EFFECTS OF DIFFERENT LAND-USE SYSTEMS ON SOIL PHYSICOCHEMICAL PROPERTIES OF A CHERNOZEM IN NORTHEAST MEXICO †

[EFECTOS DE DIFERENTES SISTEMAS DE USO DE SUELO SOBRE LAS PROPIEDADES FISICOQUÍMICAS DEL SUELO DE UN CHERNOZEM EN EL NORESTE DE MÉXICO]

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SUMMARY

Background. The soil uses have been present since man domesticated the cultivated plants and, in the process, several changes in the soil's physicochemical properties have been observed. Most of those changes have been detrimental to the soil's productivity on a sustained basis. Thus, it is important to study and analyze the changes in soil's physicochemical and hydraulic properties that get affections due to land conversion into different land-use systems. **Objective.** Assess the effect of different land-use systems on the physical, chemical, and hydrological properties of the soils in Northeast Mexico. **Methodology.** The study took place in a Chernozem soil in the Municipality of General Terán, Nuevo León, Mexico, and the land-use systems we investigated were: a citrus plantation, a grassland, an agricultural area, and the natural vegetation of the Tamaulipan Thornscrub site (MET) as a control treatment. Four composite soil samples were obtained from each site at two depths of 0-10 cm, and 10-30 cm, the chemical properties analyzed were pH and electrical conductivity (EC), and the physical properties consisted of Bulk density (BD), texture, total porosity (Tp), mechanical resistance to penetration (MRP) and field capacity (FC), permanent wilting point (PWP), available water (AW), initial infiltration (Ii), accumulated infiltration (Ai) and infiltration capacity (Ic). **Results.** The soil pH showed significant differences with depth (p=0.01), as well as the interaction of land-use depth (p=0.008), while electrical conductivity showed significant differences between land uses systems (p= 0.000); soil texture showed important differences in sand (p=0.003), silt (p=0.003) and clay content (p=0.006). There were significant differences between interaction of land-use soil depth, silt (p=0.003), and clay content (p=0.009). Soil hardness was significantly different between the diverse land-use systems (p=0.000). Concerning hydraulic properties, the water available in the place showed differences in land-use (p=0.001) and interaction land use-depth (p=0.006). Field capacity was also affected by land-use systems (p=0.000), as well as the interaction land use-depth (p=0.02); wilting point showed significant differences under distinct land use systems (p=0000), and in interaction of land use-depth (p=0003). **Implications.** More studies are needed in the short, medium and long term to monitor changes in physical, chemical, and water properties of soils under different land uses. Such information can be a guide in the proper management of these soils. **Conclusion:** From this study, it was possible to identify the negative impact that the different land-use systems have on the physical, chemical, and hydraulic properties of the soils under investigation. The hydraulic soil properties are the most affected. The information from this research can help for a better understanding of managing different land-use types in this Chernozem.
Key words: Citrus; Grassland; Tamaulipan Thornscrub; Agricultural; Chernozem; Infiltration.

RESUMEN

Antecedentes. Los usos del suelo se han hecho presentes desde que el hombre domesticó las plantas cultivadas, y, en el proceso, se han observado diversos cambios en las propiedades fisicoquímicas del suelo. La mayoría de dichos cambios han sido perjudiciales para la productividad del suelo de una manera sostenible. Por lo tanto, es importante estudiar y analizar los cambios en las propiedades fisicoquímicas e hidráulicas del suelo que se ven afectadas por el

cambio en diferentes sistemas de uso del suelo. **Objetivo.** Evaluar los efectos de diferentes sistemas de uso del suelo en las propiedades fisicoquímicas e hidrológicas en un suelo del noreste de México. **Metodología.** El estudio se ubicó en un suelo Chernozem en el Municipio de General Terán, Nuevo León, México, los sistemas de uso del suelo investigados fueron: Una plantación de cítricos, un área de pastizal, y un área de agricultura, y la vegetación natural del sitio Matorral Espinoso Tamaulipeco (MET) como tratamiento testigo. Se obtuvieron 4 muestras compuestas de suelo de cada sitio a dos profundidades de 0-10 cm y 10-30 cm, las propiedades químicas analizadas fueron pH y conductividad eléctrica (EC), las propiedades físicas consistieron en densidad aparente (BD), textura, porosidad total (Tp), resistencia mecánica a la penetración (MRP) y para las variables hídricas se evaluaron la capacidad de campo (FC), punto de marchitez permanente (PWP), agua útil (AW), infiltración inicial (Ii), infiltración acumulada (Ai) y capacidad de infiltración (Ic). **Resultados.** El pH presentó diferencias por profundidad *(p= 0.01)* y en la interacción áreas-profundidad *(p= 0.008)*, mientras que conductividad eléctrica mostró diferencias solo entre usos de suelo *(p= 0.000)*, la textura del suelo mostró diferencias importantes en arena *(p=0.003)*, limo *(p=0.003)* y arcilla *(p=0.006)*, la resistencia mecánica a la penetración presentó diferencias por uso de suelo *(p=0.000)* , en cuanto a las propiedades hídricas el agua útil presentó diferencias en uso de suelo *(p=0.001)* e interacción uso de suelo-profundidad *(p=0.006)*, la capacidad de campo presentó diferencias en uso de suelo *(p=0.000)* e interacción uso de suelo-profundidad *(p=0.02)* y el punto de marchites permanente presentó diferencias en uso de suelo *(p=0.000)* e interacción uso de suelo-profundidad *(p=0.003)*. **Implicaciones.** Es necesario más estudios a corto mediano y largo plazo, para monitorear los cambios en las propiedades físicas, químicas e hidráulicas de los suelos bajo diferentes usos. Dicha información puede ser una guía en el manejo adecuado de los suelos. **Conclusiones.** A partir de este estudio fue posible identificar el impacto negativo que los diferentes usos del suelo tienen sobre las propiedades físicas, químicas e hidráulicas del suelo investigado. Las propiedades hidráulicas del suelo son las más afectadas. La información de esta investigación puede ayudar a una mejor comprensión de la gestión de los diferentes usos del suelo en este Chernozem.
Palabras clave: Cítricos; Pastizal; Matorral Espinoso Tamaulipeco; Agrícola; Chernozem; Infiltración.

INTRODUCTION

In Mexico, there are 26 out of the 32 soil groups that the International Soil Resource Reference Base System (IUSS, 2015) recognizes, where Chernozem occupies only 1.3% of the Mexican national territory, approximately 2,553,687.5 ha (INEGI, 2016). According to INEGI (2012), in the state of Nuevo León, there is around 254,256 ha, which are equivalent to 9.96% of all the Chernozem soil acclaimed in Mexico.

In Mexico, we identify three Chernozem soil subgroups: 1) Calcic Chernozem (Ck), characterized by a layer of secondary carbonates (lime) or calcium sulfate (gypsum); 2) Haplic Chernozem (Ch), which does not present any characteristic properties, and 3) Luvic Chernozem (Cl) which shows an accumulation of clays in the subsoil (INEGI, 2017).

