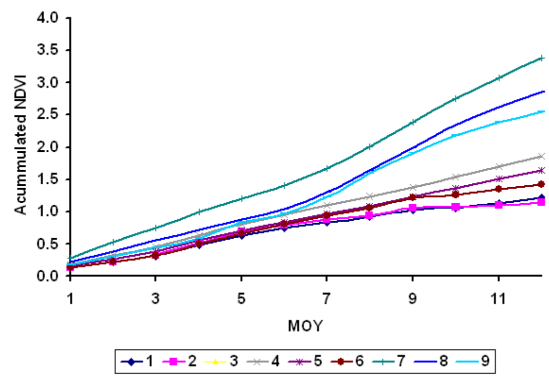

Figure 6.- Accumulated NDVI month by month.

The zone presents habitually a low natural fertility in its grounds, which entails to low yields. However, these prairies are the base of sustentation of the production systems animal, which are predominantly of extensive type, where it stands out the raising of smaller ruminates (ovine and goat) and the raising of meat cattle, being the load animal average of the order of 0.2 animals has^{-1} $year^{-1}$ units (Ovalle and Squella, 1996). In spite of the shown antecedents, a complete study of the dynamics of the vegetation in the zone does not exist, for that reason it is necessary to resort to computational models that describe quantitatively his behaviour. Most of the models related to prairies have been developed by interdisciplinary equipment of university centres, specifically by the schools of Science Range (handling of natural prairies) of the United States (Innis, 1978; Pendleton et al., 1983. Parton et al., 1993; Laurenroth et al., 1993; Hanson et al., 1994). Its main intention is the research and are complex, as much of the conceptual points of view such the computational ones, which causes that their use is restricted. Nevertheless, there are someone, thanks to its simplicity, can be implemented by fast and simple way (Smith and Williams, 1973; White et al; 1983). Despite the previous notes, a previous process of validation is required, to evaluate its behaviour and the behaviour to its reformulation, by means of the calculation of suitable parameters (Silva, 1993).

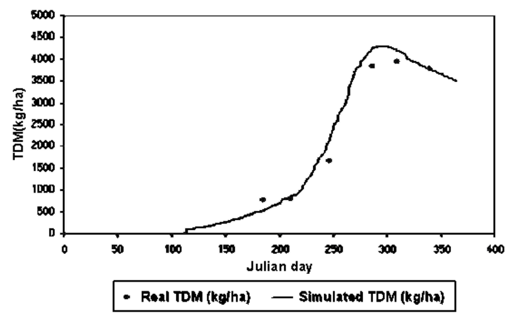

Figure 7.- Variation of the total dry matter (DM) accumulation according to the Julian day. Simulated values (__) and the real values (•) measured in field experiment. Hidango, season 1992.

Under this scheme, we have used a model divided in two levels of organization. First of them is related to the information that feeds the model, its processing and the elaboration of results archives. In a second level, the biophysical aspects are located, for which use becomes of four sub-models: Hydric balance, Phynologic, senescence and growth of the semi-arid Mediterranean prairie. In Figure 7, the real and simulated values appear, corresponding to the accumulation of the dry matter (DM) for the zone of Hidango. When analyzing this figure is given off that this model, in spite of its simplicity, reproduces the tendency of the variation in this variable. When relating, by means of regression analysis, the simulated values (y) and the measured real values in land (X), permitted to obtain a significant regression ($P \leq 0,05$), with a coefficient of determination of 97.6% and a standard error of 292.1 kg has^{-1}. Respect to the coefficients of the line of calculated regression, these parameters did not differ significantly from 0 and 1, respectively ($P > 0.05$), which indicates the slant non-existence. The RMSE between the simulated values and the land measured ones was of 306.6 kg has^{-1}, which represents a percentage deflection of a 12.4% respect to the average of the average values in land. From these results the dynamics of the prairies is easily identifiable and to distinguish from shrubs. First they have an inter-annual variability; however the others do not show it among the year. The growth of the prairies begins with the first rains of autumn, reaching its Maximum appraises in the months of August and September. By the end of September they enter in an accelerated process of senescence, which agrees with the formation of seeds and its later maturation. The production of annual dry matter is variable; according to if it is greater or smaller the degree of hydric deficit during the season. Esteem that accumulation DM of this prairie; would not surpass the 800 to 2500 kg had^{-1} in normal years.

5. CONCLUSIONS

The present work provides an analysis method oriented to the space characterization of the inter-annual dynamics of the vegetation. This analysis allows making the monitoring of the vegetation when only the NDVI is known. The advantage of the method is that the data for the classification are extracted from the series of time of NDVI. Nevertheless, the complication is in that a great number of images is needed to be able to make it. If images are used this type of analysis is very advantageous, because it would allow viewing the variation of the spatial homogeneity index among years. By the way, this variation in the borders of the zones of SHI would allow identifying the impact of a certain year in the spatial distribution of the vegetation. On the other hand, with the use of simple models of simulation it was possible to consider the beginning of the growth of the annual Mediterranean prairie, the date in which the flowering and the length of phynological cycle of this type of prairies take place. It was possible to simulate the accumulation of DM and the variation of the water content in the radial zone of the sub humid Mediterranean annual prairie, using a simple model, by means of a suitable election and calculation of the main parameters with physiological interpretation. Therefore, it was possible to relate the NDVI and the accumulation of dry matter of the semi-arid Mediterranean prairie. From this type of models and land information also it is possible to find simple algorithms that relate the calculated productivity of the prairie and radiometric indices from satellite images.

