Colegio de Postgraduados

Synthetic fertilizers and vermicompost in juvenile Persian lime (*Citrus×latifolia* Tanaka ex Q. Jiménez) trees

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ABSTRACT
Objective: To evaluate fertilization with vermicompost and NPK mineral fertilizer in young Persian lime (*Citrus×latifolia* Tanaka ex Q. Jiménez) trees.
Design/Methodology/Approach: A randomized block design was established with eight treatments and four repetitions: T1, 0 kg tree^{-1}; T2, 90-22.5-22.5 N-P-K kg ha^{-1}; T3, 2 kg tree^{-1} of vermicompost; T4, 3 kg tree^{-1} of vermicompost; T5, 4 kg tree^{-1} of vermicompost; T6, 90-22.5-22.5 N-P-K kg ha^{-1} + 2 kg tree^{-1} of vermicompost; T7, 90-22.5-22.5 N-P-K kg ha^{-1} + 3 kg tree^{-1} of vermicompost; and T8, 90-22.5-22.5 N-P-K kg ha^{-1} + 4 kg tree^{-1} of vermicompost. The study variables were tree height, stem thickness, crown diameter from North to South (N-S) and East to West (E-W), soil pH, and soil moisture (%). The data were statistically analyzed applying the MINITAB V.17 statistic through an ANOVA ($P \leq 0.05$), while a multivariate analysis was used for the means comparison.
Results: The tree height and crown diameter variables had different results in the Persian lime trees treated with 4 kg tree^{-1} of vermicompost (T5). The tree canopy had a similar development than T5 with vermicompost treatments combined with NPK mineral fertilizer.
Study Limitations/Implications: Conventional lime production indiscriminately uses synthetic fertilizers, polluting natural resources. Organic fertilizers are a nutritional alternative for the trees.
Findings/Conclusions: The vermicompost treatment efficiently maintains adequate soil moisture during the dry season, improving the growth and development of Persian lime trees.

Keywords: Nutrition, citrus, vermicompost.

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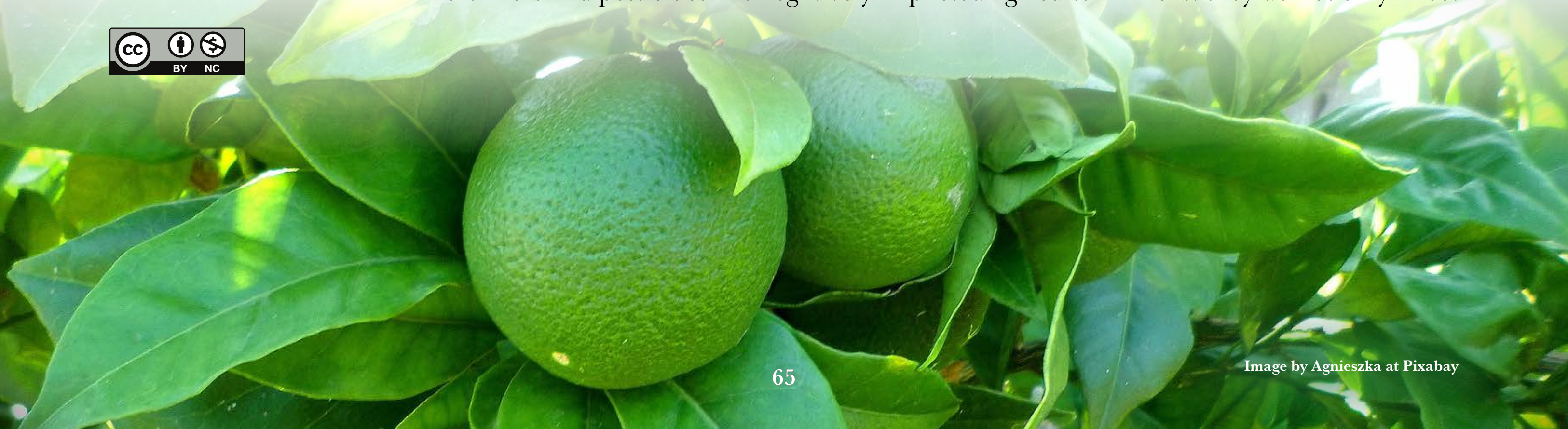
INTRODUCTION

