Article

Soil and foliar nutritional diagnosis in corn cultivation

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Abstract

It is important to define optimal fertilization doses for proper management of crop nutrition and significant improvement of harvest yield and quality. The present work was carried out in 2019 in the municipality of Texcoco, Estado de México. With the aim of evaluating five doses of fertilization based on the diagnosis of soil fertility so that through three foliar diagnostic methodologies determine the nutritional balance. The treatments evaluated were (T_0: absolute control, T_1: producer dose, T_2: 0.5 of the optimal dose, T_3: optimal dose, T_4: 1+0.5 of the optimal dose) in two varieties of corn (Estrella and Celeste). The results obtained showed that the soil is clayey, with a neutral pH, very low in Cu, low in Fe and Mn and medium in N, Zn and CEC, high in organic matter and very high in P, K, Ca, Mg and B. The diagnosis made with the three interpretation methodologies showed that nutrients N and Zn were the most deficient, while Ca and B were present at high levels. The concentration of soil nutrients and the Kenworthy foliar diagnosis showed a direct correlation for the elements Cu and Mn, while P, K, Ca, Mg and B were determined as medium and high in both the soil and the plant. For the DRIS diagnosis, medium or sufficient to high levels of Ca, Mg and B were determined both in the soil and in the plant. Finally, the concentration of Cu in the soil and plant was low, while that of B was high.

Keywords: grain yield, nutritional diagnosis, plant nutrition.

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Introduction

Fertilizers are used in crop production as they provide nutrients such as nitrogen, phosphorus and potassium that allow greater growth, development and production of these (Sedlacek *et al*., 2020). Considering the use of efficient doses of fertilizers is vital for obtaining high yields. The balanced use of fertilizers and the reduction of production costs are objectives of modern agriculture (Yousaf *et al*., 2016). The importance of a good diagnosis to develop adequate fertilizer recommendations promotes an increase in quality and productivity without deterioration of the environment. In addition, it is important to make efficient use of fertilizers to avoid unnecessary expenses and increases in production costs and to reduce environmental deterioration (Marschner, 2012).

The application of nutrients through fertilization is a common agronomic practice in corn cultivation, so that a nutritional deficiency can reduce the yield by 10 to up to 30%, before the characteristic symptoms of the deficiency appear (Morejon *et al*., 2017). Nutrient extraction is related to the nutritional harvest index, which is high for N and P, intermediate for S and very low for Ca and Mg (Fontanetto *et al*., 2006). The diagnosis of the fertility and nutritional status of plants is based on the assumption that the growth rate of plants is affected by the concentration of nutrients present in the soil and in the dry or fresh matter of the shoot. In general, the nutritional status of the leaf tissue better reflects the balance state of the plant and determines which nutrients are deficient, sufficient or in excess (Marschner, 2012).

Currently, there are several tools to determine the nutritional status of plants. Among them, the analysis of plants is efficient since the tissue is analyzed as a nutrient extractor. In this way, it is complemented by the chemical analysis of the soil and allows predicting nutritional disorders before visual symptoms appear (Prado *et al*., 2012). Plant tissue analysis has the function of improving harvest yields and quality depending on the type of crop (Imakumbili *et al*., 2020). Through this analysis, the nutrient needs and exports of the crop can be determined, nutritional deficiencies can be identified, nutritional status can be evaluated, the response to fertilizer application can be evaluated, and nutrient levels in various plant organs can be diagnosed.

The results are interpreted by comparing the concentration values of each element of the sample with the respective standard or a value considered optimal (Prado *et al*., 2012). The application of fertilizers to crops should be carried out using scientific tools such as soil, water and plant tissue analyses with the aim of avoiding losses due to leaching, volatilization and denitrification of these inputs, which directly affect the environment, in addition to increasing production costs.

Materials and methods

The experiment was developed in the ‘El Ranchito’ experimental field, in lot X-11, belonging to the Chapingo Autonomous University, Texcoco de Mora, State of Mexico. A soil sampling was carried out prior to the establishment of the crop using the zigzag method. Fifteen subsamples were collected randomly, trying that they were representative of the land, then a composite sample was formed, which was sent to the laboratory of chemical analysis of soils for the determination of its fertility, using the methods established in the Official Mexican Standard NOM-021-SEMARNAT-2000 (SEMARNAT, 2022). After obtaining the results of the soil fertility analysis, the optimal fertilization dose was estimated using the restitution method (Conde *et al*., 2018).

