Revista Mexicana de Ciencias Agrícolas
REMEXCA

DOI: https://doi.org/10.29312/remexca.v17i3.4075

Article

Optimal fertilization in rainfed corn regarding nutrient removal and soil diagnosis in small plots

---

René García-Martínez[1,§]
Eduar Antonio González-Félix[1]
Julio César Ayllón-Benítez[2]
Jesús García-Urbina[1]
Hotón Sánchez-Aguilar[1]

1 Tecnológico Nacional de México-TES Valle de Bravo-División de Ingeniería en Forestal. Carretera Federal Valle de Bravo km 30, Ejido San Antonio Laguna, Valle de Bravo, Estado de México, México. CP. 51200.

2 Tecnológico Nacional de México-TES Valle de Bravo-División de Licenciatura en Administración. Carretera Federal Valle de Bravo km 30, Ejido San Antonio Laguna, Valle de Bravo, Estado de México, México. CP. 51200.

Autor para correspondencia: rgm1117@gmail.com.

Abstract

In the south of the State of Mexico, Mexico, small corn producers obtain low yields (<5 Mg ha^{-1}) due to deficiencies in nutrition management. The research aimed to determine the fertilization dose for small rainfed corn plots, considering the condition of soil fertility and nutrient extraction by grain and stover. The research was conducted in Villa de Allende, State of Mexico, in two plots with different fertilization management. Plot A received 1 t of bovine manure compost and plot B received 30 kg of a urea + triple 17 (N-P-K) mixture. Based on soil fertility diagnosis and nutrient removal by grain and stover, fertilization doses were defined. In both plots, OM and N contents were low and Fe levels were adequate. In plot A, the soil presented high levels of P, K, Ca and Mg. The grain and stover extracted high amounts of N and K. In plot A, the need for fertilizers was concentrated on N, Fe and Zn, whereas in plot B, it was N, P, K, Ca, Mg, Fe and Zn. This generated a reduction in the need for fertilizers; in the first case, it represented a 48% saving in costs. This approach contributes to improving productivity, reducing costs and reducing environmental impact in small-scale agriculture.

Palabras clave:

Zea mays, corn nutrition, corn production, fertilization costs, soil fertility.

Introduction

Corn (*Zea mays* L.) is a staple cereal for the diet of Mexican rural families because it ensures their nutritional sustenance, and by selling surpluses, they obtain resources for other products, thereby strengthening food security (Damián-Huato *et al*., 2016).

Between 2012 and 2021, the average global corn production was 1 088.54 million tonnes, which was mostly concentrated in three countries, which contribute 63% of the total (FAOSTAT, 2023): the United States of America (32.7%), China (22.7%) and Brazil (7.85%).

Despite the importance of corn as the main food crop and the one with the largest planted area in Mexico, with 6.5 million hectares planted and an average yield of 3.7 t ha^{-1} (SIAP, 2025), there is a lag in the study of soil fertility and the generation of public policy that supports production (Vega-Álvarez *et al*., 2022).

In addition, problems such as climate change and the planting methods used affect the harvest and, therefore, the product's quality and the yields obtained (Garizurieta-Bernabe and García-Sánchez, 2024).

In particular, rainfed corn is much more susceptible to climate variability and change because it depends entirely on precipitation and temperature, which in the long term, can put the crop's productivity at risk (López-Hernández *et al*., 2025).

Nutrition management conditions corn crop yield. For instance, using fertilizers combined with improved seeds managed to increase grain yields in low-productivity regions of Mexico (Cadet-Díaz and Guerrero-Escobar, 2018).

The application of fertilizers is a main component of this crop's production process and is characterized by the application of high doses of nitrogen, reduced application of phosphorus and insignificant use of potassium (Flores-Sánchez *et al*., 2019), without using soil and plant nutritional diagnostic tools.

In crop fertilization plans, the amount of nutrients removed by harvest must be returned to the soil to maintain growth and productivity (Fernández-Escobar *et al*., 2015). It is necessary to quantify nutrient availability in the soil and estimate the amount extracted by the plant at the plot level.