The environmental awareness about pollution, environmental impacts, food safety, and food security has continuously increased in recent years. The intensive use of synthetic fertilizers and pesticides has negatively impacted agricultural areas: they do not only affect



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plant growth, but they also decrease the biological control of soil-borne diseases and reduce biodiversity, since they destroy the ecosystem, as well as the beneficial insects and the species from which birds and other animals feed (Andrade and Ayaviri, 2017; Castillo *et al.*, 2020; Castañeda *et al.*, 2021). As a consequence of the use of chemical fertilizers, nitrates run off or infiltrate into groundwater. The large amounts of fertilizers that are applied to crops are carried by water and wind before being absorbed by the plants and retained by soil particles. In developed countries, the use of synthetic fertilizers has been restricted, in favor of other forms of fertilization that are more sustainable and have less impact on the environment and public health (Eugencios *et al.*, 2017; FAO, 2020). The vermicomposting technique is a rational environmental tool, focused on the organic waste processed by earthworms. They carry out the composting process and produce a final output of high economic value called "vermicompost". Additionally, vermicompost is a clean, safe, and low-cost process for the producer (Ersahin *et al.*, 2009; Villegas and Laines, 2017).

Some earthworm species can consume organic material residues very quickly and fragment them into very small particles. This process is known as "grinder gizzard" and it is carried out by an organ of earthworms that promotes greater microbial activity. Consequently, the material (nitrogen, potassium, phosphorous, and calcium) is released and transformed into forms that are much more soluble and available to plants (Olivares *et al.*, 2012; Silveira *et al.*, 2018; Ramos *et al.*, 2019; Acosta *et al.*, 2021).

Organic fertilization in citrus trees has already been applied in Veracruz, Mexico. For example, Berdeja *et al.* (2018) evaluated the effect of two types of fertilizers (inorganic and organic) on Persian lime (*Citrus×latifolia*) fruits, proving that there are no significant differences in the values of the fruit parameters (weight, peel thickness, nutritional content, etc.). According to the results, the growth and development of the fruit achieved with organic fertilization was very similar to the fruits fertilized using an inorganic (chemical) fertilizer. Therefore, the objective of this research was to evaluate the fertilization with vermicompost and synthetic fertilizer formula in Persian lime trees recently planted in Jesús Carranza, Veracruz, Mexico.

MATERIALS AND METHODS

The experiment was carried out at the facilities of the Tecnológico Nacional de México/ Instituto Tecnológico Superior de Jesús Carraza, located in the municipality of Jesús Carranza, Veracruz, Mexico.

Figure 1. Location of the municipality of Jesús Carranza, Veracruz.

Treatments

The tree plantation was sown in December 2020. The tree management partially consisted of formative pruning and pruning of suckers and branches resulting from the pattern of the trees. Two types of foliar applications were made: 1) abamectin and humic and fulvic acids; and 2) liquid inorganic fertilizer (5.9% nitrogen+20.9% phosphorus). Additionally, hormonal applications were carried out with the Agromil V product (cytokinins, gibberellins, auxins, and folic acid).

The lime trees were nurtured at 127 days, applying the different fertilization treatments at 50 cm from the trunk of the trees (Table 1).

In the tree plantation, the different doses of fertilization based on vermicompost, and chemical formulas were evaluated. The fertilization treatments were applied per grafted Persian lime tree; some treatments were mixed with mineral fertilization based on N-P-K.

The mineral fertilization dose was determined per hectare and the dose per tree was calculated based on the planting density (357 trees per hectare). Only one full-dose application formula nutrition (N-P-K) was made per tree (Table 1).

The experimental unit consisted of two Persian lime trees, with an edge tree on each side. Each treatment has four replications, and the fertilization dose treatments are distributed in a randomized complete block design (Table 1).

