Article

Application of organic fertilizers in yield and root development in avocado cultivation

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Abstract

Mexico is a world leader in the avocado market, participates with a production of 2 029 886 tons that represents 34.3% of the world volume produced, placing it in the first exported with 45.95% and with the highest per-capita consumption, with 10 kg per year). The yields per hectare are 10.1 t ha^{-1}, which place it in fourth place worldwide (SAGARPA, 2017). The effect of a more leached compost of earthworm humus plus chemical fertilization on the root development and avocado yield was evaluated. In the experiment 3 levels of compost were applied: 100, 150 and 200 kg tree, accompanied by a conventional chemical fertilization proposed based on the nutrient diagnosis of the soil, which was 2 kg of the formula 20-10-05 per tree, plus 1.5 L of leachate in 60 L of water for each tree, equivalent to 300 L ha^{-1} per cycle. The control treatment consisted of a dose of only 2 kg per tree of the conventional formula 20-10-05 applied by the producer without the supply of organic fertilizers. The results indicated that the soil had a deficient level of Mn, low levels of N, Fe, Zn and B, an average level of Cu, while K and Ca were at high levels and N and Mg in excess. The superficial root development responded favorably to the treatments with application of organic fertilizers and had a direct correlation ($p \leq 0.05$) with the yield, as well as with the nutrient concentrations of Mg, Fe, Zn, Cu, B and organic matter obtained from sampling of soil of each treatment.

Keywords: compost, fertilization, nutritional requirements.

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Introduction

Avocado (*Persea americana* Mill.) is grown mainly in the states of Michoacán, Jalisco, State of Mexico and Nayarit and is the Mexican agricultural product that is most exported, being of great importance for the economy of Mexico (SIAP, 2016). According to Salazar-García *et al*. (1999) in the state of Nayarit, an average yield of 7.7 t h^{-1} is reached in temporary conditions and 11.14 t ha^{-1} in irrigation conditions, although with good management it is possible to achieve productions of 28 t ha^{-1}; however, in average the average yields are from 5 to 8 t ha^{-1}.

Organic fertilizers made with local materials can be an alternative for the avocado monoculture management, given the high demand for fertilizers of chemical origin, whose prices significantly increase production costs. It is known that organic matter in the soil contributes to the aggregation of mineral particles which improves the structure, reduces erosion and facilitates soil tillage, promotes porosity and increases aeration, penetration and water retention capacity (Ramírez *et al*., 2015).

The colloidal and negative charge size of the humus retains essential cations interchangeably. It also acts as a buffering agent by decreasing sudden changes in soil pH to the supply of acidic or alkaline reaction substances. Through the formation of organometallic complexes, they stabilize and release nutrients in the soil that would not otherwise be usable (Flores *et al*., 2016). With the addition of organic matter (chicken manure compost) in doses of 50 to 100 kg per avocado tree with mineral fertilization applied by fertigation, foliar nutritional assimilation is improved, especially with regard to P and K (Figueroa *et al*., 2012).

Nutrient concentrations in the leaf are higher in fertigation, due to the addition of chicken manure compost (Téliz, 2007). For its part, the application of compost and leaching of humus promote the formation of new roots by counteracting the problem of root diseases in avocado. In another study chemical and organic nutrition treatments were evaluated in avocado trees where bovine manure was applied at a rate of 50 kg tree, the formula of 200-100-200 kg ha^{-1} of (edaphic) and 30-10-15 kg ha^{-1} of Ca-Mg-B (foliar).

It was found that, in flower sprouts, the manure + edaphic + foliar treatment (41 sprouts/branch) was better than the manure + edaphic treatments (19 sprouts/branch), foliar (9 sprouts/branch) and the control (21 sprouts/branch). In addition, with 17 fruits, the manure + edaphic + foliar treatment significantly exceeded the treatments of edaphic + foliar (6 fruits), foliar (1 fruit) and the control (3 fruits). The treatment with manure + foliar had the greatest length (16 cm) of the main sprout, surpassing the manure + edaphic (7 cm) and foliar (9 cm) treatments. The edaphic + foliar treatment (75 cm^2) had a greater foliar area than the control (65 cm^2) and had the highest fruit weight with 2.62 kg 10 fruits, which was significantly greater than the control (1.51 kg 10 fruits) (Villalva *et al*., 2015).

