AGRO PRODUCTIVIDAD

Colegio de
Postgraduados

Yield of Apaxtleco Creole Chili Peppers (*Capsicum annuum* L.) under Chemical, Biological, and Organic Fertilization

Apáez-Barrios, Maricela[1]; Ayvar-Serna, Sergio[1*]; Díaz-Nájera, José Francisco[1]; Sánchez-De la Cruz Martina[1]; Zárate-Martínez, William[2]; Arispe-Vázquez, José Luis[3]; Apáez-Barrios, Patricio[4*]; Terrones-Salgado, José[5]

[1] Colegio Superior Agropecuario del Estado de Guerrero, Iguala de la Independencia, Guerrero, México. C. P. 40000.
[2] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Carretera Saltillo-Zacatecas km 342+119 No. 9515, Hacienda de Buenavista. C. P. 25315. Saltillo, Coahuila de Zaragoza, México.
[3] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Campo Experimental Iguala, Km 2.5 Carretera Iguala-Tuxpan, Colonia Centro Tuxpan Iguala de la Independencia Guerrero, México C. P. 40000.
[4] Universidad Michoacana de San Nicolás de Hidalgo-Facultad de Ciencias Agropecuarias. Prolongación calle Mariano Jiménez S/N. Apatzingán, Michoacán, México, C.P. 60670.
[5] Decanato de Ciencias de la Vida y la Salud, Escuela de Ingeniería en Agronomía, Centro de Investigación en Horticultura y Plantas Nativas, Universidad UPAEP, 21 sur No. 1103, Puebla, Puebla. C.P. 72410, México.
* Correspondence: patricio.apaez@umich.mx; sergio.ayvar@csaegro.edu.mx

ABSTRACT

Objective: To evaluate the effect of three types of fertilization —chemical, biological, and organic— on the growth, yield, and profitability of three creole chili pepper genotypes (Ancho Liso, Carricillo, and Chino) cultivated under rainfed conditions in Apaxtla de Castrejón, Guerrero, Mexico.

Design/methodology/approach: Three creole chili pepper genotypes grown in Apaxtla de Castrejón were evaluated. A randomized complete block design with a split-plot arrangement was used, where genotype was the main factor and fertilization type was the secondary factor.

Results: Highly significant differences were observed among genotypes and fertilization types, as well as a significant genotype × fertilization interaction. The Ancho Liso genotype under chemical fertilization showed the highest values for plant height (46 cm), number of fruits per plant (22.5), fresh fruit weight, and yield (2.04 t ha^{-1}), in addition to the highest net income (MXN $7,282.5 ha^{-1}) and return per unit of investment (0.23). In contrast, the Chino genotype exhibited the lowest productive adaptation, showing low fruit yields under all three fertilization types.

Study limitations/implications: Genotype selection and fertilization management are key determinants for increasing the yield of creole chili peppers.

Findings/conclusions: The genotype × fertilization interaction is decisive for optimizing creole chili pepper production. In the Ancho Liso genotype, chemical fertilization was the most effective, whereas in Carricillo, biological fertilization was as effective as chemical fertilization, and in Chino, yield was unaffected by fertilization type. These results indicate that only in the Carricillo genotype is it advisable to substitute chemical fertilization with biological fertilization without reducing crop yield while maintaining economic profitability.

Keywords: *Capsicum annuum* L., fruit yield, economic profitability.

Citation: Apáez-Barrios, M., Ayvar-Serna, S., Díaz-Nájera, J. F., Sánchez-De la Cruz, M., Zárate-Martínez, W., Arispe-Vázquez, J. L., Apáez-Barrios, P., & Terrones-Salgado, J. (2026). Yield of Apaxtleco Creole Chili Peppers (*Capsicum annuum* L.) under Chemical, Biological, and Organic Fertilization. *Agro Productividad*. https://doi.org/10.32854/d0er5j02

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Juan Francisco Aguirre Medina

Received: October 28, 2025.
Accepted: December 24, 2025.
Published on-line: March XX, 2026.

Agro Productividad, 19(1). January. 2026. pp: 231-241.