The fertilizer sources corresponded to urea (46N-0-0), triple 17 (17N-17P-17K), and vermicompost. The composition is C: 18.57%, total N: 2.24%, C/N ratio: 8.13, N-NO_3: 583 mg kg^{-1}, P: 0.12%, K: 0.79%, Ca: 1.33%, Mg: 1.21%, Na: 0.12%, Fe: 357 mg/kg^{-1}g, Zn: 91 mg kg^{-1}g, Mn: 196 mg kg^{-1}g, Cu: 38 mg kg^{-1}g, and pH: 6 (Olivares *et al.*, 2012). The variables measured were tree height, stem thickness, crown diameter from North to South (N-S) and East to West (E-W), soil pH, and soil moisture (%). The last variable was measured with a VT-05q humidity monitor hygrometer. The variables were measured at 136 days and at 164 days.

The statistical analysis of the growth and development variables of the fertilized trees was carried out with the MINITAD version 17 software, performing an analysis of variance (95% reliability), a three-dimensional relationship analysis, and a multivariate analysis.

Table 1. Fertilization treatments with vermicompost and mineral in Persian lime trees.

Treatment	Source	Soil fertilization dose
1	0	0
2	Mineral	90-22.5-22.5 NPK/tree
3	vermicompost	2 kg/tree
4	vermicompost	3 kg/tree
5	vermicompost	4 kg/tree
6	Mineral + vermicompost	90-22.5-22.5 NPK/tree+2 kg/tree
7	Mineral + vermicompost	90-22.5-22.5 NPK/tree+3 kg/tree
8	Mineral + vermicompost	90-22.5-22.5 NPK/tree+4 kg/tree

RESULTS AND DISCUSSION

The results regarding the tree height variable indicate that the T3 treatment had statistically significant differences with respect to the other treatments, although they were like the T5 treatment on the first date of sampling (136 days) (Table 2). In the second and third samplings (carried out at 164 and 244 days, respectively), there were statistically significant differences in the behavior of the T3 treatment trees than in the other treatments, but the behavior was statistically like T5.

At 288 and 356 days, the Persian lime tree with T5 was statistically higher regarding fertilization. This result indicates that the lime trees' response to the application of fertilization doses of 4 kg/tree with vermicompost. The next treatment used a dose of 2 kg tree^{-1} of vermicompost. Seven-year-old Persian lime trees have responded favorably to the use of organic fertilizers, which provide them with good nutrition for their development and growth. The recommended management dose is 15 kg tree^{-1} of kudzu applied to the soil in the months of January, April, and August. The organic fertilizer provides the following nutritional percentages: 3.73 (N), 0.189 (P), 1.96 (K), 0.78 (Ca), 0.32 (Mg), etc. (Berdeja *et al.*, 2018).

For the stem diameter variable of the lime trees (Table 3), no statistically significant difference was found between the different treatments evaluated. However, at 356 days, the stem thickness variable of the T5 treatment was higher than the control without fertilizer

Table 2. Tree height with different fertilization treatments using vermicompost and formula in 356-days old Persian lime.

Treatment	136 days	164 days	244 days	288 days	356 days
T1	62.88 A B	68.63 AB	71.8 E	73.6 E	76.7 E
T2	53.88 B	57.38 B	60.0 H	58.7 H	64.3 H
T3	73.75 A	78 A	83.5 A	73.7 D	82.5 B
T4	59.63 AB	62.38 AB	68.4 F	68.7 G	68.0 G
T5	70.50 AB	72.88 AB	77.4 B	82.0 A	86.5 A
T6	61.25 AB	66.0 AB	73.0 D	70.5 F	76.4 F
T7	60.38 AB	66.0 AB	76.5 C	78.5 C	76.8 D
T8	59.75 AB	62.25 AB	65.6 G	79.7 B	82.5 C

Means that do not share a letter are significantly different. Tukey test at 95%.

Table 3. Stem diameter in Persian lime trees.