The treatment design used was a 2x5 factorial treatment design. The first factor consisted of two varieties of corn (Estrella and Celeste). The second factor was composed of five fertilization doses (T_0: absolute control, T_1: producer dose, T_2: 0.5 of the optimal dose, T_3: optimal dose, T_4: 1+0.5 of the optimal dose). T_0 was not applied any type of fertilizer to the soil or the plant, T_1 consisted of applying the dose used by the producers of the region to the culture of corn. The optimal dose was estimated, as previously indicated, with the restitution method taking into account the results of the soil analysis and from this, the treatments T_2 and T_4 were generated. The restitution method was used to calculate the optimal dose of all nutrients.

The culture was developed under rainfed conditions and was provided with supplemental irrigations every 15 days. The treatments were arranged in a completely randomized block design with four repetitions each. The foliar sampling was carried out in each experimental unit at three months of development of the corn culture and consisted of collecting from 25 randomly selected plants leaves located opposite and under the cob, photosynthetically active, healthy, sunny, clean and without physical damage. The leaves were washed to remove impurities, dried on an oven with forced air at 70 °C to constant weight.

Subsequently, they were ground using a stainless-steel mill, 0.5 g of dry matter from each sample was weighed, which were transferred to a Kjeldahl flask and 4 ml of diacid mixture (H_2SO_4:$HClO_4$) in a ratio of 4:1 and 2 ml of H_2O_2 were added, and they were placed on a digestion plate at 230 °C for 6 h. The samples were then removed and left to cool (Jones, 2001). Each digested sample was measured to 50 ml using a volumetric flask and transferred to a previously labeled plastic container. The final samples were stored in dark conditions and room temperature.

In the digestate, the total N concentration was determined by the Kjeldahl method. P was measured through the vanadate-molybdate method, and the readings were made on an ultraviolet light spectrophotometer at 420 nm. K and Na were determined with a flame emission spectrophotometer (flame meter) and Ca, Mg, Fe, Cu and Zn with an atomic absorption spectrophotometer. B was determined by the azomethine-H method and the readings were made on an ultraviolet light spectrophotometer at 620 nm (Jones, 2001).

Foliar diagnosis. For the interpretation of the nutritional status of the plant, the following methods were used: Kenworthy balance index (Kenworthy, 1967), diagnosis and recommendation integrated system, Lucena (2002), and optimal percentage deviation (Montañés *et al*., 1991). To carry out the diagnosis with each method, optimal reference values for corn culture were sought. Kenworthy balance index operations were calculated using the following formulas. If $X < S$, then: $P = (X/S)*100$. $I = (100-P)*(V/100)$. $B = P+I$. If $X>S$, then $P = (X/S)*100$. $I = (P-100)*(V/100)$. $B = P-I$. Where: X= is the concentration value of a nutrient in the sample; S= is the concentration value of a nutrient in the reference standard; P= is the percentage of the standard; V= is the coefficient of variation; I= is the influence of variation and B= is the equilibrium index.

Decision criteria for Kenworthy BI: scarcity= 17-50; below normal= 50-83; normal= 83-117; above normal= 117-150; excess= 150-183. For the DRIS calculation, the nutritional ratios were established based on the data of the foliar analysis, N/P, N/K, N/Ca, Mg/N, K/P, Ca/P, Mg/P, Ca/P, Mg/K, Mg/Ca, etc. (Lucena, 2002), and the following equations were used: If $A/B > a/b$, then $f(A/B)= 100*\left(\frac{A/B}{a/b}-1\right)*\frac{10}{CV}$ 2). If $A/B < a/b$, then: $f(A/B)= 100*\left(1-\frac{a/b}{A/B}\right)*\frac{10}{CV}$ 3). Where: A/B is the ratio of two nutrients in the sample; a/b is the ratio of two nutrients in the reference standard and CV= is the coefficient of variation of the corresponding standard.

