



Advances in biology through agronomy, aquaculture, coastal and environmental sciences

— Volume II —

Leandri Argentel-Martínez
Ofelda Peñuelas-Rubio
Joe Luis Arias-Moscoso
Editors

Pantanal Editora

2026

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**Advances in biology through
agronomy, aquaculture, coastal and
environmental sciences**
Volume II



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Advances in Biology through Agronomy, Aquaculture, Coastal and Environmental Sciences, Volume II, is an e-book that continues the work of the first version (<https://editorapantanal.com.br/ebooks/2023/advances-in-biology-through-agronomy-aquaculture-coastal-and-environmental-sciences/ebook.pdf>), published in 2023 by Leandris Argente!-Martínez and Ofelda Peñuelas-Rubio.

Our e-book compiles 25 manuscripts that present scientific results and reviews based on biological aspects. All of them contribute to explaining the responses of living organisms to agricultural, aquaculture, and coastal ecosystems, as well as those facing fragility or threat of climate change. This e-book was edited by Leandris Argente!-Martínez, Ofelda Peñuelas-Rubio, and Joe Luis Arias-Mosc!so, members of the Consolidated Academic Group ITVAYA-CA-3.

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Agricultural gypsum with micronutrients in citrus cultivation

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Marco Antonio Gutierrez Coronado^{1*} 

Jorge Luis Virgen Velazquez¹ 

Martin Eduardo Osorio Perez¹ 

Jesus Martin Rey Icedo¹ 

ABSTRACT

Citrus production in the state of Sonora represents one of the most relevant and important sectors in the region, especially for oranges, lemons, grapefruits, and tangerines. Our soils are predominantly alkaline, with a pH of approximately 7.7, resulting in serious problems with the availability of micronutrients, specifically iron, followed by zinc, copper, and manganese. The use of agricultural gypsum in these soils helps improve their structure and induces temporary acidification, facilitating the absorption of these elements. Furthermore, the addition of humic and fulvic acids promotes the natural chelation of these minerals. This research involved the application of agricultural gypsum with micronutrients and humic and fulvic acids to orange, lemon, and mandarin trees in the soils of Yaqui Valley, Sonora, at two doses of this fertilizer formula: 25 and 50 kg per hectare. The results revealed more than a 30% increase in micronutrient accumulation and more than a 25% increase in fruit yield and quality.

Keywords: acidification, micronutrients, humic acids, fulvic acids, citrus.

INTRODUCTION

The agri-food sector is considered one of the most important for the global economy, and growing fruit is among its most profitable activities (Rinconada et al., 2022). In Mexico, the production and marketing of citrus fruits represents an attractive economic activity, both for the domestic and export markets. Among this group of fruits, oranges, lemons, tangerines, and grapefruits stand out. They are considered fruits of great importance because of their nutritional and health properties, including vitamin C, antioxidants, and pectin (Valencia; Duana, 2019).

Citrus fruits are moderate to large trees or shrubs belonging to the Rutaceae family. They have evergreen, simple, and generally oval or elliptical leaves. Their flowers are fragrant and have petals that are generally white or slightly tinged with shades of pink or purple. They produce fleshy, juicy fruits with

¹ Departamento de Biotecnología y Ciencias Alimentarias, Instituto Tecnológico de Sonora, Unidad Obregón, Campus Centro, 5 de febrero 818 sur. CP 85000, Cd. Obregón, Sonora, México.

*Corresponding author: mgutierrez@itson.edu.mx

thick rinds, containing numerous juice-filled vesicles, characterized by their high vitamin C content and acidic flavor.

According to the SIAP, 2023, Mexico ranks fourth globally as the largest producer of oranges, with a production of 4.8 million tons (MT). Veracruz, Tamaulipas, and Puebla are the main producing states, while Sonora ranks seventh, with a production of 165,475 tons (Lara et al., 2022).

With respect to lemon cultivation, Mexico ranks second globally, with a production of 3.1 MT, with Veracruz, Michoacán, and Colima standing out as the states with the highest production volume. Mexico is the third-largest producer of grapefruit worldwide, with 489,102 tons. In addition, mandarin production places Mexico 14th worldwide with more than 300,000 tons (SIAP, 2023).

Agricultural activities are negatively impacted by salinity problems and high levels of exchangeable sodium. One practice to recover degraded sodic soils and improve various physical soil properties is the application of agricultural gypsum (Trasviña et al., 2018).