Treatment	136 days	164 days	244 days	288 days	356 days
T1	7.0 A	7.3 A	9.2 A	12.3 A	17.5 A
T2	7.0 A	7.5 A	9.0 A	10.3 A	13.2 A
T3	6.2 A	7.8 A	9.4 A	11.8 A	14.7 A
T4	7.2 A	7.4 A	9.5 A	10.5 A	15.0 A
T5	7.3 A	8.0 A	11 A	12.8 A	18.6 A
T6	6.3 A	7.9 A	9.8 A	10.3 A	17.0 A
T7	7.7 A	8.3 A	11 A	11.8 A	16.9 A
T8	7.4 A	8.3 A	9.6 A	10.3 A	14.4 A

Means that do not share a letter are significantly different. Tukey test at 95%.

application. In an experiment with lime associated with coconut (*Cocos nucifera*) palms, the development and growth of the trees had a positive response to the application of organic sugarcane amendments and corn harvest waste. The incorporation of corn dry matter into the soil between the alleys improved the productivity of lime trees and the development in stem diameter and tree height (Rebolledo *et al.*, 2019).

The treatments showed statistically significant differences regarding the crown diameter variable, measured in the last sampling dates in the North to South position (Table 4). The T5 fertilization dose was higher than all treatments at 288 and 356 days. The slow release of nutrients by vermicompost in lime trees caused a response at 288 and 356 days, since only a fraction of the total nitrogen content is mineralized. However, vermicompost is a good substitute for chemical fertilization and can obtain similar results to synthetic fertilizers, given the high concentration of nitrogen in the organic matter particles. It is important to consider that 40% of phosphorus is available to trees (Olivares *et al.*, 2012).

In the crown diameter variable with orientation from East to West (Table 5), statistically significant differences were observed at 136 days with T4, T6, and T7. These three treatments had better results than other treatments; however, T8 treatment recorded higher values at 164 days. At 288 and 356 days, the T6 treatment had statistically significant differences, which were higher than the results obtained by other treatments regarding the crown development variable.

Table 4. North-South canopy diameter of lemon trees.

Treatment	136 days	164 days	244 days	288 days	356 days
T1	33.3 A	36.6 A	47.3 A	54.8 C	49.1 D
T2	33.7 A	41.4 A	54.2 A	46 G	40.1 H
T3	34.6 A	36.7 A	47.8 A	48.3 F	46.5 F
T4	32.2 A	36.8 A	47.5 A	51.6 E	47 E
T5	38.6 A	43.0 A	52.3 A	61.7 A	68.5 A
T6	35 A	37.0 A	43.1 A	60.5 B	58.5 B
T7	48 A	44.5 A	44.7 A	53.6 D	50.3 C
T8	37.2 A	41.3 A	41 A	44.9 H	43.2 G

Means that do not share a letter are significantly different. Tukey test at 95%.

Table 5. East-West canopy diameter of lemon trees.

Treatment	136 days	164 days	244 days	288 days	356 days
T1	27.2 C	34.2 B	49.8 A	58.8 B	52.3 C
T2	31.7 BC	34.2 B	45 A	39.3 G	33.5 G
T3	30.5 BC	33.7 B	37.4 A	37.8 H	30.0 H
T4	34.6 ABC	40.6 AB	47 A	49.3 F	38.4 F
T5	32.6 BC	40.6 AB	48.2 A	54.7 D	55.3 B
T6	38.6 ABC	41 AB	40.7 A	59.0 A	61.2 A
T7	42.1 AB	43.2 AB	48 A	57.3 C	43.5 E
T8	47.0 A	50.1 A	37.2 A	50.6 E	47.8 D

Means that do not share a letter are significantly different. Tukey test at 95%.

The soil pH at 136 days showed that there are statistically significant differences between treatments T1, T2, T3, T4, T5, and T7. The pH ranged from 5.8 to 7.0. The treatments with high fertilization doses had acid pH: T6 and T8 had a pH of 5.4 and 5.5, respectively. The pH in the soil at 164 days for all the treatments was neutral (7) compared to the control. At 244, 288, and 356 days, variations in soil pH were observed, without significant differences (Table 6). Regarding other research about Persian lime grafted on sour orange (*Citrus aurantium* L.), lime developed at an age of 9 and 12 years, in moderately acid soils (5.66 and 6.16 pH), at a depth of 0-30 cm in the soil profile. Consequently, pH close to neutral favor the absorption of nutrients and water. The Persian lime had more roots at a depth of 0 to 30 cm than at other depths (30 to 60 cm and 60 to 100 cm). This condition is the result of soil aeration at shallower depths (Contreras *et al.*, 2008). pH values of 6.2 were recorded in Persian lime trees managed with 1.0 kg of dry matter at the bottom of the stump and dry matter during crop development. The dry matter applied in lime trees favored growth in height and stem diameter, reinforcing the concept that "the contribution of organic fertilizers meet the nutrient requirements and demands of the crops, perhaps in a different way to the action generated by the chemical formulas" (Rebolledo *et al.*, 2019).