As background, Martínez-Gutiérrez *et al*. (2022) conducted studies in the High Valleys of the State of Mexico and estimated that the macronutrient demand (kg ha^{-1}) to harvest 12.3 t ha^{-1} of corn was as follows: 292.3 of N, 87.2 of P, 238.1 of K, 66.2 of Ca and 47.8 of Mg; for its part, the micronutrient demand (g ha^{-1}) was as follows: 201 of Cu, 586.4 of Mn, 375.6 of Zn and 115.6 of B. This ensures sustainable soil management, thereby optimizing production.

Nutritional diagnostic studies in corn report deficiencies of N, Zn, Mg and Mn in corn plots located in Texcoco, State of Mexico (Pacheco-Sangerman *et al*., 2022).

The objective of the research was to determine the fertilization dose for rainfed corn plots under different fertilization management by applying diagnostic tools of soil fertility and nutrient removal by grain and stover.

Materials and methods

The study was conducted in Loma de San Pablo, Villa de Allende, State of Mexico (2 657 m), with a temperate subhumid climate and average annual rainfall of 1 000 mm (June-October), Andosol umbric soils and pine, oak and oyamel vegetation (INEGI, 2023).

The work was carried out on two plots, where hybrid corn (Hippopotamus Asgrow®) was planted under rainfed conditions. Plot A (0.44 ha) received 1 t of bovine manure compost containing the following concentration: N= 1.24%, P= 0.4%, K= 1.6%, Ca= 2.6%, Mg= 0.87%, S= 1.3%, Fe= 1.8%, Cu= 34 ppm and Zn= 137 ppm.

Plot B (0.23 ha) received 30 kg of mineral fertilizer (15 kg urea + 15 kg triple 17 N-P-K).

DOI: https://doi.org/10.29312/remexca.v17i3.4075

The amount (kg ha^{-1}) of manure applied contributed N (28.2), P (9.1), K (36.4), Ca (59.1), Mg (19.8), S (29.5), Fe (40.9), Cu (0.07) and Zn (0.31); in contrast, the contribution of the mineral fertilizer was (kg ha^{-1}) 41.1 of N, 4.8 of P, and 9.2 of K. Historically, plot A has been fertilized with bovine compost, whereas, in plot B, mineral sources have been applied.

The sowing was carried out in May and the harvest in October 2023. The approximate grain yield was 11 Mg ha^{-1} and 10 t ha^{-1} of stover in the study plots.

In October 2023, composite samples of grain (250 g) and stover (500 g) were obtained per plot and sent to the Soil Fertility and Environmental Chemistry Laboratory of the College of Postgraduates for analysis.

N was determined by the semimicro-Kjeldahl method (Sáez-Plaza *et al*., 2013); K, Ca, Mg, Fe and Zn were determined by digestion with HNO_3-$HClO_4$ and quantification by atomic absorption spectrophotometry (Tan, 1996); P was determined by the vanadomolybdate method (Burns and Hutsby, 1986). These results were used to estimate the nutrient removal by grain and stover.

The soil fertility diagnosis was carried out with 10 (plot A) and 15 (plot B) subsamples (0-20 cm deep), generating composite samples of 500 g per plot. In agricultural systems where the soil is homogenized by tillage, simple samples collected from various points of the plots to form composite samples are a widely applied soil sampling technique (Rocco *et al*., 2016). The average fertility of a plot is determined by analyzing a composite soil sample, without requiring additional statistical data (Guarçoni *et al*., 2017).

The following properties were determined in the soil samples: pH (2:1 water-to-soil ratio; Weil and Brady, 2017), electrical conductivity (EC) (Tan, 1996), organic matter (Sleutel *et al*., 2007), N (Sáez-Plaza *et al*., 2013), P (Olsen *et al*., 1954), exchangeable cations (Havlin *et al*., 2016) and micronutrients (Tan, 1996).

