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Effect of Organic and Inorganic Fertilizers on the Yield and Quality of Jalapeño Pepper Fruit (*Capsicum annuum* L.)

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Abstract: Organic fertilizers were evaluated on jalapeno pepper (*Capsicum annuum* L.) and on their effect on the soil content of nitrogen (N), phosphorus (P), electrical conductivity (EC), pH and organic matter (OM), at the Experimental Station of the Agriculture and Zootechnics Faculty (FAZ-UJED), Ejido Venecia, Durango, México. The assayed experimental fertilizers were vermicompost (VC) with 0 and 3 Mg ha⁻¹, in factorial combination with solarized manure (SM), with 0, 40, 80, and 120 Mg ha⁻¹, and an inorganic fertilization nitrogen-phosphorus-potassium (NPK) at 150–100–00 Mg ha⁻¹. Microbiological analyses were performed to evaluate the presence of *Salmonella* spp. The highest yield was 56.2 Mg ha⁻¹ with 120 Mg ha⁻¹ SM, which was statistically similar to 40 and 80 Mg ha⁻¹; the highest P content (70.7 mg kg⁻¹) and OM (3.7%) occurred with 120 Mg ha⁻¹ SM. The inorganic fertilizer reflected the lowest OM (1.1%). Nutrients provided by SM were sufficient to satisfy the crop needs. Values of pH, EC and N were not affected by SM. The fruit quality was not affected by the organic fertilizers. Most fruits were classified as Second-Class Quality (60%), followed by First-Class Quality (25%). Microbiological analyses were negative for *Salmonella* spp., suggesting that the SM is effective in its elimination.

Keywords: manure; vermicompost; solarized manure; jalapeno pepper; jalapeno fruit; food safety

1. Introduction

The cultivation of peppers is considered an important issue to human food consumption. The world fresh pepper production in 2014 was at about 31,000,000 tonnes [1]. Mexico reached the second world place in 2014 as a green chili pepper producer, with a production volume of 2,700,000 tonnes on a harvested surface of 14,300 ha, while for 2018 the national production was estimated at 3,100,000 tonnes, with an average increase of 10.29% in four years [2]. Mexico is the first green chili pepper exporter in the world; the main export destinations are the United States and Canada. Among the principal chili pepper varieties cultivated in Mexico, we find the jalapeño pepper, serrano, habanero, poblano and morrón (bell pepper) [3].

The official agricultural SIAP on-line system (2016) reported a harvested surface of 637.8 ha and a production of 25,073.9 Mg ha⁻¹ in 2015 for the Laguna-Durango District [4], in arid northern Mexico. Nowadays, the needs to reduce the costs associated with crop fertilization and the loss of soil fertility have raised interest and called the attention of producers regarding the use of organic amenders as alternative low-cost fertilizers. The above-mentioned has the purpose to supply the minimal nutritional requirements of crops, and moreover to promote higher yields and a better fruit quality, with lower impacts on the surrounding environment and natural resources, including the soil and water [5]. In the last decades, the organic substrates have been evaluated in different ways to establish their benefits in the development of the plants; accordingly, the yield of a crop such as the chili pepper depends on the nutritional balance, mainly N and P [6]. For a jalapeno pepper crop, a dose of 40 Mg ha⁻¹ of solarized manure increased the yield by 5.98%, compared with inorganic fertilization [7]. It is well documented that the yield of a crop after the incorporation of organic substrates is an adequate indicator of its benefits in relation to other variables. In this sense, the productivity of chili pepper crop with organic fertilization increased by 44%, related by 34% to the final number of fruit, 40% to the length of the fruit and 26% to the diameter with organic fertilization compared to inorganic fertilization [5].