In all ecosystems, the soil is a fundamental component of the circle that forms the environment and produces essential environmental resources for human life (Cotler *et al*., 2007). Velázquez *et al.* (2002) estimated that the vegetation cover in Mexico should have approximately 0.7 ha per capita of wooded cover, but current data indicates that the country hosts only 0.5 ha of forest cover, and predictions say that, by 2025, it will have only 0.3 ha, a far way below the world average.

The soil does not have the same appreciation as other natural resources. Therefore, it is not considered a directly consumable good, and because of the mistake that soils are renewable on a human scale (Zinck,

2005). Soil is a dynamic ecosystem that supports multiple life forms. Therefore, when looking at the system as a whole, it is not difficult to understand or recognize the concept of soil quality or health, such as human health (El-Ramady *et al*., 2014).

One characteristic of the Chernozem soil is to exhibit a very rich upper layer of organic matter, in color black, whose name comes from the Russian words cherno and zemljá, which literally means black earth (IUSS, 2007). The Chernozem soil is formed mainly by deposits of soils called loess and calcareous substrates, which can be fluvial and lacustrine, rich in calcium carbonates. Climate and precipitation are strongly linked to the formation of the Chernozem soil (Pavlovic *et al*., 2017). Some typical properties of the Chernozem soil are a high porosity in a range of 55 to 60%, a low bulk density, and their pH varies from 6.6 to 8.5. It also stands out that they have a high field capacity and a low wilting point. (IUSS, 2015).

According to the previous information, it is of great importance to evaluate the effects of the various activities on the use of Chernozem soil. Thus, the main objective of this study is to see the changes in the physical, chemical, and hydrological properties of the soil, and to contribute to an adequate management momentum of the soil resource.

MATERIALS AND METHODS

Study Area

The study area is located in the Municipality of General Terán, Nuevo León, Mexico, at UTM

coordinates zone 14, 424,900 E; 2,799,568 N; at an altitude of 329 masl (Figure 1). It belongs to the coastal plain of the northern Gulf and to the sub-province characterized by plains and hills. It is made up of hills and plains with types of vegetation of submontane scrub, Tamaulipan thornscrub, oak forest, mesquite, and grasslands (INEGI, 1986).
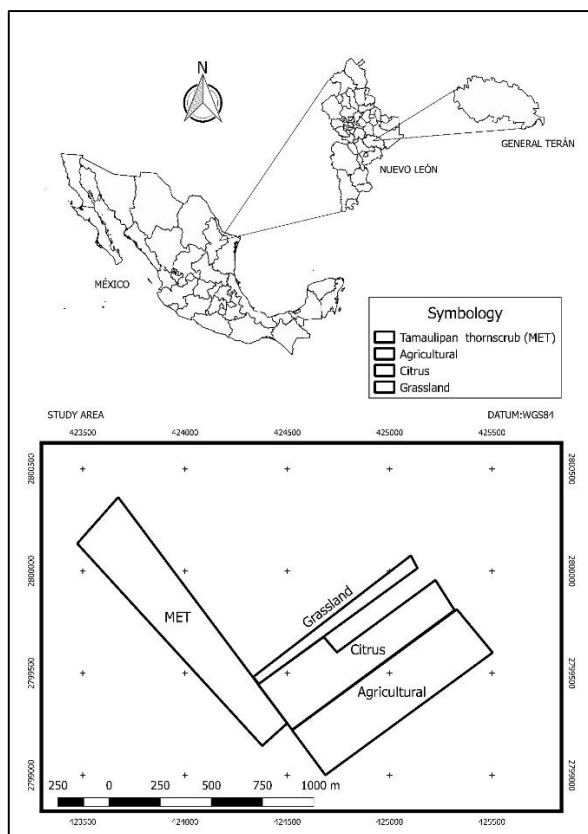

Figure 1. Location of the study area.

According to the Vaquerías weather station, the study area has an average annual temperature of 24 °C and an average annual rainfall of 637.1 mm (SMN, CNA, 2010). The soils that predominate in the area are Luvic and Haplic Kastanozems associated with Vertisols, Phaeozems, and Chernozem. (INEGI 2013). We selected four land-use systems, which correspond to the Tamaulipan thornscrub (natural vegetation, MET), an agricultural area, a citrus orchard, and a grassland. The control area (Tamaulipan thorn scrub) contains the natural vegetation of the site and does not present disturbance or anthropogenic activities that could alter the soils' physical, chemical, and hydraulic properties. The agricultural land use is 20 years old with the cultivation of corn, sorghum, and wheat, and the last five years with wheat and sorghum. It is a rainfed cropland using intensive tillage with fertilizers amendments and pesticides are not applied. In the citrus land use, oranges (Marss and Valencia variety),

and tangerines (Dancy variety) are grown, and it is 30 years old, it has a sprinkler irrigation system, and it is fertilized with 166 Kg ha of phosphonitrate added in the irrigation system, applied every six months using pesticides like abamectin, cypermethrin, and malathion. Grassland land use is 20 years old, it is a rainfed grassland, and, depending on the rain, it is harvested once or twice a year. Also, a forage harvest machine is used, fertilizers or pesticides are not applied, and the land is free of livestock.

Collection and Processing of Soil Samples

We performed the soil sampling in November 2018. Soil samples were taken from each land-use system, where eight composite soil samples of 1 to 1.5 kg were obtained; four at a depth of 0-10 cm and four at 10-30 cm, having a total of 32 samples. Later on, samples were dried in the shade and screened with a 2 mm sieve. We used methods established in the NOM-021-RECNAT-2000 (SEMARNAT, 2002) and the soil manual procedures (Woerner, 1989).

Soil Physical Properties

The Bouyoucos Densimeter method determined the soil texture, AS-09 NOM-021 RECNAT-2000 (SEMARNAT, 2002). The bulk density (BD) was determined in undisturbed samples using the gravimetric method called the cylinder, where we use a metal cylinder of 5 cm x 5 cm (volume of 98,175 cm3) (Woerner, 1989). Regarding the total porosity (Tp), this property is estimated from the bulk density values, assuming a particle density of 2.65 g cm-3 and determined according to the equation established by McPhee *et al*. (2015). The mechanical resistance to penetration (MRP) was determined directly with the use of a Yamanaka type penetrometer (22110 Orion, MKK Co., Japan).

Soil Chemical Properties

The AS-23 NOM-021 RECNAT-2000 method (SEMARNAT, 2002) determined the pH and the electrical conductivity (EC, $\mu S\ cm^{-1}$) consisted in a rapid determination in soil-water suspension matrix EC1:5 (Miller and Curtin, 2006), using a pH/conductivity meter (Corning brand, model 542, USA).

Soil Hydraulic Properties

Regarding the hydraulic variables, the double ring method determined the infiltration rate ($I = mm\ h^{-1}$), which consists of introducing two cylinders of different diameters into the soil at a depth of 10 cm. Furthermore, the method consist of taking readings about pouring the water level into the inner ring; we performed the tests in the field on undisturbed soils.

