EFFECT OF DIFFERENT LAND USE ON CHEMICAL PROPERTIES OF AN ANDOSOL IN MICHOACAN, MEXICO †

[EFECTO DE DIFERENTES USOS DE SUELO SOBRE LAS PROPIEDADES QUÍMICAS DE UN ANDOSOL EN MICHOACAN, MÉXICO]

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SUMMARY

Background: The replacement of forest vegetation with agricultural crops, and their subsequent management generate an impact on the availability of nutrients in the soil. **Objective:** To investigate the impacts of land use change from a forest ecosystem to agricultural areas with organic and conventional amendments in the chemical properties of an Andosol. **Methodology:** The chemical properties (pH, electrical conductivity [EC], soil organic matter [SOM], Na, Ca, K, Mg, Cu, Zn, Mn and Fe content) of an Andosol under different soil use systems were evaluated; one forest or control and three agricultural (queensland nut, organic avocado and conventional avocado. **Results:** The results showed that changes in land use caused a significant increase in nutrients, mainly derived from the management and application of organic and inorganic fertilizers. **Implications:** Determine if there are significant differences in agricultural areas with organic and conventional practices, with respect to those determined in a merely forestry area, considering the latter as a control, since before the changes in land use, all the areas belonged to the same ecosystem. **Conclusion:** The results showed that changes in land use and its subsequent agricultural management caused a significant increase in the availability of nutrients, derived mainly from the application of organic and inorganic fertilizers, generating a positive effect on the yields of avocado and queensland nut crops, where specifically, there were substantial increases with conventional management practices.
Keywords: organic amendments; conventional management; land use change; agricultural crops; nutrients; Andosol.

RESUMEN

Antecedentes: La sustitución de la vegetación forestal por cultivos agrícolas y su posterior manejo generan un impacto en la disponibilidad de nutrientes en el suelo. **Objetivo:** Investigar los impactos del cambio de uso del suelo de un ecosistema forestal a áreas agrícolas con enmiendas orgánicas y convencionales en las propiedades químicas de un Andosol. **Metodología:** Se evaluaron las propiedades químicas (pH, conductividad eléctrica [CE], materia orgánica del suelo [MOS], contenido de Na, Ca, K, Mg, Cu, Zn, Mn y Fe) de un Andosol bajo diferentes sistemas de uso del suelo; un bosque o control y tres agrícolas (macadamia, aguacate orgánico y aguacate convencional). **Resultados:** Los resultados mostraron que los cambios en el uso del suelo provocaron un aumento significativo de los nutrientes, principalmente derivados del manejo y aplicación de fertilizantes orgánicos e inorgánicos. **Implicaciones:** Determinar si existen diferencias significativas en áreas agrícolas con prácticas orgánicas y convencionales, con respecto a las determinadas en un área meramente forestal, considerando esta última como un control, ya que, antes de los cambios en el uso del suelo, todas las áreas pertenecían a un mismo ecosistema. **Conclusión:** Los resultados mostraron que los cambios en el uso de la tierra y su posterior manejo agrícola provocaron un aumento significativo en la disponibilidad de nutrientes, derivado principalmente de la aplicación de fertilizantes orgánicos e inorgánicos, generando un efecto positivo en los rendimientos de los cultivos de aguacate y macadamia, donde específicamente, hubo aumentos sustanciales con las prácticas de manejo convencionales.
Palabras clave: enmiendas orgánicas; manejo convencional; cambio y uso de suelo; cultivos agrícolas; nutrientes, Andosol.

INTRODUCTION

Soils are essential for life on Earth, but anthropic pressures have brought them to a critical state. Further loss of productive soils will increase food prices and potentially leave millions of people living in poverty. Careful soil management can increase food supply, functioning as a regulator of climate and the sustainability of ecosystem services (Montanarella, 2015).

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At the global level, agriculture represents one of the activities that exerts the greatest pressure on the soil resource due to the excessive use of chemical products, intensive tillage, use of heavy machinery, among others, which affect its management and short-term productivity (Babin *et al*., 2019). According to CEDRSSA (2019) this activity is carried out in almost 37.4% of the earth's surface under different management. In general, two types of management can be identified in agricultural systems: a) organic: it involves the use of agricultural waste, biodegradable waste, farm manure, waste from forests and grasslands, biofertilizers formulated based on fungi and bacteria, which allows to nourish the plant improving productivity, it also implies the restriction of the use of conventional agrochemicals (Timsina, 2018) and b); They are based mainly on the use of chemical and synthetic products, mechanization and use of modified genetic material, seeking to increase the productivity and profitability of crops (Busari *et al*., 2015).

The implementation of organic management in agriculture has had a positive impact on the chemical properties of the soil, increasing carbon and organic matter, as well as total nitrogen. It also improves cation exchange capacity, electrical conductivity, and lowers pH. However, the availability of nutrients is reduced. Although conventional agricultural management reduces the content of organic matter and carbon, it improves the availability of nutrients and crop productivity (Crittenden and Goede, 2016; Hondebrink, Cammeraat and Cerdá, 2017; Larios-González *et al*., 2014; Marín *et al*., 2017; Sihi *et al*. 2017).

