Agrociencia

HUMIDITY RETENTION IN SOIL WITH *Elaeis guineensis* Jacq. AT DIFFERENT AGES OF DEVELOPMENT

Pamela **Galicia-García**[1], Maximiano Antonio **Estrada-Botello**[1*], Salomé **Gayosso-Rodríguez**[1], Rufo **Sánchez-Hernández**[1], Carlos Alberto **Pérez-Cabrera**[2]

[1] Universidad Juárez Autónoma de Tabasco. Carretera Villahermosa-Teapa km 25, Ranchería La Huasteca 2da. Sección, Villahermosa Centro, Tabasco, Mexico. C. P. 86298.

[2] Colegio Superior Agropecuario del Estado de Guerrero. Av. Vicente Guerrero No. 81, Col. Centro , Iguala de la Independencia, Guerrero, Mexico. C. P. 40000.

* Author for correspondence: maximiano.estrada@ujat.mx

ABSTRACT

The amount of water retained by soil depends on its physical and chemical properties, as well as the type of cover or crop present. It is important to understand the effects of oil palm (*Elaeis guineensis* Jacq.) plantations on water requirements. Therefore, the objective of this study was to determine soil humidity parameters in oil palm plantations at different ages of development in Tabasco, Mexico. The experiment was conducted using a completely randomized design with three replications. Four treatments were evaluated: 5-, 11-, and 25-year-old oil palm, and pasture as a control treatment. As response variables, parameters of bulk density (*Da*), texture, field capacity (*CC*), permanent wilting point (*PMP*), electrical conductivity (*CE*), saturation point (*PS*), and soil humidity parameters including irrigation sheet (*Lr*), sheet in the infiltration rate test (Lr_{inf}), basic infiltration (*Ib*), accumulated sheet (Z), soil humidity retention curves (*CRH*), and soil humidity stress (*EHS*) were determined. *Ib* and *Z* values were determined in the surface layer; Lr, Lr_{inf}, and *CRH* at three depths (0–30, 30–60, and 60–90 cm). The results indicate that the treatments presented significant differences ($p \leq 0.05$) in all the variables evaluated; and the parameters of field capacity, permanent wilting point, initial and final humidity in the infiltration rate test, affected the humidity content in the Lr, Lr_{inf}, *CRH* and *EHS*. It is concluded that oil palm age modifies soil humidity retention parameters and influences water requirements.

Keywords: Irrigation sheet, humidity retention curve, soil humidity stress.

INTRODUCTION

The amount of water retained by soil is determined by its physical and chemical properties of the soil, as well as the type of cover present. This is because the soil is a dynamic system in which interactions develop in the pedosphere (Novillo-Espinoza *et al*., 2018), where various factors such as climate and human activities intervene (Zanor *et al*., 2018); in agricultural areas, the introduction of new crops, tillage systems, among others, modify soil properties (Hernández-Sánchez *et al*., 2019). Some of these soil modifications can be beneficial; for example, tillage promotes the circulation of water, oxygen, and nutrients to plants (Olivet-Rodríguez *et al*., 2019), which impact soil humidity content.

Citation: Galicia-García P, Estrada-Botello MA, Gayosso-Rodríguez S, Sánchez-Hernández R, Pérez-Cabrera CA. 2023. Humidity retention in soil with *Elaeis guineensis* Jacq. at different ages of development.
Agrociencia. doi.org/ 10.47163/agrociencia.v57i6.2855

Editor in Chief:
Dr. Fernando C. Gómez Merino

Received: August 14, 2022.
Approved: May 17, 2023.
Published in Agrociencia: September 1, 2023.

Therefore, agricultural soils are a topic of current importance, due to the interest in understanding and evaluating the impacts of different management practices on the sustainability of this resource. Furthermore, the environmental changes caused by the so-called global climate change predict that water scarcity will increase; therefore, it is necessary to carry out good agricultural practices to increase crop water efficiency (Delgado-Revelo and Angarita-Carrascal, 2021). This implies that soil physical and chemical properties are a fundamental part of plant production as these variables are affected by soil humidity and intervene in water infiltration (Velázquez and Lavelle, 2019) and irrigation sheet for the crop. In this sense, humidity retention curves (CRH) and soil humidity stress (EHS) curves help to understand the relationship between humidity content and its matrix potential, which reflect the soil's capacity to retain water as a function of suction (Bejar *et al*., 2020). Furthermore, the type and density of cultivation define the level of impact on hydrological properties (Bejar *et al*., 2020) and the efficient water management of the crop, both of which are key factors in mitigating foreseeable negative impacts (Arias, 2021).

Oil palm or African palm (*Elaeis guineensis* Jacq.) is an agricultural crop that has sparked debate due to its questioned negative impact on the environment (Pardo and Ocampo-Peña, 2019) which will demand a greater amount of water in the future. Furthermore, this crop has grown exponentially worldwide (Hernández, 2020). According to data from the year 2000, the harvested area was 21 257 047 ha, and by 2021 it had increased to 28 909 789 ha (FAO, 2021). This is due to the large quantities of oil extracted from its fruits, which results in a wide range of products used by humans for consumption, allowing the population's needs to be met (Tosca-Magaña and Vázquez-Vidal, 2022).

