Méndez-Moreno, José del C.; Garza-Rodríguez, Iliana M. De la; Torres-Sánchez, Sonia A.; Jiménez-Pérez, Nelly del C.; Sánchez-Lombardo, Irma; López-Martínez, Sugey; Lobato-García, Carlos E.; Morales-Bautista, Carlos M.

Changes in restored soils subject to weathering and their implication in Mexican environmental regulations

Terra Latinoamericana, vol. 39, e798, 2021, January-December
Sociedad Mexicana de la Ciencia del Suelo A.C.

DOI: https://doi.org/10.28940/terra.v39i0.798

Changes in restored soils subject to weathering and their implication in Mexican environmental regulations
Cambios en los suelos restaurados sujetos a la intemperie y su implicación en las regulaciones ambientales mexicanas

José del C. Méndez-Moreno[1], Iliana M. De la Garza-Rodríguez[2], Sonia A. Torres-Sánchez[3], Nelly del C. Jiménez-Pérez[1], Irma Sánchez-Lombardo[1], Sugey López-Martínez[1], Carlos E. Lobato-García[1], and Carlos M. Morales-Bautista[1‡]

[1] Cuerpo Académico Química Aplicada a la Gestión Ambiental. División Académica de Ciencias Básicas. Universidad Juárez Autónoma de Tabasco. Carretera Cunduacán-Jalpa km 1 Col. La Esmeralda. 86690 Cunduacán, Tabasco, México.
‡ Corresponding author (carlos.morales@ujat.mx)
[2] Facultad de Ciencias Químicas. Universidad Autónoma de Coahuila. Blvd. V. Carranza s/n esq. con Ing. José Cárdenas Valdés. Col. República Ote. 25280 Saltillo, Coahuila, México.
[3] Facultad de Ingeniería. Universidad Autónoma de San Luis Potosí. Álvaro Obregón #64, Col. Centro. 78000 San Luis Potosí, S.L.P., México.

SUMMARY

An overview of current Mexican legislation regarding soil restoration and updating needs is made through the analysis of three case studies located in the southeastern México: a) soil affected by spillage of congenital waters (Zone 1), b) soil contaminated by hydrocarbons (Zone 2) and, c) a site adjacent to urban infrastructure (Zone 3). It was performed a comparative analysis of the soils conditions in the short and long term after the anthropogenic impact and restoration process that were carried out in each studied location. It was found that important properties of the soils do not recover after the weathering process, for instance in Zone 1, DR and DA as well as %Po did not reach equivalent values to the control sample and the soil texture is different even after a long recovery period. For Zone 2, it was detected important variations in the concentration of Ca, Na and K in both the impacted and recovered soils which affect the growth of plantations. In Zone 3, there were found significative differences in DA, %Po; %L, %R, %MO and CEC parameters. The current normative considers general aspects, but does not contemplate the actual site situation, there is an information gap due to this, although it was observed achievement of physical and chemical properties for the recovery soil use in each site, it was also noticed that the evaluations do not consider if these properties can change over time due to weather conditions, therefore, they could influence the success of each restoration process in the long term. The information generated can be used to make decisions about government rescue programs for the primary sector or as a starting point in the implementation of Environmental Bases Lines (LBA) for the hydrocarbon sector.

Index words: *anthropogenic activities, hydrocarbon, metals heavy, oil production waters, soil use vocation.*

RESUMEN

Se realizó una visión general de la legislación mexicana vigente en materia de restauración del suelo y de las necesidades de actualización a través del análisis de tres estudios de caso ubicados en el sureste de este país: a) suelo afectado por derrames de aguas congénitas (Zona 1), b) suelo contaminado por hidrocarburos (Zona 2) y c) un sitio adyacente a infraestructura urbana (Zona 3). Se realizó un análisis comparativo a corto y largo plazo de las condiciones de los suelos después del impacto antropogénico y el proceso

Recommended citation:
Méndez-Moreno, J. C., De la Garza-Rodríguez, I. M., Torres-Sánchez, S. A., Jiménez-Pérez, N. del C., Sánchez-Lombardo, I., López-Martínez, S., Lobato-García, C. E., & Morales-Bautista, C. M. (2021). Changes in restored soils subject to weathering and their implication in Mexican environmental regulations. *Terra Latinoamericana 39:* 1-21. e798. https://doi.org/10.28940/terra.v39i0.798

Received: May, 23, 2020. Accepted: October, 28, 2020.
Article. Volume 39, February 2021.