The indices were calculated using the following equation: $\frac{[f(A/B)+f(A/C)+f(A/D)-f(E/A)+ +f(A/N)]}{z}$ 4). Where: A, B, C, D, E and N symbolize nutrients and z represents the functions involved in the calculation. The function (equation 4) is (+) if element A is numerator and (-) if it is denominator. The sum of the positive and negative indices must be zero so that there is a balance between the nutrients of the sample analyzed. Negative indices mean deficiency and positive indices indicate sufficiency or relative excesses. The most negative is the most deficient and those that follow indicate the order of nutrient requirements.

The percentage optimum deviation index was calculated by applying the following relationship: $DOP= \frac{C*100}{Cref}-100$ 1). Where: C= is the foliar concentration (in percentage of dry matter) of the element in the sample analyzed; Cref= is the optimum of the same element (percentage of dry matter) defined under the same conditions in which the problem sample was taken and logically, for the same crop. The sign of the DOP for a given element will be negative in the case of a deficit and positive in the case of an excess. When the sample content coincides with the reference optimum, the DOP will be equal to zero (Montañés *et al*., 1991).

Results and discussion

The presentation began with the results of fertility, showing the diagnosis of the nutritional status of the soil. Subsequently, the results of the nutritional status of the leaf tissue of the culture were shown, making the nutritional diagnosis by means of the following methods: indices of Kenworthy balance (1961), optimal percentage deviation (Montañés *et al*., 1991), and the diagnosis and recommendation integrated system (Beaufils, 1973). The tables showed the nutritional concentrations, the balance index of each nutrient and the order of nutritional requirement, highlighting the deficiencies, sufficiencies and excesses for each treatment.

Soil nutritional diagnosis

The results of the soil analysis are shown in Table 1, the diagnosis of the nutritional status of the soil indicated that the pH was neutral, which is adequate for the availability of essential nutrients. For its part, the concentration of organic matter was high, which indicates an important contribution of nutrients when decomposing, which can contribute to the nutrition of the culture of corn and improve the physical, chemical and biological properties of the soil, contributing significantly to its health and sustainability (Libohova *et al*., 2018).

Table 1. Chemical and physical analysis of the soil in the experimental units.

Parameter	Concentration	Unit	Classification
pH	6.72		Neutral
Organic matter	4.03	(%)	High
Inorganic nitrogen	28	(mg kg^{-1})	Medium
Phosphorus	64.67	(mg kg^{-1})	Very high
Potassium	927	(mg kg^{-1})	Very high
Calcium	4 245.2	(mg kg^{-1})	Very high
Magnesium	766.3	(mg kg^{-1})	Very high
Iron	5.45	(mg kg^{-1})	Low
Manganese	10.59	(mg kg^{-1})	Low
Zinc	2.88	(mg kg^{-1})	Medium
Copper	0.69	(mg kg^{-1})	Very low
Boron	3.16	(mg kg^{-1})	Very high
Cation exchange	22	(cmol kg^{-1})	Medium
Bulk density	1.16	(t m^{-3})	Clayey

The levels of N were medium, requiring the application of some fertilizer source that contains it, especially urea, ammonium nitrate or ammonium sulfate. For their part, the levels of P, K, Ca, Mg and B resulted in a very high concentration, according to the standards established by Ankerman and Large (1977); Camberato and Pan (2000). The high concentration of these nutrients is derived from the periodic applications of fertilizers that have been made on the land in years prior to the establishment of the experiment and that have been accumulated in such a way that the levels available for cultivation are excessive, in quantity and quality (Horneck *et al*., 2011).

However, the excess of P in the soil can interact negatively with calcium and with most micronutrients (Fe, Mn, Zn and Cu), either by the formation of precipitates in the soil or by immobilization processes in metabolic processes within plants, which prevents the translocation of mineral elements from the root to the different organs of the plant and consequently their assimilation (Brown and Tiffin, 1962; Verma and Minhas, 1987; James *et al*., 1995; Zhu *et al*., 2002; Zhang *et al*., 2015).