In Mexico, oil palm plantations are established in the southeastern states, including Campeche, Chiapas, Tabasco, and Veracruz (Hernández-Rojas *et al*., 2018). From 2015 to 2020, the total area planted increased 43 % (from 82 150.60 ha to 117 543.01 ha). In Tabasco, by the year 2020, it reached an area of 27 520.3 ha (FEMEXPALMA, 2021). However, there are currently no studies in the southeastern region of Mexico on the efficient use of water in oil palm plantations to ensure water availability, environmental conservation, and productivity. For this reason, the objective of this study is to determine soil humidity parameters in oil palm plantations at different ages of development in Tabasco, Mexico.

MATERIALS AND METHODS

The study was conducted in the ranchería Chipilinar Tercera Sección of the municipality of Jalapa, Tabasco, Mexico; located at coordinates 92.770278° W and 17.781667° N, at an altitude of 20 m, with annual rainfall of 3783 mm; the soil type is Chromic Lixisol.

Experimental design

Three oil palm cultivated areas of 5, 11, and 25 years of age, and one pasture (considered as a control) were selected; the experimental design was completely randomized; the design was for each depth (0–30, 30–60, and 60–90 cm). In each area, three replicates were carried out for statistical analysis.

Soil sampling

Soil sampling in each treatment was conducted during the months of May and June 2021, at three depths: 0–30, 30–60, and 60–90 cm, to determine the soil physical parameters.

Determination of variables

Texture (Bouyucos method), bulk density (*Da*, cylinder method), field capacity (*CC*, pressure pot method), permanent wilting point (*PMP*, pressure membrane), humidity content before ($\theta_{inicial\ inf}$) and after ($\theta_{final\ inf}$) the infiltration rate test, and percent humidity at saturation (PS) were determined. The percentage of soil humidity (θ_w) was determined gravimetrically, with

$$\theta_w = \frac{(Psh - Pss)}{Pss} * 100$$

where *Psh* = Wet soil weight (gr), *Pss* = Dry soil weight (gr).

In the surface layer, the infiltration rate, basic infiltration, and accumulated sheet were determined.

Infiltration rate and basic infiltration rate

The infiltration rate test was determined in each treatment using the double cylinder method with a duration of 12 hours, the data were adjusted to the Kostiakov model:

$$I = K\, t^n$$

where I = Infiltration rate (cm hr^{-1}), t = Time (min); K and n area paramters obtained by linear regression.

The basic infiltration (I_b) was obtained with the time (t_b), with t_b = -10 * n. Therefore: I_b = K * (-600 * n)^n, the value of 600 is the unit conversion factor, in cm hr^{-1}.

Accumulated sheet (Z) in infiltration test

The accumulated water sheet with the double cylinder test was obtained in two ways:

a) From the Kostiakov equation (Z_K):

$$Z_K = \frac{(K)}{60\,(n+1)} * t^{n+1}$$

where Z_k = Stored sheet according to the Kostiakov equation; t, K and n already defined. The time was obtained from the basic infiltration.

b) The field data were fitted to a potential model of the form $Z_d = a\ t^b$, where Z_d = Sheet stored with field data, a and b = are obtained from regression; time was that of basic infiltration.

At depths of 0–30, 30–60, and 60–90 cm, the following variables were determined:

Irrigation sheet (Lr)

The following equation was used to determine the irrigation sheet required for this type of irrigation:

$$Lr = \frac{(CC\text{-}PMP) * Pr}{Dw} * Da$$

where *Lr* = in cm; *CC* = Field capacity, in %; *PMP* = Permanent wilting point, in %; *Dw* = Water density, gr cm^{-3}; *Da* = Soil density, gr cm^{-3} and *Pr*= soil stratum thickness, in m. The *CC* and *PMP* were obtained from the mean averages of the results of the statistical analyses.

Water retained in the soil in the infiltration rate test (Lr_{inf}), determined with the initial and final soil humidity during the test

The L_{inf} was determined with the initial and final humidity for the three depths when the infiltration test was performed:

$$Lr_{inf} = \frac{(\theta_{final\ inf} - \theta_{inicial\ inf}) * Pr}{Dw} Da$$

where: Lr_{inf} in cm; $\theta_{inicial\ inf}$ = Gravimetric soil humidity at the beginning of the infiltration rate test, in %; $\theta_{final\ inf}$ = Gravimetric soil humidity at the end of the infiltration rate test, in %; Dw= Water density, gr cm^{-3}; Pr = Soil thickness, m; *Da* = Soil density, gr cm^{-3}. The $\theta_{inicial\ inf}$ and $\theta_{final\ inf}$ were obtained with the mean averages of the results of the statistical analyses.

Soil Humidity Retention Curves (CRH)

It was determined using the Palacios model, according to the NOM-021-RECNAT-2000 standard (SEMARNAT, 2002):

$$T = K\ (P_s)^n + C$$

where: *T* = soil tension, in atm; *Ps* = percentage of soil humidity, in decimal; *n* = exponent that depends on the physical characteristics of the soil, dimensionless; *K* = constant that depends on the texture, structure and compaction of the soil, dimensionless; and *C* = that depends on the soil characteristics, dimensionless.

$C = -\ 0.000014CC^{2.7} + 0.3$, $n = \dfrac{log\ (T_{cc} - C) - log\ (T_{pmp} - C)}{log\ (Ps_{cc}) - log\ (Ps_{pmp})}$, and $K = Ant\ log\ (log\ (T_{pmp} - C) - nlog\ (Ps_{pmp})$. The data used from *CC* and *PMP* for this equation were the mean data from the results of the statistical analyses.