Then, when the infiltration is constant, the test is completed (Zhang *et al*., 2017). An initial infiltration (Ii) relates the amount of water that infiltrates the soil after the first minute of measurement has elapsed (Ii = mm h^{-1}). An accumulated infiltration (Ai) refers to the total water that has been infiltrated through the soil in a period, e.g., 120 minutes (Ai = mm). Infiltration capacity (Ic) indicates the average infiltration speed with which the water penetrates the soil when it tends to become constant, the average of the last three measurements was taken in a period of 20 minutes (Ic = mm h^{-1}). The field capacity (FC) and the permanent wilting point (PWP) parameters were determined using the plate method and the pressure membrane at 0.3 atm for FC and 15 atm for PWP with plate extractors (Soil Moisture Equipment Corp., Santa Barbara, CA, USA). The available water content (%) is obtained from the difference between FC and PWP. We applied the gravimetric method AS-05 to determine the moisture content of the samples that were subjected to pressure in the plates, where the wet samples were placed in a drying oven at 105 °C for 24 hours. Soil dry weight was obtained according to NOM-021-RECNAT-2000 (SEMARNAT, 2002).

Statistical Analysis

Since the data did not show the assumptions of normality and equal variances according to the Shapiro Wilks and Levene tests, respectively, the arctangent transformation (f(x) = arctg x) (Sokal and Roholf, 1995) was applied for the studied variables sand, clay, silt, BD, Tp, MRP, pH, EC, FC, PWP, and AW to perform the ANOVA analysis and mean comparison following the Tukey test (P=0.05) (reference). We applied the Kruskal-Wallis analysis for variables initial infiltration, accumulated infiltration, and basic

infiltration since the data did not meet the assumptions of normality. Likewise, a Spearman correlation was carried out to observe the association between different variables. We used the SPSS® program (Statistical Package for Social Sciences, standard version 22 for Windows, SPSS Inc., Chicago, IL).

RESULTS AND DISCUSSION

According to the ANOVA, values of electrical conductivity, percentage of sand, clay, and silt, mechanical resistance to penetration, field capacity, permanent wilting point, and available water content showed significant differences (p≤0.05) among the four land-use systems (Table 1). Similarly, figures for pH and percentage of clay and silt showed significant differences (p≤0.05) between soil depths (Table 1). Likewise, concerning the interaction of land use*soil depth, and significant differences (p≤0.05) were observed in pH, FC, PWP, and AW (Table 1).

Soil Reaction (pH)

According to the assessment of NOM-021, SEMARNAT (2002), the soil has a moderately alkaline pH, with values ranging from 7.36 to 7.74. Regarding the soil depth of 0-10 cm, the lowest value (7.49) was observed in the MET, and the highest value (7.67) was found in the citrus land use, while for the soil depth of 10-30 cm, pH values ranged between 7.60 and 7.68 for the citrus and MET land-use systems, respectively (Figure 2). Strong changes in land-use modify the pH over a certain period, as has been documented by Jha *et al*. (2010) and Osman *et al*. (2013), who observed variations in pH in the different land uses while being compared to the control plot.

Table 1. Summary of the analysis of variance for some chemical (pH and electrical conductivity, EC) and physical (percentage of sand, silt, and clay; bulk density, BD; total porosity, Tp; mechanical resistance to penetration, MRP; field capacity, FC; permanent wilting point, PWP, and available Available water, AW) soil properties considering a factorial experiment array under a one-way experimental design.

Variable	Unit	FA[a]	FB[b]	Interaction (FA* FB)[c]	Levene´s Test
		(3, 31)	(1, 15)	(3, 15)	
pH		2.12[NS]	7.39[*]	5.01**	2.15
EC	µS cm^{-1}	17.08**	0.00[NS]	1.30[NS]	1.85
Sand	%	3.50*	0.00[NS]	1.42[NS]	0.77
Clay	%	5.21**	8.00**	2.36[NS]	2.49
Silt	%	3.15*	10.59**	1.06[NS]	1.94
FC	%	10.85**	0.28[NS]	3.98*	0.41
PWP	%	112.90**	0.18[NS]	9.26**	2.27
AW	%	7.94**	0.36[NS]	5.28**	0.67
BD	g cm^{-3}	2.54[NS]			2.14
Tp	%	2.47[NS]			2.13
MRP	kg cm^{-2}	42.11**			2.44

Land use factor (FA)[a], soil depth profile (FB)[b] and interaction use by depth (FA*FB)[c] **Highly significant differences (p≤0.01) *Significant differences (p≤0.05), [NS] Not significant.
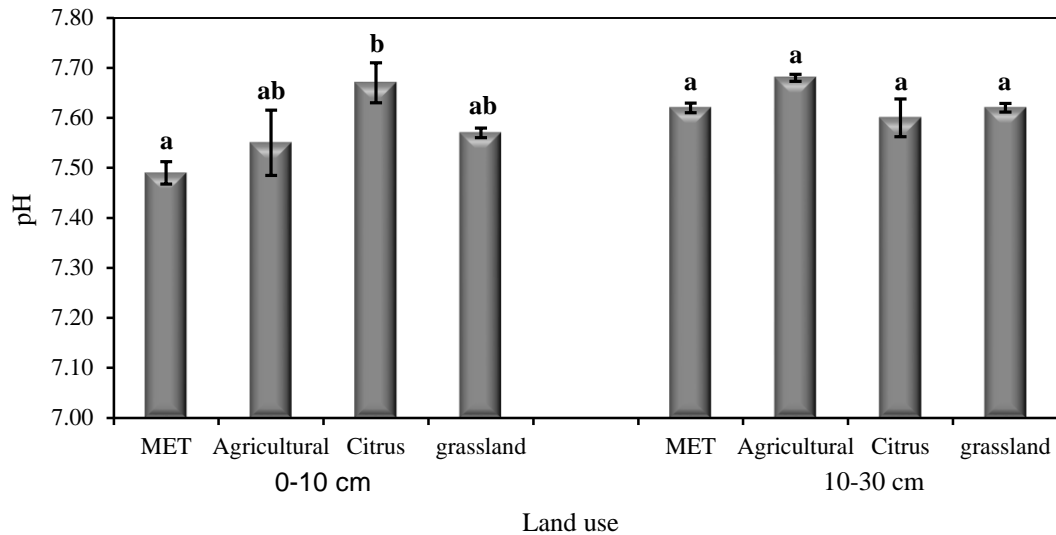
Figure 2. Mean values ± standard error (n=4) for pH at two soil depths in four land-use systems. Means with different letters at the same depth, are statistically different (Tukey p≤0.05).