As for micronutrients, the soil has low levels of iron and manganese, which can cause chlorosis problems and significantly affect processes such as photosynthesis and respiration, especially iron for its function in the electron transport chain and cofactor of enzymes (Schmidt *et al*., 2020), it is a prosthetic group of many enzymes, is also involved in the synthesis of chlorophyll and is essential for the functioning of chloroplasts (Rout *et al*., 2015). For its part, zinc was found at a medium level in the soil, this being an element of vital importance in the establishment of corn culture, since it is a precursor of tryptophan, so it contributes to a faster and more homogeneous emergence of seeds, root former and grain growth (Mortvedt, 2000). The concentration of Cu, on the other hand, was very low. Consequently, the nutrition formula was integrated 16.2-01-18.7 +1 Zn + 0.5 Cu +0.15 B, at a dose of 600 kg ha^{-1} for the optimal dose.

Kenworthy balance index

Nutrition concentration data, Kenworthy balance indexes and the order of nutritional requirement for corn of the Celeste variety are shown in Table 2.

Table 2. Nutritional diagnosis in corn of the Celeste variety with five fertilization doses using the Kenworthy balance index.

	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B	NII
					Control						
CN	1.46	0.29	2.08	0.56	0.26	163.8	41.73	16.45	9.18	16.3	902.6
KBI	58.4	98.5	102.9	148.3	86.2	104.9	63.9	63.3	81.2	95	
ONR	N> Zn> Mn> Cu> Mg> B> P> K> Fe> Ca										
					Treatment one: producer dose						
CN	2.08	0.32	2.24	0.45	0.19	188.5	61.9	17.23	10	111.3	1314.8
KBI	75.2	105	109.4	125.1	72	113.7	75.4	65.1	85.3	488.6	
ONR	Zn> N> Mg> Mn> Cu> P> K> Fe> Ca> B										
					Treatment two: 0.5 of the optimal doses						
CN	1.94	0.32	2.12	0.51	0.23	146.3	58.9	19.93	9.85	61.39	1108.6
KBI	71.4	104.1	104.7	138.2	80.2	98.7	73.7	71.3	84.5	281.8	
ONR	Zn> N> Mn> Mg> Cu> Fe> P> K> Ca> B										
					Treatment three: optimal dose						
CN	2.15	0.32	2.28	0.54	0.2	173.7	72	19.08	9.7	72.66	1182.4
KBI	77.1	104.7	110.6	144.1	74.6	108.5	81.2	69.3	83.8	328.5	
ONR	Zn> N> Mg> Mn> Cu> Fe> P> K> Ca> B										
					Treatment four: 1.5 of the optimal doses						
CN	2.06	0.3	2.28	0.47	0.21	148.4	69.65	21.95	9.65	136.3	1421.4
KBI	74.5	99.4	110.6	130.3	75.9	99.4	79.8	75.9	83.6	592	
ONR	N> Zn> Mg> Mn> Cu> Fe> P> K> Ca> B										

CN= concentration in the leaf; KBI= Kenworthy balance index; NII= nutritional imbalance index; ONR= order of nutritional requirement. Red color= deficient nutrients; green color= balanced nutrients; blue color= excess nutrients.

The analysis of the results allows us to affirm that, in all treatments, nutrients N, Zn, Mg and Mn were found to be deficient. There was Cu deficiency in the treatments T_0 (control) and T_4 (1.5 times the optimal dose). The nutrients that were within a normal interval were Fe, P, K and Cu. While Ca and B were above normal concentration and in excess, respectively. While for the Estrella variety, they are shown in Table 3. It was observed that, in all treatments, there were deficiencies of N, Zn and Mn. P, Fe and Cu were found within normal intervals.

Table 3. Nutritional diagnosis in corn of the Estrella variety with five fertilization doses using the Kenworthy balance index.