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7. REFERENCES

Castellaro G.G.1988. Elaboración de un modelo de simulación del crecimiento y fenología de la pradera mediterránea anual. Tesis Ingeniero Agrónomo. 155 p. Universidad de Chile. Facultad de Ciencias Agrarias y Forestales. Escuela de Agronomía. Santiago, Chile.

Castellaro, G.G., M. Silva y F. Santibáñez. 1994. Efecto de la radiación solar y la temperatura sobre las fenofases de las principales especies del pastizal mediterráneo anual. Av. Prod. Anim. 19: 65 –75.

Curran, P. 1980. Remote sensing systems for monitoring crops and vegetation, Progress in Physical Geography, 4: 315 - 341.

Chavez, P. S. (1996). Image-based atmospheric correction-revisited and improved. Photogrammetric Enginneering and Remote Sensing, 6(9) 1025-1036.

Diallo, O., Diouf, A., Hanan, N., Ndiaye, A . y Y. Prevost. 1990. AVHRR monitoring of savanna primary production in Senegal, West Africa: 1987-1988. International Journal of Remote Sensing, 117: 1259 - 1279.

Friedl, M. A., and Davis, F. W., 1994, Sources of variation in radiometric surface temperature over a tallgrass prairie, Remote Sens Env, 48, 1-17.

Gong, N. S., & J. R. Miller, 1995, Coniferous forest leaf area index estimation aling the oregon transects using compact airbone spectrografic imager data, Photogrametric Engineering & Remote Sensing, 61, n° 9, 1107-1117.

Goward, S. N., Cruickshanks, G. D., and Hope A. S., 1985, Observed relation between thermal emission and reflected spectral radiance of a complex vegetated landscape, Remote Sens Env, 18, 137-146.

Hanson, J.D., B.B. Baker and R.M. Bourdon. 1994. Spur 2. Documentation and User Guide. 46 p. GPSR Technical Report Nº 1. USDA. Agricultural Research Service. Great plains Systems Research Unit.

Honorato, P. R. 2000. Manual de Edafología. 267 p. 4ª Edición. Alfaomega. Ediciones Universidad Católica de Chile.
Innis, G. S. (ED). 1978. Grassland Simulation Model. 298 p. New York. Springer – Verlag.

Huete, A. R. 1988. A soil-ajusted vegetation index (SAVI). Remote Sensing of Environment 25 : 295 - 309.

Jansen, J. R., 1983, Byophisical remote sensing, Annals of the Association of American Geographers, 73: 111 - 132.

Kabat P.M. et al. 1995. Modelling and parameterization of the soil – plant – atmosphere system. A comparison of potato growth models. Wageningen Press. 513 pp.

Kaufman, Y. & D. Tanré. 1992. Atmospherically resistant vegetation index(ARVI) for EOS-MODIS, IEEE Trans. Geosci. Remote Sensing 30 : 261 - 270.

Lambin, E. F., and Strahler, A. H., 1994, Indicators of land-cover change for change-vector analysis in multi-temporal space coarse spatial scales, International Journal of Remote Sensing, 15, 2099-2119.

Lambin, E. F., and Ehrlich, D., 1996, The surface temperature-vegetation index space for land cover and land-cover change analysis, International Journal of Remote Sensing, 17, 463-487.

Liu, H. Q. and Huete, A.R. 1995. A feedback based modification of the NDVI to minimize canopy background and atmospheric noise. IEEE Trans. Geosci. Remote Sensing 33 : 457 - 465.

Loveland, T. R., Merchant, J. W., Ohlen, D. O., and Brown, J., 1991, Development of a land-cover database for the conterminous, U. S., Photo Eng Remote Sens, 57, 1453-1463.

Laurenroth, W. K., D.L. Urban, D.P. Coffin, W.J. Parton , H.H. Shugart, T.B. Kirchner and T.M. Smith. 1993. Modelling vegetation structure—ecosystem process interactions across sites and ecosystems. Ecological Modelling 67:49-80.

Morales, L., Santibáñez, F., De La Fuente, A., and Uribe, J. M. 1998. Monitoring desertification using remote sensing techniques. p. I-101 – I-131. In: Santibáñez, F. And Marin, V. (Ed.). An enviromental information and modeling system for sustainable development. Computer tools for sustainable management of arid and Antartic ecosystem. IBM, Enviromental Research Program, Universidad de Chile, Santiago, Chile. 281 p.

Morales L. & Castellaro G., 2003, Impacts du changement climatique dans la productivite primaire des herbacees de la IVeme Region du Chili. International Conference, Geomatics and Applications. Université d' Orléans, 13, 14 march.

Nemani, R., and Running, S. W., 1989, Estimation of regional resistance to evapotranspiration from NDVI and Thermal-IR AVHRR data, J Appl Met, 28, 276-284.