The agricultural system of greatest economic and social importance in the state of Michoacán is the cultivation of avocado and its permanent production (USDA, 2020). During the last decades the transformation of the potential use of Andosols towards agricultural uses has accelerated, mainly for the establishment of avocado, influenced by its productivity and profitability in the short term (Bravo-Espinoza *et al*., 2014; Orozco-Ramírez and Astier, 2017). However, various authors have stated that the change in land use has altered Andosol's ecopedology derived from the different practices used throughout its management (Galván-Tejada *et al*., 2014; Campos *et al*., 2020). Particularly in avocado orchards, the soil resource presents problems of erosion, excess fertilization and inadequate management of its cover, factors that accelerate its degradation and desertification (Chávez-León *et al*., 2012; Villanueva and Zepeda, 2018; Béjar *et al*., 2021).

According to the above, the objective of this research was to investigate the impacts of land use change from a forest ecosystem to agricultural areas with organic and conventional amendments in the chemical properties of an Andosol.

MATERIALS AND METHODS

Description of the study area

The study area is located to the east of the municipality of Uruapan, Michoacán (19° 28' 22.2' 'N and 102° 00' 19.7" W) at an altitude of 1890 m.a.s.l., it is represented mainly by Pine-oak forests and agricultural areas (Figure 1). It has a humid temperate climate with rains in the summer (Cw) (García, 2004) and temperatures between 10 and 27 °C, with an average rainfall of 1500 mm per year. The predominant soil is Andosol of volcanic origin consisting mainly of volcanic glass (Alcalá, Ortiz and Gutiérrez, 2001). During the last 60 years, extensive areas of forest have been removed to establish avocado cultivation, which has currently been an economic trigger for the region, causing an expansion in the cultivation and therefore the change of land use.

Land use characteristics

Four plots of 100 m^2 were selected under different land uses:

Pine-oak forest (T1): This system is considered native to the region, represented by a mixture of species of the genus Pinus and Quercus, among them the following stand out: *Pinus devoniana* Lindley, *Pinus pseudostrobus* Lindl, *Pinus lawsonii* Roezl, *Pinus leiophylla* Schl. and Cham, *Quercus rugosa* Neé, *Quercus laurina* Humb et Bonpl, *Arbustus xalapensis* Kunth and *Fraxinus udheii* (Wenz.) Lingelsh, without handling interventions.

Queensland nut orchard (T2): *Macadamia integrifolia* Maiden and Betche cultivation with an approximate age of 40 years. Eight years ago its management began under an organic regime, using bovine manure (N-P_2O_5-K_2O [39-37-29]) in doses of 16.66 Mg ha^{-1} year, applied in partial shade.

Avocado orchard with organic management (T3): Crop of *Persea americana* Mill var. Hass, is approximately 60 years old and like Queensland nut, eight years ago began its management under organic management, using bovine manure (N-P_2O_5-K_2O [39-37-29]) in doses of 16.66 Mg ha^{-1} year, applied in partial shade.

Avocado orchard with conventional management (T4): It is represented by *Persea americana* Mill var. Hass, with an age of 60 years, during this time it has been managed under a conventional system with the use of inorganic fertilizers and pesticide, the chemical fertilizations used are copper sulfate pentahydrate

($CuSO_4$ $5H_2O$) 600 ml ha^{-1} as fungicide and bactericide for preventive use and a foliar fertilizer CO $(NH_2)_2$, (20-30-10) in a dose of 3 kg ha^{-1} every two months and a prolonged release granule (15-00-00).

Soil sampling and analysis

Four composite soil samples were taken at two depths (0-20 and 20-40 cm), obtaining a total of 32 samples from the four land uses. The analysis was carried out at these depths, since Andosols present a deep horizon with high levels of organic matter, this interval being the soil where the greatest amount of organic matter and nutrient cycling are concentrated. The samples were taken to the Soil Laboratory of the Faculty of Forest Sciences where they were allowed to air dry and were subsequently sieved on a 2 mm metal mesh sieve, and stored for later analysis following the procedures established by the Rhoades (1982) (micronutrients by Acetate-NH4 pH 7.0 method), Lindsay and Norvell, (1978) (macronutrients by DTPA-TEA - CaCl2 pH 7.3 method) and Woerner (1989).

Chemical properties

The following properties were determined for each soil samples: pH, electrical conductivity (EC), soil organic matter (SOM), content of Na, Ca, K, Mg, Cu, Zn, Mn and Fe, which were determined by the methods described in Table 1.

Statistical analyses

The statistical analysis (analysis of variance and comparison of means using Tukey's rank test) of the soil chemical variables was analyzed through a completely random design with a factorial arrangement, being the land use factors (FA-4), soil depths (FB-2) and interaction (FA * FB). To determine the relationship between the chemical variables. All statistical analyzes were performed using version 22.0 of the SPSS software (SPSS Inc., Chicago, IL), with a confidence level of $p \leq 0.05$.

RESULTS

The factorial variance analysis indicated that the types of land use (FA), depth (FB) as well as the interaction (FA * FB) showed highly significant differences ($p \leq 0.01$) in all the chemical properties analyzed, evidencing the response to the management system (treatment). The R^2 values were high for all the variables analyzed (Table 2).

