

Foliar Fertilization in Maize (*Zea mays* L.) Grain Production: A Comparative Analysis of Application by Agricultural Drone and Conventional Spraying

Anaya-Castro, Daniel A.¹; Armenta-Bojórquez, Adolfo D.¹; Galaviz-Lara, Julián A.¹; Camacho-Báez, Jesús R.¹; Acosta-Rodríguez, José L.¹; López-Valenzuela, Blanca E.^{2*}

¹ Instituto Politécnico Nacional. Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional, Guasave, Sinaloa, México. C.P. 81049.

² Universidad Autónoma de Sinaloa. Facultad de Agricultura del Valle del Fuerte, Juan José Ríos, Sinaloa, México. C.P. 81110.

* Correspondence: blancalopezvzla@favf.mx

Citation: Anaya-Castro, D. A., Armenta-Bojórquez, A. D., Galaviz-Lara, J. A., Camacho-Báez, J. R., Acosta-Rodríguez, J. L., & López-Valenzuela, B. E. (2026). Foliar Fertilization in Maize (*Zea mays* L.) Grain Production: A Comparative Analysis of Application by Agricultural Drone and Conventional Spraying. *Agro Productividad*. <https://doi.org/10.32854/4h86wd41>

Academic Editor: Jorge Cadena Iñiguez

Associate Editor: Dra. Lucero del Mar Ruiz Posadas

Guest Editor: Juan Francisco Aguirre Medina

Received: December 14, 2025.

Accepted: March 28, 2026.

Published on-line: May 25, 2026.

Agro Productividad, 19(3). March, 2026. pp: 189-197.

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ABSTRACT

Objective: This research study aimed to evaluate two distinct methods for applying foliar fertilizers: agricultural drone application and manual backpack sprayer application (traditional method).

Design/methodology/approach: A chemical foliar fertilizer (Bayfolan Forte), an organic fertilizer (Hormonamin), and a mixture of both were evaluated in maize. A maize crop was established, and two treatment applications were carried out at 44 and 64 days after sowing. The variables assessed included plant height, ear height, foliar nutrient concentration after each application, 1,000-grain weight, and grain yield.

Results: Regarding nutrient absorption after foliar applications, Bayfolan, Hormonamin, and their mixture showed greater nutrient uptake than the control treatment (water). Moreover, among the application methods, a greater increase was observed when the treatments were applied using an agricultural drone.

Findings/conclusions: Grain yield increased when foliar fertilizers were applied with an agricultural drone compared with manual backpack spraying.

Keywords: backpack sprayer, nutrients, grain crop.

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereals worldwide, providing essential nutrients for both humans and animals, in addition to serving as a fundamental raw material for diverse industries (SIAP-SAGARPA, 2021). Despite advances in agriculture, in most cropping systems inputs are not utilized to their full potential; one reason for this is the limited implementation of improved management practices related to soil, fertilization, irrigation, among others (Martín *et al.*, 2013). Soil fertilization is one of the most costly inputs in maize production; therefore, it is of utmost importance for producers to maximize



the use efficiency of all inputs (INIFAP, 2010). One way to complement soil fertilization is through foliar fertilization, since plants are capable of absorbing nutrients through their foliage (Hu *et al.*, 2023). This type of fertilization has become a common and important practice for producers because it corrects plant nutrient deficiencies, promotes proper crop development, and improves both yield and product quality (Trinidad *et al.*, 1999). The efficiency of foliar fertilization depends on several factors that facilitate nutrient absorption. The use of adhesives and surfactants enhances the adhesion and wetting of the solution on the foliage, that is, it reduces surface tension, thereby increasing the absorption rate of applied nutrients (Omran *et al.*, 2021).