Soil Humidity Stress (EHS)

It was determined with the equation $EHS = T + PO$; where T = is the Tension, in atm (soil humidity retention curve CRH), and PO = is the osmotic pressure, in atm.
The soil humidity stress (EHS) was obtained from $EHS = PO + T$.

where PO = is the osmotic pressure, in atm.

Any soil humidity was obtained with: $PO_{psx} = PO_{sat}\ (\frac{PS}{P_{sx}})$

where PO_{psx} = Osmotic pressure for x percent soil humidity, in atm; PO_{sat} = Osmotic pressure at saturation, in atm; PS = Percent soil saturation, in decimal; and P_{sx} = Percent humidity x, in decimal.

PO_{sat} was determined with $PO_{sat} = 0.36 \times CE \times 10^3$; where: CE = Electrical conductivity, in mmhos cm^{-1}. *CE* was measured with a conductivity meter (ROHS, with an accuracy of 0.1), and humidity at saturation (*PS*) by soil saturation.

Statistical analysis

For the texture parameters, *Lr* and Lr_{inf}, no statistical analysis was performed, only the averages were obtained for their determinations. The graphs were constructed with exponential regressions.
The statistical analysis of the variables of the treatments was carried out by a comparison of means with Tukey's test, with $p \leq 0.05$ for each depth separately. The statistical package Statgraphics 2009 was used.

RESULTS AND DISCUSSION

Texture and bulk density (Da)

At depths 0–30 and 30–60 cm, the texture was different ($p \leq 0.05$) at planting age, only at the depth of 60–90 cm were they equal, with a clay texture (Tables 1, 2, and 3); however, these results are not similar to those reported by Palma-López *et al*. (2007) for a soil from the same region.
Among treatments, *Da* showed significant differences ($p \leq 0.05$) at the three depths. In the 0–30 cm depth, the 25-year treatment presented the lowest bulk density, which is due to the accumulation of organic matter over time (Hernández-Sánchez *et al*., 2019) and the movement of water in the soil (Loso *et al*., 2021). Furthermore, the 25-year-old oil palm treatment and the pasture at a depth of 0–30 cm had a loamy texture, with no

Table 1. Soil humidity parameters at 0–30 cm depth.

Parameter	Palm oil			Pasture
	5 years	11 years	25 years	
Texture	Clayey	Clay loam	Loam	Loam
Da (gr cm^{-3})	1.43a	1.33a	1.04 b	1.28 ab
CC (%)	28.49a	22.97 c	26.90 ab	22.51 c
PMP (%)	20.80a	17.71 b	17.62 c	17.42 b
†$\theta_{inicial\ inf}$ (%)	25.36a	18.58 c	21.00 b	18.90 bc
¶$\theta_{final\ inf}$ (%)	30.76a	26.02 b	29.47a	28.72a
§*Lr* (cm)	3.30	2.10	2.90	1.95
ÞLr_{inf} (cm)	2.31	3.0	2.64	3.77
CE (mmhos cm^{-1})	6.4a	6.0a	5.8a	5.6a
PS (%)	49.78a	41.26 bc	38.08 c	43.16 b

Da: apparent density; *CC*: field capacity; *PMP*: permanent wilting point; †$\theta_{inicial\ inf}$: humidity before the infiltration rate test; ¶$\theta_{final\ inf}$: final humidity in the infiltration rate test; §*Lr:* required irrigation sheet with *CC* and *PMP*; ÞLr_{inf}: water sheet retained during the infiltration test calculated with $\theta_{inicial\ inf}$ and $\theta_{final\ inf}$; *CE:* electrical conductivity; *PS*: percentage of soil saturation. Significant differences ($p \leq 0.05$) among treatments for each measured parameter are indicated by different letters.

Table 2. Soil humidity parameters at 30–60 cm depth.

Parameter	Palm oil			Pasture
	5 years	11 years	25 years	
Texture	Clayey	Clayey	Clay loam	Loam
Da (gr cm^{-3})	1.56a	1.22 c	1.40 b	1.38 b
CC (%)	28.19a	22.73a	24.99a	24.59a
PMP (%)	22.45a	14.15 c	16.57 b	17.76 b
†$\theta_{inicial\ inf}$ (%)	27.87a	17.87 c	21.85 b	18.89 bc
¶$\theta_{final\ inf}$ (%)	30.58a	22.67a	28.01a	27.14 b
§*Lr* (cm)	2.68	3.14	3.53	2.83
ÞLr_{inf} (cm)	1.27	1.76	2.59	3.41
CE (mmhos cm^{-1})	6.8a	3.3 b	3.8 b	3.3 b
PS (%)	49.38a	42.88 b	49.67a	42.95 b

Da: apparent density; *CC*: field capacity; *PMP*: permanent wilting point; †$\theta_{inicial\ inf}$: humidity before the infiltration rate test; ¶$\theta_{final\ inf}$: final humidity in the infiltration rate test; §*Lr:* required irrigation sheet with *CC* and *PMP*; ÞLr_{inf}: water sheet retained during the infiltration test calculated with $\theta_{inicial\ inf}$ and $\theta_{final\ inf}$; *CE:* electrical conductivity; *PS*: percentage of soil saturation. Significant differences ($p \leq 0.05$) among treatments for each measured parameter are indicated by different letters.

significant differences in bulk density but significant differences numerically (Table 1). On the other hand, bulk density values at the 0–30 cm depth were slightly lower than those reported by Palacios-Vélez (2002) for loam and clay loam soil, and higher than clay soil. For the depths 30–60 and 60–90 cm (Tables 2 and 3), the *Da* results were

Table 3. Soil humidity parameters at 60–90 cm depth.