Electrical Conductivity

The salinity of the soils for all land uses was classified as very low, where values less than 1000 µS cm-1 correspond to low salinity, indicating a low concentration of salts in the soil-water suspension (Woerner, 1989). The values ranged from 80.4 µS cm-1 in agricultural use to 107.7 µS cm^{-1} in MET use for the 0-10 cm soil depth profile. In contrast, for the 10-30 cm depth, it ranged from 81.4 4 (grassland) to 106.7 4 µS cm^{-1} in citrus (Figure 3). Mačkić *et al.* (2014) found electrical conductivity values in a range from 680 to 880 to µS cm^{-1} in Chernozem soil, where they

evaluated the effects of irrigation on the soil's chemical properties.

Texture

In the first depth, 0-10 cm, the textural class for the MET, citrus and grassland use was silty clay and silty clay loam for the agricultural land use. For the 10-30 cm soil depth, the MET showed a clay and the agriculture, citrus and grassland use systems exhibited a silty clay texture. In relation to sand at the 0-10 cm soil depth, the agriculture use displayed the highest (17.0 %) sand content and the highest (46.08 %) silt content; the citrus use revealed the highest (44.42 %)
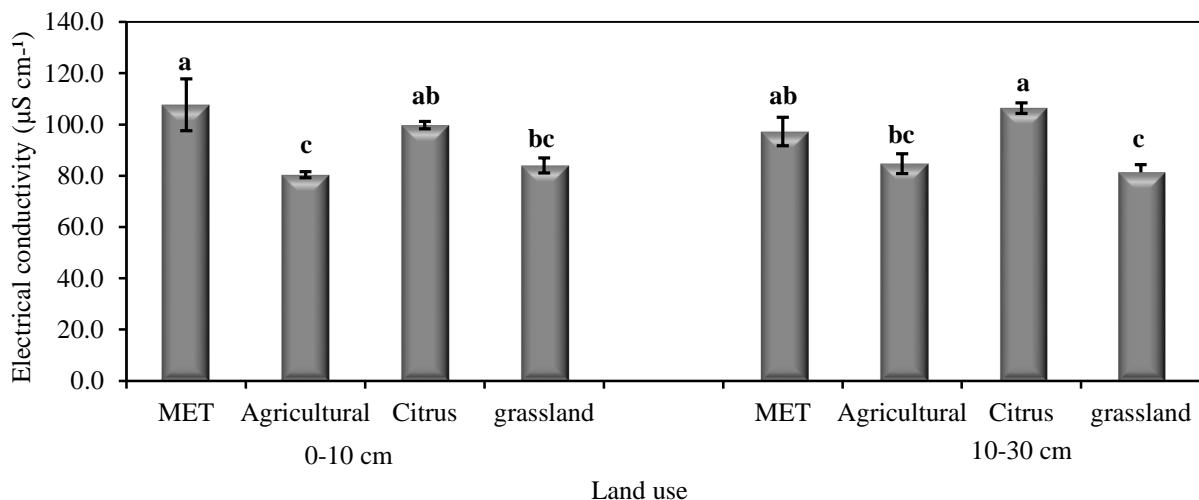

Figure 3. Mean values ± standard error (n=4) for electrical conductivity at the two soil depths in four land-use systems. Means with different letters at the same depth, are statistically different (Tukey p≤0.05).

clay content, while the use system that showed the lowest sand (11.0 %), silt (36.68 %) and clay (36.96 %) content was the citrus, MET and agriculture, respectively. For the 10-30 cm soil depth, the uses with the highest content of sand, silt and clay were the agriculture, citrus and MET with values of 13.6, 43.94, and 49.96 %, respectively. The uses with the lowest content of sand were grassland (11.54 %) and MET (12.26 %). These results are similar to those found by Yáñez (2017) in a Vertisol soil, where the values for clay ranged from 37.7% to 49.9%, for silt from 26% to 44.4% and for sand from 9.3% to 21.6%. Both, the Chernozem and the Vertisol, are rich in clays and with drastic changes in use, they are susceptible to great changes in their properties. Although texture is a stable indicator of the relative proportion of sand, silt and clay, inherent to the mineral material in its formation, it has been shown to be an indicator of the effect of soil practices, tillage, irrigation and fertilization, its effect on other physical, chemical and biological properties of the soil being of utmost importance (Narro, 1994; Sustaita *et al*. 2000; Haruna *et al*., 2017), (Figure 4).

Bulk Density and Total Porosity

We did not find significant differences between the diverse land uses for the soil bulk density and total porosity. Agreeing to the evaluation range of Woerner (1989), they showed a very low bulk density classification (BD <1.20 g cm-3). According to the acquired bulk density values, the porosity figures were estimated and based on the assessment of the Manual for Soil Analytical Procedures (Flores and Alcalá, 2010). We obtained high porosity values in grassland (59.4%) and agricultural (58.2%) to very high porosity values for citrus (64.8%) and MET (63.3%) land use. We can explain these values when considering the mechanical tillage observed in the study areas and what was mentioned by Haruna *et al* (2017), who report an improvement in the bulk density of the soil due to the tillage system reducing soil compaction.

Mechanical Resistance to Penetration

Concerning the soil hardness test, the area with the greatest resistance was the grassland (0.302 MPa), followed by the citrus (0.177 MPa), while the land uses with the lowest (0.130 MPa) resistance to penetration were the agriculture and MET (Figure 5). Gaitán and
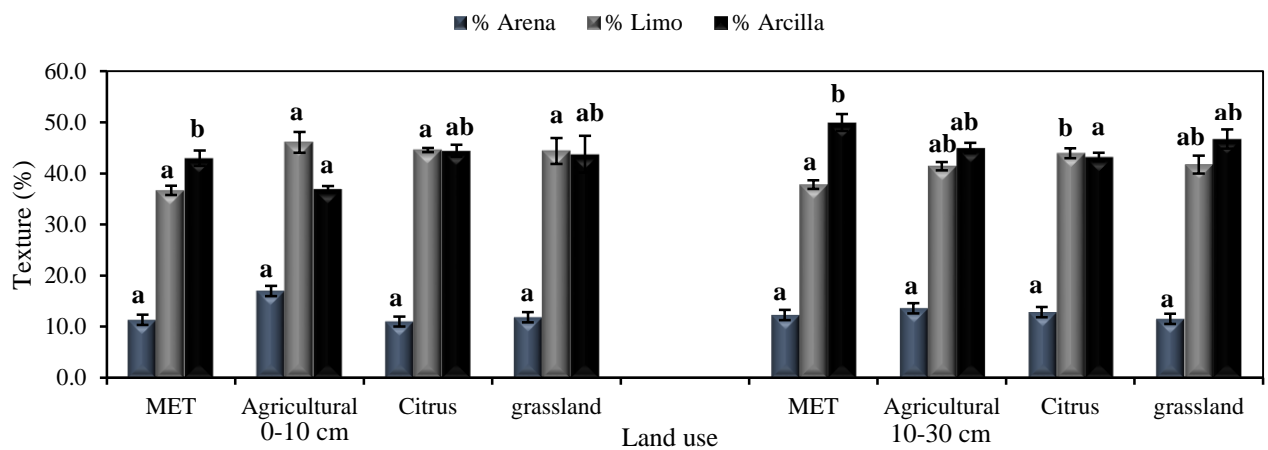
Figure 4. Mean values ± standard error (n=4) for soil particle distribution (sand, silt and clay) at two depths and four land-use systems. Means with different letters in the same depth, are statistically different (Tukey p≤0.05).
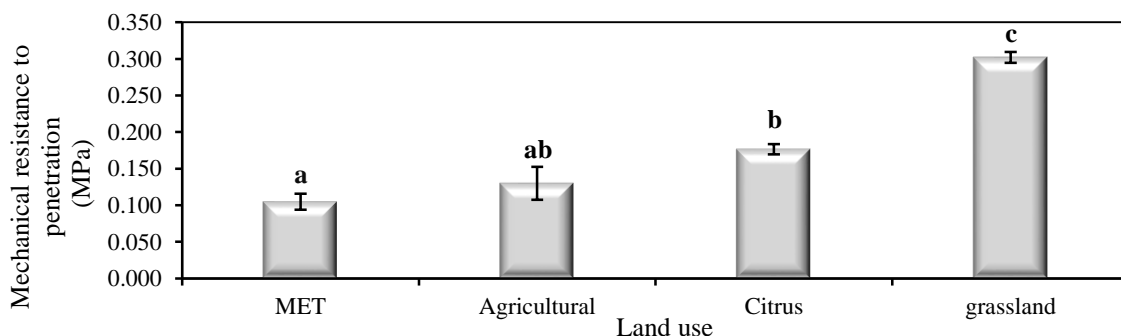
Figure 5. Mean values ± standard error (n=4) for the Mechanical Resistance to Penetration (MRP) in four land-use systems. Means with different letters, are statistically different (Tukey p≤0.05).