INTRODUCTION

Chili pepper (*Capsicum annuum* L.) is one of the horticultural crops of greatest economic, social, and cultural importance in Mexico. It constitutes a staple ingredient in the national diet and represents an important source of income for rural producers. Its fruit contains bioactive compounds such as capsaicinoids, carotenoids, and vitamins, which, in addition to providing flavor and color, contribute to the nutritional value of the diet (Mendoza-Elos *et al.*, 2020; Díaz-José *et al.*, 2023). Mexico and Central America are recognized as centers of domestication and diversification of the genus *Capsicum*; in these regions, a wide genetic variability is conserved, with numerous creole varieties adapted to specific local conditions (Carrizo-García *et al.*, 2016).

In the municipality of Apaxtla de Castrejón, Guerrero, three creole varieties with high cultural and gastronomic value predominate: Ancho Liso, Carricillo, and Chino. These varieties are cultivated in traditional agricultural systems under rainfed conditions, using farmers' own seed, open-field establishment, low planting densities, and limited management of plant nutrition and phytosanitary practices (Ayvar *et al.*, 2007). As a consequence, plants exhibit reduced vigor and greater susceptibility to pest and disease attacks, which limits fruit yield and quality.

Fertilization management is a determining factor for improving chili pepper productivity. In this regard, farmers frequently use chemical fertilizers due to their rapid effect on plant growth and yield, mainly applying formulations rich in nitrogen, phosphorus, and potassium (Mendoza-Elos *et al.*, 2020). However, the continuous and unbalanced use of these inputs has generated negative effects on soil structure and fertility as a result of degradation and salinization, in addition to increasing production costs and the risk of environmental contamination, such as water eutrophication and acidification, as well as greenhouse gas emissions (Skowrońska and Filipek, 2014; Pahalvi *et al.*, 2021). Chemical fertilizers are subject to bioconversion, leaching, and volatilization, resulting in nutrient use efficiencies ranging from 10 to 60% (Chhipa, 2017; Zulfiqar *et al.*, 2019). Among the alternatives to this problem, the use of biofertilizers and organic fertilizers stands out as a sustainable option, as they supply nutrients gradually, enhance microbial activity, and promote the biological balance of the soil (Carvajal and Mera, 2010; Singh *et al.*, 2024).

Biofertilizers, formulated with beneficial microorganisms such as *Azospirillum brasilense*, *Bacillus subtilis*, *Trichoderma harzianum*, and arbuscular mycorrhizal fungi (*Glomus intraradices*), promote biological nitrogen fixation, phosphorus solubilization, and the production of phytohormones that stimulate plant growth (Sharma *et al.*, 2020). The application of organic amendments or composts has shown positive effects on growth, flowering, and yield in horticultural crops, including serrano and habanero chili peppers (Díaz-José *et al.*, 2023; Ontiveros-Sajuan *et al.*, 2024). In traditional agricultural systems of the state of Guerrero, these types of nutrient management can contribute to restoring soil fertility, improving moisture retention, and reducing dependence on chemical fertilizers. Despite the available information on sustainable fertilization in crops, there are few studies on the response of Apaxtleco creole chili peppers to different fertilization sources. Therefore, the objective of this research was to evaluate the effect of three types of fertilization —chemical, biological, and organic— on the growth, yield, and profitability of Apaxtleco creole chili pepper genotypes cultivated under rainfed conditions in Apaxtla de Castrejón, Guerrero. The hypothesis proposes that biological and organic fertilization constitute more sustainable alternatives than chemical nutrition for achieving greater growth, yield, and profitability in Apaxtleco creole chili pepper genotypes.

MATERIALS AND METHODS

Study area

The study was conducted at the experimental field of the Centro de Estudios Profesionales del Colegio Superior Agropecuario del Estado de Guerrero (CEP-CSAEGro), located at km 14.5 of the Iguala-Cocula highway, Guerrero, Mexico, at an altitude of 640 m above sea level, with geographic coordinates 18° 22’ 52” N and 99° 33″52” W (INEGI, 2013). The climate is warm dry [Awo (w)(i)g], with summer rainfall, a mean annual precipitation of 797 mm, and an average temperature of 26.4 °C (García, 2004). Sowing was carried out on June 12, 2024.

The soil has a fine texture (61.4-77.4% clay), moderately alkaline pH (7.6), no salinity problems, 0.27% organic matter, 5.3% total nitrogen, and low levels of P and K.

Genetic material

Three creole chili pepper genotypes cultivated in Apaxtla de Castrejón were used: Ancho Liso (AL), Carricillo (CA), and Chino (CH). Seeds were obtained from fruits selected for morphological uniformity, health, and absence of pests and diseases. This genetic material was donated by local producers from the municipality.