Parameter	Palm oil			Pasture
	5 years	11 years	25 years	
Texture	Clayey	Clayey	Clayey	Clayey
Da (gr cm^{-3})	1.56a	1.23 b	1.42 b	1.39 ab
CC (%)	28.86a	24.80a	26.76a	27.30a
PMP (%)	19.82a	16.92a	19.38a	16.86a
†$\theta_{inicial\ inf}$ (%)	25.45a	17.86a	22.03a	18.7a
¶$\theta_{final\ inf}$ (%)	29.08a	21.77 c	25.21 b	21.36 c
§*Lr* (cm)	4.23	2.9	3.14	3.35
ÞLr_{inf} (cm)	1.70	1.44	1.35	1.1
CE (mmhos cm^{-1})	4.7a	3.2 b	3.3 b	3.2 b
PS (%)	53.23a	45.74 b	53.37a	48.53 b

Da: apparent density; *CC*: field capacity; *PMP*: permanent wilting point; †$\theta_{inicial\ inf}$: humidity before the infiltration rate test; ¶$\theta_{final\ inf}$: final humidity in the infiltration rate test; §*Lr:* required irrigation sheet with *CC* and *PMP*; ÞLr_{inf}: water sheet retained during the infiltration test calculated with $\theta_{inicial\ inf}$ and $\theta_{final\ inf}$; *CE:* electrical conductivity; *PS*: percentage of soil saturation. Significant differences ($p \leq 0.05$) among treatments for each measured parameter are indicated by different letters.

higher than those reported by Palacios-Vélez (2002) for lower layers, except for the 11-year-old oil palm plantation at the 30–60 cm depth.

The differences in soil texture and bulk density between the 5-year plantation and the other treatments are due to the relief of the site, which is located in the lower part of the study area with floodplain soils (Palma-López *et al*., 2007). In relation to depth, bulk density increased in all treatments (Tables 1, 2, and 3), affecting soil humidity content; in this regard, previous research mention that the increase in *Da* is associated with an increase in penetration resistance and a decrease in total porosity (Arias, 2021), which impact soil humidity content. According to these results, the 25-year-old oil palm substantially improved soil density for the depth 0–30 cm. Similar trends were reported by Yeo *et al.* (2021).

Field capacity (*CC*) and Permanent wilting point (*PMP*)

The humidity contents of *CC* and *PMP* presented significant differences ($p \leq 0.05$) among treatments for the three depths, being lower in the 11-year-old oil palm plantation for all three depths. The minimum *CC* was obtained in the 11-year plantation at a depth of 30–60 cm (*CC* = 22.73 %) and a maximum in the 5-year plantation at a depth of 60–90 cm (*CC* = 28.86 %); in regard to *PMP* a maximum was obtained in the 5-year plantation at a depth of 0–30 cm (*PMP* = 20.80 %) and a minimum in the 11-year plantation at a depth of 30–60 cm with a *PMP* = 14.15 %. Furthermore, no correlation between *CC* and *PMP* was found among treatments (Tables 1, 2, and 3), possibly due to bulk density and texture (Arias, 2021) affecting plant available water capacity (Bejar *et al*., 2020).

On the other hand, the results obtained from *CC* and *PMP* in some cases were close to those reported by Palacios-Vélez (2002) but higher than those reported by Palma *et al.* (2007).

Initial ($\theta_{inicial\ inf}$) and final ($\theta_{final\ inf}$) humidity in the infiltration rate test

Initial humidity showed significant differences among treatments ($p \leq 0.05$) for the three depths (Tables 1, 2, and 3), being lower for the 11-year-old oil palm treatment, and higher in the 5-year-old plantation, due to the soil texture and its location in the lower part of the study area. There were significant differences in final humidity among treatments ($p \leq 0.05$) in the three depths, being higher in the area with 5-year-old oil palm due to a higher $\theta_{inicial\ inf}$ compared to the other treatments (Tables 1, 2, and 3). Humidity $\theta_{inicial\ inf}$ and $\theta_{final\ inf}$ in the 25-year-old plantation were higher than the 11-year-old plantation in the three depths; this is consistent with values reported by Hermawan *et al*. (2021), who found soil humidity is higher in mature plantations than in young plantations. In addition, the incorporation of leaf litter into the soil implies greater storage capacity for water, air, root growth, and macro- and microorganism populations (Arias, 2021). On the other hand, $\theta_{inicial\ inf}$ and $\theta_{final\ inf}$ were affected by cover conditions as shown by Bejar *et al.* (2020); in this regard, Loso *et al.* (2021) found that soil humidity increases with depth during the dry season and decreases with depth during the wet season, which is consistent with this study.

Electrical conductivity (*CE*)

For the depth of 0–30 cm, the CE among treatments did not present significant differences ($p > 0.05$); however, at the depth of 30–60 and 60–90 cm, statistical differences ($p \leq 0.05$) were found among treatments (Tables 1, 2, and 3). The highest *CE* was found in the 5-year-old oil palm plantation, which coincides with Manorama *et al*. (2021), who indicate that over time the oil palm reduces the *CE*; in addition, the high concentrations of salts in the 5-year-old plantation were possibly due to its location in the lower area and its higher soil humidity, as indicated by Friedman (2005) in his research.