The organic matter content must be considered when planning the use of organic fertilizers; Vázquez-Vázquez et al. [7] found that a dose of 80 Mg ha⁻¹ of solarized manure reflected a content of 2.47% organic matter (OM) at the end of the cycle, compared to 1.61% with the inorganic fertilization treatment. Increasing the OM content contributes to nutrients of great importance for the development of the crops, and the physical properties of the soil can be improved [8]. In this sense, vermicompost is currently used as an organic substrate, and its production is carried out through biochemical and microbiological transformations of the organic matter through the digestive tract of worms [9]. This substrate, as well as municipal solid waste compost, has a high potential as a fertilizer in agriculture due to its nutritional, physical, chemical and biological characteristics, which are also reflected in the production of tomato and pepper seedlings [10], as well as pepper fruits [11], promoting a greater yield and increase in the content of photosynthetic pigments in the chili pepper crop [12].

The gained benefits after the incorporation of organic fertilizers are numerous; nevertheless, the microbiological safety of fresh products could imply a food quality risk due to the incorporation of non-composted animal manure. This is because in agricultural soils, animal manure is a known source of enteric pathogens such as *Salmonella enterica* serotype typhimurium [13]. In facing these concerns, alternatives to reduce the risk of contamination of crops by pathogens are being analyzed, such as by proposing the solarization of manure [14].

Therefore, the aim of this research was to evaluate organic fertilization with solarized manure (SM) and vermicompost (VC), compared with an inorganic NPK fertilizer, in the production, quality and safety of jalapeño pepper, as well as in soil properties.

2. Materials and Methods

2.1. Study Site

The study was conducted in the Agricultural Station of the Agriculture and Zootechnics Faculty of the Juarez University of the State of Durango (FAZ-UJED), located between the parallels 25°32' and 25°54'N, and meridians 103°19' and 103°42'W, in the Ejido Venecia, Gómez Palacio, Durango, Mexico (Figure 1). The altitude is 1100–1800 m, with a rainfall of 243 mm and annual mean temperature of 22.1 °C [15].

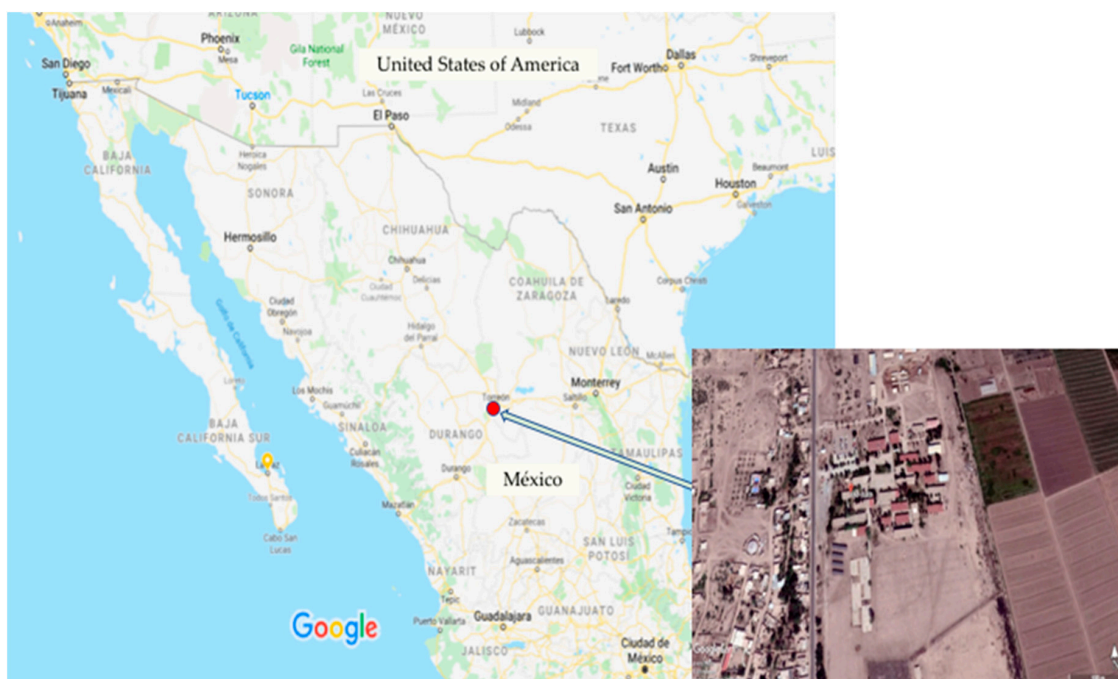


Figure 1. The geographic location of the Agriculture and Zootechnics Faculty, Juarez University of the State of Durango, northern Mexico.