	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B	NII
Control											
CN	1.35	0.26	1.72	0.58	0.26	135.9	44.65	18.13	7.3	25.16	905.9
KBI	55.3	89.6	89.4	153.9	86.3	95	65.6	67.1	72	131.7	
ONR	N> Mn> Zn> Cu> Mg> K> P> Fe> B> Ca										
Treatment one: producer dose											
CN	2.03	0.28	1.31	0.58	0.32	163.9	59.53	20.28	10	133.1	1407.4
KBI	73.8	94.2	73.6	153.6	98	105	74.1	72.1	85.3	578.7	
ONR	Zn> K> N> Mn> Cu> P> Mg> Fe> Ca> B										
Treatment two: 0.5 of the optimal doses											
CN	1.76	0.28	1.4	0.57	0.29	133.4	50.13	16.55	11.23	147.5	799.3
KBI	66.4	95	77.1	151.8	91.4	94.1	68.7	63.5	91.3	638.7	
ONR	Zn> N> Mn> K> Cu> Mg> Fe> P> Ca> B										
Treatment three: optimal dose											
CN	2	0.29	1.72	0.52	0.27	168.3	60.35	17.78	9.58	178.1	1584
KBI	73.1	96.6	89.4	140.4	88.5	106.5	74.5	66.3	83.2	765.5	
ONR	Zn> N> Mn> Cu> Mg> K> P> Fe> Ca> B										
Treatment four: 1.5 of the optimal dose											
CN	1.83	0.25	1.46	0.53	0.23	143.2	71.35	20.8	10.73	186.2	1596
KBI	68.3	86.8	79.4	142	80.2	97.6	80.8	73.3	88.8	798.8	
ONR	N> Zn> K> Mg> Mn> P> Cu> Fe> Ca> B										

CN= concentration in the leaf; KBI= Kenworthy balance index; NII= nutritional imbalance index; ONR= order of nutritional requirement; red color= deficient nutrients; green color= balanced nutrients; blue color= excess nutrients.

Ca and B, on the other hand, were present within a range classified as above normal and excessive, respectively. Correlating the foliar diagnosis of the Celeste variety with that of soils, there was a correspondence of high Ca and B in the soil and in the plant. While levels of Mn and Cu were low in soil and corn leaves. For their part, the levels of P, K, Mg and B were high in the soil, were medium in the leaf tissue. While N and Zn were medium in the soil and low in the leaf tissue; that is, there was some type of loss of these nutrients in the soil due to fixation or volatilization that prevented their use by the corn plant of the Celeste variety. The results of the foliar analysis were similar in deficiency, sufficiency and excess, between the celeste and the estrella varieties, whose results can be seen in Table 3.

Only a difference was observed between the two varieties, in the Estrella variety, Mg was in a normal range except in the T_4 treatment (1.5 of the optimal dose), while K was classified as deficient in the treatments T_1 (producer dose), T_2 (0.5 of the optimal dose) and T_4 (1.5 of the optimal dose).

Nutritional diagnosis through DRIS

The diagnosis and recommendation integrated system (DRIS) classifies the order of nutrient requirements (ONR) and the nutrient imbalance index (NII) of a leaf sample, whose results are shown in Table 4 for the Celeste variety.

Table 4. Nutritional diagnosis for corn of the Celeste variety with five fertilization doses using the diagnosis and recommendation integrated system (DRIS).

	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B	NII
					Control						
CN	1.46	0.29	2.08	0.56	0.26	163.8	41.73	16.45	9.18	16.3	149.5
DBI	-362	-12.6	-70.6	56	64.7	175.4	16.5	-43.7	42.2	283.6	
ONR	N> K> Zn> P> Mn> Ca> Cu> Mg> Fe> B										
					Treatment one: producer dose						
CN	2.08	0.32	2.24	0.45	0.19	188.5	61.9	17.23	10	111.3	1791.5
DBI	-159	-223	-186	-307	-382	78.2	177.7	-456	197.6	3051	
ONR	Zn> Mg> Ca> P> N> K> Fe> Mn> Cu> B										
					Treatment two: 0.5 of the optimal doses						
CN	1.94	0.32	2.12	0.51	0.23	146.3	58.9	19.93	9.85	61.39	612.7
DBI	-396	-117	-170	-111	-126	0	105.7	-142	109	1460	
ONR	N> Zn> K> Mg> P> Ca> Fe> Mn> Cu> B										
					Treatment three: optimal dose						
CN	2.15	0.32	2.28	0.54	0.2	173.7	72	19.08	9.7	72.66	711.5
DBI	-396	-157	-161	-127	-233	52.7	131.9	-236	113.9	1723	
ONR	N> Zn> K> P> Ca> Mg> Fe> Mn> Cu> B										
					Treatment four: 1.5 of the optimal doses						
CN	2.06	0.3	2.28	0.47	0.21	148.4	69.65	21.95	9.65	136.3	362.4
DBI	-663	-337	-251	-355	-410	-139	192.6	-351	226.8	3449	
ONR	N> Zn> K> P> Ca> Mg> Fe> Mn> Cu> B										

CN= concentration in the leaf; DBI= DRIS index; NII= nutritional imbalance index; ONR= order of nutritional requirement; red color= deficient nutrients; black color= balanced nutrients.