Experimental design and treatments

A randomized complete block design with a split-plot arrangement and four replications was used, in order to efficiently study two factors and to ensure reliability, validity, and consistency of the results. The main factor was genotype (AL, CA, CH), and the secondary factor was fertilization type: chemical (CF), biological (BF), and organic (OF), generating nine treatments (AL-CF, AL-BF, AL-OF, CH-CF, CH-BF, CH-OF, CA-CF, CA-BF, CA-OF).

In the production area of the three creole chili peppers, chemical nutritional management is commonly practiced; therefore, the treatments AL-CF, CH-CF, and CA-CF were considered regional controls against which the results obtained were compared. Each experimental unit consisted of two rows 4 m in length and 0.8 m apart, with five plants randomly selected within the useful plot for recording the response variables.

Seedling production and transplanting

Seedlings were produced in polyethylene trays with 200 cavities, using Bocashi as the substrate, which was previously sterilized. Sowing was carried out with one seed per cavity at a depth of 0.5 cm. The trays were maintained under greenhouse conditions with daily manual irrigation and preventive sanitary management.

Transplanting was carried out into the field 31 days after sowing (DAS), placing one plant per hill (planting site) at 0.4 m spacing, with 0.8 m between rows.

Crop management

Plants were managed according to the fertilization treatments evaluated.

Chemical fertilization consisted of supplying 150-80-80 (N-P-K), using ammonium sulfate (20.5% N), diammonium phosphate (18% N, 46% P), and potassium chloride (60% K) as nutrient sources.

For organic fertilization, the commercial product OganoDel® (200 kg ha^{-1}) was used. This product contains 85% organic matter, 60% humus, 10.7% humic acids, 39-37-29 (N-P-K), 18.4% sulfur, 13.6% magnesium, and 14% calcium. It was applied at transplanting and at 14, 29, 33, and 55 days after transplanting (DAT).

For biological fertilization, a mixture of *Azospirillum brasilense* (30 mL) and *Trichoderma* spp. + *Glomus intraradices* (50 mL per plant) was prepared. The source of *Azospirillum* was the commercial product AZOSPIRILLUM-GREEN®, with a concentration of 1×10^{12} CFU propagules per dose, while *Trichoderma* spp. + *G. intraradices* were obtained from TRICHS-MICS®, which contains 150 spores g^{-1} of *G. intraradices* and $2\times10^{6\prime}$conidia g^{-1} of *Trichoderma* spp. Treatments were applied as foliar sprays at transplanting and at 14, 29, 33, and 55 DAT using a 15-L backpack sprayer.

Additionally, all plants received two foliar applications of Biozyme TF® (3 mL L^{-1}) at 20 and 34 DAT to stimulate vegetative growth.

Response variables

In five plants randomly selected from each experimental unit, the following variables were evaluated: plant height, measured with a metric ruler from the collar to the apex; stem diameter, measured at the base of the stem using a vernier caliper; and the number of primary branches per plant.

At physiological maturity, fruits were harvested manually at 114 days after transplanting (DAT). The number of fruits per plant, fruit length and diameter (cm) were determined, and fresh fruits were subsequently weighed using a previously calibrated digital scale to ensure accurate weight recording. Fruits were then dried in a forced-air oven at 70 °C until constant weight was achieved to determine yield in t ha^{-1}. After recording the response variables, the product was transported to the market and sold at a price of MXN \$60.00 kg^{-1}.

Additionally, a profitability analysis was conducted using the following relationship:

$$IN = YPy - \left(\sum XiPi + CF\right)$$

where IN=net income, Y=yield (kg ha^{-1}), Py=price per kilogram, $\sum XiPi$ =sum of variable costs, and CF=fixed costs (Volke, 1982).

Statistical analysis

Data normality was assessed using the Shapiro-Wilk test to determine whether the observed values originated from a normally distributed population. Subsequently, the data were subjected to analysis of variance (ANOVA), and mean comparisons were performed using Tukey's test ($p \leq 0.05$). All statistical analyses were conducted using SAS software (SAS, 2017).

RESULTS AND DISCUSSION

The average maximum and minimum temperatures were 34.5 and 24.6 °C, respectively, while cumulative precipitation during crop development was 587 mm.