Agricultural gypsum is a very soft mineral composed of calcium sulfate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and is used as a soil amendment and fertilizer because it provides calcium and sulfur. The percentage of calcium in agricultural gypsum ranges from 18 to 22%, while the sulfur content ranges from 16 to 18%.

The results obtained from the application of agricultural gypsum to soils consistently show increases in Ca^{2+} and SO_4^{2-} (Beltrán et al., 2019). Its application improves soil properties by displacing Na^+ and occupying these exchange sites with Ca^{2+} , resulting in the formation of Na_2SO_4 , which is leached. Consequently, excess salts are eliminated, and the pH is reduced (Zenteno et al., 2020).

This compound is considered an economically viable alternative for use as a fertilizer to meet sulfur requirements and address soils deficient in this nutrient. It is also an important source of calcium (Beltrán et al., 2019).

These micronutrients are elements that are required in small quantities. However, their absence or deficiency can negatively affect crop growth, health, and yield (Ronen, 2016). Iron (Fe): Fe is considered a highly important micronutrient for plant development. It is absorbed in ferrous form (Fe^{2+}) and in organic form. It is involved in physiological processes such as respiration, chlorophyll biosynthesis, and redox reactions (Santis-Santis et al., 2019). This element functions as a structural component and as an enzyme cofactor. It is not available in plants growing in saline and calcareous soils since Fe^{3+} is insoluble at neutral and high pH. Its deficiency causes a loss of green color in leaves, known as iron chlorosis (Puente-Ramírez et al., 2022).

Copper (Cu): Cu is an important element for plants and is required at low concentrations. It acts as a catalyst in oxidation–reduction reactions. It also plays important roles in respiration and photosynthesis, in addition to its participation in plant physiological processes such as protein metabolism, nitrogen fixation, and carbohydrate distribution (León-Morales; Sepúlveda-Jiménez, 2012). It is absorbed by plants in two different forms: as a divalent ion (Cu^{+2}) in well-aerated soils and as a monovalent ion (Cu^+) in moist soils with low oxygen concentrations. At concentrations higher than those

required by plants, it can produce toxic effects, such as inhibiting root and shoot growth (Villegas-Torres et al., 2015). Zinc (Zn): Zn is a very important element for plants and is absorbed as Zn^{2+} . Among its functions. Manganese (Mn) in the Earth's crust is found in the form of oxides, carbonates, and silicates. Its total content in the soil generally ranges from 200 to 3,000 $mg \cdot kg^{-1}$ and can be found in divalent, trivalent, or tetravalent forms. However, the more oxidized forms are less readily available to plants (Franco, 2023; Gomez et al., 2006).

The present study aimed to evaluate the effects of applying agricultural gypsum to soil supplemented with micronutrients (Fe, Cu, Zn and Mn) and humic and fulvic acids through nutrient analysis and physicochemical measurements to determine its effects on the physiological, productive and quality development of citrus crops.

MATERIALS AND METHODS

The experiment was conducted in a citrus orchard (block 902) in Yaqui Valley, Sonora, Mexico, during the spring–summer cycle of 2024. A completely randomized block design was used for the citrus crops, with five treatments and ten replicates per treatment.

The treatments (Table 1) were applied at different stages of the phenological development of each fruit tree.

- Orange: (1) flowering, (2) fruit set, (3) 50% of its final size (Figure 2).
- Lemon: (1) flowering, (2) fruit set, (3) 50% of its final size (Figure 1).
- Mandarin: (1) flowering, (2) fruit set, (3) fruit at 50% of its final size (Figure 3).

Table 1. Treatments to apply to fruit trees.

Treatments	Formulation
T1	Without treatment
T2	25 $kg \ ha^{-1}$ [agricultural plaster + Micronutrients (Fe, Cu, Zn y Mn)]
T3	50 $kg \ ha^{-1}$ [agricultural plaster + Micronutrients (Fe, Cu, Zn y Mn)]
T4	25 $kg \ ha^{-1}$ [agricultural plaster + Micronutrients (Fe, Cu, Zn y Mn) + fulvic/humic acids]
T5	50 $kg \ ha^{-1}$ [agricultural plaster + Micronutrients (Fe, Cu, Zn y Mn) + fulvic/humic acids]

VARIABLES EVALUATED AND EQUIPMENT USED

- Chlorophyll index, measured with a Minolta SPAD 502 instrument.
- Nutrient concentration in leaf tissue measured with a HACH DR-3900 spectrophotometer
- Number and weight of fruits, measured with a balance scale
- Yield, measured with a balance scale