The results were compared with NOM-021-RECNAT-2000 (SEMARNAT, 2002) and reference literature (Osman, 2013; Havlin *et al*., 2016; Weil and Brady, 2017).

Nutrient extraction was estimated as the product of dry matter and nutrient concentration (Martínez-Gutiérrez *et al*., 2022). The fertilization dose was calculated using the restitution method, taking into account soil availability and target yield (Conde-Delgado *et al*., 2018; Maldonado *et al*., 2001). According to the level of sufficiency (Havlin *et al*., 2016), nutrients at high levels were not applied; for those at medium levels, the amount extracted was replaced; for those at low levels, an additional 20% of fertilizer was added.

The cost of the compost/natural/fertilizers was determined according to the needs of each plot and considering the price of the materials in the local market.

Results and discussion

The higher values of EC, P, K, Ca, Mg, Fe and Zn observed in plot A were related to the frequent application of cow manure in the production of the crop (Table 1).

Table 1. Diagnosis of soil fertility in rainfed corn plots in Loma de San Pablo, Villa de Allende, State of Mexico.

Element	Plot A	Plot B
pH	6.5 (moderately acid)	6.1 (moderately acid)
EC (dS m^{-1})	0.13 (NSE)	0.05 (NSE)
OM (%)	4.1 (low)	4 (very low)
N (%)	0.19 (low)	0.2 (low)
P (ppm)	110 (high)	7 (medium)
K (cmol^{+} kg^{-1})	3 (high)	0.3 (medium)
Ca (cmol^{+} kg^{-1})	14.4 (high)	8.4 (medium)
Mg (cmol^{+} kg^{-1})	3.8 (high)	1.2 (low)

DOI: https://doi.org/10.29312/remexca.v17i3.4075

Element	Plot A	Plot B
Fe (ppm)	55 (appropriate)	32 (appropriate)
Zn (ppm)	8 (appropriate)	0.3 (deficient)

NSE= negligible salinity effects.

The soil pH values coincide with those obtained in agricultural plots in the study region, Valle de Bravo (pH= 6.3) and Villa de Allende (pH= 5.8), in the State of Mexico (García-Martínez *et al*., 2021).

This variable affects plant growth primarily through its influence on other soil properties, including nutrient availability, elemental toxicity, and microbial activity (Osman, 2013). In addition, nutrient availability is highest in the pH range of 5.5-6.5 (Porta *et al*., 2019), and both plots are within the established range.

Regarding the low OM content observed, it was related to agricultural land use, which differs from forest plantations, where OM values are reported in a range of 4.5 to 6.2% (García-Martínez *et al*., 2024).

OM plays a key role in crop nutrition; when it decomposes, it releases nutrients, which is why it is a source of essential elements such as N, P and K (Kasifah *et al*., 2025). In addition, OM fulfills physical functions in the soil such as improving aggregation, aeration and water movement, and reducing evaporation and thermal conductivity (Osman, 2013).

In this sense, in both plots, it is necessary to increase OM levels by applying organic fertilizers.

N is the mineral nutrient that plants require in greater quantities; therefore, in soils deficient in this element, plants do not develop properly (Taiz and Zeiger *et al*., 2015). Crops absorb N in the form of nitrate (NO_3^-) through their roots, and it depends on the concentration of N in the soil, water availability and metabolic activity of the roots (Sanders and White, 2023).

According to Havlin *et al*. (2016), total N content in mineral soils ranges from 0.02 to 0.5% and is positively correlated with OM content. Due to the low N levels in the soil of the plots studied, nitrogen fertilizers must be applied to reach adequate N levels that favor the development of corn plants.

In plot A, the application of manure in each production cycle has increased P concentration. P is relatively immobile in the soil, and its movement occurs mainly through diffusion over short distances in the soil solution to the roots of the plants (Kasifah *et al*., 2025).

