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# Impact on the soil and the infiltration as a consequence of oil palm cultivation (*Elaeis guineensis* Jacq.) in Tabasco

**Hernández-Silván, J.E.**[1]**; Estrada-Botello, M.A.**[1]**; Mendoza-Palacios, J.de D.**[1]**; Gayosso-Rodríguez, S.**[1]**; Cortes-Ferra, P.D.**[1]**; Sánchez-Hernández, R.**[1*]

[1] Universidad Juárez Autónoma de Tabasco, División Académica de Ciencias Agropecuarias, Carretera Villahermosa-Teapa Km. 25, R/A La Huasteca, Segunda Sección, CP. 86280, Villahermosa, Tabasco, México.

* Correspondence: rufo.sanchez@ujat.mx

**ABSTRACT**

**Objective**: To evaluate the possible negative impacts on soil fertility, as a result of the soil use change from the grassland to oil palm.

**Design/methodology/approach**: The following variables were evaluated: soil organic matter (SOM), bulk density (BD), mechanical penetration resistance (MPR), root system distribution, and infiltration in 5-, 11- and 25-year-old oil palm plantations, as well as in an adjoining grassland —whose land use had not changed to oil palm cultivation.

**Results**: During the first years of cultivation, the substitution of the grassland for oil palm caused SOM losses, increased BD and MPR, and reduced infiltration levels. After 11 years, these effects became stable and were reversed. Therefore, in mature plantations of >25 years, the soil and infiltration conditions improved, even surpassing the grassland. These changes occur at a depth of 40 cm and are attributable to the SOM provided by the root system; consequently, root distribution does not block infiltration, becoming a beneficial factor, particularly in mature plantations.

**Study limitations/implications**: The research must be replicated under other soil conditions, in order to observe the fertility behavior.

**Findings/conclusions**: After the grassland is replaced by oil palm, soil fertility deteriorates during the first years; fertility becomes stable and recovers after 11 years. Meanwhile, the effect reverses and surpasses grassland fertility levels after 25 years.

**Keywords**: Soil use change, Environmental impact, Soil conservation, Water infiltration.

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## INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is a highly productive oleaginous plant. During the last decades, the area in which this crop is cultivated has rapidly increased worldwide. These plantations have spread in southern-southeastern Mexico, where the edaphoclimatic conditions favor its development and this trend will likely continue (Hernández-Rojas *et al.*, 2018). In Tabasco, the cultivated area grew during the last decade, raising questions about

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the real environmental impact of this crop. Therefore, international standards have been issued aimed at achieving a more harmonious relationship between oil palm cultivation and the environment. These standards include the Roundtable on Sustainable Palm Oil (RSPO) and, in Mexico, the NMX-F-817-SCFI-2020 ACEITE standard, which was issued in 2020. This Mexican standard establishes the requirements and specifications about the sustainable oil palm value chain. Both standards attempt to establish the principles and criteria of a sustainable oil palm cultivation. However, these are general guidelines that must be adjusted to the specific conditions of each productive zone. Therefore, in order to find out the impact of oil palm cultivation on the environment, we must understand the interactions between the biotic and abiotic factors of the ecosystems. Consequently, climate, soil, plant, and geo-hydrological factors variables must be included in the researches. Determining the impacts of oil palm cultivations on the water and edaphic resources of the productive areas in Tabasco require comprehensive studies, in which interdisciplinary efforts must come together. In this context, researches aimed at evaluating possible negative impacts of oil palm crops on the soil conservation are already underway. Therefore, this article includes some advances of these researches and a bibliographical analysis which answers some questions about the impact of oil palm crops. Consequently, this research opens new paths for the development of a future sustainable oil palm cultivation in the State of Tabasco.

## MATERIALS AND METHODS

The study area is located in the third section of the Chipilinar rural settlement, in the Jalapa municipality, Tabasco, at 17° 46' 52.8" N and 92° 46' 05.4" W, with an average altitude of 20 masl. The annual rainfall average is 3,783 mm, with a maximum monthly average of 728 mm (September) and a minimum monthly average of 81 mm (April) (CONAGUA, 2020). Several soils variation can be found, including sandstone lutite in the surface and polymic conglomerate lutite in the deep (Zavala-Cruz *et al.*, 2016). Based on the WRB nomenclature description of profiles and the physical and chemical analysis, the soil is classified as Chromic Lixisol (Clayic, Densic, Differentic, Humic, Profondic) (2014).