- Polar and equatorial diameters of the fruit, measured with a caliper
- Juice percentage, measured with a juicer
- Total soluble solids (°Brix), measured with a refractometer
- Titratable acidity, measured by the percentage of citric acid by titration with NaOH and phenolphthalein as indicators
- Fruit firmness, measured with a penetrometer
- Shelf life (weight loss), measured with a balance scale

The sample consisted of groups of 10 fruits per treatment per block. All harvest and postharvest measurements were taken in the morning. An analysis of variance was performed, using the LSD test ($p \leq 0.05$), with the statistical program Statgraphics Plus 5.1.

RESULTS AND DISCUSSION

Lemon cultivation

The application of the treatments increased the chlorophyll concentration during most of the measurement weeks. Compared with the other treatments, treatments T4 and T5 resulted in the highest concentrations. Compared with T1, T4 significantly differed from the control, with increases of 6.23%, 6.05%, and 4.51% at weeks 4, 7, and 8, respectively. Similarly, compared with T1, T5 was significantly different, with an increase of 4.54% for week 8 (Figure 1).

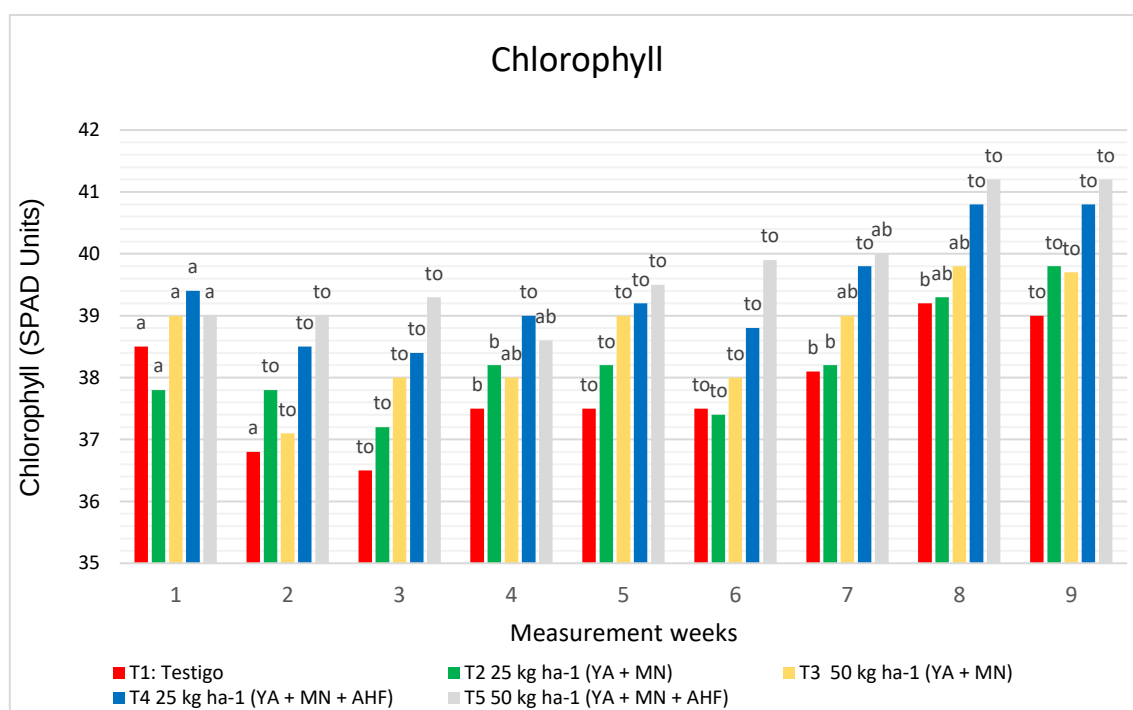


Figure 1. Chlorophyll concentration in lemon trees after application of agricultural gypsum supplemented with micronutrients.

With respect to the nutrient concentration of the leaf tissue, increases in macro- and micronutrients were detected (Table 2), with increases of up to 12.38% N, 12.28% P, 31.13% K, 24.43% Ca, 35.21% Mg, 17.27% Fe, 18% Cu, 6.66% Zn and 9.52% Mn, with treatments T3, T4 and T5 showing the greatest results.