When measuring the soil moisture (%), no statistically significant differences between the treatments were recorded. In the last dates, the highest and more homogeneous soil moisture was recorded in treatments T4 and T7 regarding the absolute control, although the treatments fertilized with vermicompost had a better response to moisture retention (Table 7). In irrigated Persian lime plantations in Nayarit, moisture did not affect nutrient concentration in the slices of the lime fruits, but it did intervene in lime flowering. Zn mainly impacts the tree with the management of irrigation water. In non-irrigated plantations, phosphorus and potassium concentrations in lime slices are lower than those found in irrigated plantations; these concentrations are also related to soil characteristics. The behavior of the nutrients of calcium, sulfur, iron, copper, and boron was the same between rainfed and irrigated lime (Mellano *et al.*, 2017).

Figure 2 shows the relationship between tree height and soil pH and moisture, where 60-80 cm tall lime trees had a 6-6.2 soil pH and 70-80% moisture. Meanwhile, 100-cm tall Persian lime trees recorded a 6.5 soil pH and 70-80% moisture.

Table 6. Soil pH in Persian lime trees.

Treatment	136 days	164 days	244 days	288 days	356 days
T1	6.6 AB	6.9 A	6.7 A	5.6 A	6.6 A
T2	6.5 AB	7.0 A	6.1 A	6.1 A	6.6 A
T3	7.0 A	7.0 A	6.3 A	5.9 A	6.7 A
T4	6.9 A	7.0 A	7.0 A	6.3 A	7.0 A
T5	6.5 AB	7.0 A	6.8 A	6.5 A	6.8 A
T6	5.4 C	7.0 A	6.6 A	5.4 A	7.0 A
T7	5.8 AB	7.0 A	6.7 A	5.8 A	7.0 A
T8	5.5 BC	7.0 A	7.0 A	5.8 A	6.8 A

Means that do not share a letter are significantly different. Tukey test at 95%.

Table 7. Soil moisture in Persian lemon trees.

Treatment	136 days	164 days	244 days	288 days	356 days
T1	31.3 A	78.8 A	66.8 A	92.5 A	100 A
T2	50 A	82.5 A	80 A	100 A	90 A
T3	27.5 A	85 A	80 A	100 A	97.5 A
T4	40 A	86.3 A	78.7 A	100 A	100 A
T5	49.4 A	81.3 A	80 A	93.1 A	100 A
T6	57.5 A	83.7 A	80 A	92.5 A	100 A
T7	33.8 A	85 A	80 A	100 A	100 A
T8	62.5 A	87.3 A	75 A	100 A	95 A

Means that do not share a letter are significantly different. Tukey test at 95%.

Regarding the relationship of the crown diameter variables measured from North to South with the soil pH and soil moisture variables, the results of the pH and soil moisture variations were more significant for lime trees with a 20-cm crown diameter, a 6.4-6.6 pH, and a 60-80 % soil moisture (Figure 3).

No variability was recorded regarding crown diameter measured from East to West, when it was correlated with the soil moisture and soil pH variables and when the crown

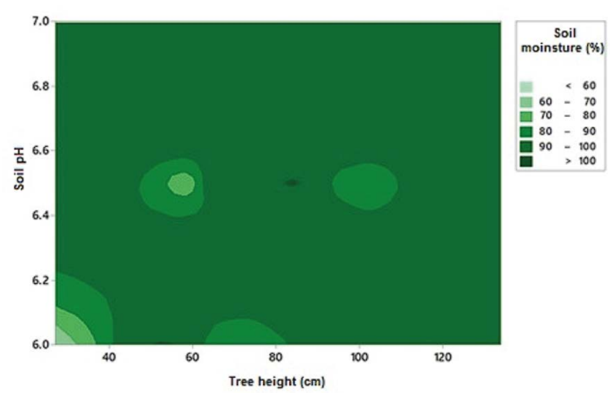

Figure 2. Relationship of lime tree height with soil pH and moisture at 356 days.