Analysis of variance showed highly significant differences ($p \leq 0.01$) among genotypes for all evaluated variables, indicating marked genetic variability among Apaxtleco creole chili peppers. Fertilization also had a significant effect on the number of branches per plant, as well as on the number and weight of fruits and fruit length and diameter. In addition, a significant genotype × fertilization interaction was observed for most variables, indicating that genotype responses varied according to the type of fertilization applied (Table 1).

On average, plant height was 36 cm, with the highest value recorded in the Ancho Liso genotype under chemical fertilization, representing increases of 8% and 18% compared with biological and organic fertilization, respectively. In contrast, the lowest growth was observed in the Chino genotype under chemical fertilization (29.15 cm). In both Carricillo and Chino, plant height was similar regardless of fertilization type. Stem diameter ranged from 0.62 to 0.78 cm, with the Carricillo genotype under biological fertilization showing the highest values. This treatment exceeded stem diameter of the same genotype under chemical fertilization by 22% and under organic fertilization by 11%, suggesting greater structural robustness under this management practice. In the Chino genotype, fertilization type did not affect stem diameter values, and compared with the other genotypes, it exhibited the lowest values overall (Table 2).

The number of branches per plant showed a similar increasing trend under biological fertilization, with the Ancho Liso creole chili presenting the highest value (5.85 branches) under this treatment. In Carricillo, biological and organic fertilization increased the number of branches by 13% and 23%, respectively, compared with chemical fertilization.

Table 1. F probability values and coefficient of variation (C.V.) by variable for genotypes, fertilization, and their interaction in Apaxtleco creole chili peppers.

Variable	Genotype (G)	Fertilization (F)	Interaction (G×F)	C.V. (%)
Plant height	0.0025**	0.0842NS	0.0483*	9.60
Stem collar diameter	0.0012**	0.1205NS	0.0135*	8.28
Number of branches per plant	0.0032**	0.0162*	0.0017**	6.90
Number of fruits per plant	0.0047**	0.0040**	0.0012**	12.90
Fruit length	0.0039**	0.0033**	0.0019**	8.56
Fruit diameter	0.1942NS	0.0146*	0.0671NS	7.08
Fresh fruit weight	0.0029**	0.0035**	0.0002**	11.18
Dry fruit weight	0.0023**	0.0031**	0.6591NS	33.69

**: Highly significant, *: Significant, NS: Not significant.

In contrast, the lowest number of branches per plant was recorded in the Chino genotype under all fertilization types evaluated.

Regarding the number of fruits per plant, the highest values corresponded to the Ancho Liso genotype under biological fertilization (22.5 fruits plant^{-1}), which was 43% higher than chemical fertilization and 25% higher than plants of the same genotype under organic fertilization (18 fruits plant^{-1}). In Carricillo, biological and chemical fertilization resulted in similar values for this variable, whereas the lowest fruit production was observed in Carricillo under organic fertilization (9.1 fruits plant^{-1}) (Table 2).

Fruit length varied significantly among genotypes and fertilization types, with the highest values observed in Carricillo under organic fertilization (8.93 cm) and Ancho Liso under chemical fertilization (8.61 cm), while the lowest values were recorded in the Chino genotype (5.21-6.29 cm) (Table 2).

Regarding fresh fruit yield, Ancho Liso plants were generally the most productive, whereas the Chino creole exhibited the lowest yield. Chemical fertilization was the most favorable treatment for increasing fresh fruit yield, as it promoted the highest response, with an average of 1.56 t ha^{-1}.

The genotype × fertilization interaction showed a highly significant effect, since Ancho Liso plants under chemical fertilization achieved the highest fruit yield (2.04 t ha^{-1}), compared with 0.66 t ha^{-1} produced by Carricillo under organic fertilization (Figure 1). It is important to note that in the Carricillo genotype, biological fertilization resulted in yields similar to those obtained with chemical nutrition, indicating that in this genotype, synthetic fertilizers can be replaced with environmentally friendly sources without reducing productivity.

Table 2. Plant height (PH), stem collar diameter (SCD), number of branches per plant (NBP), number of fruits per plant (NFP), and fruit length (FL) as a function of genotype and fertilization type in Apaxtleco chili pepper.