It is essential to know the nutritional requirements particularly when the expected yields are low, to provide sufficient essential elements that promote greater productivity of the avocado production system (Etchevers, 1999). The objective of the study was to evaluate the application of compost and leachate of earthworm humus in the variables of yield and superficial root development to be incorporated into a program of fertilization in avocado cv. Hass in the Huaquechula region, Puebla, in order to reduce costs and increase productivity.

Materials and methods

The present study was conducted in 2015 on a site with avocado trees of 14 years old, planted at a density of 8 x 8 in the town of Tlapetlahuaya, municipality of Huaquechula, Puebla. The plot is located at an altitude of 1 640 meters above sea level, with an average annual temperature of 21.7 °C and precipitation of 931.5 mm. Soil samples were collected at a depth of 30 cm from the soil surface, in the drip area and 40 subsamples to complete 1.5 kg. In order to obtain the parameters required to determine the fertility of the soil, the samples were processed in the laboratory of the company NutreLab SA de CV analyzing pH, organic matter, EC, CIC, Dap, N, P, K, Ca, Mg, Fe, Mn, Zn, Cu and B, using the methodologies indicated in NOM-021-2000.

Simultaneously, the foliar sampling was done by collecting from 40 randomly selected trees mature leaves, from the 4 fully developed cardinal points, from fruiting terminal shoots coming from the spring flow, healthy (without physical, chemical or affected by pests or diseases), 5 to 7 months old (Maldonado, 2002). The leaves taken in each foliar sampling were placed in paper bags and transported in a cooler until they entered the laboratory, taking as a reference what was done by Maldonado *et al*. (2007); Maldonado *et al*. (2008). In the laboratory the leaves were washed, dried at 70 °C to constant weight, ground in a stainless steel mill with 40 mesh.

From the processed sample 0.5 g placed in a Kjeldal flask was taken and digested with 4 mL of diacid mixture (4:1 sulfuric acid and perchloric acid), plus 2 mL of hydrogen peroxide (30% hydrogen peroxide), to accelerating the reaction was heated to 260 °C in a Lindenberg SB brand stove. Once the extract was obtained, the elements N, P, K, Ca, Mg, Fe, Mn, Zn, Cu and B were determined, using the methodologies proposed by Etchevers (2001). Once the foliar analyzes were obtained, they were interpreted using the Balance Index (Kenworthy, 1973).

In the experiment three levels of compost were applied: 100, 150 and 200 kg tree, accompanied by a conventional chemical fertilization proposed based on the nutrient diagnosis of the soil, which was 2 kg tree of the formula 20-10-05, more 1.5 L of leachate in 60 L of water for each tree, equivalent to 300 L ha^{-1} per cycle. The study of the superficial roots was evaluated by taking samples of the drip zone of each tree by excavations of 80 cm^3, the 40 samples were taken on August 22, 2015, 161 days after the application of compost and 107 days after the application of chemical fertilization.

The roots were separated by sieving the soil, the fresh weight was recorded and then dried in an oven at 75 °C for 72 h to obtain dry weight based on the methodology proposed by Villalva *et al.* (2015). The control treatment consisted of a dose of only 2 kg $tree^{-1}$ of the conventional formula 20-10-05 applied by the producer without the supply of organic fertilizers. The chemical fertilization was carried out on May 7, 2015 and was applied in the drip area of the trees. Eight treatments mentioned below were proposed where each randomly chosen avocado tree was considered as an experimental unit.

The treatments were: conventional dose, balanced formula based on soil analysis, conventional + 100 kg of compost, conventional + 150 kg of compost, conventional plus 200 kg of compost, balanced + 100 kg of compost, balanced + 150 kg of compost, balanced + 200 kg of compost, with five repetitions per experimental unit (tree). The variables determined were: fruit yield (kg tree), superficial root development by tree, nutrient diagnosis of the soil before and after the application of fertilizers. The change in the nutrient parameters of the soil was evaluated and the amount of nutrients, yield and surface root development was correlated using the Pearson correlation matrix.

Results and discussion

Nutrient diagnosis of the soil and foliar at the beginning of the productive system

In order to identify the nutritional and fertility conditions of the soil of the avocado orchard under study, a nutritional analysis was performed. Table 1 shows the parameters obtained in the initial soil analysis. The results indicated that the soil had a slightly acidic pH, very high in P, K, Mg and Cu, a low level of N, Ca, Mn, Zn and B (Ankerman, 1977).