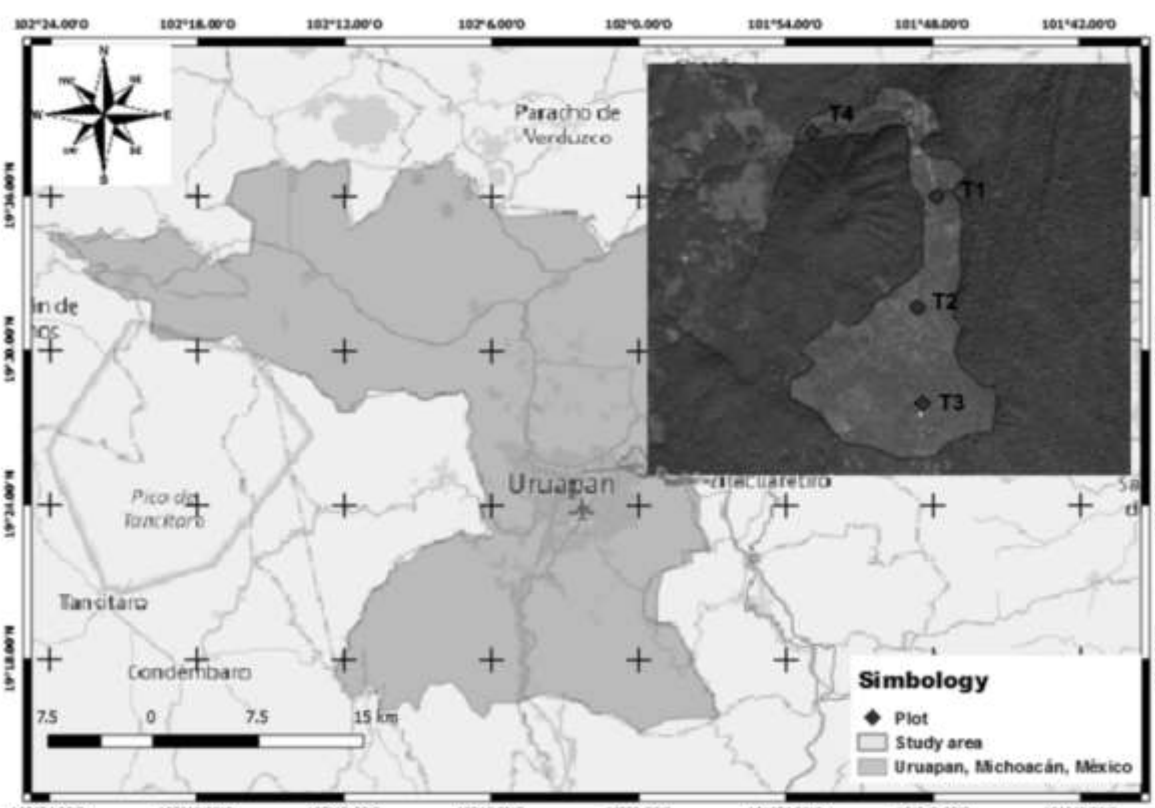

Figure 1. Location of the study area.

Table 1. Methods for determining soil chemical properties.

Variable	Method	Unit
pH	Electrometric method AS-23 de la NOM-021-RECNAT-2000	
EC	Rapid determination in soil-water suspension 1:5 (Woerner, (1989).	µS cm^{-1}
SOM	Walkley and Black Modified (Woerner, 1989)	%
Na	Acetate-NH_4^+ pH 7.0 (Rhoades, 1982).	cmol kg^{-1}
Ca	Acetate-NH_4^+ pH 7.0 (Rhoades, 1982).	cmol kg^{-1}
K	Acetate-NH_4^+ pH 7.0 (Rhoades, 1982).	cmol kg^{-1}
Mg	Acetate-NH_4^+ pH 7.0 (Rhoades, 1982).	cmol kg^{-1}
Cu	DTPA-TEA - $CaCl_2$ pH 7.3 (Lindsay and Norvell, 1978).	mg L^{-1}
Zn	DTPA-TEA - $CaCl_2$ pH 7.3 (Lindsay and Norvell, 1978).	mg L^{-1}
Mn	DTPA-TEA - $CaCl_2$ pH 7.3 (Lindsay and Norvell, 1978).	mg L^{-1}
Fe	DTPA-TEA - $CaCl_2$ pH 7.3 (Lindsay and Norvell, 1978).	mg L^{-1}

pH

According to Tukey test ($p \leq 0.05$) the pH presented significant differences and the same trend in both depths where; the forest system (T1), organic queensland nut (T2) and organic avocado (T3) (fluctuating from 5.59 to 6.36 in the first 20 cm and from 5.14 to 5.73 in 20-40 cm) presented a slightly acidic pH, while T4 differed by showing a neutral pH (Figure 2).

Electrical conductivity (EC)

The application of organic and conventional amendments had a significant effect on the elevation of the EC compared to the organic queensland nut system (T2) and conventional avocado (T4), respectively. However, in the organic avocado (T3) the same trend was not observed. For the first depth (0-20 cm) the values fluctuated between 171.69 to 366.38 µS cm^{-1}, while, in the second (20-40 cm) there was a decrease that ranged from 48.63 to 197.76 µS cm^{-1}. Tukey's test ($p \leq 0.05$) showed similarity in EC between T1 and T3, as well as in T2 and T4 (Figure 3).

Soil organic matter (SOM)

The conventional avocado (T4) presented the highest values in the SOM content of 15.9%, while the organic avocado (T3) the lowest with 5.56%, being statistically different, however the forest system (T1) and organic queensland nut (T2) had a similar behavior oscillating between 13% for the first depth (0-20 cm). In the second depth (20-40 cm) the T4 was statistically different compared to the rest of the treatments (Figure 4).