In soils of humid and tropical regions, extractable P content is lower than in arid and semiarid areas; to ensure the availability of this element to plants, it is advisable to apply mineral or organic fertilizers (Havlin *et al*., 2016). In the long term, the use of organic fertilizers rapidly increases the P fractions available in the soil and slowly regulates pH and phosphatase (Zhang *et al*., 2021).

In the soil of plot A, there was 10 times less K content than in plot B. In agricultural plots in the study region, values of 2.23 to 3.88 $cmol^+ kg^{-1}$ K are reported (García-Martínez *et al*., 2021). Although the total K content in the soil may exceed the needs of plants during the growing season, only a part is available to them (Havlin *et al*., 2016) and in the corn crop, it is the second element that is most extracted by the grain during its growth (Martínez-Gutiérrez *et al*., 2022).

The Ca content in plot A was 1.7 times higher than in plot B. Ca moves in the soil mainly by mass flow, and its availability can be significantly affected by the level of soil moisture (Benton, 2012), particularly under rainfed conditions.

The supply of Ca to the soil solution is possible because this element is found in calcium-containing minerals, Ca complexes and soil organic matter, as well as Ca retained by cation exchange in clay and organic colloids (Weil and Brady, 2017).

The higher Fe content in plot A was associated with the constant application of organic fertilizers. The application of compost and other organic fertilizers can improve iron availability by chelating Fe, thereby increasing its availability (Yang *et al*., 2024).

DOI: https://doi.org/10.29312/remexca.v17i3.4075

The concentration and nutrient removal by grain differed between plots (Table 2). In the present study, the order of nutrient removal by grain in plot A was N> K> P> Mg> Ca> Zn> Fe and in plot B, it was N> K> P> Mg> Ca> Fe> Zn.

For corn grain, Martínez-Gutiérrez *et al*. (2022) report data for the removal of N (14.3 kg Mg^{-1}), K (2.9 kg Mg^{-1}), P (2.3 kg Mg^{-1}), Mg (1 kg Mg^{-1}), Ca (0.1 kg Mg^{-1}) and Zn (16.5 g Mg^{-1}). According to Fornari *et al*. (2020), N and K are the nutrients that corn plants require in greater quantities.

Table 2. Concentration and removal of nutrients in rainfed corn grain (11 t ha^{-1}) in Loma de San Pablo, Villa de Allende, State of Mexico.

Element	Plot A		Plot B	
	Concentration (%)	Removal (kg Mg^{-1})	Concentration (%)	Removal (kg Mg^{-1})
N	1.7	17	1.27	12.7
P	0.88	8.8	0.68	6.8
K	0.94	9.4	0.69	6.9
Ca	0.07	0.7	0.07	0.7
Mg	0.16	1.6	0.1	1
Fe	0.0056	0.056	0.0067	0.067
Zn	0.0061	0.061	0.004	0.04

In stover, the high demand for N, K, and Ca was also evident (Table 3). In plot A, where compost was applied, the removal of these elements was greater.

Table 3. Concentration and nutrient removal in rainfed corn stover (10 t ha^{-1}) in Loma de San Pablo, Villa de Allende, State of Mexico.

Element	Plot A		Plot B	
	Concentration (%)	Removal (kg Mg^{-1})	Concentration (%)	Removal (kg Mg^{-1})
N	0.99	9.9	0.65	6.5
P	0.08	0.8	0.07	0.7
K	0.92	9.2	0.73	7.3
Ca	1.02	10	0.73	7.3
Mg	0.13	1.3	0.14	1.4
Fe	0.19	1.9	0.18	1.8
Zn	0.0019	0.019	0.0018	0.018

Fertilization dose and fertilizer cost

Nutrient demand was calculated for a target yield of 11.5 Mg ha^{-1} of grain and 10 Mg ha^{-1} of stover. In plot A, the demand (kg ha^{-1}) was as follows: N (294.5), P (109.2), K (200.1), Ca (110), Mg (31.4), Fe (19.6) and Zn (0.89). In plot B, the demand (kg ha^{-1}) was as follows: N (208.8), P (85.2), K (152.4), Ca (81), Mg (25.5), Fe (18.8) and Zn (0.7).