Genotype	Fertilization type	PH (cm)	SCD (cm)	NBP (No./plant)	NFP (No. plant)	FL (cm)
Ancho Liso	Biological	42.6 ab¶	0.7 ab	5.85 a	22.5 a	6.37 cd
	Organic	38.95 abc	0.68 ab	5.1 abc	18 ab	7.23 bc
	Chemical	46.0 a	0.75 ab	4.9 bc	15.7 bc	8.61 ab
Carricillo	Biological	37.4 bcd	0.78 a	5.25 abc	14.95 bc	7.65 abc
	Organic	30.25 d	0.7 ab	5.70 ab	9.1 d	8.93 a
	Chemical	32.55 cd	0.64 b	4.65 c	14 bc	8.18 ab
Chino	Biological	33.7 cd	0.64 b	4.45 c	12.35 cd	5.70 d
	Organic	33.35 cd	0.62 b	4.50 c	12.9 cd	5.21 d
	Chemical	29.15 d	0.62 b	4.85 bc	14.4 bc	6.29 cd
Mean		35.99	0.68	5.02	14.87	7.13
Prob. F		0.0483*	0.0135*	0.0017**	0.0012**	0.0019**
HSD$_{0.05}$		16.85	0.16	1.40	13.40	3.72

¶=means with different letters within each column differ statistically (Tukey, $p \leq 0.05$). HSD$_{0.05}$=honestly significant difference. **: Highly significant, *: Significant.

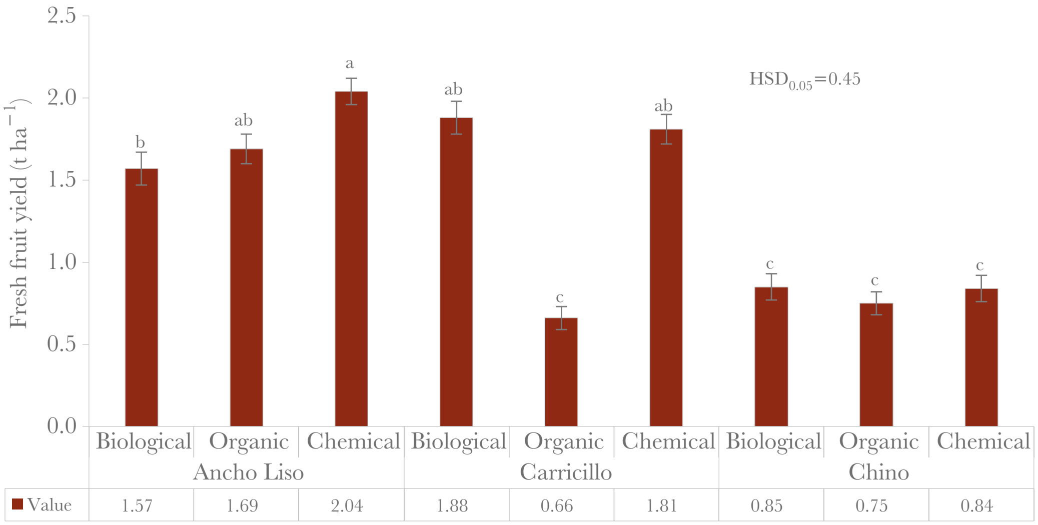

Figure 1. Fresh fruit yield of creole chili peppers under three types of fertilization. $HSD_{0.05}$=honestly significant difference.

Regarding profitability, the results indicate significant differences due to treatment effects. The Ancho Liso genotype under chemical fertilization showed the highest net profit (MXN \$7,282.5 ha^{-1}) and the most favorable benefit-cost ratio (RUI=0.23), followed by the same genotype under organic fertilization, with a net profit of MXN \$1,494.90 and a RUI of 0.006. Carricillo under biological fertilization, although with a lower margin, also showed positive profitability (RUI=0.04).

In contrast, treatments associated with the Chino genotype resulted in economic losses under all three fertilization types, indicating lower adaptation or productive potential under the agroecological conditions of the region. A similar situation was observed for Carricillo under chemical and organic fertilization, which also resulted in economic losses (Table 3).

Table 3. Profitability of the nine treatments (MXN \$ ha^{-1}).

Treatment	TC	TI	NI	RUI
Ancho Liso + Chemical Fert.	31,357.50	38,2640.00	7,282.50	0.23
Ancho Liso + Organic Fert.	24,637.50	26,132.40	1,494.90	0.06
Ancho Liso + Biological Fert.	24,483.00	24,766.00	283.00	0.01
Chino + Chemical Fert.	31,357.50	10,822.00	−20,535.53	−0.65
Chino + Organic Fert.	24,637.50	9,276.40	−15,361.10	−0.62
Chino + Biological Fert.	24,483.00	10,183.60	−14,299.40	−0.58
Carricillo+ Chemical Fert.	31,357.50	25,023.60	−6,333.90	−0.20
Carricillo + Organic Fert.	24,637.50	9,895.20	−14,742.30	−0.60
Carricillo + Biological Fert.	24,483.00	25,370.80	887.80	0.04

TC=Total cost, including fixed costs (land preparation, fertilization, weed control, pest and disease management) plus variable costs (biofertilizer, fertilizers, and labor); TI=Total income; NI=Net income (TI=total income-TC=total costs); RUI=Return per unit of investment.