Table 2. Analysis of variance of soil chemical properties, F values and R^2.

Variables	FA, $F_{(3,24)}$	FB, $F_{(1,24)}$	FA*FB, $F_{(3,24)}$	R^2
pH	24.916**	25.949**	3.807**	0.77
CE	20.094**	80.474**	1.639^{NS}	0.82
SOM	36.536**	75.621**	1.575^{NS}	0.85
Na	106.170**	136.658**	117.062**	0.98
Ca	156.557**	436.464**	69.124**	0.97
K	246.621**	23.460**	9.912**	0.96
Mg	133.871**	275.020**	2.736**	0.96
Cu	351.702**	1135.927**	383.505**	0.98
Zn	1500.557**	3819.019**	1363.809**	0.89
Mn	573.267**	379.097**	308.127**	0.99
Fe	79.393**	65.108**	21.621**	0.98

** Highly significant differences ($p \leq 0.01$); * Significant differences ($p \leq 0.05$); NS, Not significant ($p > 0.05$). FA= land use factor; FB= depth factor; FA*FB= interaction of factors; F= Fisher values.

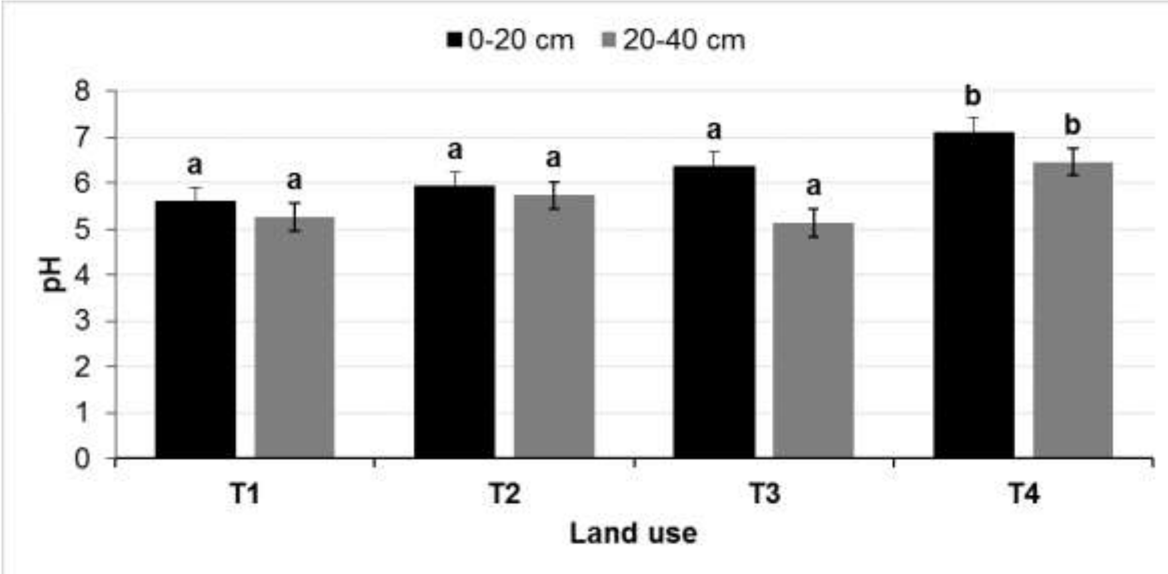

Figure 2. Mean pH with standard deviation for four treatments at two soil depths (0-20 and 20-40 cm) T1: Forest, T2: *Macadamia integrifolia* Maiden & Betche with organic management, T3: *Persea americana* Mill var. Hass with organic management and T4: *Persea americana* Mill var. Hass with conventional management.

Macro nutrients

Figure 5 shows the means comparison tests for the different macro nutrients evaluated. The Na values varied from 0.25 to 0.94 cmol kg^{-1} in the first soil depth (0-20 cm) and from 0.24 to 0.45 cmol kg^{-1} in the second soil depth (20-40 cm). The conventional system (T4) was statistically different from the organic systems (T2 and T3) and forest (T1), however, the organic systems presented a similar behavior for both depths.

The Ca availability was high for all treatments except for forest system (T1) which presented adequate concentrations (7.97 cmol kg^{-1} for the first soil depth and 7.12 cmol kg^{-1} for the second). All treatments were statistically different. However, the conventional system (T4) presented the highest concentrations at both soil depths (33.69 and 14.86 cmol kg^{-1}, respectively).