de restauración que se llevó a cabo en cada caso de estudio. Se encontró que propiedades importantes de los suelos no se recuperaron después del proceso de intemperizado. Por ejemplo, en la Zona 1, DA, DR y %Po no alcanzaron valores equivalentes a los del suelo testigo aun después de un tiempo prolongado de recuperación. En la Zona 2, se detectaron variaciones importantes en las concentraciones de Ca, Na y K tanto en el suelo impactado como en el recuperado, lo cual afecta el crecimiento de plantaciones. En la Zona 3, se encontraron diferencias significativas en parámetros como: DA, %Po; %L, %R, %MO y CEC. Se encontró una brecha de información en la normativa actual que considera aspectos generales, pero no considera la situación real del sitio, aunque se observó el cambio de propiedades físicas y químicas para el uso de recuperación del suelo en cada sitio, también se observó que las evaluaciones no consideran si estas propiedades pueden cambiar con el tiempo debido a las condiciones climáticas y por lo tanto podrían influir en el éxito de cada proceso de restauración a largo plazo. La información generada puede ser utilizada para tomar decisiones sobre los programas de rescate del gobierno para el sector primario o como punto de partida en la implementación de Líneas Bases Ambientales del sector de hidrocarburos.

Palabras clave: *actividades antropogénicas, hidrocarburos, metales pesados, agua de producción petrolera, vocación de uso de suelos.*

INTRODUCTION

Diverse human activities have brought changes in the environment in such a magnitude that they have put the ecological balance at risk. To alleviate this, international agreements have been settled, nevertheless, each country legislates its laws or norms according to its public politics (Acselrad *et al.*, 2010). However, in some countries, most laws still lack of specific studies with multidisciplinary approaches that allow the reduction of environmental impacts associated with certain activities, such as soil changes and profiting agroforestry of contaminated areas that have been restored (Azamar and Ponce, 2015).

In this context, the Mexican Environmental Legal Framework has evolved over time and the environmental impacts caused by the different productive sectors are continuously evaluated to establish legal statutes in order to protect the environment and public health, as well as promoting the optimal use of natural resources (Chávez-León *et al.*, 2012; Asprilla-Lara and Castro-Valencia, 2016); despite these efforts, the laws continue to be nonspecific for each site, many studies have determined that although a great part of the jurisprudence considers important parameters such as the concentration of the pollutant and its toxic effects, it leaves out factors that could influence the behaviour of both indicators such as the diverse relief and climates in Mexico (Kolb and Galicia, 2018; Macías *et al*., 2018); in several studies, it has been indicated that in many cases, federal environmental norms left out the particularities of each demarcation and for these reasons, some environmental diagnoses are usually wrong (Hatch, 2018).

A worrying topic is the fertility of the restored soils, as it has been found that the conditions of these depend on each remediation technique (Trujillo-Narcía *et al.*, 2012; Pérez-Hernández *et al.*, 2013). In soils with hydrocarbons and their derivatives presence, Hernández-García *et al.* (2016) and Adams *et al*. (2016) have found that the residual fraction after treatment contains mostly polar hydrocarbons, usually associated with water repellency and low primary production in the cultivation; in addition, Morales-Bautista *et al.* (2016) found that the stability and removal of the pollutant depend on the soil type emphasizing it when compares the salts removals in affected sites by oil production waters to those with a more clayed texture tend to retain the contaminant, consequently, the treatment times and the amounts of the pollutant removed are different in each case.

Generally, the negative impacts on the environment are usually linked to industrial activities, but some reports mention other sources such as the activities of the agricultural and services sectors, which indirectly cause changes in the environment, by adding other factors, they promote the degradation of soil, as well as air and water pollution (Ocampo, 2011; Olmos-Martínez *et al*., 2013). It should be noted that this is not an isolated issue for a specific area of the Mexican Republic, for decades, in most of the states the ecosystems have been overexploited or deforested, this has contributed to the habitat loss for many species along with other negative impacts, some of them with a very significant public order such as access to water and health effects on the population (Kjellstrom *et al*., 2010; Ellison, 2015).

One of the Mexican states with a high degree of degradation of its ecological environment is Tabasco; this area has great natural resources reserves that have favored for decades diverse economic activities like forestry, livestock, and agriculture, as well as natural gas and crude petroleum extraction activities. Although, the latter has also contributed to the degradation of the environment and constant social claims for spills (Chan-Quijano *et al*., 2015). Different studies agree that the changes in the soil of tropical regions in México are mainly associated to three factors: the first one is correlated to the type of climate (floods and droughts), the second includes anthropogenic activities as intensive crops, urbanization, and oil industry and, the third factor involves the changes in soil use (Pérez-Vidal *et al*., 2010; Palma-López *et al.,* 2017).