Penón (2003) also found that the lowest (0.105 MPa) value of MRP was observed in the shallowest depth (0-10 cm) in agricultural soils. In this regard, Luna *et al.* (2021) establish that the mechanical resistance to penetration increased up to 222% compared to the control areas due to the absence of vegetation and the impact of plant cover removal practices.

Field Capacity, Permanent Wilting Point and Available Water

The field capacity varied in the different soil uses, and the MET displayed the highest value (43.2%) in both depths, followed by the agriculture, grassland, and citrus systems. Regarding the soil depth (10-30 cm), the order from high to low values was for MET, grassland, citrus, and agriculture, respectively. Concerning the permanent wilting point, the MET land-use system showed the highest value (36.2%) for both depths, followed by the grassland and citrus, and finally, the agriculture use showed a value of 19.0%. Considering the available water content for the depth

0-10 cm, the area that exhibited the highest percentage (17.8%) was agricultural use, followed by the MET, citrus, and the grassland use (10.5%). On the other hand, there were small differences for depth 10-30 cm. However, the uses MET, citrus and grassland increased their available water by 26.02, 14.84 and 24.56%, respectively, while the agriculture use decreased its content by 37.43%. In contrast to sandy soils, clayed-textured soils registered the highest FC, PWP and AW percentages. In soils with a high percentage of sand, the lowest values of FC, PWP and AW (from 10 to 20%) have been documented (Assi *et al.*, 2019; Marimon-Junior *et al.*, 2019). Soils with a sandy texture, along with a high bulk density and a low porosity percentage, have a high undesirable influence on the hydroedaphic properties of the soil (Santra *et al.*, 2018) (Figures 6, 7 and 8). A non-parametric Kruskal-Wallis test was performed for the initial infiltration variables (Ii), accumulated infiltration (Ai) and infiltration capacity (Ic) (Table 2). Significant differences were found in all infiltration traits ($p \leq 0.5$) and among the four land uses studied.
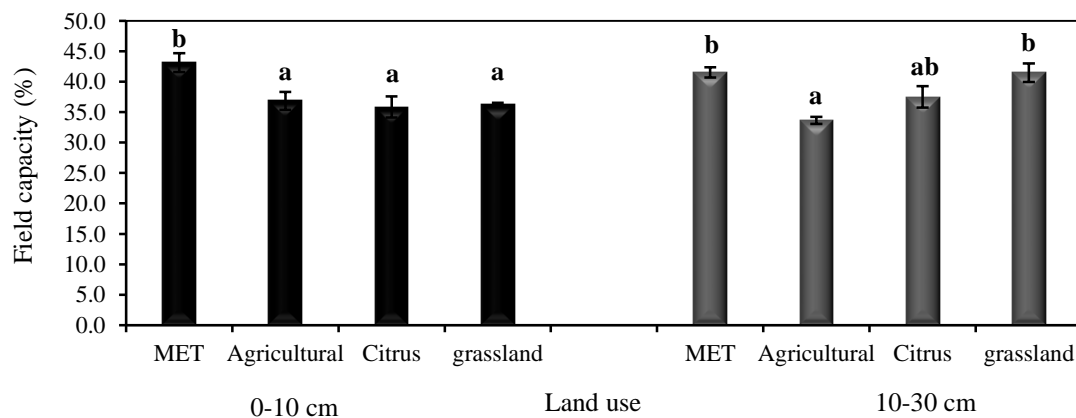

Figure 6. Mean values $\pm$ standard error (n=4) for field capacity at two soil depths in four land-use systems. Means with different letters in the same depth, are statistically different (Tukey $p \leq 0.05$).