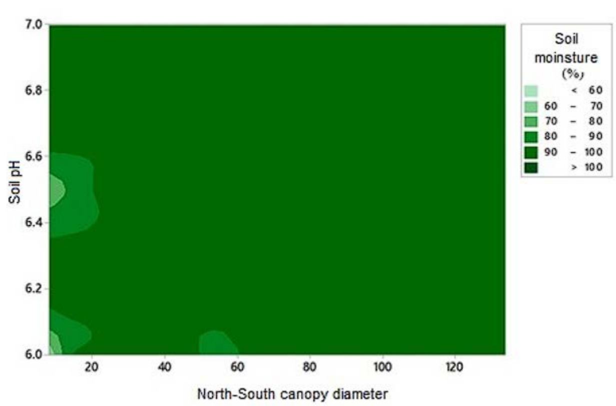

Figure 3. Relationship between the canopy diameter of the North-South tree, with the pH and moisture of the soil at 356 days of age.

diameter was greater than 20 cm. The soil moisture and soil pH variables are closely correlated with the development of the canopy. This phenomenon can have a positive or negative influence —*i.e.*, water deficit can induce flowering in lime trees (Vélez *et al.*, 2012) (Figure 4). When studying the processes that intervene in the growth and development of trees and the characteristics of the soil, the response variables that intervene in the process of chemical and organic fertilization were unified. Table 8 shows the resulting means. Therefore, the fertilization doses based on mineral and vermicompost (T5 and T7) have the best response, enhancing the growth and development of Persian lime trees. The fertilization dose recommended for commercial purposes in organic and agroecological plantations belong to T5. The lime growth variables can be influenced by soil moisture since it participates in stomatal conductance and citrus transpiration processes. That is to say, in the drought stage the trees that were subjected to mineral fertilization could present water stress, which would impact the physiological processes, consequently stopping the development of the leaves and causing wilting and curling (Vélez *et al.*, 2012).

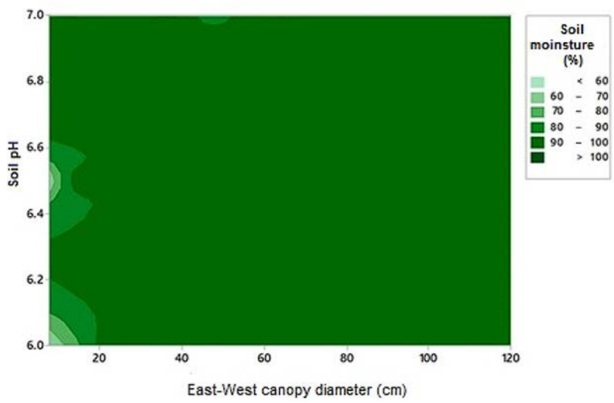

Figure 4. Relationship of canopy diameter of the East-West tree with the pH and soil moisture at 356 days of age.

Table 8. Means and standard deviations of the multivariate analysis of the different vermicompost and mineral treatments.

Treatment	Mean	Standard deviation
T1	41.39	28.89
T2	38.97	27.60
T3	41.29	31.31
T4	41.12	29.03
T5	45.74	30.82
T6	43.75	29.81
T7	43.8	30.02
T8	42.83	29.69

CONCLUSIONS

The treated Persian lime trees had a greater growth and development than the trees to which no nutrients were applied. Applying 4 kg tree^{-1} of vermicompost increased tree height and crown development. The applications of a mixture of vermicompost and synthetic formula led to a better tree canopy development; however, tree height was similar to the height of trees fertilized with vermicompost. A slightly acidic pH in the soil and treatments managed with vermicompost-based fertilizers had a neutral tendency which improves nutrient assimilation. In the dry season, the rainfed lime trees fertilized with vermicompost had a better response to moisture retention in the soil.

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