An important issue that has not received proper attention is that, after environmental emergencies, such as floods, the population has migrated to low-income residential complexes with critically overcrowded conditions. This phenomenon has contributed to limited access to public services, especially, water. It must be pointed out that most of these sites do not have adequate drainage due to the presence of elevated aquifers and the remarkable supersaturation of septic material or the fact that wastewater treatment plants do not fully operate (Gama *et al*., 2011). Both situations lead to water and soil contamination, as well as the presence of outdoor sewage and as a consequence population is constantly exposed to infectious diseases (Perevochtchikova and Lezama, 2010). To implement a proper infrastructure for all economic sectors, the national regulatory framework contemplates as mandatory to establish technical feasibility studies that frame social, economic, and environmental issues, all of them reflected in an Environmental Impact Manifest (MIA). Though, most of these studies have been carried out without multidisciplinary approaches, being mostly technical analysis (Martínez-Zurimendi *et al*., 2015; Hernández Melchor *et al*., 2016).

For example, the construction regulations in urban areas of Tabasco, consider that 5% of the whole construction area must be destined to green areas; however, the National Norm NMX-AA-164-SCFI-2013, mentions that the green area in a construction site must be 30% of the total, this regulation coincides with some decrees in the European Union (Article 10 of the Habitat's Directive (92/43/EEC), which specifies the guidelines to establish green infrastructures in highly populated areas, as well as some ASTM guidelines for establishing green roofs (E2397 and WK25385). All of them stand the importance of these percentage for conserving the environment as places for the development of the public sphere (Higuera-Zimbrón and Rubio-Toledo, 2011; Rodríguez-Jiménez *et al*., 2014; Donaldson an João, 2019; Terkenli *et al*., 2020; Aprile *et al*., 2020).

However, in Mexico some standards are not mandatory and low-cost species are regularly planted in the green area, they serve as an architectural attraction, but are not exactly endemic (López-Hernández and Rodríguez-Luna, 2014; Asprilla-Lara and Castro-Valencia, 2016; Dissanayake *et al.*, 2019) affirmed that if there is no balance between the population percentage of population and plant cover, heat islands are favored, with concomitant overexploitation of natural resources and the generation of psychosocial problems. Moreover, Capdepont-Ballina and Marín-Olán (2014) reported the advantages that represent endemic plant diversity in urban areas, since the establishment of endemic animals is favored, water infiltration is improved and thermal inversion, as well as the air quality, are both enhanced. Furthermore, Maiolo *et al.* (2020) and Aprile *et al*. (2020) found that this strategy also reduces air conditioning use and electricity consumption. It must be added that in areas with high population density, the presence of trees allows social recreation. Fett *et al.* (2019) observed a depress reduction in people who have recreational spaces compared to those who do not have this benefit.

Although the above shows evidence of the importance of green areas in urban zones, it also shows us that there must be a norm that regulates the type of plants that should be introduced; for example, in some Latin American countries, it has been decided to follow international methodologies with adverse results. There are cases where trees that have been planted do not correspond to soil conditions and, consequently, civil infrastructure is damaged by roots (Vargas-Garzón and Molina-Prieto, 2010; Pérez-Medina and López-Falfán, 2015; De la Barrera *et al.*, 2016). In other cases, green areas are filled with construction waste to prevent the rooting of planted species and, generally, they can't survive (Allen *et al.*, 2010; Daza-Torres *et al.*, 2014).

On the other hand, the southeastern region of Mexico has been an area that has experienced large transitions related to law reforms proclaimed in 2013, especially in the energy sector and recently, with the implementation of a refinery and other industrial developments. Some studies have found that the environmental regulations do not take into account the evaluation of negative impacts in restored areas, especially those with the presence of residual hydrocarbons, nor have they evaluated the susceptibility to spills and their impacts in agricultural areas adjacent to oil pipelines, considering that nowadays, the spills are mainly due to the theft of fuels (commonly known in Mexico as "guachicoleo") (Checa-Artasu, 2014; Vargas, 2015; Barreda, 2018). It must be noted that remediation technologies are different and depend on the type of impact and hence, it turns out that each particular site represents a specific problem to be analyzed (Morales-Bautista *et al*., 2017). On this issue, most of the researchers agree that considerations such as the Maximum Permissible Limit (MPL), are not ideal diagnostic parameters nor environmental assessments since in some restored areas (with concentrations of pollutants below the MPL), persist alterations such as low hydraulic conductivity, compaction and water repellency and the development of plants or yield of crops is affected (Trujillo-Kanga, 2015; Domínguez-Rodríguez *et al*., 2020).