2.2. Experimental Section

At the end of the summer agricultural season in 2014, a jalapeño pepper crop (*Capsicum annum* L.) c.v. “Grande” was established to evaluate different doses of organic fertilizers. The study factors were the solarized manure (SM) and vermicompost (VC). The main soil properties at the experimental site were: the clayey texture (45% clay, 24% sand, 31% silt); pH: 7.8; EC: 4.27 dS m⁻¹; OM: 2.31%; inorganic N: 22.6 mg kg⁻¹; and P: 16.6 mg kg⁻¹. Plantlets were established on April 11th 2014; the planting systems were in a bed with a 30 cm distance between plants and 50 cm between the rows. A T-tape drip irrigation was installed and designed for an irrigation program of 6 h per day, every third day.

In order to carry out the manure solarization process, one-meter high piles were made with 25% humidity and covered with plastic. The time for the solarization process took one month. The SM doses were 0, 40, 80 and 120 Mg ha⁻¹; the doses for VC were 0 and 3 Mg ha⁻¹; and the inorganic fertilizer dose was 150–100–00 kg ha⁻¹ (N–P–K), using urea and monoammonium phosphate (MAP) as source of N and P, for 10 treatments with three repetitions. The experimental treatments in Mg ha⁻¹ (except NPK, in kg ha⁻¹) were: (1) SM 0 + VC 0, (2) SM 0 + VC 3, (3) SM 40 + VC 0, (4) SM 40 + VC 3, (5) SM 80 + VC 0, (6) SM 80 + VC 3, (7) SM 120 + VC 0, (8) SM 120 + VC 3, (9) 150–100–00 kg ha⁻¹ (N–P–K) + VC 0, and (10) 150–100–00 kg ha⁻¹ (N–P–K) + VC 3. The organic fertilizers were applied manually and incorporated with disc harrow on March 11th, 2014.

The nutrients content of the SM and VC are shown in Table 1. A commonly used digestion of compost was used to prepare the samples for analysis; this method measures all of a nutrient that is present in compost, whether it is in a plant-available form or not, so that the result is known as the total nutrient analysis. The total N was analyzed via the Kjeldhal method, and ammonium was determined via the distillation method [16]. The total P was analyzed by colorimetry; potassium, calcium, magnesium, sodium, molybdenum, iron, zinc and copper were analyzed in total form by atomic absorption, with digestion in a mixture of hydrochloric-perchloric acid; the pH and EC were determined in a relation of amender:water of 1:2; the organic matter was determined by calcination [17].

Table 1. The nutrients content of the solarized manure (SM) and vermicompost (VC).

Chemical Composition	SM	VC
Nitrogen (N) (as N _{total}), %	1.12	1.36
Ammonium (NH ₄ ⁺), mg kg ⁻¹	1135.00	40.00
Phosphorus (P), %	0.35	0.66
Potassium (K), %	3.27	2.63
Calcium (Ca), %	3.38	3.47
Magnesium (Mg), %	0.71	0.71
Sodium (Na), mg kg ⁻¹	0.97	0.73
Molybdenum (Mo), mg kg ⁻¹	560	5.1
Iron (Fe), mg kg ⁻¹	12,300	7800
Zinc (Zn), mg kg ⁻¹	198	252
Copper (Cu), mg kg ⁻¹	45	112
pH	7.6	9.84
Electrical conductivity (EC), dS m ⁻¹	8.30	11.48
Organic matter (OM), %	54.70	42.36