Table 1. Initial analysis of soil fertility.

pH	EC (dS m^{-1})	OM (%)	N	P	K	Na	Ca^{+2}	Mg^{+2}
			(mg kg^{-1})					
5.92	1.11	3.5	10.5	46.53	237.65	18.4	1879.5	509.7
Slightly acidic	Low	Medium	Low	Very high	Very high	Low	Medium	Very high

Fe^{+2}	Mn^{+2}	Zn^{+2}	Cu^{+2}	B	CIC ($cmol^{+}$ kg^{-1})	Apparent density (t m^{-3})
(mg kg^{-1})						
3.67	2.36	1.04	2.38	0.72	16.25	1.12
Very low	Very low	Low	Very high	Low	Medium	Very low

While the CIC was medium and the density was low. This meant that it is necessary to restore deficient nutrients and reduce the application of elements that are in excess to level fertility and improve crop development. The foliar analysis interpreted by the Kenworthy balance index technique, indicated that the nutrients Ca, Cu, Mn and B were found in the foliage at a level below normal, while Zn, P and Mg, in the normal range and in excess Fe, N and K. Based on these results, correspondence was found in soil level and foliage for nutrients Ca and Mn.

On the other hand, while K was high on the ground and in the foliage. The mismatch between the nutrients of the soil and foliage can be attributed to the fact that the farmer fertilizes foliarly and some that are deficient in the soil were located in high concentration in the foliage. The high level of Cu in the soil was due to its contribution in the tree trunk and its accumulation in the soil, but which was not absorbed in the foliage.

It can be seen that the high concentrations of P, K and Mg in the soil reflected normal concentrations in the avocado foliar area, Ca was found in a medium concentration in the soil, but not in the foliar area, which could be explained as Kass (2007) mentions because this nutrient is considered as a stationary element within plants. There is very little calcium translocation in the phloem's conductive tissues and the ability to absorb calcium is limited, because it is absorbed only through the young apexes of the roots.

Table 2. Mineral composition of avocado foliage cv. Hass.

	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
			(%)					(mg kg^{-1})		
C	4.03	0.13	2.42	0.35	0.57	136.1	127.2	32.6	29.6	64.84
IB	177.5	88.11	256.9	31.93	100.8	129	74	85.51	73.89	81.33
				ORN= Ca> Cu> Mn> B> Zn> P> Mg> Fe> N> K						
				Below normal		Normal		Excess		

C= nutritional concentration, IB= Kenworthy balance index. Source: own elaboration.

The foliar concentrations of Mn, Cu and B coincide with the low amount of these elements in the soil, as does Zn, which, although in a foliar form is in a just normal concentration in the soil, has a low concentration.

Superficial root development

In order to see if there were significant differences due to the application of compost as padding and promoter of superficial roots in avocado, the analysis of variance (Anova) was performed, which is shown in Table 3. It could be evidenced that a significance of 0.001 was obtained, which shows that there is high significance in the different treatments evaluated in terms of the result of the parameter of superficial radical development.

Table 3. Anova of superficial root development of avocado cv. Hass.

	Sum of squares	gl	Quadratic mean	F	Sig.
Between groups	1894.709	7	270.673	5.41	0.001
Within groups	1400.835	28	50.03		
Total	3295.544	35			

SPSS 20 statistical package.

In the test of comparison of means by Tukey three homogeneous subgroups were obtained that allow to locate the treatments with significant differences. The treatments with the greatest amount of new roots were those that had medium to high levels of compost applied to the soil. It is worth mentioning that the analysis of variance results with significant differences in all the treatments that had organic fertilizer application with respect to the control group and the nutritional balance treatment that did not contemplate the organic fertilizer, so it is conclusively verified that there is an impact positive in the soil that allowed the development of new roots from the first application.

The effect of organic matter on radial development is attributable to its influence on the structure and aggregation of the soil, of factors such as (1) soil fauna; (2) microorganisms; (3) environmental variables; (4) inorganic cementing agents; and (5) the roots. In recent years Six *et al*. (2004); Bronick and Lal (2005) have published the relationship of organic matter with radical systems and their relationship with soil structure, in ecosystems and agriculture. Also Gregory *et al*. (2006) and Hinsinger *et al*. (2009) have published the importance of the dynamics of the biochemical and biogeochemical properties of the rhizosphere and its relationship with soil aggregation.