Figure 7. Mean values $\pm$ standard error (n=4) for permanent wilting point at two soil depths in four land-use systems. Means with different letters in the same depth, are statistically different (Tukey $p \leq 0.05$.)
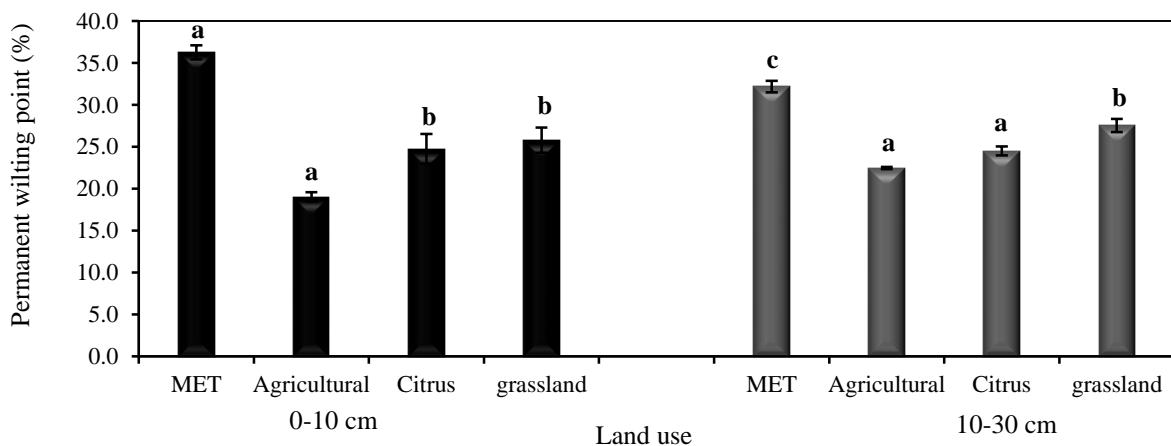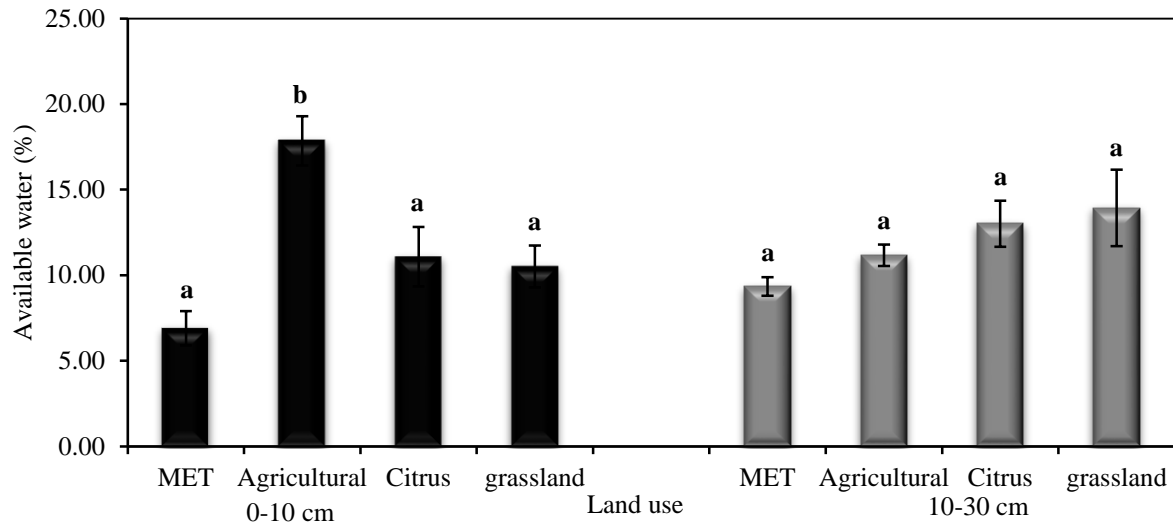
Figure 8. Mean values ± standard error (n=4) for available water at two soil depths in four land-use systems. Means with different letters in the same depth, are statistically different (Tukey p≤0.05).

Table 2. Kruskal-Wallis H statistics for the variables initial infiltration (Ii), accumulated infiltration (Ai) and infiltration capacity (Ic).

Statistic	Ii (mm h^{-1})	Ai (mm)	Ic (mm h^{-1})
n	12	12	12
Asymptotic significance	0.031*	0.033*	0.018*
Half	1,380.00	561.25	173.25
Median	1,260.00	452.00	88.50
χ^2	8.89	8.72	10.00

** Highly significant differences (p≤0.01), * Significant differences (p≤0.05).

Table 3 shows the Mann-Whitney U test for the infiltration variables studied: initial infiltration (Ii), accumulated infiltration (Ai), and infiltration capacity (Ic). For the initial infiltration, it was found that there are significant differences (p≤0.05) between the uses MET- Agriculture, MET-Grassland, Agriculture - Citrus. In relation to the accumulated infiltration (Ai), significant differences (p≤0.05) in all the uses were observed, except in the MET-Agriculture. Regarding the infiltration capacity (Ic), we found significant differences (p≤0.05) in all uses, except in the MET-Agriculture use system.

Infiltration Rate

The land uses that showed lower infiltration rates were agriculture 194 (mm h^{-1}) and grassland (90 mm h^{-1}), while the MET 406 (mm h^{-1}) and citrus (899 mm h^{-1}) presented the highest infiltration rates. The infiltration

rate began to stabilize at minute 35 for all land uses. Karlin *et al* (2019) determined that the change in land use influence the reduction of the infiltration capacity, mainly in agriculture. Yimer *et al* (2008) reported a lower infiltration rate in cultivation and grassland use compared to a control soil use (forest stand plot). These results are similar to our infiltration rate findings, in which the agriculture and grassland use showed a considerable reduction compared to the MET use, while the citrus use exhibited a higher infiltration rate than the MET use. The infiltration rates are altered with a high bulk density and a low porosity (Figure 9).

Table 3. Mann-Whitney U comparison paired tests between land uses for initial infiltration (Ii), accumulated infiltration (Ai) and infiltration capacity (Ic).

U de Mann-Whitney test	Ii (mm h^{-1})	Ai (mm)	Ic (mm h^{-1})
MET - Agriculture	0.05*	0.28[NS]	0.12[NS]
MET - Citrus	0.51[NS]	0.05*	0.05*
MET - Grassland	0.04*	0.05*	0.05*
Agriculture - Citrus	0.05*	0.05*	0.05*
Agriculture - Grassland	0.25	0.05*	0.05*
Citrus - Grassland	0.05*	0.05*	0.05*

**Highly significant differences (p≤0.01); *Significant differences (p≤0.05); [NS] Not significant (p>0.05).
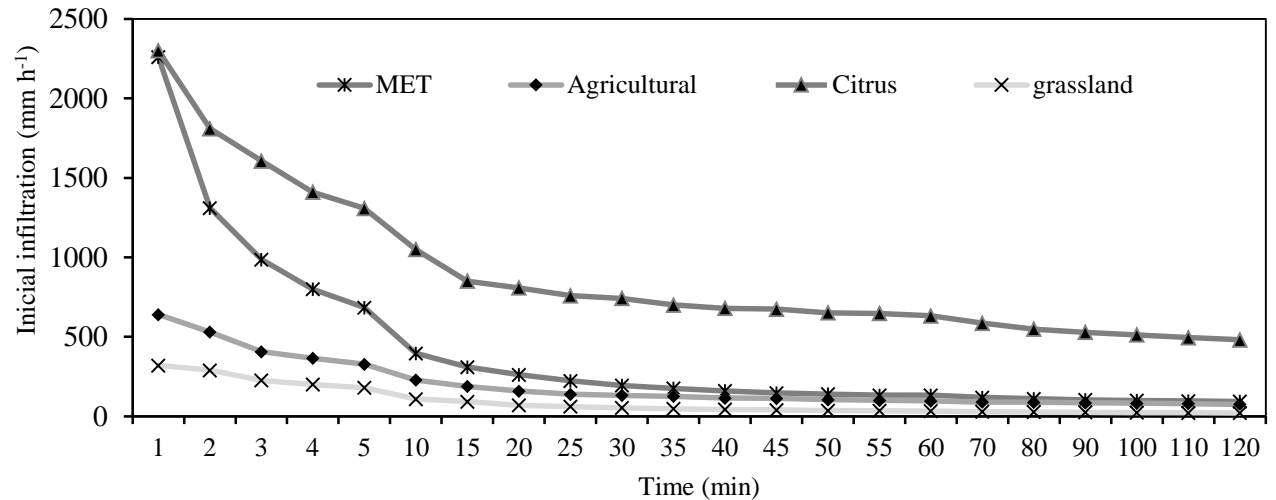
Figure 9. Average infiltration curves in a Chernozem soil in four land-use systems.