The higher fruit yield observed in the Ancho Liso genotype under chemical fertilization can be attributed to the fact that this treatment resulted in the greatest plant height and among the highest values for stem collar diameter and fruit length. Likewise, the significant differences observed among genotypes indicate genetic variability among Apaxtleco creole chili peppers from the state of Guerrero, which is consistent with reports by Sahmat *et al.* (2024) and Baruah *et al.* (2024), who indicate that productive responses in *Capsicum* spp. are strongly influenced by the genotype × environment interaction. In the present study, the interaction with fertilization type was decisive, showing that genotypes respond differently to the type of nutritional management applied.

Chemical fertilization promoted the highest values of plant height, fruit weight, and yield, which is consistent with findings reported by Díaz-José *et al.* (2023), Kunwar *et al.* (2024), and Chemweno *et al.* (2025), who observed increases in biomass and fruit number in regional chili peppers under readily available mineral sources. In this study, the chemical source supplied exclusively nitrogen, phosphorus, and potassium, which are primary nutrients essential for vegetative growth and fruit filling. Their rapid availability favored a more immediate response in the Ancho Liso genotype, which exhibited high efficiency in the uptake and use of these elements, particularly nitrogen. According to Guo *et al.* (2024), nitrogen is associated with increased chlorophyll synthesis and photosynthetic activity. The higher solubility of mineral salts allowed a continuous supply of N, P, and K during critical crop stages, resulting in more vigorous plant development and higher average fruit weight. This behavior suggests that Ancho Liso has high nutritional demand and lower dependence on biological mineralization processes, which explains its greater response to chemical management compared with organic or biological sources.

However, biological fertilization stood out for promoting more balanced vegetative structures, expressed as a greater number of branches and increased stem thickness, which could contribute to improved productivity, as reported by Helbert *et al.* (2024), who evaluated the effect of biological fertilization on habanero chili under protected conditions. In the Carricillo genotype, biological fertilization based on inoculation with plant growth–promoting microorganisms (PGPR and arbuscular mycorrhizal fungi) showed efficiency comparable to that of chemical fertilization, suggesting greater compatibility of this genotype with rhizospheric microbiota. Recent studies have demonstrated that mycorrhizae enhance phosphorus uptake in soils with alkaline pH, while bacteria such as *Azospirillum* spp. stimulate root development and atmospheric nitrogen assimilation, which can partially compensate for the absence of mineral fertilizers (Giri *et al.*, 2025; Peng *et al.*, 2025). This symbiotic interaction enables more sustained nutrient supply and improves tolerance to drought or nutrient-deficient conditions, explaining why Carricillo maintained similar yields under both biological and chemical fertilization.

Organic fertilization, although resulting in intermediate yields, showed positive effects on fruit quality and an acceptable economic response in the Ancho Liso genotype. This behavior is consistent with the findings of Islas-Valdez *et al.* (2025), who reported that organic matter improves soil moisture retention and the availability of essential micronutrients, thereby contributing to a favorable physiological balance for fruit formation. However, the time required for the mineralization of organic compounds and the slow release of N, P, and K may have limited the initial crop response, particularly in soils such as those used in the present study, which are characterized by low organic matter content and a pH above 7.5 (Naz *et al.*, 2022). This likely explains the lower yields observed compared with those obtained under chemical fertilization.

In terms of profitability, the superiority of the Ancho Liso + chemical fertilization treatment indicates a strong response of this genotype to mineral nutrient sources under the edaphoclimatic conditions of the state of Guerrero. Nevertheless, biological fertilization proved to be a viable alternative from both an economic and environmental perspective, particularly in the Carricillo genotype, where positive profitability and improvements in morphological traits suggest a balance between productivity and sustainability. Overall, the results indicate that for the Ancho Liso genotype, chemical nutrition is the most appropriate option for achieving higher production and economic profitability. In contrast, in the Carricillo genotype, production under biological and chemical fertilization was statistically similar, indicating that synthetic fertilizers can be replaced with biological inputs without reducing the yield of Apaxtleco creole chili peppers. This substitution may reduce environmental impacts while maintaining acceptable profitability. Furthermore, this biologically based management approach aligns with the challenges and goals proposed by FAO (2017) and represents a viable strategy for strengthening regional productivity without compromising agroecosystem health.