Fertilizer concentration in the solution is also critical, since excessively high concentrations may cause foliar burn (Vuković *et al.*, 2014; Xu *et al.*, 2022). The methods commonly used for the application of agrochemicals and foliar fertilizers involve spray systems such as manual or electric backpack sprayers, hydraulic tractor sprayers, or airplanes. In many cases, these devices are not optimally calibrated, and product application may result either in spray evaporation or, conversely, in the application of excessive solution. This can alter the way droplets reach the leaves, compromise nutrient absorption, and generate adverse effects on the environment and human health (Crause *et al.*, 2023; Dantas *et al.*, 2021). In recent years, the use of drones for agrochemical application has increased because they offer important advantages, including greater precision, operational ease, and the ability to access virtually any type of terrain (Guebsi *et al.*, 2024). The use of drones in agriculture began with multispectral imaging, which allows farmers to detect water stress, nutritional deficiencies, diseases, and pests in plants long before they become visible to the naked eye (Mulla, 2013).

In addition, multispectral imaging facilitates biomass monitoring and crop yield estimation, helping farmers optimize the use of resources such as water and fertilizers, thereby contributing to a more sustainable and efficient agriculture (Zhang *et al.*, 2025). Precision agriculture is based on the optimization of crop inputs. For this purpose, technological tools such as global positioning systems, irrigation devices, fertilizers and pesticides, as well as climatic sensors, are employed. Although there are various technological tools that support this approach, the way drones operate and the ease of their use have driven the development of specialized drones for agricultural applications (González *et al.*, 2016). When pesticides are applied, the spray system used by drones exhibits greater efficiency than that used traditionally, increasing droplet coverage, density, and uniformity (Xiao *et al.*, 2020). Consequently, improved utilization can enhance agrochemical efficiency and reduce the quantities required (Zhang *et al.*, 2018). In pesticide application, droplet volume and distribution may reduce pesticide use when applied at a spray flow rate of 15 L ha^{-1} (Qin *et al.*, 2016). The smaller the spray droplet, the less solution volume is required to cover the same foliar surface; therefore, the amount of liquid applied per hectare can be reduced while maintaining the same amount of agrochemical per hectare. By decreasing droplet size, greater contact of the solution with the foliar surface is achieved (Changfeng *et al.*, 2021), thus increasing the likelihood of deeper liquid penetration into the sprayed plant (Murillo *et al.*, 2013). In recent years, the use of drones for pesticide application in agriculture has contributed to reducing agrochemical inputs for the control of pests,

diseases, and weeds. These applications are generally accompanied by foliar fertilizers; however, there are no evaluations of their efficiency under these conditions of substantial water reduction per hectare. Therefore, the impact of foliar fertilization using drones in maize cultivation was evaluated.

MATERIALS AND METHODS

Site location

The study was conducted during the November 2023-May 2024 growing season at the experimental field of the Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional de Sinaloa (CIIDIR-SINALOA), located in Guasave, Sinaloa (25° 32' 48.3" N, 108° 28' 56.2" W).

Soil sampling and land preparation

Nitrogen fertilization was applied before sowing at a rate of 350 kg ha⁻¹ of urea. After application, the field was harrowed to ensure incorporation into the soil. Sowing was carried out on November 7, 2023, using the maize hybrid DEKALB-4050[®]. Weed control during the experiment was performed manually, and a second application of 350 kg ha⁻¹ of urea was carried out.

Experimental design

The treatment arrangement followed a 4×2 factorial design with three replicates per treatment in a randomized complete block design, where four different fertilization levels and two application methods were tested, for a total of 24 experimental units (EU). The experimental area for each treatment consisted of 11 rows, each 20 m long. Sampling was carried out within the treatment net plot, which consisted of 4 linear meters from the two central rows. For the fertilization levels, the following treatments were used: a chemical foliar fertilizer, Bayfolan Forte[®]; an organic fertilizer, Hormonamin[®]; a mixture of both; and water as the control. The synthetic foliar fertilizer Bayfolan Forte[®] contained macro- and micronutrients, in addition to indole-3-acetic acid, whereas the organic foliar fertilizer Hormonamin[®] also contained macro- and micronutrients as well as amino acids.