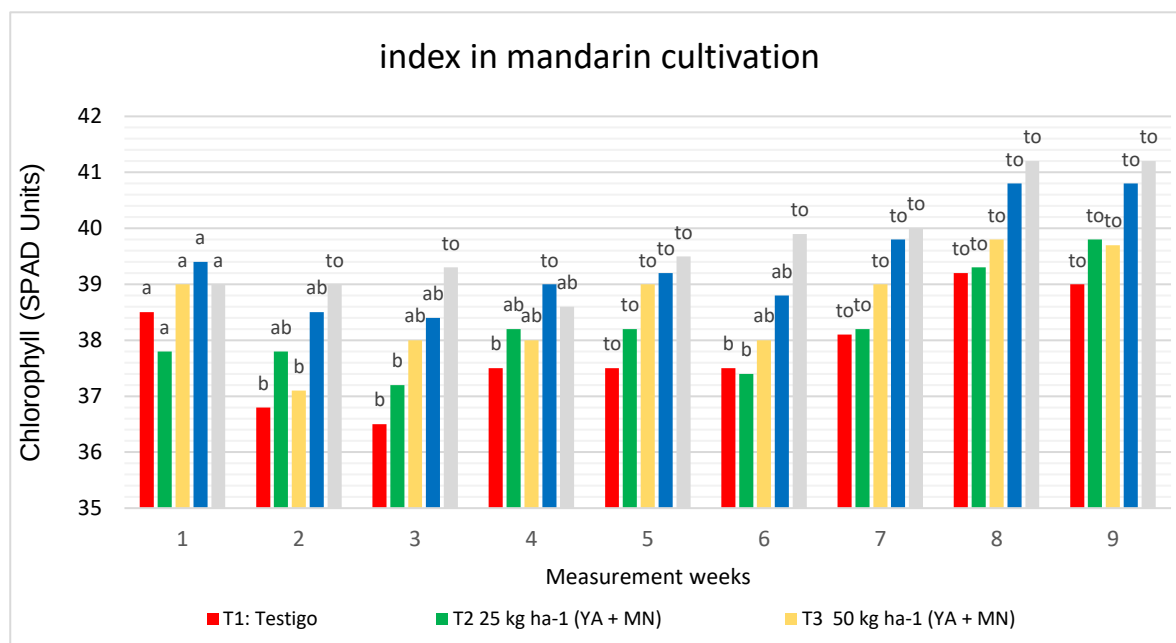


Figure 2. Chlorophyll concentration in mandarin trees after application of agricultural gypsum with micronutrients

Table 2. Nutrient concentration of leaf tissue in lemon trees after application of agricultural gypsum supplemented with micronutrients.

Cultivation stage	Treatments	N	P	K	AC	Mg	Faith	Cu	Mn	Zn
		%					ppm			
Start of flowering	T1	2.11	0.38	2.35	2.12	0.55	78	25	25	23
	T2	2.33	0.44	3.20	2.84	0.69	94	54	49	30
	T3	3.09	0.49	3.30	2.23	0.69	119	53	33	33
	T4	2.81	0.48	3.30	2.48	0.46	128	57	44	38
	T5	2.22	0.52	3.10	2.21	0.55	93	52	36	29
Fruit set	T1	2.40	0.89	2.70	2.72	0.95	99	31	38	34
	T2	3.03	1.05	3.40	2.96	0.91	122	43	48	39
	T3	2.89	1.10	3.20	3.11	1.08	125	36	44	40
	T4	2.39	1.36	3.30	3.16	1.01	145	43	40	46
	T5	2.54	1.35	2.94	2.81	0.99	108	41	42	49
Fruit formation	T1	2.64	0.58	1.62	2.10	0.64	154	23	30	25
	T2	2.88	0.64	1.94	2.55	0.79	184	29	34	30
	T3	3.18	0.73	1.99	2.84	0.80	193	28	33	37
	T4	3.29	0.81	2.40	2.83	0.79	195	30	35	39
	T5	2.75	0.99	1.88	2.80	0.88	196	33	40	38
Reference:		2.20-	0.10-	1.00-	1.50-	0.20-	50-	8-40	20-	50-
Plant Analysis Handbook		2.70	0.30	2.00	4.00	0.50	300		500	100

Tangerine cultivation

The application of the treatments increased the chlorophyll concentration during most of the measurement weeks (Figure 2). Compared with T1, T2, and T3, T4 and T5 presented the highest concentrations. Compared with the control treatment, treatment T4 resulted in a statistically significant difference, with an increase of 4.31% by week 4. Moreover, compared with T1, T5 showed statistically significant differences, with increases of 5.22%, 7.22%, 6.64%, and 5.91% for weeks 2, 3, 6, and 9, respectively.

