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A STUDY OF THE NUTRITIONAL DIAGNOSIS ON APPLE CROPS USING MULTISPECTRAL INDICES IN A SEMI-ARID ENVIRONMENT (CHIHUAHUA, MEXICO)

ANÁLISIS DEL ESTADO NUTRICIONAL EN MANZANOS EN UN AMBIENTE SEMIÁRIDO MEDIANTE EL EMPLEO DE ÍNDICES MULTIESPECTRALES (CHIHUAHUA, MEXICO)

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Abstract

The effect of anomalies of foliar mineral nutrients on the nutritional behavior of apple crops has been evaluated using parameters obtained by means of remote sensing techniques. Twenty-five plots in commercial orchards were selected in the five most important municipalities of Chihuahua State, Mexico in which the main nutritional parameters were measured (N, P, K, Ca, Mg, Fe, Zn, Mn, Cu, and B). Important deficiencies of these nutrients were detected in 88% of the analyzed crops. These deficiencies showed significant correlation with the spectral data (SPOT5) and with the NDVI elaborated from these data. The mathematical models obtained showed high determination coefficients for most of the mineral elements; concretely, nitrogen and calcium presented the best results (0.80 and 0.76, respectively).

Keywords

Nutritional deficiencies; nitrogen; remote sensing; NDVI; apple.

Resumen

Se ha evaluado el efecto en las anomalías de los nutrientes minerals foliares en el comportamiento nutricional de los cultivos de manzanos utilizando parámetros obtenidos mediante técnicas de teledetección. Se seleccionaron veinticinco

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parcelas en fincas comerciales de los cinco municipios más importantes del estado de Chihuahua (México), en los que se midieron en campo los principales parámetros nutricionales (N, P, K, Ca, Mg, Fe, Zn, Mn, Cu y B). Se detectaron importantes deficiencias de estos nutrientes en el 88% de los cultivos analizados. Estas deficiencias mostraron una correlación significativa con los datos espectrales (SPOT5) y con el NDVI elaborado a partir de estos datos. Los modelos matemáticos obtenidos proporcionaron altos coeficientes de determinación para la mayoría de los elementos minerales; concretamente, el nitrógeno y el calcio presentaron los mejores resultados (0.80 y 0.76, respectivamente).

Palabras clave
Deficiencias nutricionales; nitrógeno; teledetección; NDVI; manzano.

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1. INTRODUCTION

The nutritional elements have specific functions in the life of plants, at the structural level (Al-Obaid et alli, 2010) as well as through their transport and in osmotic adjustment processes. In fruit trees like apple, the timing and the form of application of fertilization may influence not only growth but also the yield of crops, as well as affecting the different forms of storage and mobilization of nutrients in the plants (Neilsen et alli, 2006). As a result, the trees will have higher levels of these elements quickly available for the initial growth of leaves, flowers, and fruits (Dong et alli, 2005).

The nutritional diagnosis of crops is a tool that allows one to determine the source of anomalies in the nutritional state, through the analysis and interpretation of morphological, physical, and chemical characteristics of the plants. Its importance is due to the fact that the potential of crops is expressed as a production of high yield and quality (Jiménez, 2009). Traditionally, the procedures used to perform these diagnoses have been based on techniques of field or laboratory analysis, the former having the obvious disadvantage of providing a late identification of nutritional disorders - when they have already affected growth and yield. On the other hand, laboratory techniques are more accurate but they involve a large number of processes, associated with sampling, transportation, preparation, analysis, and interpretation of results.

The existence of a strong, linear, and positive correlation between some nutrients and the leaf chlorophyll, photosynthesis, protein synthesis, and nitrogen (N) levels (Boussadia et alli, 2010) means that remote sensing techniques can provide a platform to evaluate the nutritional conditions of the plants and the response of growth. Remote sensing allows one to measure the reflectance of the incident light at different wavelengths, which has been associated with plant growth and yield.

The vegetative indices allow users to relate the differences in reflectance to changes in the characteristics of the canopy (Gonzalez-Dugo et alli, 2013; Contreras et alli, 2014). The Normalized Difference Vegetation Index (NDVI), which combines the reflectance signals of the near-infrared (NIR) part of the electromagnetic spectrum, has broad acceptance based on its ease of use; it requires only two wavelengths and the characteristics of the plant that has been used for the correlation (Ruimy, Sangier & Dediu, 1994). The NDVI is a measure of the photosynthetic capacity of the plants and the stomatal resistance with respect to the transfer of water vapor, and it is used to evaluate the concentration of N in the plant, the chlorophyll content, the biomass of green leaves, and the grain yield (Solari et alli, 2008). Studies on spectral reflectance indicate that there is a direct relationship between the percentage of photosynthesis, light absorbance, and concentration of leaf nitrogen (Broge & Leblanc, 2000). A less-than-optimal N content in the vegetation cover is easily detectable (Schröder et alli, 2000), while excess N is not estimated adequately (Wood et alli, 1993). However, Blackmer, Schepers & Varvel (1994) showed that with the reflectance measured at 550 nm good correlations between the foliar N concentration and estimated chlorophyll are obtained, but a wide range of available N is required (Zarco et alli, 2004).