Although there is a large number of reports mentioning the effects of hydrocarbons on soils, the long-term impact of residual hydrocarbon has been scarcely attended. For example, Kuppusamy *et al.* (2020) and Cui *et al.* (2020) indicated that biogeochemical processes are involved in the degradation of hydrocarbons and that the resulting products may exhibit toxicity or water repellency; regarding this, Beesley *et al.* (2010) and Shahsavari *et al.* (2019) found that some of these components can biomagnify them and confer toxicity on living beings, especially, aromatic fractions and heavy metals; Adams *et al.* (2016) reported that disposition of these compounds depends both on the type of soil (considering factors such as: pH value, organic matter amount and percentage of clays) as well as the type of hydrocarbon and the spilled amount; in addition, other studies such as those from Zavala-Cruz *et al.* (2005) and Akande *et al.* (2018) mentioned that these parameters define the type of plant to be sown, since some species are usually tolerant to soil conditions and do not absorb the contaminant, whereas others take them as a nutritional source and tend usually to bioaccumulate them.

A topic that has recently become interesting is that in Mexico there are few studies about reforestation in restored sites, in some remediation processes, organic matter is added to help the survival of plants that allow returning the vocation of land use, whereas other procedures consider that plants are part of the remediation stage and they are subsequently removed. In the environmental programs focused on urban areas, the reforestation procedures are generally carried out without supervision and, most of the time induced species are sown (Ruiz-Luna *et al*., 2019). Currently, the launching of the program “Sowing Life” seeks to potentiate forestry and/or agricultural development, mainly in the southeast region of Mexico. However, no evidence has been found if this program will consider that some of these areas have high demographic influence, overexploited and/or contaminated by various industries, overgrazing and/or agricultural activities (Guzmán Luna *et al*., 2019; Gómez-Mellado *et al*., 2020).

In this sense, environmental management of agricultural and urbans zones for forest development is not a new issue, most studies have established which kind of plant to sow or to induce based on satellite spatial modelling studies and, in areas where industrial and agricultural activities are combined (Oldoni *et al*., 2019; Damian *et al*., 2020); other studies like that of Angelopoulou *et al.* (2019) found that these studies must be constantly updated due there are changes in the soils by civil works such as roads and flood protection embankments, which are added to the restored soils, Pannecoucke *et al.* (2020) and Kiani *et al.* (2020) mentioned that the horizons of the soils are homogenized, so the reading determined by the satellite can vary, they also determined that fertility conditions are usually different from those reported in neighboring areas; some phytoremediation works coincide in the success of these technologies, based on establishing studies of soil fertility conditions and the type of pollutant present, on the one hand, seeks removal, but on the other, biomagnification must be prevented and, in the case of sites with presence of hydrocarbons, it is recommended studying the water potential by means of the water repellency (Chan-Quijano *et al*., 2015; Marín-García *et al*., 2016; Domínguez-Rodriguez *et al.,* 2020)

In this context, although current Mexican economic strategies are committed to the hydrocarbon sector and the rescue of the agricultural sector, little attention has been paid to restored soils with the presence of residual hydrocarbons in which they are going to implement programs in these two sectors, a specific topic is the Environmental Base Lines (LBA) of the energy sector, this tool was recently created and is based on the study of all environmental impacts related to pollution spills from the hydrocarbon sector, especially in areas where operations of the private sector are required. It has been noted that to establish the environmental impact in restored soils, evaluations are firstly based on the parameters described in NOM-021-SEMARNAT-2000 and, later, a comparison is made with literature data. However, this procedure does consider that many restored soils horizons have been homogenized and, in general, they lose their original characteristics; as a result of this phenomena, some studies classify this kind of restored soils as Anthrosols or Technosols according to their pedogenesis, it is noticeable that by taking these terms into account, a proper selection of the plants to be induced can be accomplished (SEMARNAT, 2002; Salgado-García *et al*., 2016; Córdova-Ávalos, 2018).