2.3. Yield and Fruit Quality

For the yield assessment, seven cuts of fruits were made at 50, 71, 84, 94, 106, 120 and 134 days after the transplant in 12 central plants per experimental unit; for this purpose, the size of the useful plot was 8.64 m². The quality of the fruits was evaluated according to the classification of Vázquez et al. [7], based on the length of the fruit. In order to evaluate the innocuousness of the fruits, a sampling of each of the treatments was carried out 84 days after the transplant, and a microbiological analysis was made in the Biotechnology Laboratory of FAZ-UJED. An amount of 25 g of jalapeño pepper ripe fruit was placed in 225 mL of buffered peptone water, shaken and incubated for 24 h at 35 ± 2 °C; subsequently, a subsample of 0.5 mL of each treatment was taken and placed in 10 mL of tetrathionate broth, before being incubated for 24 h at 42 ± 0.5 °C. Later, they were seeded on brilliant green agar and incubated for 24 h at 35 ± 2 °C. For the colonies suspected of being *Salmonella*, biochemical tests were performed using lysine and iron agar (LIA), triple sugar iron (TSI), after which they were incubated for 24 h at 35 °C, in an Ecoshel® incubator (Ecoshel Technology Ltd., Mcallen TX USA), model 9165. The procedure followed the technique for the identification and isolation of *Salmonella* spp., according to the method described by the US Department of Agriculture, Food Safety and Inspection Service USDA-FSIS [18].

2.4. Soil Analysis

At the end of the experiment, soil samples were collected with an AMS® soil auger (AMS, Inc., American Falls, ID 83211, USA); the soil samples were taken at depths of 0–15 cm, 15–30 cm and 30–60 cm to determine the effect of the experimental doses of organic fertilizers on the soil. The analyzed parameters are shown in Table 2. The analytical methods were those described in the Official Mexican Standard Norm NOM-021-SEMARNAT-2000 [19].

Table 2. Methods applied for the soil analysis, according to the Standard Mexican Norm (*).

Parameter	Abbreviation	Unit	Method
Inorganic nitrogen	N	mg kg ⁻¹	Steam drag with Devarda's alloy and magnesium oxide method
Phosphorus	P	mg kg ⁻¹	Olsen method
Electric conductivity	EC	dS m ⁻¹	Saturated extract conductivity
Organic matter	OM	%	Walkley and Black method
Hydrogen potential	pH		Potentiometer
Texture		%	Bouyoucos method

(*) Standard Mexican Norm NOM-021-SEMARNAT-2000 [19].

2.5. Experimental Design and Statistical Analysis

The experiment that was establishment was based on a random block design with an arrangement in strips and with three replications. The data were analyzed with an analysis of variance (ANOVA) at two levels and with pair-wise comparisons, and a correlation coefficient was calculated. Statistical analyses were generated with the SAS-STAT® software (version 9.3, © SAS Institute Inc., SAS Campus Drive, Cary, North Carolina 27513, United States of America) for Windows [20].

3. Results and Discussion

3.1. Yield

According to the ANOVA, the VC reflected a non-significant effect on the yield of the pepper crop; this may be due to the fact that the applied dose of 3 Mg ha⁻¹ could be low, compared with other studies. Although in previous studies there was a significant difference in the yield of a lettuce crop when fertilizing with a dose of 20 Mg ha⁻¹ VC compared with a dose of 10 Mg ha⁻¹ [21], in this research we applied 3 Mg ha⁻¹ due to its high cost and because this dose is commonly used by the producers of the study region. Considering the averages, the SM reflected a yield of 49.6 Mg ha⁻¹ with the application of 3 Mg ha⁻¹ VC, compared with the yield of 50.2 Mg ha⁻¹ produced by SM without VC; moreover, it was detected that the interaction of VC with SM evidenced non-significant differences within each harvest, whose main effects that we found are presented in Table 3. On the other hand, the doses of SM exerted a significant effect on the yield; anyway, the treatments that received N, either as inorganic fertilizer or as manure, promoted a higher yield than the control. It is clear that the non-application of SM produced the lowest yields (33.08 and 35.69 Mg ha⁻¹) (Table 3A); in contrast, the doses of 40 and 80 Mg ha⁻¹ reflected higher yields (54 and 55 Mg ha⁻¹) than that of the SM control, as well as that of the inorganic fertilizer (49.6 Mg ha⁻¹). In sum, all doses of SM reflected a higher yield than the inorganic fertilizer, with 120 Mg ha promoting the greatest effect, producing 56.2 Mg ha⁻¹ ($p < 0.05$) (Table 3B). The obtained results coincide with those previously reported by Vázquez et al. [7], who obtained a production of 58.07 and 54.66 Mg ha⁻¹ with doses of 40 and 60 Mg ha⁻¹ of solarized cow manure.