The main objective of this work was to assess the effect of the lack and excess of foliar mineral nutrients (N, P, K, Ca, Mg, Fe, Zn, Mn, Cu, and B) on the nutritional behavior of the apple tree and to examine the evolution of some parameters obtained with ground detection systems using images of the sensor SPOT5, with spectral information in the visible and near-infrared wavelengths. Spectral models of this fruit tree, which take into account the concentrations of the most important nutrient elements, can help to establish a proper physiological evaluation of the tree in a short period of time.

2. MATERIALS AND METHODS

2.1. STUDY AREA

The study area is located in the agricultural region of Chihuahua (Mexico), between the geographical coordinates 28°13'19" to 28°59'35" N and 106°34'39" to 107°10'33" W, covering a total area of 2,035 km². In this area has been analyzed 25 plots, within commercial apple orchards, characterized (Figure 1). Topographically, it is characterize by a plain that is shaped irregularly by the Pedernales, San Juan, Salitrera, Chuchupate, Sierra Azul and Sierra Rebote, where the only water contribution comes from precipitation. This zone has a mean annual rainfall of 415.7 mm and an annual average temperature of 14.6 °C (CNA, 2010), generating semi-arid

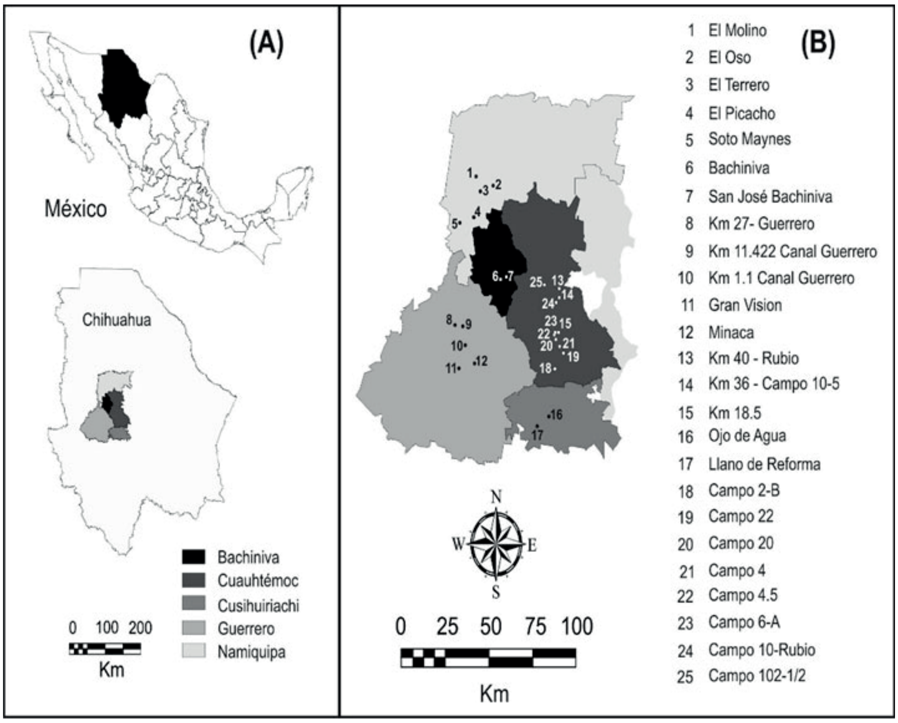

FIGURE 1. GENERAL LOCATION OF THE STUDY AREA: A) LOCATION OF CHIHUAHUA STATE, MEXICO. B) TOWNS WHERE THE APPLE ORCHARDS ARE DISTRIBUTED. Source: Autors.

climatic conditions. This dynamic has caused an overexploitation of the water resources, 569.4 Hm^3 being extracted annually while only 115 Hm^3 are provided by natural recharge (CNA, 2010). The soils of the region are characterized by being poor (GEC, 2013), with low contents of organic matter and deficiencies of nitrogen, calcium, magnesium, manganese, copper, iron, and zinc –which give rise to low agricultural production averaging 9.85 t/ha/year (INEGI, 2012).

2.2. SAMPLING AND ANALYSIS OF NUTRIENTS IN LEAVES

Sampling was carried out on the middle section of the vegetative branches, in trees selected at random (at a height between 1 and 2 meters). The main characteristics are presented in Table 1.