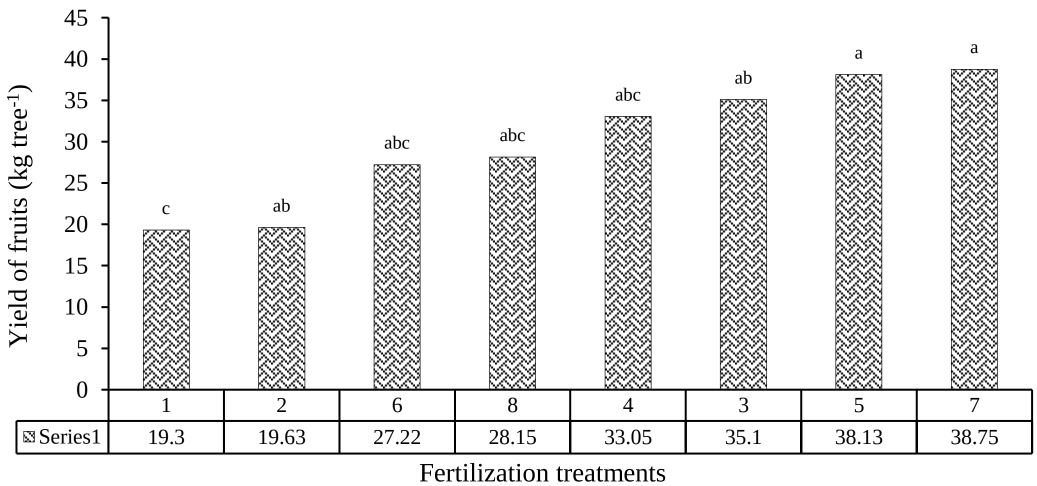

Figure 1. Tukey means comparison test for root development. a, b and c = subsets with significant differences (Tukey ≤ 0.05).

As can be seen in Figure 1, it is clear that the application of compost increased the amount of new roots produced by avocado trees. The evaluated root development can directly impact the next cycle of flowering and fruit production, because there will be a greater amount of roots with the ability to absorb nutrients and better nourish the tree. The promotion of new roots could allow trees with root disease problems to minimize their effects and increase their yield gradually. The treatments without compost application and leachate of earthworm humus lagged far behind in the production of new roots.

Avocado yield

With the data obtained, the test of equality of variances of Levene was performed and the results of the Analysis of variance (Anova) of the performance factor of the experiment in question, which are presented in Table 4.

Table 4. Anova of avocado cv. Hass yield.

	Sum of squares	gl	Quadratic mean	F	Sig.
Between groups	1445.164	7	206.452	3.1	0.015
Within groups	1864.55	28	66.591		
Total	3309.714	35			

SPSS 20 statistical package.

As can be seen in Figure 2, there are significant differences between treatments, and with the Tukey test the homogeneous subsets formed are observed. In Figure 2 it is denoted that the treatments without application of compost and leachate produced less kg of fruits per tree and therefore are located within the subgroup of lower production.