The soil fertility diagnosis was used to define the amount of each nutrient to be applied. In plot A, the needs (kg ha^{-1}) were N (353.4), Fe (19.6) and Zn (0.89). In plot B, the requirements were N (250.6), P (85.2), K (152.4), Ca (81), Mg (30.6), Fe (18.8) and Zn (0.84). This information was used to select the fertilizer sources and amounts to be used in each plot (Table 4).

Table 4. Source and estimated dose of mineral fertilizer for rainfed corn in Loma de San Pablo, Villa de Allende, State of Mexico.

Fertilizer	Plot A (kg ha^{-1})	Plot B (kg ha^{-1})
Urea	768	139

Fertilizer	Plot A (kg ha^{-1})	Plot B (kg ha^{-1})
Triple 18	0	847
Calcium nitrate	0	221.2
Magnesium sulfate	0	191.25
Iron sulfate	122.5	117.5
Zinc sulfate	2.5	2.3

The cost of fertilization per hectare was $22 884.50 in plot A and $44 166.10 in plot B. In the first, urea accounted for 80% of the total cost, whereas in the second, triple 18 (N-P-K) contributed 54%.

The differences reflect variation in initial soil fertility and nutrient removal by the harvest, which is consistent with Havlin *et al*. (2016), who emphasize that efficient management must consider both factors. Also, Fageria (2009); Fornari *et al*. (2020) point out that N and K are the most limiting nutrients in corn, so their supply must be ensured.

From an economic and environmental perspective, manure management in plot A represented an advantage because the total cost of fertilization was reduced by 40% compared to plot B. This is consistent with Yang *et al*. (2024), who document that organic amendments improve soil fertility and reduce dependence on synthetic inputs, in addition to improving the availability of micronutrients such as Fe and Zn through chelation processes.

Fertilization constitutes the main component of the cost of corn production in the State of Mexico (63% in high-potential packages), which highlights the need to optimize its application through fertility diagnostics and efficient nutrient management (Amaya-Pérez *et al*., 2025).

The technological packages of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP, by its Spanish acronym), by establishing standard proportions (105N-92P-90K), can cause nutritional excesses or deficiencies by not considering soil variability. To improve technology adoption, financial support and economic incentives are required to facilitate access to mineral fertilizers and increase the productivity of small producers, since a 10% increase in government support could increase national corn production (Guerrero *et al*., 2023; Ayllon-Benítez and Cardoso-Jiménez, 2025).

Conclusions

The application of organic fertilizer in plot A generated better soil fertility condition, particularly in the content of P, K, Ca, Mg, Fe and Zn. With both the application of manure and mineral fertilizer, the nutrients that were removed in greater quantities, by grain and stover, were N and K.

Plot A, where bovine manure was applied, did not require the application of P, K, Ca and Mg; this situation represented a 43% reduction in fertilizer costs; however, it demanded 41% more N than the plot where mineral fertilizer was applied.

To guarantee the economic and environmental sustainability of the crop, it is crucial to move towards specific fertilization strategies based on soil analysis and practices adapted to the local conditions of the region, particularly in small producers’ plots, where studies are scarce.

Bibliography

1 Amaya-Pérez, F. S.; Martínez-Damián, M. A. y Sangerman-Jarquín, D. M. 2025. Análisis de paquetes tecnológicos para la producción de maíz en el Estado de México. Revista Mexicana de Ciencias Agrícolas. 16(4):1-9. Doi: 10.29312/remexca.v16i4.3583.

2 Ayllon-Benítez, J. C. y Cardoso-Jiménez, D. 2025. Análisis económico actual del maíz en México, periodo 1981-2022. Revista Mexicana de Ciencias Agrícolas. 16(4):1-11. Doi: 10.29312/remexca.v16i4.3701.