TABLE 1 – SAMPLES CHARACTERISTICS (Source: Autors)

Nº	LOCALITY	IRRIGATION SYSTEM	VARIETY	AGE OF THE TREE	TREE SPACING VVSPACING (M)
1	El Molino	Gravity	G.D.	20	P.P. 3.3*4.0
2	El Oso	Micro aspersion	G.D.	15	S. 5.1*4.1
3	El Terrero	Micro aspersion	G.D.	20	S. 5.6*4.9
4	El Picacho	Micro aspersion	G.D.	25	S. 5.1*6.0
5	Soto Máynez	Gravity	G.D.	18	S. 4.3*2.3
6	Bachiniva	Gravity	G.D.	25	P.P. 4.0*3.7
7	Sn. J. Bachi.	Gravity	G.D.	26	P.P. 6.3*4.5
8	km 27-Carr-M	Micro aspersion	R.D.	15	S. 5.0*5.0
9	km 11.4 Can	Micro aspersion	G.D.	25	C G 4.4*2.6
10	km 1.1 Can	Gravity	G.D.	25	P.P. 4.0*4.0
11	Gran Visión	Micro aspersion	G.D.	30	S. 5.0*4.4
12	Miñaca	Micro aspersion	G.D.	20	S. 5.0*4.5
13	Rubio (km-40)	Gravity	G.D.	20	S. 4.7*6.0
14	Field 10-A	Gravity	G.D.	15	P.P. 2.2*4.3
15	km 18.5-Rubio	Micro aspersion	G.D. - R.D.	10	P.P. 1.5*4.3
16	Ojo de Agua	Micro aspersion	G.D. - R.D.	20	P.P. 5.5*5.5
17	Llanos' Reforma	Gravity	G.D. - R.D.	20	P.P. 2.5*3.1
18	Field 2-B	Micro aspersion	R.D.	15	P.P. 2.9*4.7
19	Field 22	Micro aspersion	G.D.	10	S. 5.2*3.7
20	Field 20	Micro aspersion	G.D.	12	S. 4.4*2.4
21	Field 4	Micro aspersion	G.D.	20	S. 5.0*6.2
22	Field 4-1/2	Gravity	G.D. - R.D.	25	S. 5.3*5.9
23	Field 6-A	Micro aspersion	G.D.	6	P.P. 4.6*3.0
24	Field 10	Gravity	R.D.	8	S. 4.6*3.1
25	Field 102-1/2	Gravity	G.D.	30	P.P. 6.1*6.1

G.D.: Golden Delicious, R.D.: Red Delicious. P. P.: Planting Pattern, S.: Staggered. C.G.: Curves at ground level.

To avoid the high variation in the concentrations of the essential elements in the apple leaves during the period of vegetative growth, it was decided to take samples of leaves during the period of minimum oscillation of the nutrient concentrations. To study the natural defoliation, five shoots were marked per tree and the number of leaves was recorded every 15 days, according to the methodology of Yuri (2002). The determination of the total concentrations of the elements (nitrogen, phosphorus, potassium, calcium, magnesium, iron, boron, manganese, zinc, and copper) was conducted according to the methodology proposed by Etchevers (1992); subsequently, the ranges of classification were compared and the results interpreted (Shear & Faust, 1980).

2.3. SPECTRAL INFORMATION

In this work images provided by the satellite SPOT 5 have been used. But the impossibility of knowing a priori if cloud cover was absent in the images captured, in relation to their correct analysis, made six field campaigns of leaf sampling necessary - during the production cycle of the year 2012, every 15 days from late May until mid-August. Various images acquired, needed for cover the study area, that obtained on June 18 was established as optimal for use, while the sampling date of June 15 was determined as the most propitious for the analysis of the correlation between the two sets of data. The image used was geometrically corrected, using control points, by the Miramón software (Pala & Pons, 1996). The atmospheric effect on the electromagnetic signal was removed, using the 6S radiative transfer model (Vermote et alli, 1997), as was as the distorting effect of the topography on the lighting conditions (Riaño, Chuvieco & Aguado, 2003). From the rectified image spectral information from the red and near-infrared bands was obtained, as well as the ratio of the differences of the two bands, to give the normalized difference vegetation index (NDVI), that shows high correlation with the green biomass and primary productivity (Cabrera-Bosquet et alli, 2011).

2.4. STATISTICAL ANALYSIS

For the determination of the predictive model of the concentrations of the nutrient elements in apple leaves, the predictive variables used were the average values of reflectivity in the SPOT-B2 and SPOT-B3 bands, as well as the average NDVI values (Table 2), in each of the experimental plots. This information corresponded to the average nutrient concentration values in each plot. A linear regression model was applied to determine the relationships between the concentrations of nutrient elements reported in situ and the spectral information for each of the bands and the NDVI, in order to measure the magnitude of the relationships and their statistical significance. Subsequently, the Pearson correlation coefficient, used for quantitative variables (minimum interval scale), was applied; this measures the degree of covariance between different variables related linearly (Spiegel, 1992).

TABLE 2 – MAIN FEATURES OF THE SPOT 5 IMAGES USED (Source: Autors)

Band	**Band width (µm)**	**Spectral region**	**Spatial resolution**
SPOT-B2	0.61 – 0.68	Red	10
SPOT-B3	0.78 – 0.89	Near infrared	10
Index	**Equation**		**Spatial resolution**
NDVI	$\rho_{NIR}-\rho_R / \rho_{NIR}+\rho_R$		10

3. RESULTS AND DISCUSSION

The results are presented as an analysis of the leaf nutrient concentrations and their degree of correlation with the spectral data. Deductions are provided for macronutrients (concentrations expressed in percentages) and for micronutrients (expressed in mg/kg).