Initial Infiltration

The land use that showed the highest initial infiltration was the citrus area, followed by the MET use, while the agriculture and grassland use displayed the lowest infiltration. These results agree with those observed by Yáñez *et al*. (2018), where they reported significant changes in the initial infiltration, mainly in the grassland and plantation areas. Vittala *et al*. (2017) attributed the initial infiltration to the texture of the soils, with sandy soils showing the highest initial infiltration, while clayed soils showed the lowest since the Chernozem soil is characterized by having a high clay content, up to 49.96% (Figure 10).

Accumulative Infiltration

The accumulated infiltration showed significant differences ($p \leq 0.05$) for all areas. The lowest accumulated infiltration values belong to the grassland and agricultural land use, while MET and citrus showed the highest infiltration (Figure 13). Shrestha and Lal (2008) reported similar results on the accumulated infiltration in grasslands and agricultural areas), while the control area showed an accumulated infiltration behavior similar to that found in the present study since agriculture and grassland exhibited the lowest accumulated infiltration values (Figure 11).
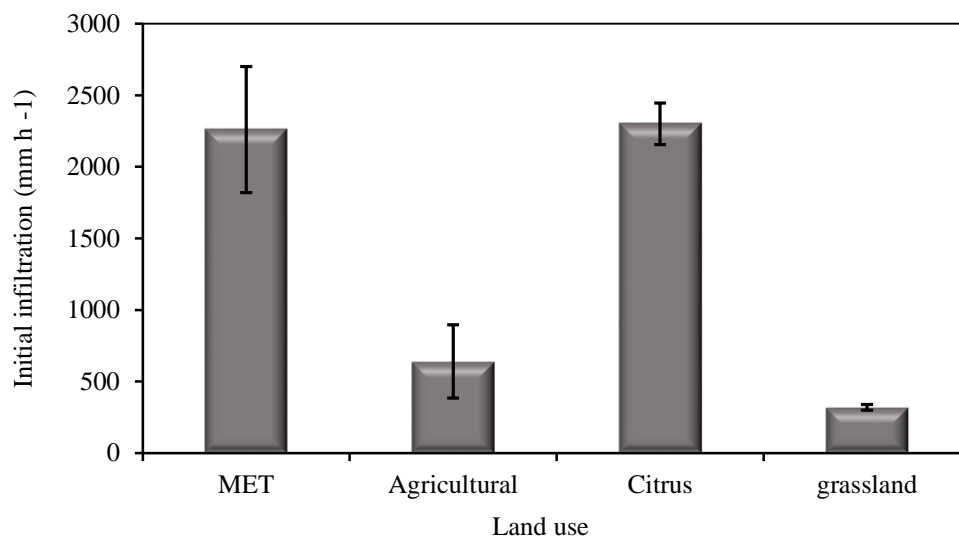

Figure 10. Mean values ± standard error (n=3), average initial infiltration values at four land uses.
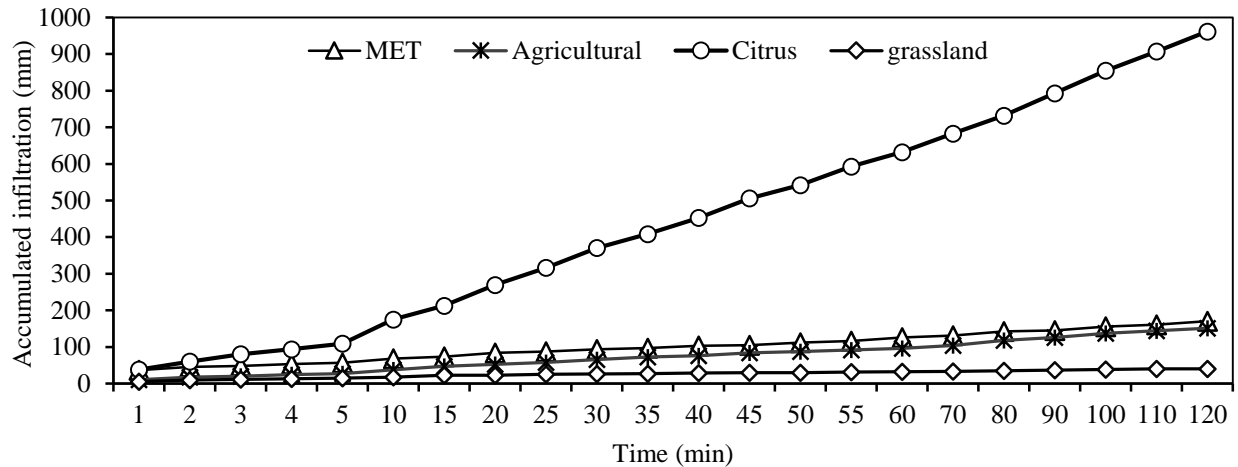
Figure 11. Cumulative average infiltration in four land-use systems.

Infiltration Capacity

The infiltration capacity varied according to land uses. The citrus area had the highest value, followed by the MET, agriculture, and grassland (Figure 12), indicating that the lowest value was 22.53%, lower than the MET control area, and the land-use with the highest Ic was 515.05% higher than the MET. Khaledian *et al*. (2012) and Fan *et al*. (2013) found similar results since they reported a decrease in infiltration capacity concerning their control area and attributed it mainly to the high impact of tillage and soil compaction, as well as deforestation. On the other hand, Bi *et al*. (2014) found a high infiltration capacity in soils with natural vegetation (control) since the vegetation cover enhances the properties that favor soil infiltration.

Correlation Between Physicochemical and Hydroedaphic Variables

For the depth 0-10 cm, it was found that the pH only correlates with FC and this correlation is negative. In relation to electrical conductivity (EC), it showed a significant correlation with the variables PWP, Ii, and Ic. The bulk density (BD) maintains a negative and highly significant correlation with Ii and Ic. Porosity (Po) is negatively but significantly related to AW and highly significant to Ii. On the other hand, the clay variable maintains an important correlation with the permanent wilting point PWP. While the mechanical resistance to penetration (MRP) showed a positive correlation with the accumulated infiltration (Ai). The initial infiltration variable (Ii) was positively and significantly correlated with the infiltration capacity (Ic), For the depth of 10-30 cm, the ARC variable and the silt were highly correlated, while FC, showed a highly
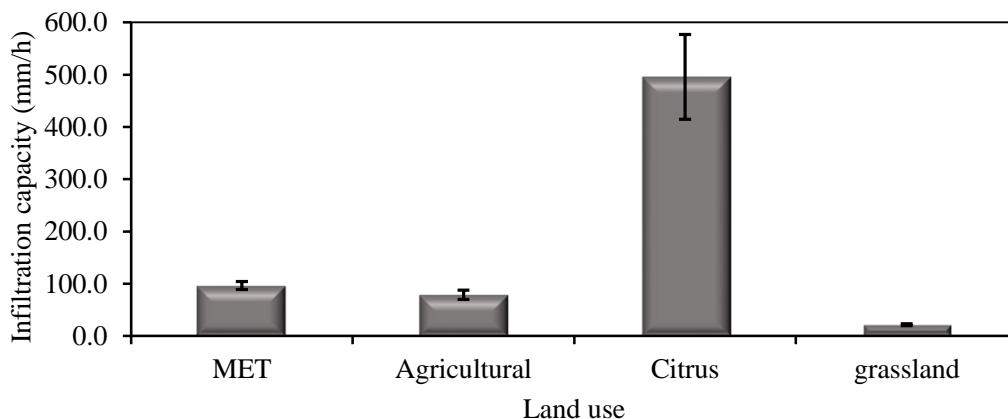