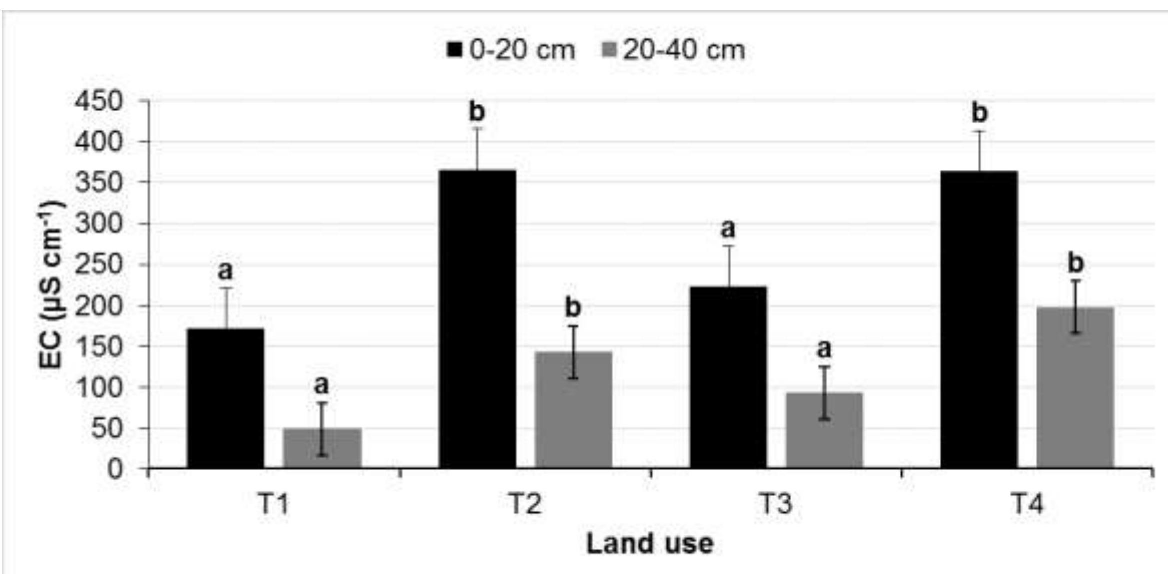

Figure 3. Mean EC with standard deviation for four treatments at two soil depths (0-20 and 20-40 cm) T1: Forest, T2: *Macadamia integrifolia* Maiden & Betche with organic management, T3: *Persea americana* Mill var. Hass with organic management and T4: *Persea americana* Mill var. Hass with conventional management.

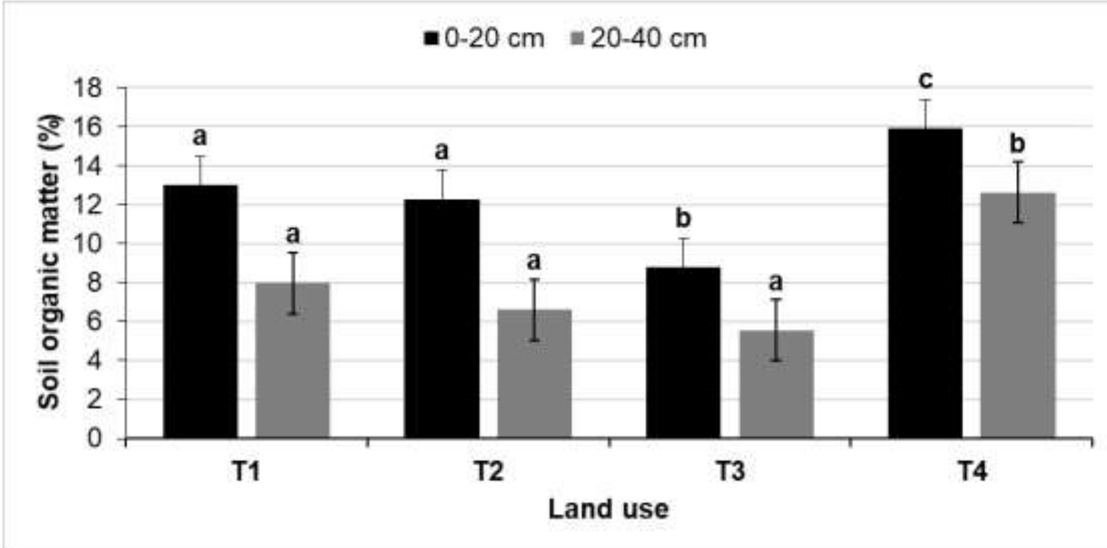

Figure 4. Mean SOM with standard deviation for four treatments at two soil depths (0-20 and 20-40 cm) T1: Forest, T2: *Macadamia integrifolia* Maiden & Betche with organic management, T3: *Persea americana* Mill var. Hass with organic management and T4: *Persea americana* Mill var. Hass with conventional management.

For the case of K, there were no statistical differences between forest systems (T1) and organic (T2 and T3), but in conventional (T4), finding the highest concentration of K (6.38 cmol kg^{-1}). In the second depth, the behavior was similar, although a slight decrease is observed, oscillating between 0.74 and 4.53 cmol kg^{-1}.

In the case of Mg, the values of the first soil depth ranged from 2.73 to 5.91 cmol kg^{-1}, in the second soil depth there was a decrease in all evaluated land uses, finding concentrations of 0.83 to 3.59 cmol kg^{-1}. Similar values were observed between T1 and T3, while T2 and T4 were statistically different.

In general, the macro nutrients presented a similar trend, finding in all cases the highest concentrations in the conventional system, and the opposite in the forest system.

Micro nutrients

The Cu availability between the evaluated treatments ranged from 0.57 to 2.16 mg L^{-1} in the first soil depth and from 0.35 to 1.05 mg L^{-1} for the second soil depth. The conventional system presented the highest concentrations, due to the inorganic fertilization applied, however, the T3 also presented high concentrations (1.70 mg L^{-1} of 0-20 cm and 0.98 mg L^{-1} of 20-40 cm), finding significant differences between T3 and T4. On the other hand, T1 and T2 were similar and did not present statistical differences (Figure 6).