Saturation humidity (*PS*)

Humidity values at saturation presented significant differences ($p \leq 0.05$) in the treatments at each depth; the 25-year-old oil palm treatment at depth 0–30 cm was lower, possibly due to a greater amount of leaf litter in the soil which increased the organic matter content. At all depths, *PS* was higher in the 5-year old treatment (Tables 1, 2, and 3). Furthermore, it increased with depth as reported by Romero-Campos *et al*. (2020) in their research. On the other hand, this variable describes the water content in saturated soil (Birle *et al*., 2008), an important factor for water flow modeling.

Basic infiltration rate (*Ib*) and accumulated infiltration rate (*Z*)

The results of infiltration rate and accumulated sheet (Z_k and Z_d) in the treatments showed significant differences ($p \leq 0.05$). In both variables, the 25-year old oil palm crop presented the highest values, and the 5-year old plantation the lowest (Table 4 and Figure 1). This means that the age of the palm influences the rate of water infiltration over time, increasing as cavities are formed in the soil as a result of the root system's growth and soil management, both of which affect the humidity retention capacity (Bejar *et al*., 2020).

Table 4. Infiltration velocity parameters and accumulated sheet.

Parameter	Palm oil			Pasture
	5 years	11 years	25 years	
Ib (cm hr^{-1})	1.74 bc	2.68 ab	3.55a	1.02 c
Z_K (cm)	17.11 b	22.24 b	52.35a	45.7 b
Z_d (cm)	18.80 c	26.82 b	54.45a	42.01 b

Ib: basic infiltration; Z_K: from Kostiakov equation; Z_d: results from modeling with field data. Significant differences ($p \leq 0.05$) among treatments for each measured parameter are indicated by different letters.

The accumulated sheets (Z_k and Z_d) were higher for the 25-year-old palm and lower for the 5-year-old palm. With respect to Z_k in the pasture, 5 and 11-year-old palm treatments, no significant differences were found ($p > 0.05$); however, the latter two treatments were numerically lower than the pasture. Significant differences were found in relation to the Z_d variable, with the same tendencies as with Z_k. These findings suggest that soil use and crop management had an impact on the accumulated sheet, which is consistent with Lugo-Valenzuela *et al.* (2022).

The accumulated sheet obtained from the Kostiakov equation was 6 % lower on average in the oil palm treatments compared to the sheet obtained from field data modeling, and slightly higher at 2 % in the pasture treatments.

Initial irrigation sheet (*Lr*) and retained sheet during infiltration rate test (Lr_{inf})

The 25-year-old oil palm required an Lr of 9.6 cm up to a depth of 90 cm, while the 5-year-old oil palm required an Lr of 10.21 cm and 9.1 cm for the pasture. Regarding Lr_{inf}, the 10-year-old oil palm treatment had the lowest amount of water stored (Lr_{inf} = 5.3 cm) to 90 cm depth and the 25-year-old oil palm treatment stored 6.6 cm; however, the pasture treatment stored 8.3 cm. These values were affected by humidity contents (*CC*, *PMP*, $\theta_{inicial\ inf}$, and $\theta_{final\ inf}$), texture, and *Da* (Tables 1, 2, and 3); applied sheets decrease in comparison to depth and the retained sheet (L_{inf}) during the infiltration test, affected by initial humidity content, soil texture, and *Da* (Tables 1, 2, and 3).

Soil Humidity Retention Curves (*CRH*)

Humidity retention curves were different among treatments at different depths (Figure 2). In the 5-year-old oil palm plantation, it showed the highest soil humidity at