With respect to the nutrient concentration of the leaf tissue, increases in macro- and micronutrients were detected (Table 3), with increases of up to 31.82% N, 10.76% P, 14.06% K, 25.57% Ca, 19.35% Mg, 39.50% Fe, 40.00% Cu, 50% Zn and 21.74% Mn, with treatments T3, T4 and T5 showing the greatest results.

Table 3. Nutrient concentration of leaf tissue in mandarin trees after application of agricultural gypsum with micronutrients.

Cultivation stage	Treatment	N	P	K	AC	Mg	Faith	Cu	Zn	Mn
				%				ppm		
Bloom	T1	2.0c	0.5b	2.32b	2.1c	0.5c	110c	14c	15b	23c
	T2	2.4b	0.5b	2.61ab	2.3bc	0.6bc	118c	16bc	16b	26bc
	T3	2.4b	0.5b	2.68a	2.5a	0.7ab	139b	18ab	17b	25bc
	T4	2.7a	0.7a	2.63ab	2.5ab	0.7ab	160a	18ab	18ab	29ab
	T5	2.7a	0.7a	2.76a	2.6a	0.7a	155ab	19a	21a	31a
Fruit set	T1	2.4ab	0.5a	2.01b	1.2b	0.5b	117c	15b	32ab	46b
	T2	2.3b	0.5a	2.29a	2.3a	0.6ab	122c	19a	34ab	58ab
	T3	2.4ab	0.5a	2.38a	2.1a	0.7a	184b	18ab	30b	56ab
	T4	2.6a	0.6a	2.46a	2.3a	0.7a	190ab	19a	38ab	66a
	T5	2.6a	0.7a	2.46a	2.5a	0.7a	208a	20a	44a	68a
Fruits at 50% of their development	T1	2.4a	0.6a	0.99a	1.9b	0.5a	119b	16a	42b	50b
	T2	2.4a	0.5a	1.11a	2.1ab	0.6a	139ab	15a	59a	56b
	T3	2.4a	0.6a	1.21a	2.5a	0.6a	153a	15a	52ab	54b
	T4	2.5a	0.5a	1.31a	2.2ab	0.6a	163a	16a	56ab	57b
	T5	2.61a	0.58a	1.0a	2.5ab	0.5a	148ab	16a	63a	75a
Reference		3.00– 3.40	0.15– 0.25	0.90– 1.10	1.50– 4.00	0.17– 0.44	60–150	5–35	20–75	20–200

Orange Cultivation

The chlorophyll levels significantly differed between the treated trees and the control. During week one, the control had 42 SPAD units, whereas treatment 4 had 44 SPAD units. Similarly, at week two, treatments 4 and 5 yielded the best results, with increases of more than 12%. In week 10, all the treated trees outperformed the control, with 46 SPAD units versus 42 SPAD units. In week 11, there were no differences, but the treated trees still outperformed the control. Week 16 showed the greatest

improvement, with treatment 5 having more than 48 SPAD units compared with 42 SPAD units in the control, representing a 15% increase (Figure 3, Figure 4).



Figure 3. Orange plants at 50% fruit development.