TABLE 3 – MINERAL ELEMENT CONCENTRATIONS IN APPLE LEAVES IN EACH PLOT

MACRONUTRIENTS (%)						MICRONUTRIENTS (MG/KG)				
Plot	**N**	**P**	**K**	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**	**B**	**Cu**
1	1.55	**0.2**	0.84	0.58	0.15	**57**	18	4	**35**	2
2	1.68	0.09	0.84	0.21	0.14	46	20	5	**39**	2
3	1.56	0.12	0.83	0.58	0.14	43	14	6	**40**	1
4	1.24	0.08	0.59	0.48	0.14	48	**38**	4	**31**	1
5	1.64	0.13	0.62	0.85	0.15	**62**	16	5	**32**	2
6	**1.78**	0.05	0.51	0.49	0.19	**73**	**29**	**20**	**29**	**8**
7	1.67	0.12	0.66	0.58	0.18	45	12	4	**35**	2
8	**1.71**	**0.17**	0.79	0.43	0.19	**95**	**33**	6	**34**	3
9	**1.85**	0.07	0.69	0.32	0.17	**77**	**25**	3	**45**	2
10	1.27	0.11	0.7	0.64	0.17	**71**	13	4	**33**	1
11	1.72	0.09	0.81	0.33	0.15	**93**	**36**	4	**37**	**5**
12	**1.88**	0.07	0.65	0.87	0.18	**75**	**29**	5	**37**	2
13	**2.14**	0.06	0.64	0.67	0.19	**73**	23	4	**30**	1
14	**2.25**	0.09	0.69	0.63	0.19	**103**	14	4	**40**	2
15	**1.86**	0.07	0.88	0.71	0.17	**97**	**36**	5	**33**	2
16	1.47	0.1	0.65	0.65	0.2	**98**	21	4	**28**	1
17	**1.73**	**0.18**	0.74	0.67	0.19	**143**	14	4	**34**	2
18	**1.72**	0.08	0.65	0.55	0.15	**109**	20	3	**39**	1
19	**1.89**	0.07	0.54	0.77	0.21	**119**	**48**	**26**	**35**	2
20	1.5	**0.18**	0.69	0.73	0.14	**130**	**25**	5	**31**	2
21	**2.18**	0.06	0.53	0.57	0.2	**101**	23	6	**34**	2
22	**1.67**	**0.15**	0.61	0.61	0.18	**75**	22	4	**36**	3
23	**1.95**	0.08	0.57	0.65	0.16	**80**	**28**	12	**33**	2
24	**2.27**	0.08	0.57	0.62	0.17	**64**	11	5	**55**	2
25	**2.03**	0.07	0.87	0.81	0.15	**70**	17	4	**42**	2

In bold font, sufficient levels on parameters. Interpretation (Shear and Faust, 1980): N = ≤ 1.5 % = Deficiency; 1.7-2.5 % = Sufficiency; ≥ 2.8 % = Excess. P ≤ 0.13 % = Deficiency; 0.15-0.30 % = Sufficiency; ≥ 1.25 % = Excess. K ≤ 1.0 % = Deficiency; 1.5-2.0 % = Sufficiency; ≥ 3.1 % Excess. Ca ≤ 0.7 % = Deficiency; 1.5-2.0 % = Sufficiency; ≥ 3.1 % = Excess. Mg ≤ 0.25 % = Deficiency; 0.26 a 0.85 % = Sufficiency; ≥ 1.0 % = Excess. Fe (mg/kg) ≤ 50 = Deficiency; 51-250 = Sufficiency; ≥ 350 = Excess. Mn (mg/kg) ≤ 25 = Deficiency; 25-150 = Sufficiency; ≥ 200 = Excess. Zn (mg/kg) ≤ 14 = Deficiency; 15-100 = Sufficiency; ≥ 400 = Excess. B (mg/kg) ≤ 20 = Deficiency; 20-60 = Sufficiency; ≥ 100 B = Excess. Cu (mg/kg) ≤ 4 = Deficiency; 5-12 = Sufficiency; ≥ 75 = Excess.

Table 3 shows the summary of the nutritional analysis, and figures 2 and 3 describes standardized values of the nutrient concentration obtained for 25 plots on the sampling date of July 15.

The statistical analyses are shown as the models obtained by the mathematical fitting of the data for each of the nutrients to the independent variables generated from the satellite data (Table 4).