The results indicated that the DRIS diagnosis classifies N, Zn, P, K, Ca and Mg as deficient in all treatments. On the other hand, Mn, Fe, Cu and B were classified in a normal range. The T_4 treatment (1.5 of the optimal dose) was the one that had the highest number of deficient nutrients. The control, on the other hand, was the one that had less deficient nutrients, N, K and P were deficient in this treatment. The remaining treatments T_1 (producer dose), T_2 (0.5 of the optimal dose) and T_3 (optimal dose) had deficiencies of N, K, P, Zn, Ca, Mg and Fe. In the case of Mn, Cu and B, they were present in normal concentrations.

For its part, the Estrella variety whose results are shown in Table 5, Mg was in a normal range except in the T_4 treatment (1.5 of the optimal dose), where it was below normal. K was classified as deficient in the treatments T_1 (producer dose), T_2 (0.5 of the optimal dose) and T_4 (1.5 of the optimal dose). Deficiencies of N, K and P are recorded for the control, while in the other treatments, deficient levels of N, P, K, Zn, Mg, Ca and Fe are reported. Nutrients such as Mn, Cu and B were at concentrations of sufficiency in all treatments. Although the soil showed high levels of P, K, Ca, Mg and B, the DRIS indicated that the plant maintained medium and low values for these nutrients.

Table 5. Nutritional diagnosis in corn of the Estrella variety with five fertilization doses using the diagnosis and recommendation integrated system (DRIS).

	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B	NII
						Control					
CN	1.35	0.26	1.72	0.58	0.26	135.9	44.65	18.13	7.3	25.16	239
KBI	-421	-62.2	-160	70.1	57.5	99.7	43.1	7.4	30.4	574	
ONR	N> K> P> Zn> Cu> Mn> Mg> Ca> Fe> B										
						Treatment one: producer dose					
CN	2.03	0.28	1.31	0.58	0.32	163.9	59.53	20.28	10	133.1	1491.2
KBI	-666	-372	-628	-218	-128	-54.8	190.6	-324	230.4	3333	
ONR	N> K> P> Zn> Ca> Mg> Fe> Mn> Cu> B										
						Treatment two: 0.5 of the optimal doses					
CN	1.76	0.28	1.4	0.57	0.29	133.4	50.13	16.55	11.23	147.5	1503.6
KBI	-857	-378	-542	-240	-209	-193	224.2	-586	275.4	4009	
ONR	N> Zn> K> P> Ca> Mg> Fe> Mn> Cu> B										
						Treatment three: optimal dose					
CN	2	0.29	1.72	0.52	0.27	168.3	60.35	17.78	9.58	178.1	1844.8
KBI	-865	-463	-470	-398	-336	-115	239.4	-683	304.4	4631	
ONR	N> Zn> K> P> Ca> Mg> Fe> Mn> Cu> B										
						Treatment four: 1.5 of the optimal doses					
CN	1.83	0.25	1.46	0.53	0.23	143.2	71.35	20.8	10.73	186.2	1787.2
KBI	-986	-589	-633	-394	-474	-229	263.3	-499	321.9	5006	
ONR	N> K> P> Zn> Mg> Ca> Fe> Mn> Cu> B										

CN= concentration in the leaf; DBI= DRIS index; NII= nutritional imbalance index; ONR= order of nutritional requirement; red color= deficient nutrients; black color= balanced nutrients.