CONCLUSIONS

The genotype × fertilization type interaction significantly influenced morphological, productive, and economic variables, indicating differential responses to fertilization strategies. The Ancho Liso genotype under chemical fertilization achieved the highest fruit yield and the greatest profitability. In the Carricillo genotype, biological fertilization produced fruit yields and morphological trait values comparable to those obtained with chemical fertilization and resulted in positive net income. In contrast, the Chino genotype exhibited low productivity and economic losses under all fertilization types evaluated.

ACKNOWLEDGMENTS

The authors thank the producers of Apaxtla de Castrejón, Guerrero, for donating the genetic material of the three creole chili peppers for research purposes under different environmental conditions, with the aim of generating sustainable management strategies for the production of this horticultural crop for the benefit of the population of the state of Guerrero.

REFERENCES

Ayvar, S. S., Mena B. A. y Durán R. J. A. (2007). El cultivo de chile criollo y su manejo integrado. Iguala, Gro., México. 79 p.

Baruah, J., Begum, T., & Lal, M. (2024). Estimation of environment stability for fruit yield and capsaicin content by using two models in *Capsicum chinense* Jacq (Ghost Pepper) with multi-year evaluation. *Peer J*, 12, e17511. https://doi.org/10.7717/peerj.17511.

Carrizo-García, C., Barfuss, M. H., Sehr, E. M., Barboza, G. E., Samuel, R., Moscone, E. A., & Ehrendorfer, F. (2016). Phylogenetic relationships, diversification and expansion of chili peppers (*Capsicum*, Solanaceae). *Annals of botany, 118*(1), 35-51. https://doi.org/10.1093/aob/mcw079.

Carvajal Muñoz, J. S., & Mera Benavides, A. C. (2010). Fertilización biológica: técnicas de vanguardia para el desarrollo agrícola sostenible. *Producción + limpia, 5*(2), 77-96.

Chemweno, S. J., Owusu Kwakye, D., Rachmilevitch, S., Ephrath, J., & Lazarovitch, N. (2025). Root growth and yield responses to nitrogen levels in bell pepper (*Capsicum annuum*) cultivation: balancing nutrient efficiency and productivity. *Frontiers in Plant Science*, 16, 1589560. https://doi.org/10.3389/fpls.2025.1589560.

Chhipa, H. (2017). Nanofertilizers and nanopesticides for agriculture. *Environmental chemistry letters, 15*(1), 15-22. https://doi.org/10.1007/s10311-016-0600-4.

Díaz-José, J., Andrés-Meza, P., González-Cuevas, B. M., Leyva-Ovalle, O. R., & Cebada-Merino, M. (2023). Chemical and organic fertilization on the yield of Serrano pepper (*Capsicum annuum* L.) in Veracruz, Mexico. *Revista BioCiencias*, 10. e1472. https://doi.org/10.15741/revbio.10.e1472.

FAO (2017). The future of food and agriculture – Trends and challenges. Rome. https://www.fao.org/3/i6583e/i6583e.pdf. Fecha de consulta: 22 de octubre de 2025.

García, E. (2004). Modificación al sistema de clasificación climática de Köppen. Universidad Nacional Autónoma de México. Distrito Federal, México. 90 p.

Giri, B. R., Chattaraj, S., Rath, S., Pattnaik, M. M., Mitra, D., & Thatoi, H. (2025). Unveiling the Molecular Mechanism of *Azospirillum* in Plant Growth Promotion. *Bacteria, 4*(3), 36. https://doi.org/10.3390/bacteria4030036.

Guo, P., Ren, J., Shi, X., Xu, A., Zhang, P., Guo, F., & Jiang, C. (2024). Optimized nitrogen application ameliorates the photosynthetic performance and yield potential in peanuts as revealed by OJIP chlorophyll fluorescence kinetics. *BMC Plant Biology, 24*(1), 774. https://doi.org/10.1186/s12870-024-05482-x.