### Experiment description and study variables

Three contiguous oil palm plantations of different ages were selected, as well as an adjoining grassland. The following treatments were evaluated: a 5-year-old young plantation (Treatment 1); an 11-year-old full production plantation (Treatment 2); a 25-year-old plantation (Treatment 3); and an adjoining grassland (Treatment 4). Treatment 4 maintained the original grassland use and was considered as control.

Samples were collected following a zigzag route, until the total surface was covered. Each area provided two series of 20 samples. In order to determine SOM, the first set of samples was collected at 4 different depths (0-40, 40-80, 80-120, and >120 cm) (Walkley and Black, 1932). In order to determine BD, the second set of samples was obtained using a soil-push probe with a known volume cylinder (Blake and Hartage, 1986). At the same time, the mechanical penetration resistance (MPR) was tested in the same sampling areas, using a cone penetrometer (Dexter *et al.*, 2007).

An adaptation of the Hagg (1997) method was used to describe the root system distribution: three plants were selected per each treatment. Three trial pits were dug next to each palm. Cartesian grids were marked out in the walls of the trial pits. Samples were taken at four depths (0-40, 40-80, 80-120, and >120 cm) in the Y vertical axis. Meanwhile samples were taken at six different distances from the stipe base (stem) in the X horizontal axis (0, 50, 100, 150, 200, and 250 cm). The soil samples from each XY grid were dried on a forced air oven at 105 °C. Subsequently, the samples were weighted and crushed and the roots were separated using a double sifter: the first (dry), with a number 18 sift (1 mmØ); the second (wet), with a number 25 sift (710 $\mu$mØ). The roots obtained from the second sifting were dried and added to the roots obtained from the first sifting. The root percentage of each sample was obtained using the relation between the weight of the dry root mass and the initial total mass weight of each soil sample, multiplied by 100. In order to determine the infiltration rate, three repetitions were carried out in each study area, using the doble ring infiltrometer method described by Kostiakov-Lewis (Delgadillo *et al.*, 2016).

The information obtained was processed using an analysis of variance (ANOVA), a correlation analysis, and Tukey tests. The SAS statistical software version 6.12 for Windows was used.

## RESULTS AND DISCUSSION

### Soil changes that can be attributed to oil palm

Organic matter (SOM) —the world's highest carbon reservoirs— is one of the major indicators for the evaluation of the impact that crops have on the soil (Gallardo, 2017). Table 1 shows the impact that crops have on some edaphic quality indicators.

Table 1 shows that the greatest changes in SOM and bulk density (BD) dynamics take place in the upper layers, particularly up to a depth of 40 cm. During the first cultivation years, the SOM percentage falls below the percentage of its initial condition —when the currently oil palm plantations were grasslands. This reduction in SOM contents is reversed

**Table 1**. Soil Organic Matter (SOM) content and bulk density (BD) levels in oil palm plantations of different ages respect to an adjacent grassland, according to the depth of the soil.

| Treatments | Variables | Soil depth (cm) | | | |
|---|---|---|---|---|---|
| | | **0-40** | **40-80** | **80-120** | **>120** |
| Oil Palm 5 years | SOM (%) | ►1.65±0.20 b | 0.74±0.24 b | 0.45±0.17 b | 0.33±0.08 a |
| Oil Palm 11 years | | 2.21±0.46 b | 0.58±0.28 b | 0.25±0.07 b | 0.00±0.00 b |
| Oil Palm 25 years | | 4.68±1.18 a | 1.11±0.06 a | 0.92±0.29 a | 0.32±0.10 a |
| Grassland | | 3.47±0.61 a | 1.53±0.19 a | 1.17±0.18 a | 0.61±0.06 a |
| Oil Palm 5 years | BD ($Mg\ m^{-3}$) | 1.43±0.20 a | 1.56±0.04 a | 1.56± 0.10 a | 1.57±0.06 a |
| Oil Palm 11 years | | 1.33±0.06 a | 1.22±0.07 c | 1.24±0.11 b | 1.27±0.06 b |
| Oil Palm 25 years | | 1.04±0.16 b | 1.40±0.11 b | 1.42±0.18 a | 1.54±0.07 a |
| Grassland | | 1.29±0.14 a | 1.45±0.07 b | 1.38±0.13 a | 1.38±0.06 a |