All of the above makes the need to establish scientific studies that serve as decision-making tools in investment programs targeted to a vocation for agricultural use in either restored or nearby sites in oil facilities. This information can contribute to the design of government development plans, in addition to giving a perspective of the need to update the current environmental regulations. For these reasons, we decided to measure the changes in the properties of the remediated soils from three different perspectives: the first case study was an area affected by the congenital water spill and was recently restored with calcium oxide (Zone 1). The second case was an area contaminated by hydrocarbons and that was restored (Zone 2), and the third case (Zone 3) was a site adjacent to the development of urban infrastructure. The three study areas are located in the municipality of Cunduacán, Tabasco, México. The demarcation of the study was secluded only to this municipality in order to diminish the effects of environmental conditions (Angel-Meraz *et al*., 2009) and because most of the predominant land units of this region are alluvial and with a vocation for agricultural use (Zavala-Cruz *et al*., 2014).

MATERIALS AND METHODS

General Considerations

During June 2018, a sampling process was performed and geological strata were taken according to the procedures described in the methodology. In each obtained sample, the physical and chemical properties of the affected areas were evaluated and compared with a control sample to establish significant differences and possible effects.

It is pertinent to mention that although the contaminant spills from Zones 1 and 2 occurred on different dates (2015 and 2013, respectively), there is evidence of the soils conditions after the remediation process in both areas, so this data allowed us a proper comparison of the changes that have occurred during the weathering period and by comparing with the current conditions of the sites, led us to determine if the remediation and weathering process could direct the types of activities to be developed in each site, with special attention to those related to the primary sector in Zones 1 and 2, whereas in Zone 3 the purpose was to evaluate the soils conditions impacted by a construction site to verify the type of organic cover to be implemented. Also, to mention plants, animals, or other organisms, their common as well as scientific names are indicated. The scientific names are written in italic letter considering the international nomenclature to botanical science, zoology, bacteria, and growing plants.

Study Areas

Zone 1. For this site, based on the report of Morales-Bautista *et al.* (2016) (this was considered as a reference sample of treated soil or TR1), which identified and appraised the zone by a spill of with congenital waters (oil production wastewater), the site is located at the rural area named Cumuapa, of the municipality of Cunduacán, Tabasco.

Zone 2. According to the report by Morales-Bautista *et al.* (2014) (this was considered as a reference sample of treated soil or TR2), these authors mention that the site was restored after an oil spill, the area is located in the rural community of Miahuatlán 2da. Sección, municipality of Cunduacán, Tabasco.

Zone 3. This is a site with recent civil works, located on the periphery of the capital of the municipality mentioned above. Buildings destined for higher education and scientific research were built in this place which also presented a zone destined as a conservation or green area. Since it is a low area and with clayey soils, in addition to clearance, some horizons of the soil were removed or homogenized and subsequently compacted. To raise the level, it was filled with a mixture of sand, soil removed and remaining construction materials (Morales-Bautista *et al*., 2017) (this was considered as a reference sample of treated soil or TR3); although it is a fact that with these works the edaphological classification is lost, usually organic coverage is always implemented (Carbajal *et al*., 2019), that is why when the construction works finished, San Agustín grass (*Stenotaphrum secundatum*) was rolled over the conservation area (Sastry *et al*., 2019).

In each zone, directed sampling was performed with shovels and peaks, three geological strata were taken (problems) and another three samples were taken from a non-impacted surrounding area with similar edaphological characteristics (control). In all cases, the samples were taken from the first horizon to the phreatic level, thereby, in Zone 1 the sample was ~70 cm deep, the Zone 2 of ~80 cm and, the Zone 3 of ~50 cm. The positions of each samples are expressed in Table 1.

Parameters Determined

Each soil was placed on a plastic membrane, homogenized (control on one side and problems on the other), and then a quartering sampling method was performed to take three proportional parts of each soil (approximately 3 kg for each sample). All the samples were preserved and transferred to the laboratory, where roots and rocks were removed. The soils were dried at 105 °C, ground, and screened.

Finally, for all samples (controls and problems), were determined the parameters specified in Table 2 (n=3); the methods used were as specified by the Mexican norm NOM-021-RECNAT-2000 (SEMARNAT, 2002), Domínguez and Aguilera (1989) and Domínguez-Rodríguez *et al*. (2020).