The benefits of the use of manure as a fertilizer have been previously reported by other authors; in this context, Figueroa et al. [22] concluded that it is possible to partially or totally substitute the inorganic fertilizers with manure in corn forage, obtaining dry matter yields equal or greater than the ones obtained using only inorganic fertilizer. This confirms that manure can be used as a viable option to totally or partially replace inorganic fertilizers in the cultivation of different crops.

3.2. Fruit Quality

Fruits were collected and measured for their size-type classification (Figure 2); fruits of second quality reached the highest percentage in all the treatments, attaining up to 58% with a dose of 80 Mg ha⁻¹ SM, which follows the fact that, on average, harvests were made every 14 days, only taking into consideration the easy detachment of the peduncle. In addition, the size corresponding to this quality is the most accepted by the food industry. First class-size quality fruits reached more than 30% in all treatments. The percentages of the third quality varied from 7.6% for the control to 12% for the dose of 80 Mg ha⁻¹; however, fruits from the fourth quality (the lowest size quality for the market) did not reach 1% in any treatment. In any case, no significant differences were detected between the treatments for the different fruit qualities (Figure 3).

The obtained results coincide with those reported previously for a jalapeno pepper crop, with doses of 20, 40, 60 and 80 Mg ha⁻¹ of SM and a dose of inorganic fertilization; a similar fruit quality with similar treatments was obtained; these authors reported percentages from 46.1 to 50.5% for first quality fruits, 43.4 to 46% for second quality fruits, less than 10% for third quality fruits and less than 1% for fourth quality fruits [7].

Table 3. A comparison of the yield means for a jalapeño pepper crop in Gómez Palacio, Durango., Mexico, in seven harvest dates and the total yield; (A): Effects of the experimental doses, (B): Effects of the organic fertilizers.

SM	Doses VC	Number of Harvests							Total Yield
		1	2	3	4	5	6	7	
Mg ha ⁻¹		Days after Transplant							Mg ha ⁻¹
		50	71	84	94	106	120	134	
A: Effects of experimental doses									
0	0	0.78	1.08	6.02	7.90	6.55	6.64	4.11	33.08
	3	0.91	1.54	6.13	7.30	8.82	7.28	3.71	35.69
40	0	1.34	1.93	9.97	10.06	11.18	10.64	9.88	54.99
	3	1.17	2.84	9.92	9.91	10.34	11.26	8.08	53.52
80	0	1.48	2.73	10.07	10.98	11.68	11.29	8.83	57.07
	3	1.17	2.66	9.51	10.67	11.35	11.08	6.54	52.97
120	0	1.27	1.81	9.49	11.02	13.01	9.03	10.66	56.28
	3	1.58	3.83	8.99	11.26	10.21	12.74	7.45	56.06
150-100-00	0	1.06	2.20	8.58	10.05	10.63	8.20	8.76	49.47
	3	0.80	1.71	7.37	9.99	9.87	13.06	6.99	49.77
B: Effects of organic fertilizers									
VC	0	1.19	1.95	8.82	10.00	10.61	9.16	8.45	50.18
	3	1.12	2.52	8.38	9.83	10.12	11.08	6.55	49.61
SM	0	0.84 c	1.31 b	6.08 c	7.60 b	7.69 b	6.96 b	3.91 b	34.39 c
	40	1.25 ab	2.39 ab	9.95 a	9.98 a	10.76 a	10.95 a	8.98 a	54.26 ab
	80	1.33 a	2.69 a	9.79 ab	10.82 a	11.52 a	11.19 a	7.68 ab	55.02 ab
	120	1.42 a	2.82 a	9.24 ab	11.14 a	11.61 a	10.89 a	9.05 a	56.17 a
Inorganic	150-100-0	0.93 bc	1.95 ab	7.97 b	10.02 a	10.25 a	10.63 a	7.87 ab	49.62 b



(a)

(b)

Figure 2. Sampling (a) and measurement (b) of fruits for the yield and size-quality classification.