Figure 12. Mean values $\pm$ standard error (n=4) of infiltration capacity in four land-use.

significant correlation with the PWP. Pishnamaz *et al.* (2021) found a significant and positive correlation between EC and PWP, clay content, and PWP. These results agree with those of the present study, observing high percentages of clays and intense tillage in the agriculture and citrus areas. In their study with loess soils, Qiao *et al.* (2019) found a significant correlation between the FC with sand, silt, clay, and PWP. Thus, suggesting that clays and sands play an extremely important role in the hydroedaphic properties of the predominantly clayed soils, such as the Chernozem and loess soils.

The citrus land use presented the highest values in some of the hydraulic properties, especially in those carried out in the field. Citrus roots have a type of tap root and extend up to 6 meters vertically and horizontally, being in the first 30 cm soil depth where the root system develops in greater proportion, for the absorption of water and nutrients (Orduz and Matteus, 2012). López (2014) mentioned that the infiltration rate is not determined by the type of soil or land use, but by external factors. Blackburn *et al* (1992) also determined that texture is not a property directly related to infiltration, but rather to plant communities, and Archer *et al.* (2002) mentioned that dead roots or the remains of the root system create macropores where water circulation is greater. (Tables 4 and 5).

Table 4. Spearman's correlation coefficients for the physicochemical and hydroedaphic variables at the soil depth of 0-10 cm. Soil reaction (pH), Electrical conductivity (EC), Sand, Clay, Silt, Bulk density (BD), Total porosity (Tp) Mechanical resistance to penetration (MRP), Field capacity (FC), Permanent wilting point (PWP), Available water (AW), Initial infiltration (Ii), Accumulated infiltration (Ai), Infiltration capacity (Ic)

	pH	EC	BD	Tp	Sand	Clay	Silt	MRP	FC	PWP	AW	Ii	Ai
EC	-0.029	-											
BD	0.008	-0.493	-										
Tp	-0.031	-0.493	**-0.99**[**]	-									
Sand	0.058	-0.311	0.342	-0.388	-								
Clay	-0.006	0.229	-0.119	0.164	**-0.808**[**]	-							
Silt	0.006	0.025	-0.151	0.145	0.03	**-0.50**[*]	-						
MRP	0.177	-0.242	0.12	-0.137	-0.263	0.039	0.3	-					
FC	**-0.656**[**]	0.435	-0.052	0.082	-0.275	0.215	0.206	-0.295					
PWP	-0.473	**0.585**[*]	-0.245	0.274	-0.435	**0.497**[*]	0.206	-0.047	**0.591**[*]	-			
AW	0.276	-0.479	0.495	**-0.50**[*]	0.394	-0.48	0.425	0.05	-0.171	**-0.82**[**]	-		
Ii	-0.145	**0.667**[*]	**-0.86**[**]	**0.871**[**]	-0.421	0.313	-0.114	-0.529	-0.536	0.307	-0.536	-	
Ai	0.28	-0.014	-0.071	0.06	-0.389	0.414	-0.29	**0.688**[*]	-0.137	0.13	-0.137	-0.043	-
Ic	0.137	**0.634**[*]	**-0.69**[*]	**0.676**[*]	-0.289	0.146	0.156	-0.335	-0.133	-0.081	-0.133	**0.802**[**]	0.148

Coefficients in bold indicate significant (p≤0.05*) and highly significant (p≤0.01**) correlations.

Table 5. Spearman's correlation coefficients for the physicochemical and hydroedaphic variables at the soil depth of 10-30 cm. Soil reaction (pH), Electrical conductivity (EC), Sand, Clay, Silt, Field capacity (FC), Permanent wilting point (PWP) and Available water (AW).

Variable	pH	EC	Sand	Clay	Silt	FC	PWP
EC	-0.283	-					
Sand	-0.06	0.276	-				
Clay	-0.006	-0.377	-0.367				
Silt	-0.042	0.257	0.051	**-0.927****			
FC	-0.119	0.053	-0.21	0.328	-0.352	-	
PWP	-0.348	0.138	-0.284	0.456	-0.451	**0.724****	-
AW	0.182	-0.026	0.016	-0.47	0.485	0.235	-0.435

Coefficients in in bold indicate significant (p≤0.05*) and highly significant (p≤0.01**) correlations.

CONCLUSIONS

The anthropogenic effects on the Chernozem soil show that the physical, chemical and hydraulic properties are heavily affected due to the removal of its natural vegetation and replacement with agriculture. Mainly, the agricultural and grassland uses had a lower initial infiltration, accumulated infiltration, infiltration capacity, and infiltration rate, while the citrus land use had the greatest increase, surpassing the control area (Tamaulipan thornscrub). Field capacity and permanent wilting point decreased concerning the control area, while available water increased in all land-use systems.

Due to the change in land use, physical properties such as texture showed slight variations in fractions of sand, silt, and clay. The mechanical resistance to penetration shows an increase in all land-use types compared to the control, with the grasslands showing the greatest increase in mechanical resistance. About the chemical properties, higher values were obtained in the pH in all uses compared to the control in-depth 0-10 cm, EC values in MET showed the highest value in the depth of 0-10 cm, while for the depth 10-30 cm the citrus land use presents the highest value.

Through this study, it was possible to identify the negative impact occurred with the land-use change on the physical, chemical, and hydraulic properties, highlighting that the hydraulic properties were the most affected. The information from this research can be useful for a better understanding of managing different land-use types in these Chernozems.

Conflict of interest. The authors declare that there is no conflict of interest in the present research and data.

Compliance with ethical standards. Does not applies.

Data availability. Data are available with Rodolfo Alejandro Martinez-Soto (alejandro50cnt@hotmail.com) upon request.

Author contribution statement (CRediT). R. A. Martínez-Soto – Conceptualization, formal analysis and writing original draft., **M. I. Yáñez Díaz** - Conceptualization, software, methodology and Data curation., **I. Cantú-Silva** - Methodology, formal analysis, supervision and writing – review & editing., **H. González-Rodríguez** – Conceptualization, data curation and supervision., **J. G. Marmolejo-Moncivais** - Formal analysis, software, conceptualization and supervision.

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