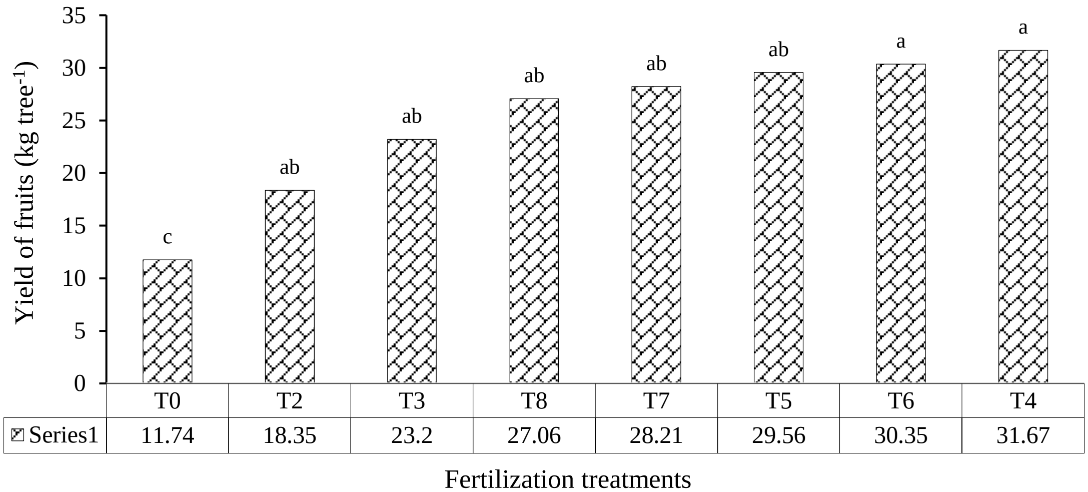

Figure 2. Test comparison of means by Tukey performance avocado cv. Hass. Data with different letters present significant differences (Tukey $\leq$ 0.05).

With the Tukey test, two homogeneous subgroups were obtained, where significant differences were observed between treatment 1 (control) and treatment 6 and 4, of 100 and 150 kg of compost application respectively. It is noted that the highest performance was in treatments with average levels of compost application. The yield per treatment evaluated shows in Figure 2, that the behavior of this variable was superior where there was application of compost, but at medium levels, this is possibly due to high compost applications affecting the temporary retention of nutrients to the tree that influence in lower yields in the short term.

Correlations of nutritional parameters with performance means and superficial root development

The Pearson correlation matrix shown in Table 5, showed differences that report significance with respect to the means obtained of yield and root development of the experimental design evaluated and its relation to the amount of specific nutrients in the soil. The performance correlations with the nutritional data obtained in the final sampling of the experiment and that present some kind of correlation.

Table 5. Nutritional concentration-performance correlations.

Variable	Concept	Root development	K	B
Yield	Correlation	0.727^{*}	0.7	0.762^{*}
	Sig. (bilateral)	0.041	0.053	0.028
	N	8	8	8

It can be seen that the yield showed a positive correlation with root development; that is to say, that to a greater amount of roots the plant absorbed better the necessary nutrients to increase the yield of the fruits. Similarly, the B show a positive correlation with performance considering a significance of $\alpha = 0.05$. The K was very close to presenting significance with the yield parameter.

For its part, Figure 3 shows a positive trend with the increase in root development promoted by organic fertilization in combination with mineral nutrients. It has been determined that humic and fulvic substances favor plant growth directly through physiological and nutritional effects. Some of these substances function as natural plant hormones (auxins and gibberellins) and are capable of improving seed germination, radical initiation and can serve as a source of nitrogen, phosphorus, sulfur and micronutrients.

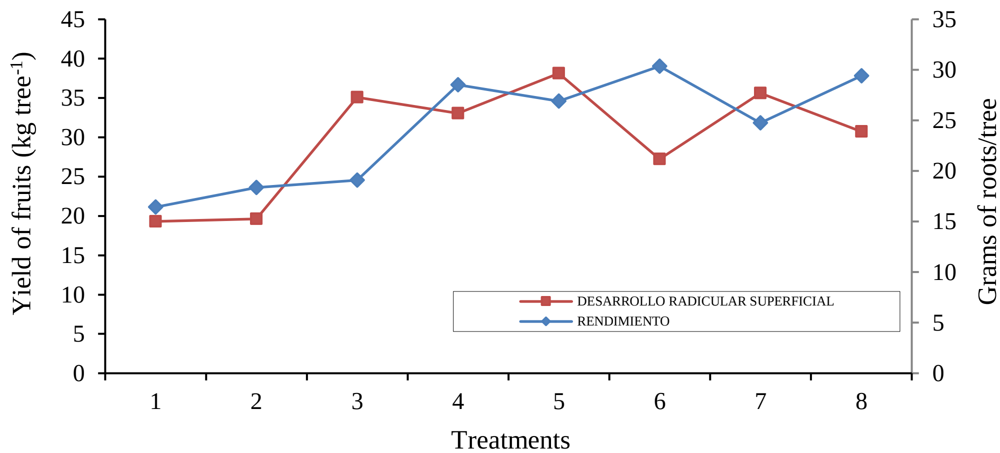

Figure 3. Correlation between yield and root development.

With organic matter physical characteristics are improved such as porosity, water retention, permeability, etc. and the microbial flora is stimulated which in turn facilitates the transformation of soil compounds into available nutrients such as Zn, Cu and B for crops.