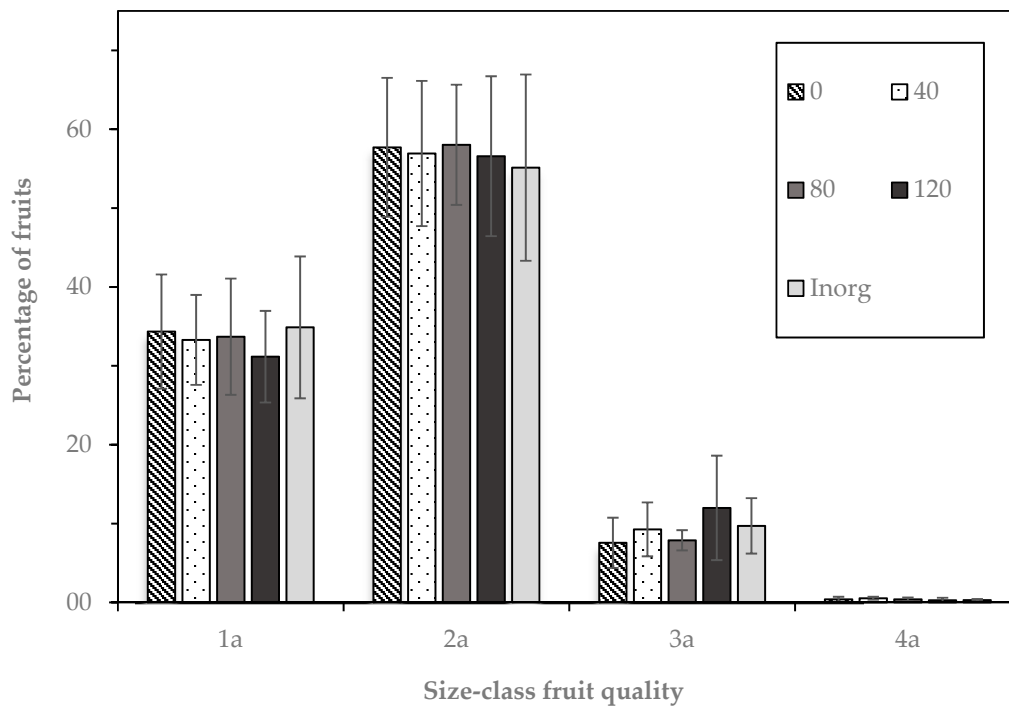


Figure 3. The percentage of the size-class quality of harvested fruits and the differences between the solarized manure treatments.

3.3. Safety

The presence of the pathogenic bacteria *Salmonella* spp. was not detected in the analyzed fruit samples, which allows for the interpretation that solarization is a process that is useful for eliminating this pathogen. This evidence matches with a previous study, which reported that the thermophilic solarization of manure is an effective active method for the control of manure-borne pathogens; this means that if the technique is applied correctly, the pathogen content in the original material decreases drastically [23].

3.4. Soil Properties

The effect of the VC on the evaluated soil variables was not significant, possibly because the applied dose was only 3 Mg ha⁻¹. In contrast, other researchers found that the N and P content in soil increased significantly with a dose of 15 Mg ha⁻¹ of VC in a tomato crop, compared to non-fertilized plots [24]. Given that the application of VC did not generate significant effects, the results are shown as averages of the SM main effects. The values of the pH varied from 7.8 to 8.1 at different depths and treatments. The highest pH value (8.1) was obtained with 120 Mg ha⁻¹ SM, and the lowest values (7.8) were observed for the control, the treatment with a dose of 40 Mg ha⁻¹, and with the inorganic fertilization. At a depth of 0–15 cm, the pH values were 7.8 for the control, the 40 Mg ha⁻¹ dose, and with the inorganic fertilization, and they reached 7.9 with 80 Mg ha⁻¹ and 120 Mg ha⁻¹ doses (Table 4). The increase in pH may result from the applied manure doses, since other authors reported an increase in the soil pH when evaluating the effectiveness of 10 organic fertilizers in wheat (*Triticum aestivum*) c.v. Batán F96 [25]. The results suggest that, although the highest doses of SM (80 and 120 Mg ha⁻¹) showed the highest pH values, this was not enough evidence to change the classification of the soil; hence, the study soil was classified as moderately alkaline in the different treatments, according to the Standard Mexican Norm NOM-021-RECNAT-2000 [19].