In the case of Zn, the behavior was different: the forest system (T1) and conventional avocado (T4) were differentiated by their low and high concentration in the 0-20 cm soil depth (1.24 and 6.16 mg L^{-1}, respectively), the same happens in the 20-40 cm soil depth (0.72 and 3.24 mg L^{-1}). In addition, organic queensland nut (T2) and organic avocado (T3) did not present statistical differences and are related by the organic fertilization used. The behavior of Fe was similar.

In soil depth 0-20 cm, conventional avocado (T4) (2.63 mg L^{-1}) had the highest Mn concentrations and forest system (T1) the lowest (1.18 mg L^{-1}), being statistically different from each other compared to T2 and T3 that were similar (without significant differences). The second soil depth (20-40 cm) presented the same trend.

Table 3 shows the optimal values of the macro and micronutrient soil concentration levels, determined for the avocado cultivation in the region (Coria, 2009; Sotelo-Nava *et al*., 2017). Carrying out a comparative analysis with the averages of both depths of the present investigation, it can be seen that the conventional avocado use presented a high availability for all nutrients, unlike Mn with an optimal level. Particularly Mg, Ca, K and Cu presented high levels in all land uses, with the exception of Ca and Mg for forest use and organic avocado respectively, which presented slightly low availability. In general, micronutrient concentrations showed a similar trend between forest, queensland nut and organic avocado land uses.

Table 4 shows the production performance of each evaluated system, where the organic avocado system (T3) decreases by 58% compared to the conventional (T4).

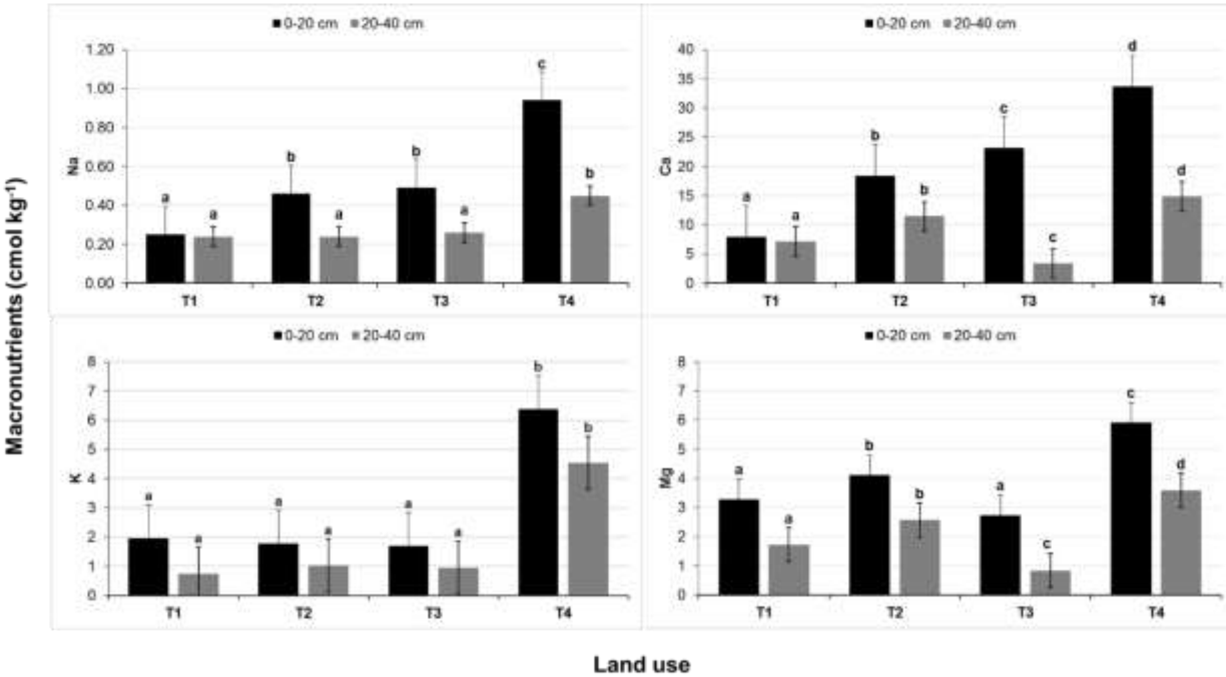

Figure 5. Average and standard deviation of macronutrients at two soil depths (0-20 and 20-40 cm) T1: Forest, T2: *Macadamia integrifolia* Maiden & Betche with organic management, T3: *Persea americana* Mill var. Hass with organic management and T4: *Persea americana* Mill var. Hass with conventional management.