3 Benton, J. J. 2012. Plant nutrition and soil fertility manual. 2nd Ed. CRC press: Florida, USA. 273 p.

4 Burns, I. G. and Hutsby, W. 1986. Critical comparison of the vanadomolybdate and the molybdenum blue methods for the analysis of phosphate in plant sap. Communications in Soil Science and Plant Analysis. 17(8):839-852.

5 Cadet-Díaz, S. and Guerrero-Escobar, S. 2018. Factores que determinan los rendimientos de la producción de maíz en México: evidencia del censo agropecuario 2007. Agricultura, sociedad y desarrollo. 15(3):311-337. Doi: 10.22231/asyd.v15i3.848.

6 Conde-Delgado, L. M.; Alia-Tejacal, I.; Valdez-Aguilar, L. A.; Ariza-Flores, R.; Juárez-López, P.; Pérez-Arias, G. A.; Pelayo-Saldivar, C.; León-Sánchez, F. D. y Martínez-Morales, A. 2018. La dosis de fertilización afecta el rendimiento y calidad en limón Persa (*Citrus latifolia* Tan.). Acta Agrícola y Pecuaria. 4(1):1-9. Doi: https://doi.org/10.30973/aap/2018.4.1/1.

7 Damián-Huato, M. A.; Romero-Arenas, O.; Sangerman-Jarquín, D. M.; Reyes-Muro, L.; Parraguirre-Lezama, C. y Orozco-Cirilo, S. 2016. Maíz, potencial productivo y seguridad alimentaria: el caso de San Nicolás de Los Ranchos, Puebla-México. Nova Scientia. 8(16):352-370. https://www.scielo.org.mx/pdf/ns/v8n16/2007-0705-ns-8-16-00352.pdf.

8 Fageria, N. K. 2009. The use of nutrient in crop plants. CRC Press: Florida, USA. 31-163 pp. doi.org/10.1201/9781420075113.

9 FAOSTAT. 2023. FAOSTAT-Statistical Databases. Organización de las Naciones Unidas para la Agricultura y la Alimentación. https://www.fao.org/faostat/es/#data/QCL.

10 Fernández-Escobar, R.; Sánchez-Zamora, M. A.; García-Novelo, J. M. y Molina-Soria, C. 2015. Nutrient removal from olive trees by fruit yield and pruning. HortScience. 50(3):474-478. Doi: 10.21273/HORTSCI.50.3.474.

11 Flores-Sánchez, D.; Navarro-Garza, H. y Pérez-Olvera, M. A. 2019. Balance de nutrientes en sistemas de cultivo de maíz y retos para la sustentabilidad. Ingeniería Agrícola y Biosistemas. 11(2):97-109. Doi: 10.5154/r.inagbi.2017.11.017.

12 Fornari, A. J.; Caires, E. F.; Bini, A. R.; Haliski, A.; Tzaskos, L. and Joris, H. A. W. 2020. Nitrogen fertilization and potassium requirement for cereal crops under a continuous no-till system. Pedosphere. 30(6):747-758. Doi: 10.1016/S1002-0160(20)60035-2.

13 García-Martínez, R.; Cortés-Flores, J. I.; López-Jiménez, A.; Etchevers-Barra, J. D.; Carrillo-Salazar, J. A. y Saucedo-Veloz, C. 2021. Rendimiento, calidad y comportamiento poscosecha de frutos de aguacate ‘Hass’ de huertos con diferente fertilización. Revista Mexicana de Ciencias Agrícolas. 12(2):205-2018. Doi: 10.29312/remexca.v12i2.2232.

14 García-Martínez, R.; Hernández-Soto, F. N.; Emeterio-Moreno, J. y Colín-Velázquez, M. K. 2024. Diferencias en la fertilidad del suelo en cuatro plantaciones forestales comerciales de pino en Amanalco, Estado de México. Revista Mexicana de Ciencias Forestales. 15(85):150-170. Doi: 10.29298/rmcf.v15i85.1462.