Helbert, M. M., Narvaez, I. S. T., & Matu, J. A. C. (2024). Uso de biofertilizantes en la producción de Chile Habanero (*Capsicum chinense* jacq.) en condiciones protegidas. *P'unguari Juáta Revista Multidisciplinaria de Ciencias, 1*(1), 34-52.

Islas-Valdez, S., Sproull, R., Sumners, T., & Wagner, N. (2025). Effect of Organic Amendments and Biostimulants on Zucchini Yield and Fruit Quality Under Alkaline Conditions. *Agriculture, 15*(19), 2078. https://doi.org/10.3390/agriculture15192078.

Kunwar, P. B., Khatri, S., & Bhusal, T. N. (2024). Effect of NPK Levels on Growth and Yield of Sweet Pepper (*Capsicum annum*) under Different Growing Conditions in Arghakhanchi, Nepal. *Nepalese Horticulture, 18*(1), 8-17. https://doi.org/10.3126/nh.v18i1.72671.

Ontiveros-Sajuan, M. L., Hernández-Ramos, J., García-Magaña, J. J., Moguel-Ordóñez, Y. B., & Herrera-Basurto, J. (2024). Morfometría y rendimiento de *Capsicum chinense* Jacq. en Arteaga, Michoacán. *Revista mexicana de ciencias agrícolas, 15*(6), https://doi.org/10.29312/remexca.v15i6.3763.

Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., & Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. In Microbiota and biofertilizers, Vol 2: Ecofriendly tools for reclamation of degraded soil environs (pp. 1-20). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-61010-4_1.

Peng, Z. C., Xing, Y. X., Ma, Y. H., Li, S. H., Jia, Y. X., Yang, H. C., & Zhang, F. H. (2025). Arbuscular mycorrhizal fungi enhance soybean phosphorus uptake and soil fertility under saline-alkaline stress. *Scientific Reports, 15*(1), 31792. https://doi.org/10.1038/s41598-025-15910-z.

Mendoza-Elos, M., Zamudio Alvarez, L. F., Cervantes Ortiz, F., Chable Moreno, F., Frías Pizano, J., & Gámez Vázquez, A. J. (2020). Rendimiento de semilla y calidad de fruto de chile habanero con fertilización química y orgánica. *Revista Mexicana de Ciencias agrícolas, 11*(8), 1749-1761. https://doi.org/10.29312/remexca.v11i8.1960.

Naz, M., Dai, Z., Hussain, S., Tariq, M., Danish, S., Khan, I. U., ... & Du, D. (2022). The soil pH and heavy metals revealed their impact on soil microbial community. *Journal of Environmental Management,* 321, 115770. https://doi.org/10.1016/j.jenvman.2022.115770.

Sahmat, S. S., Rafii, M. Y., Oladosu, Y., Jusoh, M., Hakiman, M., & Mohidin, H. (2024). Unravelling the dynamics of genotype and environment interactions on chilli (*Capsicum annuum* L.) yield-related attributes in soilless planting systems. *Scientific Reports, 14*(1), 1698.

SAS (2017). SAS/STAT User's guide, version 9.4. SAS Institute Inc. North Caroline, USA.

Singh, S., Devi, N. B., Divya, D., Kumar, A., Singh, S., Tyagi, G., & Kumar, A. (2024). Soil fertility management: Role of organic amendments and bio-fertilizers: A review. *International Journal of Research in Agronomy, 7*(12), 766-772. https://doi.org/10.33545/2618060X.2024.v7.i12j.2253.

Sharma, D., Gahtyari, N. C., Chhabra, R., & Kumar, D. (2020). Role of microbes in improving plant growth and soil health for sustainable agriculture. In Advances in plant microbiome and sustainable agriculture: diversity and biotechnological applications (pp. 207-256). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-15-3208-5_9.

Skowroñska, M., & Filipek, T. (2014). Life cycle assessment of fertilizers: a review. *International Agrophysics, 28*(1). 101-110. https://doi.org/101:110. 10.2478/intag-2013-0032.

Volke, H. V. (1982). Optimización de insumos en la producción en la agricultura. Colegio de Postgraduados, Chapingo. México. 61 p.

Zulfiqar, F., Navarro, M., Ashraf, M., Akram, N. A., & Munné-Bosch, S. (2019). Nanofertilizer use for sustainable agriculture: Advantages and limitations. *Plant science*, 289, 110270. https://doi.org/10.1016/j.plantsci.2019.110270.