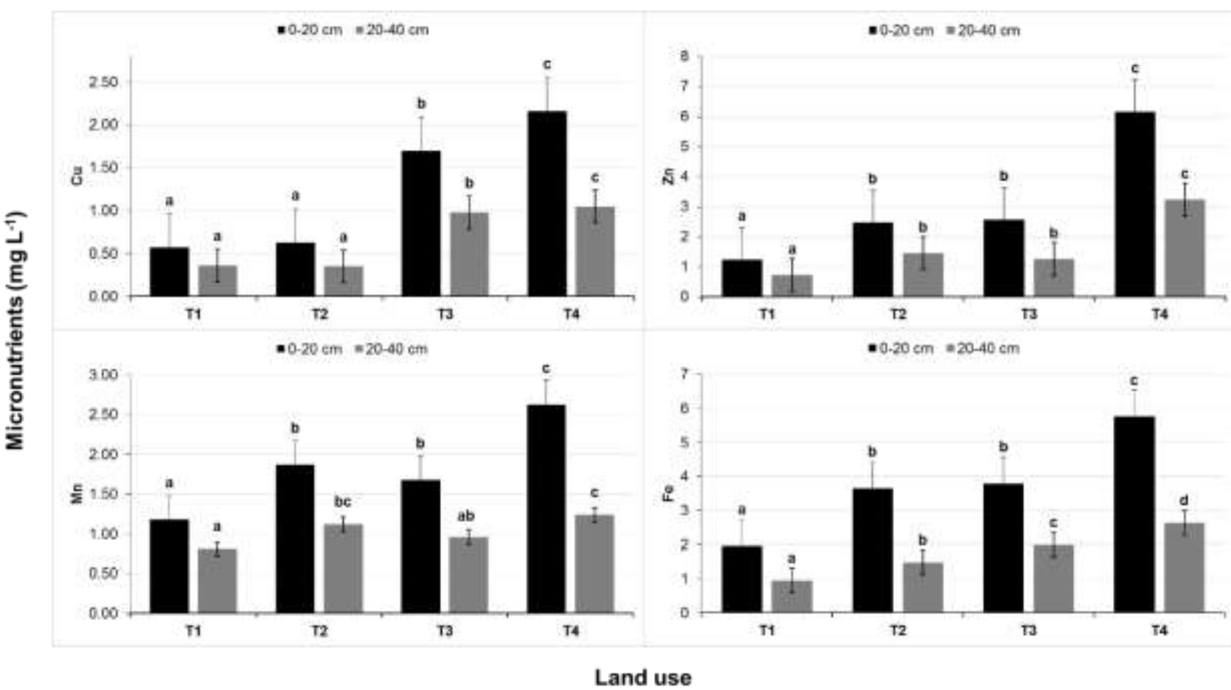

Figure 6. Average and standard deviation of micronutrients at two soil depths (0-20 and 20-40 cm) T1: Forest, T2: *Macadamia integrifolia* Maiden & Betche with organic management, T3: *Persea americana* Mill var. Hass with organic management and T4: *Persea americana* Mill var. Hass with conventional management.

Table 3. Adequate levels of macro and micronutrients soil content in the different land uses for the avocado cultivation.

Element	Adequate levels	T1-Forest	T2-Queensland nut	T3-Organic avocado	T4-Conventional avocado
Ca (ppm)[1]	2000	1508.60[l]	2993.18[h]	2648.44[h]	4855.30[h]
K (ppm)[1]	300	526.79[h]	545.12[h]	514.74[h]	2134.22[h]
Mg (ppm)[1]	250	304.56[o]	408.17[h]	217.47[o]	579.64[h]
Cu (ppm)[2]	5-15	29.49[h]	31.23[h]	86.11[h]	102.05[h]
Zn (ppm)[2]	30-150	64.08[o]	128.87[o]	125.11[o]	307.34[h]
Mn (ppm)[2]	30-500	54.58[o]	82.02[o]	72.45[o]	106.23[o]
Fe (ppm)[2]	50-200	81.76[o]	143.58[o]	161.87[o]	234.89[h]

Source: Coria (2009)[1] y Sotelo-Nava *et al*. (2017)[2]. h = high, o = optimal and l = low.

Table 4. Production characteristics and tree density of the evaluated land uses.

Land use	Manage-ment	Density (Trees/ha^{-1})	Yields (Mg ha^{-1})
T1 Forest	N.A.	600	N.A.
T2 Queensland nut	Organic	100	3.20
T3 Avocado	Organic	100	6.25
T4 Avocado	Conventional	100	15.00

Note: N.A. = not applicable

DISCUSSION

The Andosols are characterized by their high content of organic matter, for which the depth 0-40 cm was evaluated, considered as the depth interval with the highest nutrient cycling (Vivanco *et al*., 2010; Luna *et al*., 2021), However, Dubrovina and Bautista (2014) point out that the avocado root system is distributed as follows: 50% in the first 30 cm, 30 to 40% in the 30-60 cm and in the deepest part the anchor roots (> 100 cm), which could be a limitation to determine the dynamics of nutrients in the crop, thus representing an opportunity for subsequent studies where it would be important to analyze the entire soil horizon and other parameters associated with the cycling of nutrients such as physical and biological properties.

The use and management of the soil affects its chemical properties (Zajícová and Chuman, 2019). The replacement of native vegetation by agriculture modifies the nutrient cycle in the soil (Matson, Parton, Power and Swift, 1997), affecting its productivity (di Gerónimo *et al*. 2018), as well as causing effects on the distribution and supply of nutrients in the soil (Takoutsing *et al*. 2016).

In general, the Andosol under study showed a neutral pH, considering these pH ranges optimal for the establishment of avocado cultivation in both modalities of agricultural management (Schwentesius *et al*., 2021). Particularly, the pH of forest use presented values similar to those obtained in other forest soils in the region (Jordán *et al*., 2009). Specifically in forest and organic uses, the pH was moderately low compared to the conventional one, which could be attributed to the continuous incorporation of organic matter, the formation of humus and organic acids due to the decomposition of organic matter in these evaluated areas (Sihi *et al*., 2017).