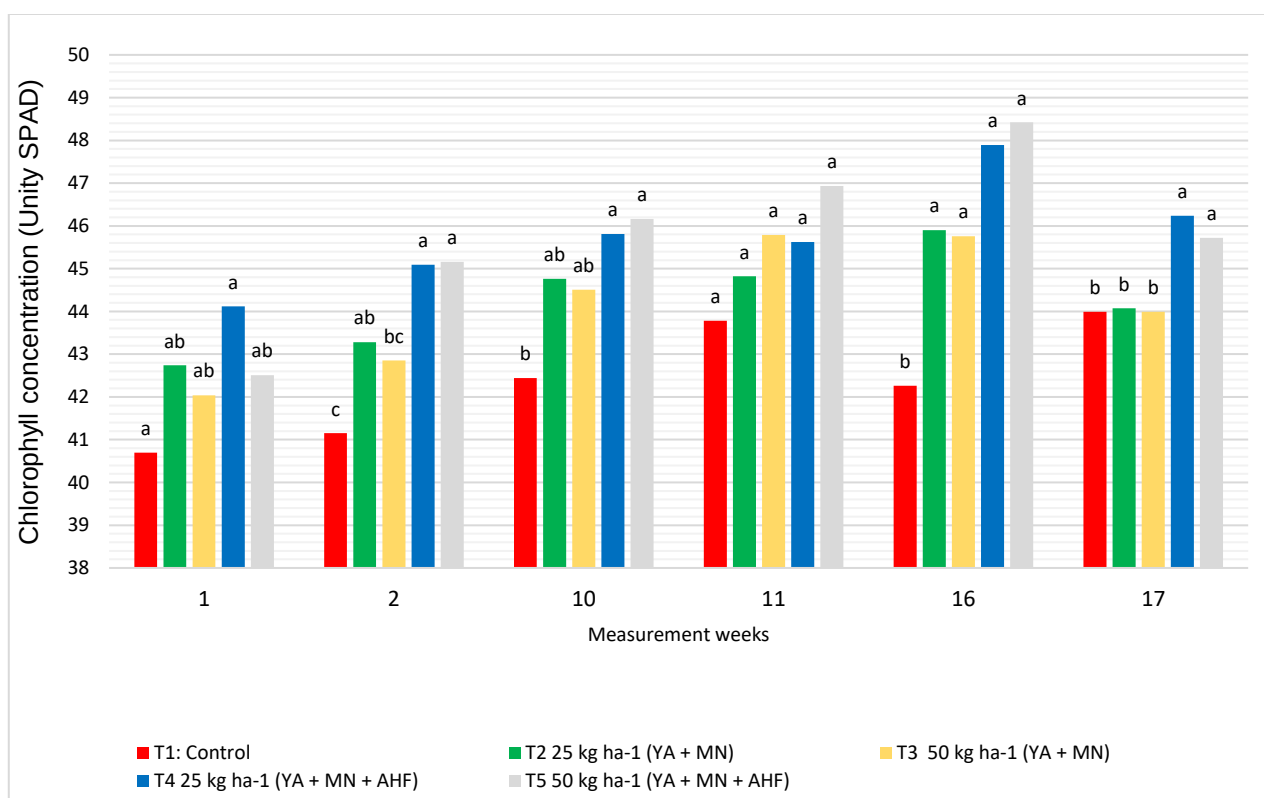


Figure 4. Chlorophyll levels in orange trees treated with agricultural gypsum plus micronutrients and humic and fulvic acids. Means with the same letter within each column are not significantly different (Tukey, $P \leq 0.05$). ns = not significant.

Table 4. Response of the application of agricultural gypsum with micronutrients and humic and fulvic acids to the components of orange yield and quality.

Treatments	Numer of fruits	Fruit weight (g)	Polar diameter (mm)	Ecuatorial diamater (mm)	Yield per tree (kg tree ⁻¹)
T1: Control	243 a	216.71 b	76.88 a	73.64 a	50.96 a
T2: 25 kg ha ⁻¹ (YA + MN)	189 a	226.99 ab	77.80 a	74.28 a	46.08 a
T3: 50 kg ha ⁻¹ (YA + MN)	216 a	238.42 a	79.20 a	75.44 a	46.78 a
T4: 25 kg ha ⁻¹ (YA + MN + AHF)	362 a	227.65 ab	78.08 a	74.60 a	63.13 a
T5: 50 kg ha ⁻¹ (YA + MN + AHF)	238 a	224.99 ab	78.28 a	74.28 a	55.08 a

Means with the same letter within each column do not differ statistically (Tukey, $P \leq 0.05$). ns = not significant.

With respect to yield components (Table 4), a 50% increase in the number of fruits was found in treatment 4, with 25 kg of gypsum with acids, a 12% increase in fruit weight, and a 25% increase in fruit yield, with 63 tons per hectare compared to 50 tons per hectare for the control, which was also highly significant in treatment 4.

With respect to fruit quality, in terms of dimensions, there were no statistically significant differences, although the fruit in the treated trees was slightly larger, while the shape and quality of the fruit remained the same.

In terms of the fruit quality parameters (Table 5), the juice percentage was greater in treatment 5, which was approximately 20% greater, although all the treatments significantly outperformed the control. The total soluble solids content did not differ, with slightly higher levels in the treated fruit. Acidity remained within normal ranges, and the Brix/acidity ratio was also within normal limits. With respect to firmness, the fruit showed no problems and was within normal limits, with values ranging from 91 to 96 N, with the treated fruit exhibiting the best firmness.