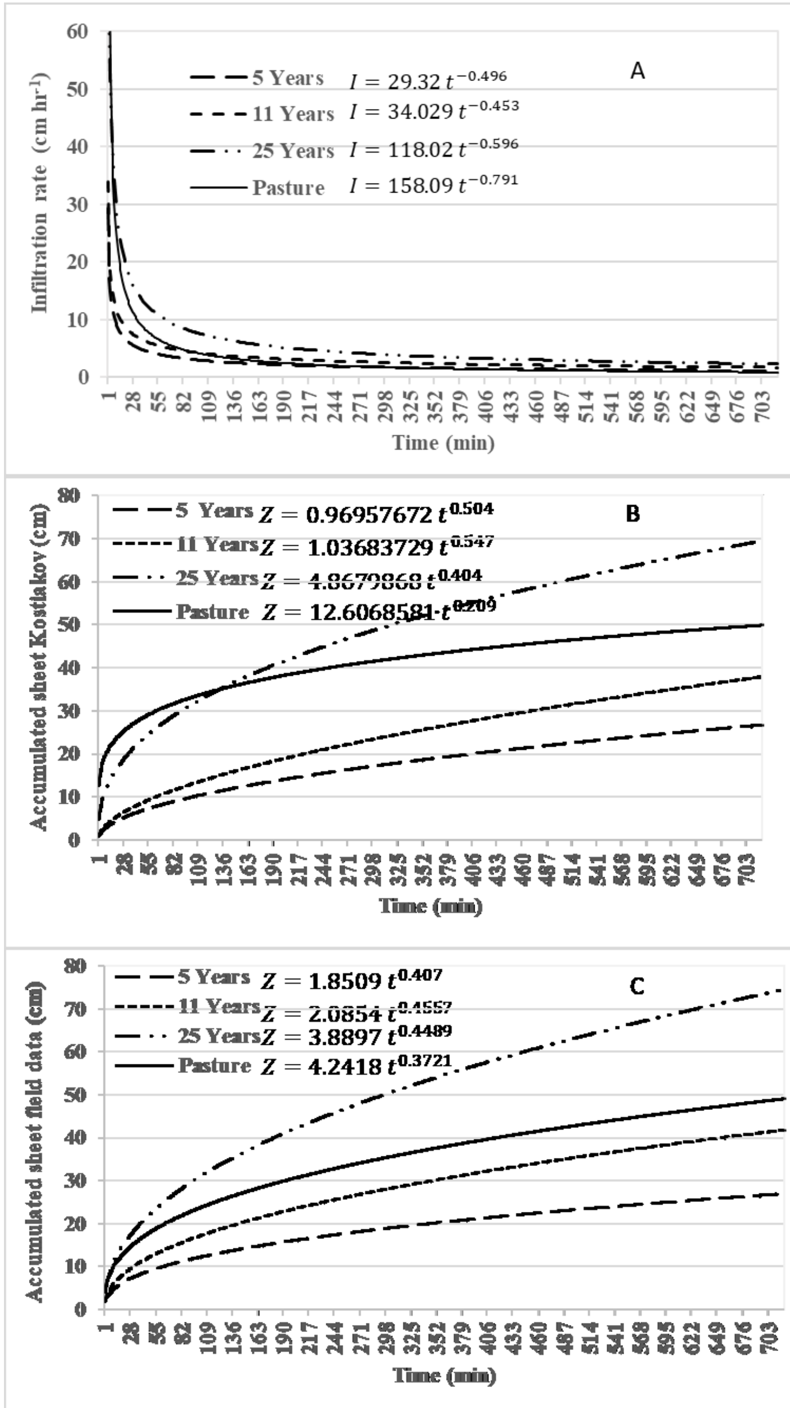

Figure 1. A: Infiltration rate (Kostiakov equation); B: accumulated sheet from the Kostiakov equation (Z_k); C: accumulated sheet with field data fitted to a potential model (Z_d).

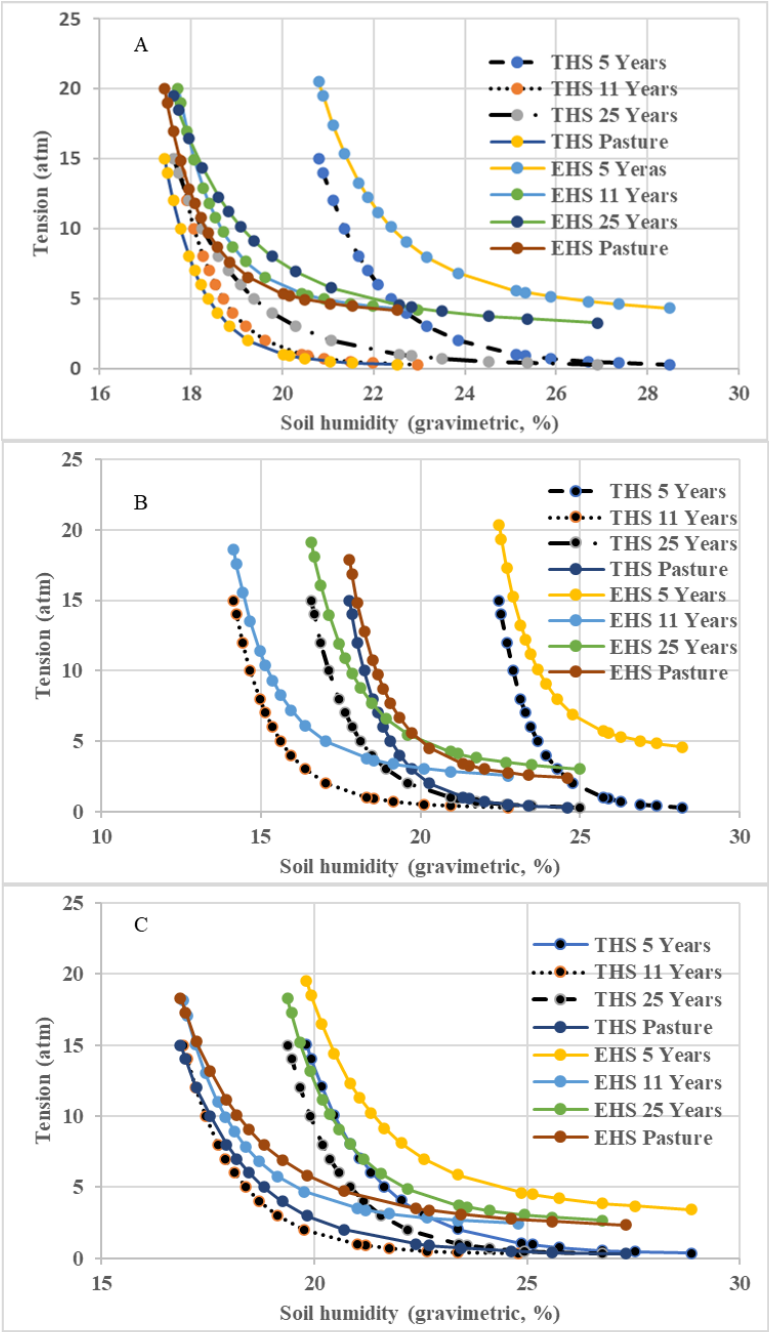

Figure 2. Humidity retention curves for the treatments. A: at a depth of 0–30 cm, B: at a depth of 30–60 cm, C: at a depth of 60–90 cm.