Table 4. A comparison of the means of the soil variables at the end of the 2014 summer agricultural season in a jalapeño pepper crop with SM and inorganic fertilizers; Gómez Palacio, Durango., Mexico.

SM and NPK Doses/Depth of Sampling	pH	EC dS m ⁻¹	N mg kg ⁻¹	P mg kg ⁻¹	OM %
Control					
0–15	7.8 a	5.9 a	31.9 a	46.4 ab	2.6 a
15–30	7.9 a	2.5 a	12.6 a	16.4 ab	1.5 ab
30–60	8.0 a	3.7 a	6.6 a	3.6 a	2.6 a
40 Mg ha ⁻¹					
0–15	7.8 a	4.9 a	36.2 a	45.9 ab	3.3 a
15–30	7.9 a	2.3 a	13.5 a	17.5 ab	1.5 ab
30–60	8.0 a	3.6 a	7.7 a	3.2 a	3.0 a
80 Mg ha ⁻¹					
0–15	7.9 a	4.9 a	32.3 a	56.3 ab	3.6 a
15–30	7.9 a	2.8 a	16.3 a	25.9 a	1.7 a
30–60	7.9 a	4.0 a	8.6 a	3.9 a	2.9 a
120 Mg ha ⁻¹					
0–15	7.9 a	5.3 a	38.6 a	70.7 a	3.7 a
15–30	7.8 a	2.5 a	13.7 a	16.5 ab	1.3 ab
30–60	8.1 a	4.2 a	6.3 a	4.3 a	2.6 a
150–100–00					
0–15	7.8 a	4.3 a	34.6 a	17.1 b	2.6 a
15–30	7.9 a	1.8 a	5.9 a	5.5 b	1.1 b
30–60	8.0 a	4.0 a	9.0 a	5.1 a	2.8 a

According to the classification proposed by Castellanos [26], the analyzed soil is a saline type, since the EC oscillated from 4.3 to 5.9 dS m⁻¹ at a depth of 0–15 cm. For the 15–30 cm depth, we found a moderately saline soil for the different treatments, except for the soil with inorganic fertilization, which reflected a value of 1.8 dS m⁻¹, corresponding to a soil with very low content of salts (Table 4). The increase in EC with organic fertilizers was also reported for the production of cucumber fertilized with different organic substrates (solarized cow manure, solarized goat manure and vermicompost), where the salt content increased as the decomposition of the substrates progressed, causing a notable increase in its concentration and in the EC value. In this case, because a drip irrigation was applied, the highest moisture content was found in the upper layer of the soil, which explains why the highest EC values were found at a 0–15 cm depth [27]. The highest OM value that was found was 3.7% at a depth of 0 to 15 cm with a dose of 120 Mg ha⁻¹ of SM, and the lowest value was 1.1% at a depth of

15–30 cm with the dose of inorganic fertilization (Table 4). The increase of soil OM is related to the incorporation of manure doses; other authors found that a soil with organic amendments in the form of SM caused a significant difference in the stability of its aggregates due to the percentage of OM and other agglutinating agents present in the soil compared to a soil without amendments [28].

In this study, the increase in the OM content corresponds to 0.7% with a dose of 40 Mg ha⁻¹, 1% with a dose of 80 Mg ha⁻¹, and 1.1% with a dose of 120 Mg ha⁻¹, compared to the control; this increase in the soil OM content coincides with the values reported by Trejo-Escareño et al. [29], who reported an increase of 1% in the OM content compared to the control at the end of the first year, after applying doses of 40, 80, 120 and 160 Mg ha⁻¹ of cattle manure as fertilizer for the production of corn forage. A quadratic numerical model expressing the OM increases as a function of the SM doses was derived (Figure 4).