Table 5. Response of the application of agricultural gypsum with micronutrients and humic and fulvic acids on postharvest fruit parameters: juice, acidity, Brix, and firmness in oranges.

Treatments	Percentage of juice (%)	TSS (% °Brix)	Titulable acidity (%)	Firmeza (N)
T1: Control	42.85 b	12.20 a	1.22 a	91.00 a
T2: 25 kg ha ⁻¹ (AP + MN)	46.41 ab	12.20 a	1.33 a	94.00 a
T3: 50 kg ha ⁻¹ (AP + MN)	46.91 ab	12.60 a	1.35 a	96.00 a
T4: 25 kg ha ⁻¹ (AP + MN + AHF)	46.88 a	12.60 a	1.27 a	91.00 a
T5: 50 kg ha ⁻¹ (AP + MN + AHF)	49.79 a	12.80 a	1.33 a	93.00 a

Means with the same letter within each column do not differ statistically (Tukey, $P \leq 0.05$). ns = not significant.

In terms of orange fruit size (Table 6), the greatest percentage was found for medium- to large-sized trees, exceeding 80% for the treated trees and approximately 20% or less for small-sized trees, whereas the control group reported the greatest number of small fruits.

During the flowering stage, no statistically significant differences in nitrogen concentration were detected, although the treated trees experienced slightly greater increases. For phosphorus, both treatments 2 and 5 were the best, with 0.58% and 0.60%, respectively, compared with 0.45% in the control, with highly significant differences. In treatment 4, the greatest difference in potassium concentration was detected, which was also significant. Calcium and magnesium were not significantly different. In terms of micronutrients, iron had the best effect, with almost 200 ppm in treatment 5 compared with 138 ppm in the control, representing an increase of more than 40%. Copper, zinc, and manganese had similar effects, with treatment 5 exhibiting the best results and highly significant increases of 23%, 24%, and 66%, respectively.

Table 6. Response of the application of agricultural gypsum with micronutrients and humic and fulvic acids on orange fruit size.

Treatments	Small-sized fruits (%)	Medium-sized fruits (%)	Large fruits (%)
T1: Control	16.68 ab	63.81 a	19.51 ab
T2: 25 kg ha ⁻¹ (AP + MN)	2.08 b	46.61 a	51.31 a
T3: 50 kg ha ⁻¹ (AP + MN)	11.79 ab	48.64 a	39.57 ab
T4: 25 kg ha ⁻¹ (AP + MN + AHF)	23.81 a	66.10 a	10.09 b
T5: 50 kg ha ⁻¹ (AP + MN + AHF)	3.31 b	58.63 a	38.06 ab

Means with the same letter within each column do not differ statistically (Tukey, $P \leq 0.05$). ns = not significant.

Table 7. Response of the nutrient concentration in orange leaves to the application of agricultural gypsum supplemented with micronutrients and humic and fulvic acids.

Crop stage	Treatments	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn
		----- (%) -----					----- (ppm) -----			
Flowering	T1	2.60a	0.45b	1.30c	2.26a	0.37a	138ab	13c	25a	30c
	T2	2.64a	0.58a	1.46bc	2.28a	0.40a	128b	14bc	25a	28c
	T3	2.82a	0.56ab	1.66ab	2.54a	0.44a	176ab	17a	30a	35bc
	T4	2.84a	0.54ab	1.86a	2.41a	0.51a	167ab	14bc	31a	44ab
	T5	2.78a	0.60a	1.70ab	2.54a	0.53a	195a	16ab	31a	50a
Fruit filling	T1	2.44a	0.61a	1.01a	2.12bc	0.52a	121b	15a	41b	45b
	T2	2.49a	0.55a	1.10a	2.07c	0.56a	141ab	18a	56a	59ab
	T3	2.70a	0.61a	1.28a	2.60ab	0.56a	155ab	17a	56a	56ab
	T4	2.77a	0.65a	1.41a	2.42ab	0.56a	163a	18a	61a	69a