Equal letters mean they are statistically equal to a probability level of $p \leq 0.05$.
► Mean comparisons are made within each layer or depth.

in >25-year-old plantations, which even exceed the grassland's SOM contents. However, the said contents can only be found in the 0-40 cm layer; the effect is watered down at a greater depth, although this trend remains, with a less marked effect, at the deepest layers. In some soil use changes —for example, agroforestry systems deforested to set up grasslands—, SOM increases during the first years after the change; afterwards, the effect fades away. Salvador-Morales *et al.* (2017) point out that the low carbon-to-nitrogen ratio of the waste that becomes part of the soil is responsible for this situation: at a 12-15 ratio, waste decomposes at a fast pace, releasing nutrients and non-mineralized remainders. This remainder accumulates low SOM quantities which become part of the soil; however, waste with high carbon-to-nitrogen ratios (18-24) causes decomposition to take place at a slower pace and higher MOS content tends to accumulate. The said SOM accumulation entails several physical benefits, such as an improved soil structure, as a consequence of the increase of stable macroaggregates —which improve porosity and infiltration, reduce compaction (as bulk density (BD) decreases), improve rhizosphere conditions, and reduces hydric erosion (Sánchez-Hernández, 2017). The effect of this benefit is clearer in the topmost layer (Table 1), where the SOM concentration is higher; BD decreases in >25-years old plantations, reaching lower levels than the grassland. According to Sánchez-Hernández *et al.* (2017), the formation of aggregates can mainly be attributed to SOM; however, the most resistant or humidified SOM provides stability to the aggregates and consequently to the structure —as well as other properties that are linked to the said structure, such as BD and compaction. They also point out that a greater supply of organic waste in the soil modifies the size and stability of the aggregates, improves hydraulic conductivity (K), and diminishes penetration resistance (compaction), particularly in surface soil. However, they warn that these effects are not permanent; modifications take place as fresh organic waste runs out.

Figure 1 shows the compaction levels of the evaluated plantations, as well as of the adjoining grassland.

Therefore, up to a depth of 35 cm, 25-year-old plantations and the grassland keep the lowest compaction levels. At a >35 cm depth, only the grassland maintains low compaction

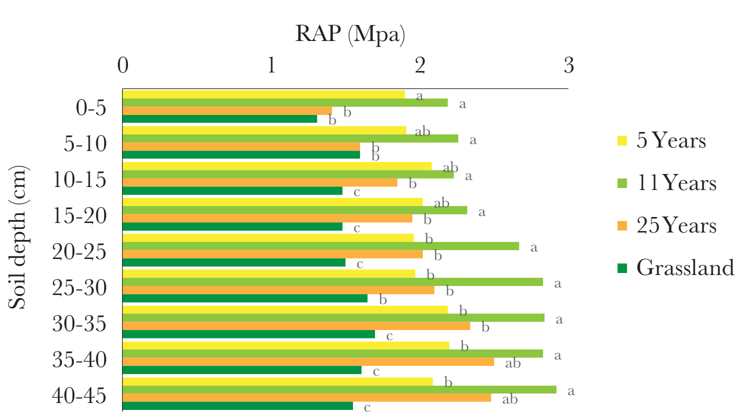


**Figure 1**. Soil compaction levels expressed as Resistance Against penetration (RAP) in Oil palm plantations and an adjacent grassland. Equal letters mean they are statistically equal to a probability level of p≤0.05. Mean comparisons are made within each layer or depth.

levels. However, compaction levels do not exceed 3 MPa —the critical value that prevents an appropriate root development— in any plantation, although compaction levels come close to those crucial levels, at a ≥35-cm depth.

## Root system distribution

Table 2 compares the volume of roots with the volume of the sampled soil. Significative differences (Duncan $P<0.05$) were found, depending on the age of the plant.

Therefore, regardless of the age of the plant, its roots are distributed in a cone-shaped pattern. The volume of the root system is mostly distributed up to 40 cm deep and one meter around the trunk (Table 3).