TABLE 4 – REGRESSION MODELS FOR ALL NUTRIENTS AND THE INDEPENDENT VARIABLES GENERATED FROM SPOT5 DATA (Source: Autors)

Nutrient	Models	r^2	Independent variable	Unit
Nitrogen	Y = -2.199 X 2 + 2.964 X + 1.225	0.802	NDVI	%
Phosphorus	Y = 0.079 X 0.3	0.706	NDVI	%
Potassium	Y = -1.245 X3 + 1.139 X2 + 0.165 x + 0.439	0.711	NDVI	%
Calcium	Y = - 0.739 X 2 + 1.044 X + 0.301	0.762	NDVI	%
Magnesium	Y= -0.168 X 2+ 0.162 X + 0.161	0.689	NDVI	%
Iron	Y= 2.1 X 2+ 100.7 X * 7.8	0.613	SPOT5-B3	mg/g
Manganese	Y = - 47.1 X 2 + 34.6 X + 24.5	0.777	SPOT5-B3	mg/kg
Zinc	Y = 494.2 X 3 – 999.6 X 2 + 656.2 X+ 134.7	0.615	NDVI	mg/kg
Boron	Y = 127.3 X 2 – 166.2 X + 85.5	0.536	SPOT5-B3	mg/kg
Copper	Y = -9.97 X 2 + 0.406 X + 1.9427	0.608	SPOT5-B2	mg/kg

3.1. EFFECTS OBSERVED IN THE ANALYSIS OF MACRONUTRIENTS

The concentration of total N in the leaves of the apple trees was highest in all plots (Figure 2) in the early part of the physiological crop cycle (starting from the last days of May); it subsequently decreased during the growth season, since this element is used in the cell division and elongation required for fruit growth. The farm plots in the municipalities of Bachíniva, Namiquipa, and Cusihuiriachic showed a negligible relationship with the N in the leaves. The sites of the municipality of Guerrero were recorded as having average conditions, while the rest belonged to the municipality of Cuauhtemoc, where the greatest concentration of foliar N was found. One can appreciate the relationship between the leaf N concentration and the data obtained with the remote sensors regarding the biophysical characterization, due to the optical properties of the green leaves, where the absorption in the red part of the electromagnetic spectrum was very high. The model that represents this relationship is second order, with r^2 = 0.802. These effects coincide with those found by Solari et alli (2008), who pointed out that NDVI is widely used since it is adaptable to almost any condition. Deficiencies of N in apple trees are associated with vegetation index values of 0.2 to 0.4; the optimal N concentration (2% total N) corresponds to a value of 0.5 for this index and excess N to the range 0.6 to 0.92.

Trees having deficiencies of K, where values ranged from 0.20 to 0.95 NDVI. In relation to this, Liu & Hute (1995) suggested that the NDVI results depend on the hypothesis considered in relation to the structure of the problem. Other work (Amado, 1994), in which 58 plots of apple trees in the State of Chihuahua were analyzed, showed that 23% of these farmlands had low levels of K, leading to the conclusion that the best effects of this nutrient gave an average yield (35.5 t/ha).

Calcium (Ca) deficiencies are common in the Sierra de Chihuahua and the results of this research indicate that 96% of the samples taken in the 25 plots had low concentrations of Ca. These data match those of Fallahi (1997), where low amounts of this element caused the presence of the condition «bitter pit», which is related inversely to the concentration of Ca in the fruit and directly to the levels of Mg, K, P, and N.

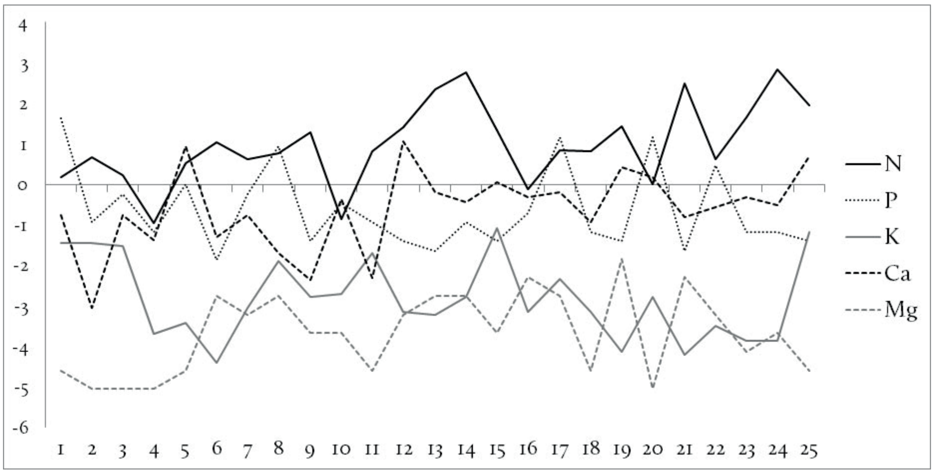

FIGURE 2. Y-AXIS, VALUES REFER TO SAMPLES PLOTS (SEE TABLE 1). X-AXIS, STANDARDIZED VALUES OF THE MACRONUTRIENT CONCENTRATION OF APPLE ORCHARDS. DATA BELOW 0 SHOW DEFICIENCIES ON PLANT OF MINERAL ELEMENT CONCENTRATIONS. N: NITROGEN, P: PHOSPHORUS, K: POTASSIUM, CA: CALCIUM, MG: MAGNESIUM. Source: Autors.