In Table 6 it can be seen that there was a positive correlation with C, Organic Matter, Ca, Mg, Fe, Zn, Cu and B. This result coincides with Yamada (2000) who mentions that Ca and B are essential nutrients importance for the development of apical sprouts and root tips. Without these nutrients, the growth of new shoots and that of new roots is stopped and for a good root system to develop, it is necessary that B be in adequate quantities at the same place where the roots grow since it acts simultaneously with Ca.

Table 6. Correlations nutritional concentration-superficial root development.

Variable	Concept	Yield	C	MO	Ca	Mg	Fe	Zn	Cu	B
Root development	Correlation	0.727*	0.742*	0.741*	0.7	0.849**	0.758*	0.847**	0.933**	0.941**
	Sig. (bilateral)	0.041	0.035	0.035	0.053	0.008	0.029	0.008	0.001	0
	N	8	8	8	8	8	8	8	8	8

Liderman (1989) mentions that with increasing the organic matter in the soil there is an increase in the concentration of nutrients and in microbial populations and that it offers the soil an aeration and drainage capacity that avoids excess water, which gives the conditions necessary for optimal root development. The composting and leaching applications of earthworm humus contained significant amounts of microelements, which in general raised the level of the latter in the soil of all the experimental units evaluated to which they were applied.

Figure 4 shows the high correlation that the superficial root development had with the concentrations of B in the different treatments. The pattern of the line of the graphs is very similar between both parameters. Similarly, Cu and Zn presented the same patterns of correlation with root development (Figure 5 and 6).

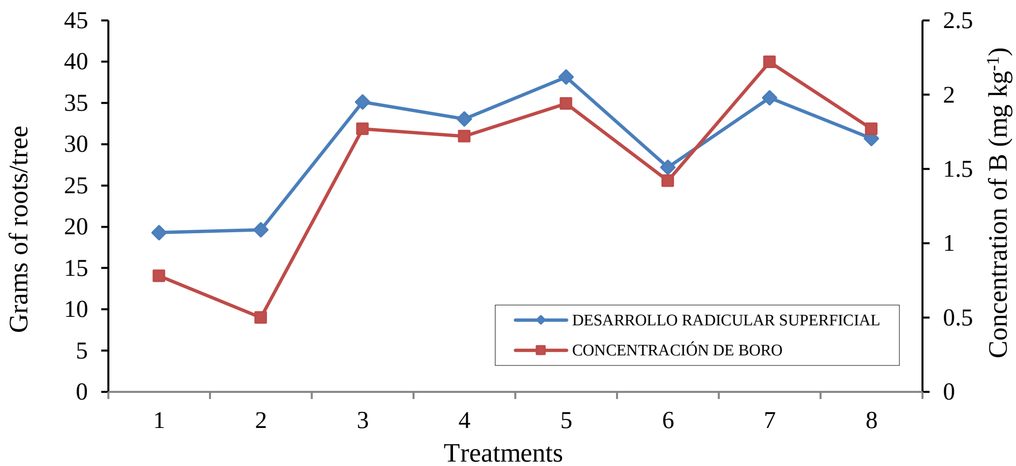

Figure 4. Correlation between root development and nutrient concentration of B in the soil after the fertilization treatments applied.