Crop stage	Treatments	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn
		----- (%) -----					----- (ppm) -----			
	T5	2.79a	0.70a	1.05a	2.64a	0.58a	157a	18a	65a	62ab
Fruits at 50% of development	T1	2.50a	0.62a	1.07b	2.08a	0.56a	123c	15a	40b	38a
	T2	2.48a	0.56a	1.11ab	2.13a	0.59a	143bc	17a	54ab	48a
	T3	2.65a	0.64a	1.30a	2.53a	0.57a	157ab	18a	56a	57a
	T4	2.79a	0.64a	1.31a	2.25a	0.58a	163ab	20a	60a	63a
	T5	2.83a	0.68a	1.27ab	2.68a	0.62a	171a	20a	59a	65a
Refference*		2.20 –	0.12 –	1.20 –	1.10 –	0.30 –	60 –	6 –35	25 –	25 –
		3.50	0.50	3.00	4.00	0.50	250		150	200

Means with the same letter within each column do not differ statistically (Tukey, $P \leq 0.05$). ns = not significant.

During the fruit set stage, the concentrations of none of the macronutrients (N, P, K, Ca, and Mg) significantly differed, although the treated trees presented relatively high concentrations. For micronutrients, the same trend continued, with higher concentrations reported in the treated trees than in the control. At the 50% fruit development stage, the concentrations of nitrogen, phosphorus, calcium, and magnesium did not significantly differ, whereas the concentration of potassium significantly differed. In terms of micronutrients, there were considerable increases in the treated trees compared with those in the control (Table 7).

CONCLUSION

The addition of micronutrients (Fe, Cu, Zn, and Mn) is highly important for citrus crops, as these trees have specific nutrient requirements. This integrated management ensures that nutrients are efficiently available to the plant, improving its physiological parameters, yield, and quality.

The application of agricultural gypsum with micronutrients, humic acids, and fulvic acids improves nutrient availability to the plant, efficiently meeting its nutritional needs.

A significant positive effect on the physiological variables, such as the chlorophyll index and nutrient concentration in the leaf tissue, was detected for the lemon, orange, and mandarin crops. Similarly, improvements in yield variables such as the number and weight of fruit and yield, as well as in quality parameters such as increased polar and equatorial diameters, juice percentage, total soluble solids (TSS), titratable acidity, fruit firmness, and shelf life, were observed.

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About the editors



 **Dr. Leandris Argente-Martínez**

Professor and Senior Researcher "C" at the National Technological Institute of Mexico, Valle del Yaqui Campus (ITVY). Member of the National System of Researchers, Level 1. Professor with a Desirable Profile (PRODEP) from the Mexican Ministry of Public Education. Leader of the ITVAYA-CA-3 Academic Group. Leader of the BioSecuraNet International Network. PhD in Biotechnology Sciences. Research focuses on physiological mechanisms, anaplerotic pathways, and molecular mechanisms activated by organisms during their adaptation to abiotic stresses. Use of molecular markers of organismal tolerance to abiotic stress (salinity, drought, and heat). Application of stable isotope techniques to monitor biochemical reactions in cells and tissues. Application of univariate and multivariate experimental techniques for data processing. Contact email: oleinismora@gmail.com



 **Dra. Ofelda Peñuelas-Rubio**

Professor and Senior Researcher "C" at the National Technological Institute of Mexico, Valle del Yaqui Campus (ITVY). Member of the National System of Researchers, Level 1. Professor with Desirable Profile (PRODEP) from the Mexican Ministry of Public Education, member of the ITVAYA-CA-3 Academic Group. Mexico. She completed two postdoctoral fellowships (January 2016 - December 2017) within the CONACYT National Fellowship Program at the Interdisciplinary Research Center for Regional Integral Development, Sinaloa Unit, of the National Polytechnic Institute, in the area of Rhizosphere Molecular Ecology. She holds a PhD in Sciences specializing in Biotechnology. Contact email: ofeperub@gmail.com



 **Dr. Joe Luis Arias-Moscoso**

Professor and Senior Researcher "C" at the National Technological Institute of Mexico, Valle del Yaqui Campus (ITVY). Member of the National System of Researchers, Level 1. Professor with Desirable Profile (PRODEP) from the Mexican Ministry of Public Education, member of the ITVAYA-CA-3 Academic Group. Mexico. She completed two postdoctoral fellowships (January 2016 - December 2017) within the CONACYT National Fellowship Program at the Interdisciplinary Research Center for Regional Integral Development, Sinaloa Unit, of the National Polytechnic Institute, in the area of Rhizosphere Molecular Ecology. She holds a PhD in Sciences specializing in Biotechnology. Contact email: jarias.moscoso@itvy.edu.mx



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