Relationship of the results of soil fertility and foliar diagnosis

The three methodologies of interpretation of foliar analysis agree that the most deficient nutrients were N and Zn in all treatments in both varieties, which coincide in their level of deficiency determined in the soil. The deficiency of N in all treatments is mainly because it is the nutrient most required by the crop and is also easily lost from the soil, so it was not enough to cover the demand of the crop. According to Below (2010), N most often limits the growth and yield of corn, because plants require relatively large amounts of N (1.5 to 3.5% of dry weight of the plant), and this is more easily lost by different processes. The low contents of Zn are explained due to the high concentration of P in the soil, an element that reacts by retaining it and generating its deficiency in plants (Adriano and Murphy, 1970).

For their part, Mg, Mn and Cu fluctuated between the range of deficiency and normal in the three methodologies, indirectly expressing the low concentrations. In the DRIS methodology, P, K and Fe were classified as deficient, while in Kenworthy and DOP, these nutrients were present in a normal concentration. Except for B in the DRIS protocol. These methodologies indicated that Ca and B were in excess.

According to the Kenworthy diagnosis, the treatment that had the most nutritional deficiencies in both varieties was T_4, with the T_2 treatment being the one that reported a better nutritional balance in the Estrella variety. According to the DRIS methodology, the treatment with fewer nutrient deficit levels was the control in both varieties; the greatest deficiencies were recorded in the T_4 treatment for the Celeste variety. On the other hand, the DOP diagnosis indicates that for the celeste variety all treatments had deficient levels of nutrients, while in the Estrella variety, the T_2 treatment was the treatment with fewer deficient levels and the T_4 treatment with greater nutritional deficiencies.

The deficiency of micronutrients can be attributed to the very high concentration of P in the soil. An excess of P interacts negatively with most micronutrients (Fe, Mn, Zn and Cu), either by the formation of precipitates in the soil or by metabolic processes in plants that prevent the translocation of nutrients from the root to the rest of the parts of the plant, referred by authors such as Brown and Tiffin (1962); Verma and Minhas (1987); James *et al*. (1995); Zhu *et al*. (2002); Zhang *et al*. (2015). Mechanisms that explain the reduction of Fe by application of P may be the inhibition of the absorption of Fe by the roots, inhibition of the transport of Fe from the roots to the shoots, and the internal immobilization of Fe in the plant (Ayued, 1970; Elliott and Lauchli, 1985; Moraghan and Mascagni, 1991; Fageria, 2001).

Regarding P and K, in the soil analysis, these were classified as very high, which explains what was obtained in the diagnostic methodologies of Kenworthy and DOP, which center these nutrients in a normal concentration. On the other hand, the contents of Ca and B in the soil were classified as very high. When comparing this classification with the results of the three methodologies where, as in the soil, they were classified as excessive, a great correlation can be observed between the nutritional levels of the soil and those shown by the plant. An excess of Ca can cause K deficiency motivated by insufficient absorption of this, due to Ca-K antagonism, it can induce ferric chlorosis and immobilize zinc, copper and phosphorus, causing the deficiency of these elements. Like K, high levels of Ca can cause important antagonisms with P and Mg.

Conclusions

The diagnosis determined the soil as clayey, with neutral pH, very low in Cu, low in Fe and Mn, medium in N, Zn and CEC, high in organic matter and very high in P, K, Ca, Mg and B. The three foliar interpretation methodologies determined different deficiencies and ONRs, in the same variety and between treatments. However, in the three methodologies it was found that the nutrients N and Zn were the most deficient, while Ca and B were present at high levels. For the celeste variety, the three methodologies coincided in determining N, Mg, Mn, and Zn as deficient. While in the estrella variety, N and Zn were diagnosed as deficient, while the other elements did not coincide.

The diagnostic methods Kenworthy balance and DOP indices agreed that N, Mg, Mn, and Zn were the most deficient in the celeste variety, while in the estrella variety, N, Mn, Zn, and Cu were diagnosed as the most deficient.

Foliar diagnosis using Kenworthy balance and DOP indices had a positive correlation between the high concentration of Ca and B in the soil in both corn varieties, while Mn and Cu were low in soil and foliage. While the elements P, K Ca, Mg and Zn had no correlation since in the soil they were medium and high and in the foliage they were different. For the DRIS diagnosis, medium or sufficient to high levels of Ca, Mg and B were determined both in the soil and in the plant. Finally, the concentration of Cu in the soil and plant was low, while that of B was high.

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