the same tension as the other treatments. For the 0–30 cm depth, the 11-year, 25-year, and pasture treatments presented similar graphs; for the 30–60 cm depth, the 25-year oil palm and pasture were similar; at the 60–90 cm depth, the CRH of the 5-year and 25-year oil palm were similar, this is due to soil texture and humidity content (*CC* and *PMP*). The CRHs were influenced by the age of the oil palm, which has an impact on crop productivity. Additionally, soil use and management (Bejar *et al*., 2020) and humidity contents (Birle *et al*., 2008) influence retention curves, which in turn influence plant growth (Singh *et al*., 2019).

Soil Humidity Stress (*EHS*)

The 5-year-old oil palm treatment presented the highest *EHS* and the highest humidity contents at all three depths (Figure 2). It was found that *EFH* is inversely proportional to depth in each treatment; this coincides with Romero-Campos *et al*. (2020) who reported that in the first 30 cm more tension is required to retain water, while at lower depths less tension is required due to the higher water content in the soil. Stress depends on the magnitude of the matrix potential, as well as water content, pore size, particle surface properties, and soil water surface tension (Whalley *et al*., 2013). Furthermore, *CE* is an important factor in the construction of *EHS* curves, as soil gypsum concentration is reported to affect *CRH* (Aldaood *et al*., 2014) and these in turn affect *EHS* curves.

The soil humidity stress curves were affected by oil palm when they reach an age of 25 years compared to pasture; this is supported by Yeo *et al.*, (2021) who indicate that the change of land use from forest to oil palm improves the physical properties of the soil. Furthermore, they modify the characteristics *CC*, *PMP*, *PS*, *CE*, and *Da*, and contribute to efficient water management (Arias, 2021).

According to the results, these soils are suitable for oil palm production, When there is an excess of salts, high potentials have an impact on the plant. Plants raise the tension to overcome the osmotic potential, which prevents them from absorbing water even in humid soils. Salinity, on the other hand, causes a decrease in growth and yield, and water stress during critical phenological stages of the crop can have an impact (Sing *et al.*, 2019).

CONCLUSIONS

Oil palm cultivation alters soil humidity parameters by changing physical and chemical properties over time. Oil palm cultivation conserves soil humidity, improves water infiltration rate, and increases the accumulated sheets in the soil profile. Textural differences in the study area influenced the construction of humidity tension and humidity stress curves for oil palm production.

ACKNOWLEDGMENTS

We thank the Programa para el Desarrollo Profesional Docente (PRODEP) through project UJAT-CA-242, for the support for this work.

REFERENCES

Arias ANA. 2021. Agua y nutrición: eficiencias necesarias frente al cambio y la variabilidad climática. Palmas 42 (1): 81–95.

Aldaood A, Bouasker M, Al-Mukhtar M. 2014. Soil–water characteristic curve of gypseous soil. Geotechnical and Geological Engineering 33 (1): 123–135. https://doi.org/10.1007/s10706-014-9829-5

Bejar SJ, Cantú SI, Yáñez-Díaz MI, Luna-Robles EO. 2020. Curvas de retención de humedad y modelos de pedotransferencia en un andosol bajo distintos usos de suelo. Revista Mexicana de Ciencias Forestales 11 (59): 31–50. https://doi.org/10.29298/rmcf.v11i59.666

Birle E, Heyer D, Vogt N. 2008. Influence of the initial water content and dry density on the soil-water retention curve and the shrinkage behavior of a compacted clay. Acta Geotechnica 3: 191–200. https://doi.org/10.1007/s11440-008-0059-y

Delgado-Revelo T, Angarita-Carrascal E. 2021. Eficiencia del agua en el Magdalena, factor clave para el desarrollo sostenible y productivo en la región. Fedepalma 594: 23–25.

FEMEXPALMA (Federación Mexicana de Palma de Aceite). 2021. Anuario Estadístico 2021. Federación Mexicana de Palma de Aceite. Villahermosa, México. https://femexpalma.com.mx/femexpalma.ftp/anuario_estadistico_2021.pdf (Retrieved: March 2023).

Friedman SP. 2005. Soil properties influencing apparent electrical conductivity: a review. Computers and Electronics in Agriculture 46 (1): 45–70. https://doi.org/10.1016/j.compag.2004.11.001

FAO (Food and Agriculture Organization of the United Nations). 2021. FAOSTAT. Crops and livestock products. United Nations Food and Agriculture Organization. Rome, Italy. https://www.fao.org/faostat/en/#data/QCL/visualize (Retrieved: March 2023).

Hernández CM. 2020. El cultivo de palma de aceite desde el punto de vista ambiental, económico y social. Boletín El Palmicultor 581: 24–26.

Hernández-Rojas DA, López-Barrera F, Bonilla-Moheno M. 2018. Análisis preliminar de la dinámica de uso del suelo asociada al cultivo palma de aceite (*Elaeis guineensis*) en México. Agrociencia 52 (6): 875–893.