With respect to the statistical models derived from the interpretation of the spectral signatures, the percentage of Ca in the leaf, and the NDVI, a second-order regression was obtained with r^2 = 0.76, 0.43% to 0.70% Ca corresponding to NDVI values of 0.2 to 0.94. These results are similar to those cited by Tucker & Sellers (1986) and Ritchie (2003), who - working with optical remote sensors, to measure biophysical indicators and detect their spatial variability - established that most green leaves reflect or disperse the majority of light in the near-infrared band.

Regarding the measured concentrations of magnesium (Mg), 97.3% of them showed strong deficiencies of this element. This matches work which demonstrates that the lack of Mg causes a decrease in the synthesis of lipids (García et alli, 2008), proteins (Al-Obaid et alli, 2010), and carbohydrates (Carvalho & Zonette, 2004). According to Stiles (1994), the Mg requirements of apple trees fluctuate between 25 and 35 kg/ha/year, of which approximately half is accounted for by the fruits. The relationship between the concentration of Mg and the NDVI was highly significant (r^2 = 0.69), as represented by a second-order model. All values (about 0.20% Mg in the leaf) corresponded to NDVI values of 0.2 to 0.94. The interaction of solar radiation with molecules within plant leaves controls the reflectance of the visible and near-infrared (280-800 nm) parts of the spectrum (Curran et alli, 2001). In our case, this indicates the existence of plots with strong nutritional deficiencies of Mg.

3.2. EFFECTS OBSERVED IN THE ANALYSIS OF MICRONUTRIENTS

Deficiencies of iron (Fe) in cultivated apple trees are not common in the zone of study. However, in the present work, 28% of samples manifested a deficiency of this nutrient (Figure 3). The relationship between the leaf Fe concentration and the near-infrared band of the electromagnetic spectrum (SPOT5-B3) showed an r^2 of 0.613, as represented by an equation of the second order; leaf Fe levels from 40 to 110 mg/kg represent sufficiency.

The analyses of manganese (Mn) showed that 62% of the soils possessed average amounts of this nutrient, 33% had optimal amounts, and only 5% had very high concentrations, so it will be hard to achieve a response to the application of this element. Correction of Mn deficiencies in plants will be better achieved through foliar application or fertirrigation. The spectral index of Mn formed by the concentration of this nutrient and the near-infrared band (SPOT5-B3) showed a highly significant statistical correlation (r^2 = 0.777), when represented as a quadratic equation with a negative slope. This includes Mn values between 10 and 30 mg/kg, indicating plots with nutrient deficiencies which correspond to reflectivity values between 0.5 and 1.0 µm.

Regarding zinc (Zn), 93.3% of the samples represented deficiencies. The best fit of the data was obtained with a cubic model, with a determination coefficient of 0.61. However, these values are not very convincing, since a concentration of 4 mg/kg Zn corresponded to two values of NDVI (0.45 and 0.78).

For boron (B), 100% of the apple leaf samples were found to have a sufficient (and typical) concentration frrom 20 to 60 mg/kg). The correlation between the B concentration (mg/kg) and the reflectance in band 3 of the SPOT5 was the poorest of all the nutrients (r^2 = 0.54).

Finally, the copper (Cu) concentration data indicate that only 6% of the apple plots were within the range of nutritional sufficiency while 94% had severe deficiency (≤ 4.0 Cu mg/kg). The relationship between the concentration of this nutrient and the red band (SPOT5-B2) fitted best a second-order model with a negative slope and a statistically significant coefficient of determination (r^2 = 0.61).

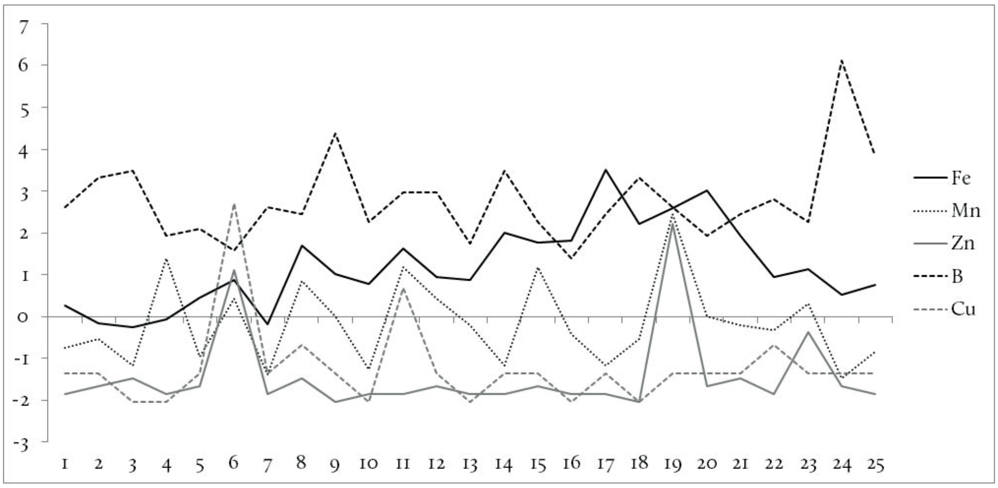

FIGURE 3. Y-AXIS, VALUES REFER TO SAMPLES PLOTS (SEE TABLE 1). X-AXIS, STANDARDIZED VALUES OF THE MICRONUTRIENT CONCENTRATION OF APPLE ORCHARDS. DATA BELOW 0 SHOW DEFICIENCIES ON PLANT OF MINERAL ELEMENT CONCENTRATIONS. FE: IRON, MN: MANGANESE, ZN: ZINC, B: BORON, CU: COPPER.
Source: Autors.