15 Garizurieta-Bernabe, J. y García-Sánchez, E. 2024. Tecnificación del cultivo de maíz como estrategia para el desarrollo regional de Veracruz. Agricultura, Sociedad y Desarrollo. 21(3):348-368. Doi: 10.22231/asyd.v21i3.1609.

16 Guarçoni, M. A.; Álvarez, V. V. H. y Moreira, S. F. 2017. Fundamentação teórica dos sistemas de amostragem de solo de acordo com a variabilidade de características químicas. Terra Latinoamericana. 35(4):343-352. https://doi.org/10.28940/terra.v35i4.172.

17 Guerrero, P. L.; Leos, J. A.; Palacio, V. H. y Ocampo, J. G. 2023. Precios de garantía y sus efectos sobre las pequeñas explotaciones agrícolas de México. Agricultura, Sociedad y Desarrollo. 20(2):248-265. Doi: 10.22231/asyd.v20i2.1565.

18 Havlin, J. L.; Tisdale, S. L.; Nelson, W. L. and Beaton, J. D. 2016. Soil fertility and fertilizers. 8th Ed. Pearson. Noida, Uttar Pradesh, India. 528 p.

19 INEGI. 2023. Anuario estadístico y geográfico de los Estados Unidos Mexicanos. Instituto Nacional de Estadística y Geografía. 752 p.

DOI: https://doi.org/10.29312/remexca.v17i3.4075

20 Kasifah, K.; Bilad, M. R. and Baja, S. 2025. Application of rice straw and corn straw compost for enhancing phosphorus availability in ultisol and corn plants. Cleaner Waste Systems. 10(100213):1-8. Doi: 10.1016/j.clwas.2025.100213.

21 López-Hernández, N. A.; Martínez-Sifuentes, A. R.; Halecki, W.; Trucíos-Caciano, R. and Rodríguez-Moreno, V. M. 2025. An assessment of the impact of climate change on maize production in Northern Mexico. Atmosphere. 16(4):1-21. https://doi.org/10.3390/atmos16040455.

22 Martínez-Gutiérrez, A.; Zamudio-González, B.; Cardoso-Galvão, J. C.; Espinosa-Calderón, A.; Tadeo-Robledo, M.; Vázquez-Alarcón, A. and Villegas-Aparicio. 2022. Efecto de aminoácidos foliares en la extracción y remoción de nutrientes en maíz. Revista Fitotecnia Mexicana. 45(2):173-181. Doi: 10.35196/rfm.2022.2.173.

23 Olsen, S. R.; Cole, C. V; Watanabe, F. S. and Dean, L. A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular 939. Washington, United States of America. 19 p.

24 Osman, K. T. 2013. Soils. Principles, properties and management. Springer. London, LND, England. 271 p.

25 Pacheco-Sangerman, F.; Prado-Hernández, V.; Maldonado-Torres, R. y Robledo-Santoyo, E. 2022. Diagnóstico nutrimental del suelo y foliar en el cultivo de maíz. Revista Mexicana de Ciencias Agrícolas. 13(6):1079-1090. Doi: https://doi.org/10.29312/remexca.v13i6.2691.

26 Porta, C. J.; López-Acevedo, M. y Poch, R. M. 2019. Edafología. Uso y protección de suelos. 4ª Ed. Madrid, MD, España. 619 p.

27 Rocco, C.; Duro, I.; Rosa, S.; Fagnano, M.; Fiorentino, N.; Vetromile, A. and Adamo, P. 2016. Composite vs. discrete soil sampling in assessing soil pollution of agricultural sites affected by solid waste disposal. Journal of Geochemical Exploration. 170:30-38. doi.org/10.1016/j.gexplo.2016.08.004.

28 Sáez-Plaza, P.; Navas, M. J.; Wybraniec, S.; Michalowski, T. and García-Asuero, A. G. 2013. An overview of the Kjeldahl method of nitrogen determination. Part II. Sample preparation, Working Scale. Instrumental Finish and Quality Medio Control. Critical Reviews in Analytical Chemistry. 43(4):224-272. Doi: 10.1080/10408347.2012.751787.