These results match the findings of Ortiz and Fernández (2000) who reported that most of the volume of the root system —which is basically made of horizontally-growing radicles with anchoring functions— is found up to a depth of 50 cm. According to Arias (2020), several factors impact root growth and development. Regulating temperature —which can be achieved through plant coverage during the first years of life— favors the oil palm rhizosphere. On the contrary, rain-saturated soil can reduce the oxygen available for roots and can cause damage, as their susceptibility to pests and diseases increases (Vignola *et al.*, 2017). Soil porosity also affects roots. Low porosity has a negative impact on root growth; <50% total porosity can reduce root density up to 87% (Arias, 2020). Meanwhile, water deficit in the soil can diminish plant yield and growth, as a consequence of the stomatal closure that reduces the photosynthetic rate, interferes with carbon dioxide assimilation, and causes female inflorescence abortion (Vignola *et al.*, 2017).

**Table 2.**

| Plantation age | Roots/soil (%) |
|---|---|
| 5 years | 0.09 b |
| 11 years | 0.21b |
| 25 years | 0.55 a |

Equal letters mean they are statistically equal to a probability level of Duncan $p \leq 0.05$.

**Table 3**. Roots distribution of Oil palm (*Elaeis guineensis* Jacq.) to different Soil depth and stem distances.

| Soil depth (cm) | Roots/Soil (%) | Distances (cm) | Roots/Soil (%) |
|---|---|---|---|
| 0-40 | 0.7922 a | 0 | 0.4450 a |
| 40-80 | 0.2100 b | 50 | 0.3642 a |
| 80-120 | 0.0944 b | 100 | 0.2725 a |
| >120 | 0.0561 b | 150 | 0.2208 a |
| | | 200 | 0.2242 a |
| | | 250 | 0.2025 a |

Equal letters mean they are statistically equal to a probability level of Duncan $p \leq 0.05$.

**Infiltration rate**

Several elements impact water flow in the soil and have repercussions on oil palm cultivation, including the calculation of the infiltration rate and the strip tillage which play a crucial role, as key components of the hydrological cycle (Luna *et al.*, 2020). There were no significative differences in basic infiltration rates (Table 4). However, according to the mean data, the age of the plant does impact the infiltration rate: a faster infiltration rate can be observed as the age of the oil palm crop increases. This can be caused by the increase of the root area and the OM of the oil palm crop (Table 1) which, in comparison with pasture, improve soil porosity and root content (Arias, 2020), consequently facilitating water flow. These data match other studies which point out that the infiltration rate is greater in cultivated soils than in bare soil, reducing the volume of water that is lost through evaporation and increasing the volume of water resources available for plants (Tapia *et al.*, 2020). However, some authors point out that soil uses associated with anthropic activities —such as agriculture, grazing, and forest management— can have a negative impact (Luna *et al.*, 2020). On the contrary, our infiltration rate data point out that palm has improved some properties.

Meanwhile, compared with the grassland used as control (Table 4), there are significative differences ($p<0.05$) with regard to strip tillage, which is clearly affected by the age of the plant.

Consequently, the plant's physiological process could require more water; the reduction of the humidity content in the soil enables water penetration. In this regard, Luna *et al.* (2020) point out that the crop's characteristics—including the ripeness degree, structure, and composition of the plant— and the edaphic variables —bulk density, organic layer thickness, and humidity— cause variations in the infiltration rate.

## CONCLUSIONS

The land use change from grassland to oil palm cultivation has a negative impact on the soil during the first years in which that crop is grown: soil organic matter (SOM) is lost and BD and compaction increase, while infiltration rate also diminishes. Those effects become stable and revert to the original conditions 11 years later; particularly, >25-year-old plantations recover SOM and improve the abovementioned variables, sometimes even surpassing the grassland conditions. Most changes take place at a 0-40 cm depth and they can be attributed to the SOM content provided by the root system. Although the root system is superficial, it does not represent any kind of impediment to infiltration;

**Table 4**. Infiltration speed and water level accumulated in a period of 12 hours.

| Treatments | Infiltration speed basic (cm $hr^{-1}$) | Water level accumulated (cm)* |
|---|---|---|
| 5 years | 3.13 (±4.66) a** | 23.72 (±6.97) ab |
| 11 years | 1.94 (±1.60) a | 44.91 (±29.36) ab |
| 25 years | 5.61 (±3.20) a | 75.83 (±35.48) c |
| Grassland | 1.74 (±0.76) a | 16.07 (±6.97) a |

*For a time of twelve hours, ** ($p<0.05$).

on the contrary, it plays a beneficial role in mature plantations, improving the soil and consequently infiltration.

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