4. CONCLUSIONS

Nutritional deficiencies in apple trees (especially for N, P, Ca, Mg, and Fe) have been detected in 88% of the plots. These results reflect the field conditions that prevail in Chihuahua, especially the tendency of some of the regional fruit growers towards the organic production of apples, implying a decline in the addition of chemical fertilizers to the soil, causing a long term decrease in agricultural production.

The use of remote sensing techniques in the nutritional diagnosis of apple trees is a tool with great advantages. The correlations between the concentrations of elements in studied crops and spectral data, obtained through mathematical models of the first, second, and third order, have been satisfactory. In general, a better relationship with the spectral data was found for the leaf macronutrients, particularly nitrogen.

REFERENCES

Al-Obaidi, J.R., Mohd-Yusuf, Y., Chin Chong, T., Mhd-Noh, N., Toman, R.Y.: «Identification of a portial oil palm polygalacturonase inhibiting protein (EgPGIP) gene and its expression during basal stem rot infection caused by Ganodermia boninense», *African Journal of Biotechnology* 9 (2010), pp. 7788-7797.

Amado, Á.J.P.: «Efecto de la fertilización potásica al suelo sobre la producción del manzano (Malus pumilla Mill)», *Terra* 12 (1994) pp. 362-369.

Blackmer, T.M., Schepers J.S., Varvel, G.E.: «Light reflectance compared with other nitrogen stress measurements in corn leaves», *Agron. J.* 86 (1994), pp. 934–938.

Boussadia, O., Steppe, K., Zgallai, H., Ben El Hadj, S., Braham, M., Lemeur, R., Van Labeke, M.C.: «Effects of nitrogen deficiency on leaf photosynthesis, carbohydrate status and biomass production in two olive cultivars 'Meski' and 'Koroneiki'», *Scientia Horticulturae* 123 (2010) pp. 336-342.

Broge, N.H., Leblanc, E.: «Comparing prediction power and stability of broadband and hyper spectral vegetation indices for estimation of green leaf area index and canopy chlorophyll density», *Remote Sensing of Environment* 76 (2000) pp. 156-172.

Cabrera-Bosquet, L., Molero, G., Stellacci, A., Bort, J., Nogués, S., Araus, J.: «NDVI as a potential tool for predicting biomass, plant nitrogen content and growth in wheat genotypes subjected to different water and nitrogen conditions», *Cereal Research Communications* 39 (2011) pp.147-159.

Carvalho, R., Zonette, F.: «Contenido de carbohidratos en brotes y tallos de árboles de manzana durante el otoño y el invierno en la región de baja ocurrencia de frío», *Revista Brasileira de Fruticultura Jabotical* 26 (2004) pp. 202-205.

Comisión Nacional del Agua: «Subregiones Hidrológicas Escala 1:250,000. República Mexicana», México, D.F. Disponible en: http://www.siga.cna.gob.mx/metadatos/huracanes/Subregiones.Hidrológicas. [octubre 2012]. (CNA, 2010).

Contreras, S., Pérez-Cutillas, P., Santoni, C.S., Romero-Trigueros, C., Pedrero, F., Alarcón, J.J.: «Effects of Reclaimed Waters on Spectral Properties and Leaf Traits of Citrus Orchards», *Water Environmental Research* 86 (2014) pp. 22-42.

Curran, P.J., Dungan, J.L., Peterson, D.L.: «Estimating the foliar biochemical Concentration of leaves reflectance spectrometry testing the Kokaly and Clark methodologies», *Remote Sensing of Environment* 76 (2001) pp. 349-359.

Dong, S., Cheng, L., Scagel, C.F., Fuchigami, L.: «Timing of urea application affects leaf and root N uptake in young Fuji/M.9 apple trees», *Journal of Horticultural Science and Biotechnology* 80 (2005) pp.116-120.

Etchevers, B.J.D.: *Manual de Métodos para análisis de suelos, plantas, aguas y Fertilizantes. Análisis rutinario en estudios y programas de fertilidad*. Laboratorio de Fertilidad, C. P. Montecillo, Estado de México, 1992.

Garcia, D. E., Medina, M.G., Clavero, T., Cova, L.J., Dominguez, C., Baldizan, A.: «Nutritional characterization of six fodder species foliage with emphasis in their polyphenolic profiles», *Revista Científica, FCV-LUZ* 18 (2008) pp. 188-196.