Foliar applications

A conventional backpack sprayer and a commercial AGRAS T40 drone (Figure 1) were used for foliar applications. Two foliar fertilizer applications were performed at 44 and 64 days after sowing (DAS). The doses used for drone application were calibrated to 20 L ha⁻¹, whereas those used for backpack sprayer application were 200 L ha⁻¹. Eight treatments with three replicates were established (Table 1).

Variables evaluated

A physicochemical soil analysis was conducted in accordance with the criteria established in the Mexican Official Standard NOM-021-RECNAT-2000, published in the Official Gazette of the Federation. Soil pH and electrical conductivity were determined using method AS-02, whereas organic matter percentage was estimated through organic



Figure 1. Foliar application in maize at 44 DAS using a drone.

Table 1. Description of treatments, applied doses, and solution concentrations expressed in $L ha^{-1}$ for the different treatments evaluated.

Treatment	Application method	Applied dose	Concentration in solution (%)
Control (water)	Drone	$20 L ha^{-1}$	0
Bayfolan Forte	Drone	$3 L ha^{-1}$ plus 17 L of water	15
Hormonamin	Drone	$3 L ha^{-1}$ plus 17 L of water	15
Bayfolan Forte + Hormonamin	Drone	$3 L ha^{-1}$ of Bayfolan Forte + $3 L ha^{-1}$ of Hormonamin + 14 L of water	30
Control (water)	Manual backpack sprayer	$200 L ha^{-1}$ of water	0
Bayfolan Forte	Manual backpack sprayer	$3 L ha^{-1}$ plus 197 L of water	1.5
Hormonamin	Manual backpack sprayer	$3 L ha^{-1}$ plus 197 L of water	1.5
Bayfolan Forte + Hormonamin	Manual backpack sprayer	$3 L ha^{-1}$ of Bayfolan Forte + $3 L ha^{-1}$ of Hormonamin + 194 L of water	3

carbon content by the Walkley and Black (1934) method according to AS-07. Phosphorus analysis was performed using the Olsen *et al.* (1954) method, corresponding to AS-10. Nutrient analysis (K^{1+} , Ca^{2+} , Mg^{2+} , and Na) was carried out using method AS-12 with ammonium acetate, and total nitrogen was determined by the Kjeldahl method, all in accordance with NOM-021.

Foliage wetting among application methods was compared using water-sensitive cards. Patil and Chetan (2018) reported that, following foliar fertilizer application, nitrogen, phosphorus, potassium, calcium, magnesium, zinc, manganese, and iron may require up to 10 days for absorption. Therefore, foliage samples for nutrient analysis were collected 10 days after treatment application.

Leaves were collected from the different treatments and washed to remove possible residues. Subsequently, they were dried in a FELISA oven for 72 h at 70 °C. Once dried, the samples were processed using a Thomas electric mill for foliar nutrient analysis, following the methodology described by Alcantar and Sandoval (1999). Wet digestion was performed using a sulfuric acid and perchloric acid mixture. Nitrogen concentration was determined by the Kjeldahl method, phosphorus by the yellow vanadate-molybdate method, potassium by flame emission flame photometry, and calcium, magnesium, iron, manganese, zinc, and copper by atomic absorption spectrophotometry.

Plant height and ear height were also evaluated using a graduated ruler at 120 DAS after flowering. Subsequently, measurements were taken at 180 DAS, once the grain had reached 15% relative moisture, to determine grain specific weight, which consisted of weighing 1,000 grains from each experimental unit (EU) on a precision balance. Grain yield was assessed by harvesting ears from the net plot, shelling them with a commercial sheller, and scaling the results to $t\ ha^{-1}$.

Statistical analysis

To interpret the response variables, an analysis of variance (ANOVA) was performed. Differences among treatments were assessed using Tukey's test at a significance level of $\alpha=0.05$ in all experiments, using SAS software version 9.1 (2004).