In contrast, conventional use showed a significant increase in the pH and EC variables, which could be associated with the accumulation of salts in the soil due to the use of chemical fertilizers (Sihi *et al*., 2017). In this sense, Fernández *et al*. (2016) mention that these products increase the availability of nutrients causing a dissociation in the form of ions, which has repercussions in elevations of the EC and pH, explaining the results of the present study, which coincide with other authors such as Orozco *et al*. (2016) who evaluated and found the same trend in organic and conventional (chemical) fertilization. According to Suazo-Ortuño *et al*. (2014), the availability of nutrients is subject to the degree of acidity or alkalinity of the soil, finding an optimal nutritional range in pH of 5 to 7, coinciding with the trend of the nutrients evaluated in this study.

Otherwise, Larios *et al*., 2011, mention that these conventional practices in the short and medium term threaten the sustainability of the soil, furthermore to the opposition of the farmer in using organic practices since generate economic losses, which accelerates the soil degradation (Salinas *et al*., 2005).

In general, the content of SOM in organic management tends to be higher compared to conventional uses. However, we found the opposite behavior in our results, where the SOM content was higher in the conventional system (T4), which may be due to the use of chemical fertilizations that have a direct effect on the mineralization of SOM and microbial biomass (Julca-Otiniano *et al*., 2006). On the other hand, Mogollon *et al*. (2010) point out that soils with biological degradation show a decrease in the mineralization of organic matter and carbon, as well as a decrease in the biological activity of the soil.

The results indicated that the use of conventional avocado showed more availability of macro and micronutrients, compared to the other uses evaluated, which may be consistent with other studies on similar crops and management (Chung *et al*., 2008; Méndez-García, Palacios-Mayorga and Rodríguez-Domínguez, 2008; Bayuelo, Ochoa, de la Cruz and Muraoka, 2019), this behavior is mainly attributed to the contribution of minerals through soil chemical fertilizers. According to Suárez (1998), Álcala (2002) and Téliz and Mora (2015), Andosol is one of the best soils for the establishment of avocado due to its physical attributes (high porosity and low apparent density) that make it have a better root development. However, Andosols in the State of Michoacán present low availability of micro and macro nutrients, being necessary the application of organic and chemical fertilizers (Tapia *et al*., 2014). Therefore, it can be established that the availability of nutrients evaluated in this study fulfill the nutritional requirements of avocado.

The results of Ca, K and Mg contents for agricultural crops, presented a behavior similar to those reported by Sotelo-Nava *et al*. (2013) in an Andosol under avocado production, who suggest that these minerals should be reduced from the fertilization formulas because they are found in high contents in the soil, which could benefit the productivity of the crops.

In general, Cu presented a high concentration in the agricultural land uses, and could be associated with the type of agricultural management that includes periods without fallow or crop rotation, making them susceptible to the accumulation of heavy metals in the soil such as Cu, Mn and Zn, related to specific sources such as fertilizers, pesticides, compost derived from conventional solid waste and manure, affecting the health of the plant and consumers (Kabata and Pendias, 2004; Alloway, 2013; Pulido *et al*., 2015).

On the other hand, organic management showed increases in the availability of K, Ca, Zn, Cu, Fe and Mn with respect to forest use, however, the nutritional contribution of organic fertilizers is minimal compared to inorganic fertilizers, which is consistent with the results of this research (Timsina, 2018). Although the availability of Fe was optimal for forest use, it presented values below those of agricultural uses, coinciding with other investigations carried out in soils of the same region (Huerta, 2018; Campos *et al*., 2020), who explain that the low concentration of Fe is due to the fact that the Fe^{2+} and Fe^{3+} forms react forming fractions of very low solubility such as: ferrinihydrite $Fe(OH)_3$ and goethite (FeOOH) mainly (Loeppert Hossner and Amin, 1984).

The agricultural practices implied an enrichment of nutrients in the studied Andosol, according to Pengue (2009), monocultures cause a selective extraction of nutrients from the soil, generating a dependence on mineral fertilizations (organic and chemical) to recover its level of fertility. In this sense, Maldonado-Torres *et al*. (2007) mention that deficiencies and excesses of nutrients can cause factors such as antagonisms and synergisms, affecting the nutrition and productivity of the crop.

Likewise, continuous fertilization can cause environmental problems such as soil contamination, eutrophication of water bodies and nutritional stress in crops derived from a shortage or excess of nutrients (Riskin *et al*., 2013). Therefore, Raymundo *et al*. (2009) and Bravo-Espinoza *et al*. (2012) suggest the implementation of adequate soil resource practices that allow mitigating the environmental effects of the leaching of agrochemicals. On the other hand, De la Tejera *et al*. (2013) point out that the state of Michoacán should be involved in the regulation of the use of agrochemicals, which will allow establishing awareness measures to prevent environmental damage and the population.

CONCLUSIONS

The changes in land use and its subsequent agricultural management caused significant variations in the availability of nutrients, pH and electric conductivity of the Andosol.

In general, the Andosol evaluated presented an adequate nutritional condition for the establishment and development of the avocado crop. However, agricultural practices such as the application of organic and inorganic fertilizers increase the availability of nutrients in the soil, which was particularly demonstrated in the conventional avocado land use.

The order of macro and micronutrient concentrations in the land use systems showed the same trend at both soil depths: conventional avocado> organic queensland nut> organic avocado> forest.

The average concentration of nutrients show the same trend for both soil depths as follows: Macronutrients Ca>Mg>K>Na, and Micronutrients Fe>Zn>Mn>Cu.

The results of this study allow to establish sustainability criteria in the management of soil and crops in the Uruapan region of Michoacan state.

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