Gobierno del Estado de Chihuahua (GEC): *Cartografía de uso de suelo y vegetación del Estado de Chihuahua E. 1:50.000.* Secretaría de Desarrollo Rural, Dirección de Desarrollo Forestal (2013)

Gonzalez-Dugo, V., Zarco-Tejada, P., Nicolás, E., Nortes, P.A., Alarcón, J.J., Intrigliolo, D.S., Fereres, E.: «Using high resolution UAV thermal imagery to assess the variability in the water status of five fruit tree species within a commercial orchard», *Precision Agriculture* 14 (2014) pp. 660-678.

Fallahi, E.: «Preharvest nitrogen optimization for maximizing yield and postharvest fruit quality of apples», *Acta Horticulturae* 448 (1997) pp. 415-419.

Huete, A.R.: «A soil-adjusted vegetation index (SAVI)», *Remote Sensing of Enviromental* 25 (1988) pp. 295-309.

Instituto Nacional de Estadística y Geografía (INEGI): «Anuario estadístico, Chihuahua. Agricultura. Superficies sembradas y cosechadas», en Volumen y valor de la producción agrícola por tipo de cultivo, principales cultivos y municípios. 2012. p.458.

Jiménez, V.M.: *Propiedades ópticas del trigo y deficiencias del Nitrógeno*. Colegio de Postgraduados. 2009. 51 p.

Liu, H.Q., Hute, A.: «A feedback based modification of the NDVI to minimize canopy background and atmospheric noise», *Geoscience and Remote Sensing* 33 (1995) pp. 457-465.

Neilsen, D., Neilsen, G.H., Herbert, L.C., Millard, P., Guak, S.: «Allocation of dry matter and N to fruit and shoots in dwarf apple in response to sink size and N availability», *Acta Horticulturae* 721 (2006) pp. 33-40.

Pala, V., Pons, X.: «Incorporation of relief in polynomial-based geometric corrections», *Photogrammetric engineering & Remote Sensing* 61 (1996) pp. 935–944.

Riaño, D., Chuvieco, E., Aguado, I.: «Assessment of different topographic Corrections in Landsat TM data for mapping vegetation types», *IEEE Transactions on Geosciences and Remote Sensing* 41 (2003) pp.1056–1061.

Ritchie, L.G.: *Use of ground-based canopy reflectance to determine ground cover, nitrogen and water status and final yield in wheat*. Utah State University Logan, UT, USA. 2003.

Ruimy, A., Sangier, B., Dediu, G.: «Methodology for the estimation of terrestrial primary production from remotely sensed data», *Journal Geophysical Research* 99 (1994) pp. 5263–5283.

Shear, B.C., Faust, M.: «Nutritional ranges in deciduous tree fruit and nuts», *Horticultural Reviews* 2 (1980) pp. 142-163.

Schröder, J.J., Neeteson, J.J., Oenema, O.L., Struik, P.C.: «Does the crop or the soil indicate how to save nitrogen in maize production? Reviewing the state of the art», *Field Crops Research* 66 (2000) pp.151-164.

Solari, F., Shanahan, J., Ferguson, R.B., Gitelson, A.A.: «Actives sensor reflectance measurements of corn nitrogen status and yield potential», Agronomy Journal 100 (2008) pp. 571-579.

Spiegel, M.: «'Correlation Theory' Ch. 14 en Theory and Problems of Probability and Statistics», en 2nd Ed. New York. McGraw-Hill. 1992, pp. 294-323.

Stiles, W.C.: «Phosphorus, Potassium, Magnesium and Sulfur Soil Management», en: A. Brooke Peterson and Robert G. Stevens (eds.). Tree Fruit Nutrition. A comprehensive Manual of Deciduous Tree Fruit Nutrientes Needs. Yakima; Washington, D.C. 1994: Good Fruit Grower, pp. 63-70.

Tucker, C.J., Sellers, P.A.: «Satellite remote Sensing of primary production», *International Journal of Remote Sensing* 7 (1986) pp.1395–1416.

Vermote, E.F., Tanré, D., Herman, M., Morcrette, J.J.: «Second simulation of the satellite sign signal in the solar spectrum, 6s: an overview», *IEEE Transactions on Geoscience and Remote Sensing* 35(1997) pp. 675–686.

WOOD, C.W., REEVESAND, D.W., HIMELRICK, D.G.: «Relationships between chlorophyll meter readings and leaf chlorophyll concentration, N status, and crop yield: A review», *Agronomy Society of New Zealand* 23 (1993) pp.1-9.

YURI, J.A.: «El receso en frutales», en Boletín Técnico Volumen 2 Número 4. Centro de Pomáceas, Universidad de Talca. 2002.

ZARCO, P.J., MILLER, J.R., BERJÓN, A., AGÜERA, J.: «Hyper spectral index and model simulation for chlorophyll estimation in open-canopy tree crops», *Remote Sensing of Environment* 90 (2004) pp. 463-476.

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