RESULTS AND DISCUSSION

The soil exhibited a loam texture and neutral pH. Electrical conductivity indicated a low salt content, with low organic matter content and an adequate cation concentration. Phosphorus content was high, whereas the remaining nutrients fell within the normal range for this soil type. Water-sensitive cards change from yellow to bluish green upon contact with liquids. As shown in Figure 2, the solution applied with the drone produced a smaller droplet size and a greater wetted foliar area than the traditional application method, in which droplet size was larger and part of the foliage remained unreached by the solution.



Figure 2. Comparative assessment of water-sensitive cards and foliage following foliar applications with both application methods.

The treatment consisting of a mixture of Bayfolan Forte and Hormonamin, which had a high fertilizer concentration (30%) and was applied by drone, did not show foliar burn damage. This differs from the findings reported by Vuković *et al.* (2014) and Xu *et al.* (2022), who indicated that a high fertilizer concentration in the solution causes foliar burn. This outcome may be attributed to the smaller droplet size produced by the drone, which delivers a lower amount of fertilizer per unit of foliar contact area.

Foliar nutrient analysis

First application

The treatments receiving foliar fertilizer showed a marked increase in nutrient absorption, with statistically significant differences compared with the water control. However, no differences were observed among these treatments in the absorption of nitrogen (N), phosphorus (P), and calcium (Ca). Regarding application methods, no statistically significant differences were detected for most nutrients; nevertheless, when fertilizers were applied by drone, potassium and calcium values were statistically higher than those obtained when fertilizers were applied using a manual backpack sprayer (Table 2).

Second application

After the second application, increases in foliar nutrient concentration were observed. Bayfolan, Hormonamin, and their mixture showed increases in most nutrients, with statistically significant differences compared with the water control, but no differences among them. Although the same amount of fertilizer was used in both application methods, drone application resulted in higher concentrations of phosphorus, potassium, and calcium (Table 3).

According to Wyatt *et al.* (2017), the application of foliar fertilizers with very small droplet size is not particularly favorable for nutrient absorption, since such small droplets tend to evaporate more rapidly because of the extremely thin film they form; consequently, because they remain in contact with the foliage for a shorter period, part of the fertilizers may not be absorbed. The results obtained in this study differ from that report, as foliar nutrient analyses showed that foliar fertilizers applied by drone led to greater absorption

Table 2. Comparison of means for macronutrient concentration in foliage 10 days after the first application at 44 DAS. Means followed by the same letter within each column are not significantly different according to Tukey's test ($\alpha \leq 0.05$).

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Water	2.49 b	0.39 b	1.72 d	1.77 b	1.12 c
Bayfolan Forte	2.93 a	0.45 a	1.72 a	2.41 a	1.22 a
Hormonamin	2.92 a	0.43 a	1.55 b	2.34 a	1.14 ab
Mixture	2.98 a	0.46 a	1.43 c	2.25 a	1.11 b
Application method					
Drone	2.83 a	0.43 a	1.49 a	2.29 a	1.06 a
Manual backpack sprayer	2.89 a	0.43 a	1.37 b	2.09 b	1.07 a

Table 3. Comparison of means for macronutrient concentration in foliage 10 days after the second application at 64 DAS.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Water	4.16 b	0.43 b	1.16 b	1.72 b	0.73 b
Bayfolan Forte	4.70 a	0.64 a	1.69 a	2.34 a	1.07 a
Hormonamin	4.54 a	0.67 a	1.65 a	1.99 ab	1.06 a
Mixture	4.46 a	0.69 a	1.69 a	2.07 ab	1.08 a
Application method					
Drone	4.45 b	0.62 a	1.61 a	2.13 a	0.98 a
Manual backpack sprayer	4.57 a	0.59 b	1.48 b	1.93 b	0.98 a

Means with the same letter in each column do not show a statistically significant difference, according to Tukey ($\alpha \leq 0.05$).

of most nutrients than traditional application. This may be attributed to the drone's ability to cover a larger proportion of the foliar area while flying over the crop, so that, although evaporation may occur more rapidly, the overall absorption area is greater.