Hernández-Sánchez JM de los D, Figueroa-Sandoval B, Martínez-Menes MR. 2019. Propiedades físicas del suelo y su relación con la plasticidad en un sistema bajo labranza tradicional y no labranza. Revista Mexicana de Ciencias Agrícolas 10 (22): 53–61. https://doi.org/10.29312/remexca.v0i22.1858

Hermawan B, Agustian I, Hasanudin H, Herawati R, Gonggo M. 2021. Spatiotemporal variability in soil water content profiles under young and mature oil palm plantations in north Bengkulu Regency. International Journal Advanced Science Engineering and Information Technology 11 (1): 259–265.

Loso S, Sudradjat, Hariyadi, Yahya S, Sutand A. 2021. The role of several methods of drainage and fertilization levels on growth and yield of oil palm plants (*Elaeis guineensis* Jacq.). Asian Journal of Microbiology Biotechnology Environmental Science 23 (1): 51–60.

Lugo-Valenzuela H, Prado-Hernández JV, Vázquez-Peña MA, Pineda-Pineda J, Velázquez-López N. 2022. Caracterización hidrodinámica del modelo Green y Ampt en un suelo con mejoradores orgánicos. Biotecnia 24 (3): 15–21. https://doi.org/10.18633/biotecnia.v24i3.1627

Manorama K, Kumar BA, Suresh K, Venkata PM, Kumar RM, Harinarayana P. 2021. Mulching and technological interventions avoid land degradation in an intensive oil palm (*Elaeis guineensis* Jacq.) production system. Land Degradation and Development 32 (13): 3785–3797. https://doi.org/10.1002/ldr.3886

Novillo-Espinoza ID, Carrillo-Zenteno MD, Cargua-Chávez JE, Nabel-Moreiral V, Albán-Solarte E, Morales-Intriago FL. 2018. Propiedades físicas del suelo en diferentes sistemas agrícolas en la provincia de Los Ríos, Ecuador. Temas Agrarios 23 (2): 177–187.

Olivet-Rodríguez YE, Ortiz-Rodríguez A, Cobas-Hernández D. 2019. Effect of two minimized farming systems on the humidity of a Fluvisol soil for the cultivation of bean (*Phaseolus vulgaris* L.). Centro Agrícola 46 (1): 18–23.

Palacios-Vélez E. 2002. ¿Por qué, cuándo, cuánto y cómo regar? Para lograr mejores cosechas. Editorial Trillas: Ciudad de México, México. 217 p.

Palma-López DJ, Cisneros-Domínguez J, Moreno-Cáliz E, Rincón-Ramírez A. 2007. Suelos de Tabasco: su uso y manejo sustentable. Colegio de Postgraduados, ISPROTAB, Fundación PRODUCE Tabasco. Villahermosa, México.

Pardo EL, Ocampo-Peña N. 2019. Contexto del impacto ambiental de la palma de aceite en Colombia. Revista Palmas Bogotá (Colombia) 40 (3): 79–88.

Romero-Campos M, Cid-Lazo G, González-Robaina F, López-Seijas T. 2020. Curvas tensión humedad y función conductividad hidráulica en suelos pardos. Revista Ingeniería Agrícola 10 (2): 21–27.

SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales). 2002. Norma Oficial Mexicana NOM-021-RECNAT-2000, que establece las especificaciones de fertilidad, salinidad y clasificación de suelos. Estudios, muestreo y análisis. Diario oficial de la Federación. México. http://legismex.mty.itesm.mx/normas/rn/rn021-02.pdf (Retrieved: March 2023).

Singh J, Varma SK, Bhatia JN, Raj L. 2019. Effect of different soil moisture regimes and salinity level on growth and yield in mustard. Indian Journal of Agricultural Research. 53 (4): 488–491. https://doi.org/10.18805/IJARe.A-5124

Tosca-Magaña SA, Vázquez-Vidal V. 2022. Impacto de la palma de aceite en México en el ámbito económico. Publicaciones e Investigación 16 (3). https://doi.org/10.22490/25394088.6604

Velázquez E, Lavelle P. 2019. Soil macrofauna as an indicator for evaluating soil-based ecosystem services in agricultural landscapes. Acta Oecologica 100: 103446. https://doi.org/10.1016/j.actao.2019.103446

Whalley WR, Ober ES, Jenkins M. 2013. Measurement of the matric potential of soil water in the rhizosphere. Journal of Experimental Botany 64 (13): 3951–3963. https://doi.org/10.1093/jxb/ert044

Yeo JG, N'Dri JK, Edoukou EF, Jean-Luc DS. 2020. Changes in surface soil properties and macroinvertebrate communities with the conversion of secondary forests to oil palm (*Elaeis guineensis*) plantations. Crop and Pasture Science 71 (9): 837–849. https://doi.org/10.1071/CP19370

Zanor GA, López-Pérez ME, Martínez-Yáñez R, Ramírez-Santoyo LF, Gutiérrez-Vargas S, León-Galván MF. 2018. Mejoramiento de las propiedades físicas y químicas de un suelo agrícola mezclado con lombricompostas de dos efluentes de biodigestor. Ingeniería, Investigación y Tecnología 19 (4): 1–10. https://doi.org/10.22201/fi.25940732e.2018.19n4.036