Nemani, R., Pierce, L., Running, S., and Goward, S., 1993, Developing Satellite-derived Estimates of Surface Moistures Status, J Appl Meteo, 32, 548-557.

Ovalle, C., J. Aronson, A. Del Pozo, and J. Avendaño. 1990. The espinal: agroforestry systems of the mediterranean type climate region of Chile. Agroforestry Systems 10: 213 – 239.

Ovalle, M. C. y F. Squella. 1996. Terrenos de pastoreo con pastizales anuales en el área de influencia climática mediterránea. Capítulo 39. p. 429 - 466. In Ruiz, N.I. Praderas para Chile. 2ª edición.. Instituto de Investigaciones Agropecuarias (INIA). Ministerio de Agricultura. Santiago.

Parton, W.J., M.O. Scurlock, D.S. Ojima, T.G. Gilmanov, R.J. Scholes, D.S. Schimel, T. Kirchner, J.-C. Meneaut, T. Seastedt, E. García Moya, A. Kamnalrut and J.I. Kinyamario. 1993. Observations and modelling of biomass and soil organic matter dynamics for the grassland biome worldwide. Global Biogeochemical Cycles 7: 785 - 809.

Paul, K.L., P.J. Polglase, A.M. O'Connell, J.C. Carlyle, P.J. Smethurst and P.K. Khanna. 2002. Soil nitrogen availability predictor (SNAP): a simple model for predicting mineralisation of nitrogen in forest soil. Australian Journal of Soil Research 40: 1011 – 1026.

Pendleton, D.F., J.W. Menke, W.A. Williams and R.G. Woodmansee. 1983. Annual Grassland Ecosystem Model. Hilgardia 51: 1 – 44.

Price, J. 1992. Estimation vegetation amount from visible and near infrared reflectances. Remote Sensing of Environment 41 : 29 - 34.

Rouse J., R. Hass, J. Schell, D. Deering y J. Harlan. 1976. Monitoring the vernal advancement of retrogradation of natural vegetation. NASA/GSFC, Type III Final Report, Geenbelt MD, 371 pp.

Shannon, E. 1988. Simulación de Sistemas. Diseño, Desarrollo e Implantación. 427 p. Editorial Trillas. México. DF.

Raissouni, N., and Sobrino, J. A., 1998, Land cover dynamic monitoring in the Southwest Mediterranean Basin using the Global Land 1-KM AVHRR project data set, Proceedings of the "Satellite-based observation: A tool for the study of the Mediterranean basin" symposium, Tunis, on 23-27 November.

Santibañez, F., 1986, Rasgos Agroclimáticos Generales de la Zona Arida Chilena, Revista de la Sociedad Chilena de la Ciencia del Suelo, 5, 1-28.

Silva, G. M. 1993. Papel del enfoque de sistemas en la investigación en producción animal. Capítulo. XII. p. 148-164. In Silva, G.M. y M. A. Mancilla. Análisis de sistemas en producción animal. Teoría y aplicaciones. Facultad de Ciencias Agrarias y Forestales, Universidad de Chile.

Smith, R.C.G. and W. Williams. 1973. Model development for a deferred-grazing systems. J. Range Manage. 26: 454-460.

Sobrino, J. A., Raissouni, N., 2000, Toward remote sensing methods for land cover dynamic monitoring. Application to Morocco, International Journal of Remote Sensing, vol. 21, 2, 353-366.

Soil Survey Staff. 1992. Keys to soil taxonomy. 5th ed. United States Department of Agriculture – Soil Conservation Service . Technical Monograph Nº19. 541 p. Pocahontas Press. Blacksburg, Virginia. USA.

Steel, R.G.D., & J.H. Torrie. 1988. Bioestadística. Principios y procedimientos. 622 p. McGraw-Hill, New York. USA.

Sther, W.K. 1982. regulación de la fenología y extracción de nitrógeno de la pradera mediterránea anual. Tesis Ingeniero Agrónomo. 82 p. Universidad de Chile. Facultad de Ciencias Agrarias, Veterinarias y Forestales. Escuela de Agronomía. Santiago, Chile.

Townshend, J. R., 1994, Global data sets for land applications from the Advanced Very Hight Resolution Radiometer, International Journal of Remote Sensing, 15, 3319-3332.

Tucker, C. J., Townshend, J. R., and Goff, T. E., 1985, African land-cover classification using satellite data, Science, 227, 369-375.

White, D.H., P.J. Bowman, F.H.W. Morley, W.R. MacManus, and S. J. Filan. 1983. A simulation model of a breeding ewe flock. Agricultural Systems 10: 149-189.

Wight, J.R. and R.J. Hanks. 1981. A water-balance, climate model for range forage production. J. Range Manage. 34: 307 - 311.

Williams, J.R., C.A. Jones and P.T. Dyke. 1990. The Epic Model. Cap. 2. p. 3 - 92. En A. N. Sharpley and J. R. Williams. EPIC. Erosion/productivity Impact calculator: 1. Model documentation. Edts.. U. S. Department of agriculture Technical Bulletin Nº 1768.