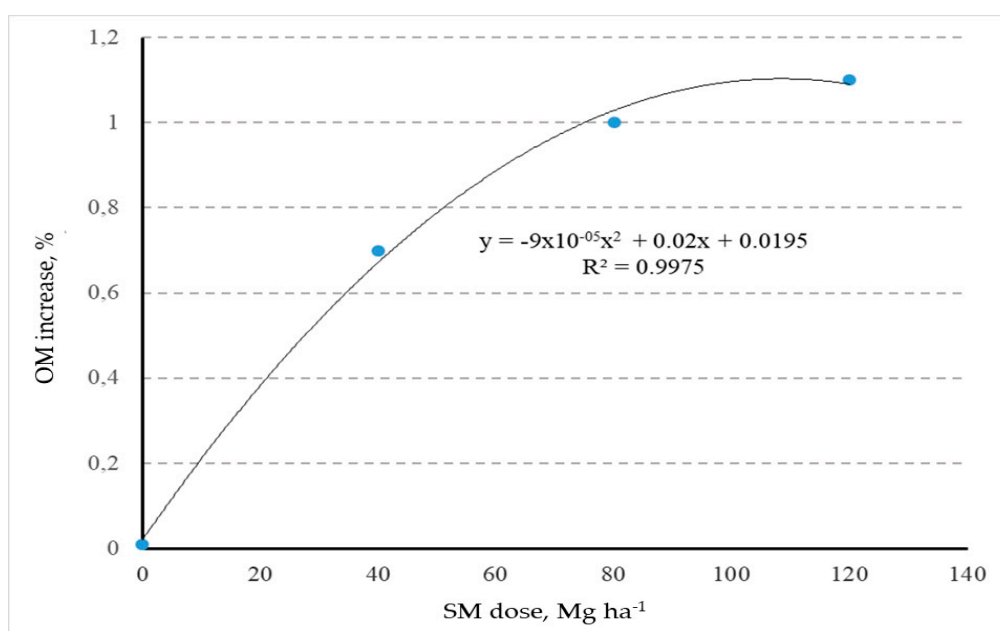


Figure 4. Preliminary quadratic function expressing the effect of SM doses (Mg ha⁻¹) on OM increases (%).

At the same time, the N content reflected a non-significant effect, reaching its highest values from 31.9 to 38.6 mg kg⁻¹ at a 0–15 cm depth, with a tendency to decrease with depth, with values from 5.9 to 16.3 mg kg⁻¹ at 15–30 cm, and 6.3 to 9.0 mg kg⁻¹ at 30–60 cm (Table 4). Similar results were reported by the mentioned authors, who, after ten years of application of manure for the production of fodder corn, found average nitrate values of 23.4, 37.8, 39.8 and 43.3 mg kg⁻¹ in soil samples fertilized with doses of 40, 80, 120 and 160 Mg ha⁻¹ [29]. On the other hand, the highest P content was detected for a 0–15 cm depth, with values from 17.1 to 70.7 mg kg⁻¹, similarly to N. The P concentrations varied according to the depth, varying from 5.5 to 25.9 mg kg⁻¹ at a 15–30 cm depth and 3.2 to 5.1 mg kg⁻¹ at a 30–60 cm depth (Table 4).

4. Conclusions

The nutrients provided to the soil by the applied doses of SM are enough to satisfy the studied jalapeno crop needs. It is important to mention that the reached yield with a dose of 120 Mg ha⁻¹ was significantly higher than that of the inorganic fertilization. Nevertheless, the applied doses of VC showed a non-significant contribution to the yield under the prevailing soil conditions.

The practice of fertilization with organic amendments allowed for the development of fruits with a commercial quality that compete directly in the market with fruits conventionally produced with inorganic fertilization.

The results of the assayed microbiological analyses suggest that the applied method for the solarization of manure is effective for controlling and eliminating colonies of the pathogenic bacteria *Salmonella* spp.

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