29 Sanders, Z. P. and White, C. M. 2023. Can nitrogen recommendations for corn production be improved through spatially explicit crediting of cover crops and soil organic matter? Smart Agricultural Technology. 6:100336. Doi: 10.1016/j.atech.2023.100336.

30 SEMARNAT. 2002. Secretaría de Medio Ambiente y Recursos Naturales. Norma Oficial Mexicana (NOM-021-RECNAT-2000), que establece las especificaciones de fertilidad, salinidad y clasificación de suelos. Estudios, muestreo y análisis. Diario Oficial de la Federación. 113-185 pp. https://www.ordenjuridico.gob.mx/Documentos/Federal/wo69255.pdf.

31 SIAP. 2025. Servicio de Información Agroalimentaria y Pesquera. Cierre de la producción agrícola. Anuario Estadístico de la Producción Agrícola. Maíz Grano. https://nube.agricultura.gob.mx/cierre-agricola/.

32 Sleutel, S.; Neve, S.; Singier, B. and Hofman, G. 2007. Quantification of organic carbon in soils: a comparison of methodologies and assessment of the carbon content of organic matter. Communications in Soil Science and Plant Analysis. 38(19-20):2647-2657. Doi: 10.1080/00103620701662877.

33 Taiz, L.; Zeiger, E.; Moller, I. M. and Murphy, A. S. 2015. Plant physiology and development. New York, United States of America. 756 p.

34 Tan, K. 1996. Soil sampling, preparation, and analysis. Marcel Dekker, Inc. New York, USA. 407 p.

35 Vega-Álvarez, I.; Flores-Sánchez, D.; Escalona-Maurice, M. J.; Castillo-González, F. y Jiménez-Velázquez, M. A. 2022. Tlaxcala, investigación en maíz nativo y mejorado: problemática, campos del conocimiento y nuevos retos. Revista Mexicana de Ciencias Agrícolas. 13(3):539-551. https://www.scielo.org.mx/pdf/remexca/v13n3/2007-0934-remexca-13-03-539.pdf.

36 Weil, R. R. and Brady, N. C. 2017. The nature and properties of soils. 15ta Ed. Pearson. Harlow, Essex, England. 1 104 p.

37 Yang, F.; He, B.; Dong, B. and Zhang, G. 2024. Film mulched ridge-furrow tillage improves the quality and fertility of dryland agricultural soil by enhancing soil organic carbon and nutrient stratification. Agricultural Water Management. 292(108686):1-9. https://doi.org/10.1016/j.agwat.2024.108686.

38 Zhang, Y.; Gao, W.; Luan, H.; Tang, J.; Li, R.; Li, M.; Zhang, H. and Huang, S. 2021. Long-term organic substitution management affects soil phosphorus speciation and reduces leaching in greenhouse vegetable production. Journal of Cleaner Production. 327(4):1-12. Doi: 10.1016/j.jclepro.2021.129464.

Revista Mexicana de Ciencias Agrícolas

DOI: https://doi.org/10.29312/remexca.v17i3.4075

Optimal fertilization in rainfed corn regarding nutrient removal and soil diagnosis in small plots

Journal Information
Journal ID (publisher-id): remexca
Title: Revista Mexicana de Ciencias Agrícolas
Abbreviated Title: Rev. Mex. Cienc. Agríc
ISSN (print): 2007-0934
ISSN (electronic): 2007-9934
Publisher: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias

Article/Issue Information
Date received: 01 February 2026
Date accepted: 01 April 2026
Publication date: 01 May 2026
Publication date: May-Jun 2026
Volume: 17
Issue: 3
Electronic Location Identifier: e4075
DOI: 10.29312/remexca.v17i3.4075

Categories

Subject: Article

Keywords:

Keywords:

corn nutrition
corn production
fertilization costs
soil fertility
Zea mays

Counts

Figures: 0
Tables: 4
Equations: 0
References: 38