Plant height, ear height, and 1,000-grain weight

Plant height ranged from 2.93 to 3.01 m among treatments, with no statistically significant differences observed. Likewise, ear height showed no statistically significant differences, ranging from 1.40 to 1.46 m ($\alpha \leq 0.05$). Similarly, no statistically significant differences were found between application methods for either variable. The 1,000-grain weight ranged around 345 g and did not show statistically significant differences among treatments. Likewise, no statistically significant differences were observed between application methods ($\alpha \leq 0.05$). These results are consistent with those reported by Jakab *et al.* (2017), who evaluated different foliar fertilizers applied individually and in mixtures using the traditional method and likewise found no statistically significant differences in maize 1,000-grain weight.

Grain yield

Bayfolan Forte and Hormonamin resulted in the highest grain yields (12.28 and 12.67 t ha⁻¹, respectively) compared with the water control; however, no significant differences were observed when both fertilizers were applied in combination ($\alpha \leq 0.05$). It can also be observed that application method produced a statistically significant difference in mean yield, which was higher when fertilizers were applied by drone than when they were applied with a manual backpack sprayer (Figure 3).

Ciampitti *et al.* (2010) evaluated different foliar fertilizers and found that treatments with greater nutrient absorption achieved higher maize grain yield, which is consistent with the results obtained in the present study, where greater nutrient uptake was associated with greater grain production. The grain yield results also agree with those reported by Jakab *et al.* (2017), in which foliar fertilizer mixtures produced lower yields than when the fertilizers were applied separately using the traditional backpack sprayer method.

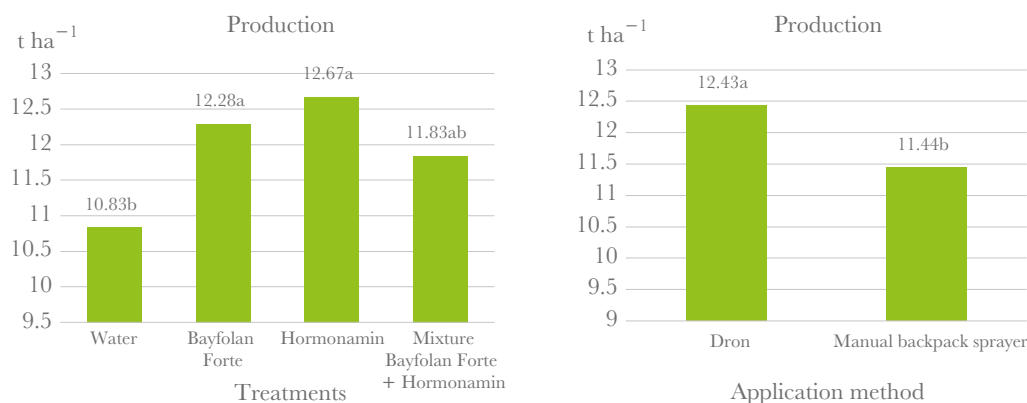


Figure 3. Comparison of mean grain production at different levels (fertilizers) and factors (application methods) studied in the factorial design evaluated at t ha⁻¹. Means with the same letter in each column do not show a statistically significant difference, according to Tukey ($\alpha \leq 0.05$).

CONCLUSIONS

The application of foliar fertilizers by drone provided greater foliar surface coverage and enhanced the absorption of most nutrients compared with the traditional application using a manual backpack sprayer. The droplet distribution and size achieved by the drone prevented maize plants from exhibiting damage, even when a high fertilizer concentration was applied in the solution. Overall, foliar fertilizer application by drone increased maize grain yield compared with conventional application.

ACKNOWLEDGMENTS

The authors express their gratitude to the Department of Agricultural Biotechnology of the Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional (CIIDIR), Sinaloa Unit, of the Instituto Politécnico Nacional (IPN). Appreciation is also extended to the SIP-IPN Project, registration number SIP-20230238, and to CONAHCYT for the support provided under grant number 1239260.

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