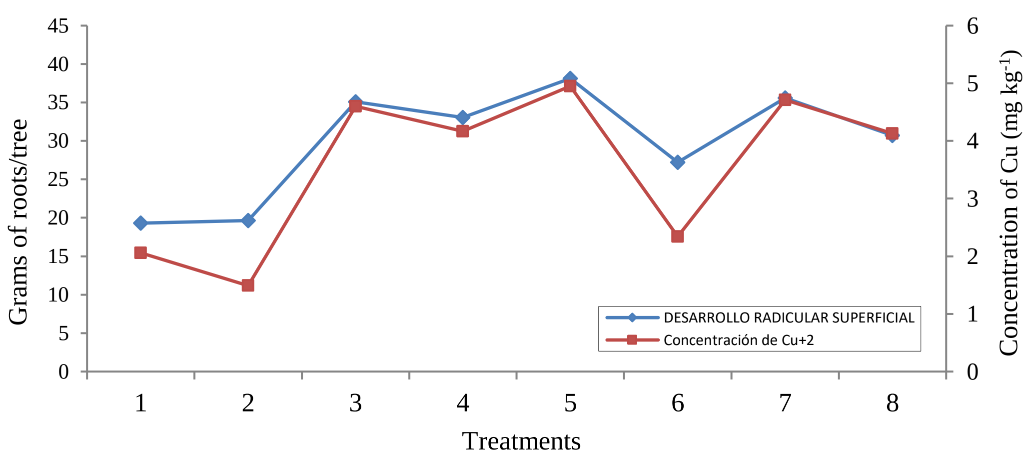

Figure 5. Correlation between root development and nutritional concentration of Cu^{+2} in the soil after the fertilization treatments applied.

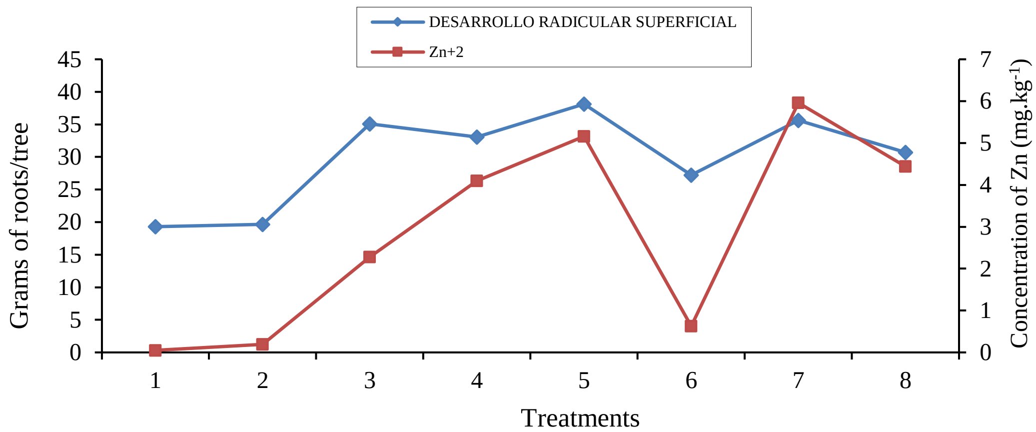

Figure 6. Correlation between root development and nutritional concentration of Zn^{+2} in the soil after the fertilization treatments applied.

The correlation between root production and nutrient absorption is associated with the low mobility of copper and Zn in the soil, as well as the contribution of dead roots in the supply of nutrients. For example, it has been determined that, when harvesting crops, the stored C derived from the roots reaches 50% of the total C, while only 13% corresponds to aerial biomass (Gale *et al*., 2000a).

The roots are influenced by the soil in which they live, so when the soil is compacted or has low nutrient content or the water is limited or there are other problems, the plants will not grow well. The physical pressure of the roots growing through the soil helps form aggregates with neighboring particles. When the vegetative material is returned to the soil, it will become the primary food source for bacteria, fungi and the plants themselves.

Conclusions

The soil diagnosis indicated N, Fe, Mn, Zn and B as the most limiting, Ca in medium concentration and P, K, Mg and Cu as those with the highest concentration. The foliar diagnosis using the Kenworthy Balance method indicated that this order of nutritional requirement Ca> Cu>Mn> B> Zn> P> Mg> Fe> N> K, with Ca, Cu and Mn being the most limiting, while the N and K those of greater concentration, having little correlation between the soil and the foliage due to the foliar fertilization that is carried out in the avocado orchard.

The application of organic fertilizers such as compost and leaching of earthworm humus partially supplies the nutritional demand of the avocado crop but should be considered as a complement to a more holistic management of the productive system, as well as amendments to improve soil fertility. they will allow to improve the productive characteristics in a short to medium term. Regarding the yield of the avocado crop, we can deduce that the application of organic fertilizers does not act immediately in the system in this productive aspect, but that it generates the necessary conditions to improve productivity in later cycles, as was appreciated in the development superficial root canal evaluated, CIC and correlation with the absorption of Cu, Zn and B.

In superficial root development, a favorable response was observed in the treatments in which the organic fertilizers were part, so it can be concluded that there is an effect on this analyzed variable. This root development will allow better use of soil nutrients, better yield and better health with respect to root disease problems.

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