Additionally, for Zone 1, the presence of the following metals was also determined: Pb, Ni, Zn, Cd, Cu, Cr, Mg, Na, Ca, K, Fe, V; the determination of the metals was based on the methods of the aforementioned regulation and those provided by the Mexican norm NOM-147-SEMARNAT/SSA1-2004 SEMARNAT (2007) and Asia *et al.* (2007).

Also, in Zone 2, it was determined the content of total petroleum hydrocarbons (TPH) based on NOM-138-SEMARNAT-SSA1-2012 (SEMARNAT, 2013) with modifications by Pons-Jiménez *et al.*

Table 1. Sampling points location.

15 Q								
Zone 1			Zone 2			Zone 3		
Control 1.1	487487.87 m E	1982962.99 m N	Control 2.1	468193.36 m E	1990937.57 m N	Control 3.1	482064.00 m E	1998679.18 m N
Control 1.2	487658.90 m E	1989860.05 m N	Control 2.2	468200.26 m E	1990446.77 m N	Control 3.2	482072.12 m E	1998652.84 m N
Control 1.3	487600.76 m E	1990031.30 m N	Control 2.3	468188.75 m E	1990957.31 m N	Control 3.3	482054.84 m E	1998634.98 m N
Problem 1.1	487604.91 m E	1989935.91 m N	Problem 2.1	468198.57 m E	1990973.75 m N	Problem 3.1	482079.66 m E	1998598.11 m N
Problem 1.2	487699.97 m E	1989966.89 m N	Problem 2.2	468211.34 m E	1990966.37 m N	Problem 3.2	482104.25 m E	1998591.15 m N
Problem 1.3	487739.82 m E	1989906.85 m N	Problem 2.3	468215.61 m E	1990979.13 m N	Problem 3.3	482087.50 m E	1998571.44 m N

In Universal Transverse Mercator or UTM.

Table 2. Physicochemical parameters are determined in T1 and TP1.

Parameter	Nomenclature and units	Method
Hydrogen potential	pH	In water (relation soil/water 1:2)
Electric conductivity	CE in dS m^{-1}	Saturation extracted and conductimeter
Real density	DR in g cm^{-3}	Pycnometer
Apparent density	DA in g cm^{-3}	Test-tube
Porosity	Po in %	Test-tube approximate method
Field capacity	CC in %	Columns of Colman
Organic material	MO in %	Walkley and Black
Cation exchange capacity	CEC in $cmol^{+}$ kg^{-1}	Saturation with CH_3COONH_4 and titration with HCl
Texture	Sand (A), Clay (R) and Silt (L), all in %	Bouyoucos

(2011) and Morales-Bautista *et al.* (2020); TPH extracts were subsequently subjected to an analysis of SARA fractions for determining the percentages of saturated hydrocarbons (%S), aromatic hydrocarbons (%Arom), polar resins (%Res) and asphaltenes (%Asf), these procedures were accomplished through a chromatographic separation process in a silica column as established by Kharrat *et al.* (2007) and Díaz-Ramírez *et al.* (2008). To improve the selectivity, solvent mixtures were used following the exposed by Marín-García *et al.* (2016).

The experimental design was carried out in completely randomized (treatments n = 3; control T, problem TP and remediated soil of reference TR) for each variable under study (with three replicas each); to the results are performed statistical analysis to out (ANOVA, significance level of 0.05) and a Tukey Test (HSD or Honestly-significant-difference) to evaluate differences between the treatments (T, TP and TR); all this, in the R-Project (Statistical Program version 3.5.3) (Cuevas *et al*., 2004).

RESULTS AND DISCUSSION

Zone 1

Table 3, shows the results of the tests performed on the control and problem samples in Zone 1 (T1 and TP1), the reference data (TR1) are also included.

When comparing the results of each of the properties in Zone 1, the ANOVA analysis showed that there are differences between all the treatments for each of the parameters ($P < 0.05$), therefore, the treatments were evaluated in terms of HSD to determine which treatment is different from the others.

In the case of pH, it was found that when comparing T1 and TR1, as well as in TR1 and TP1 there are significant differences (HSD > 1.021) but, between T1 and TP1 there are no significant differences (HSD < 1.021), the reason why it is deduced that when treating the soil, the pH changes, but after the weathering period, it returns to the original conditions. Comparing the pH of the samples in terms of the Mexican standard (NOM-021-RECNAT-2000) (SEMARNAT, 2002), TR1 is classified as strongly alkaline, whereas TP1 and T1 are considered as moderately alkaline; several reports mention that pH is an important factor for the development of microbiota and the provision of essential nutrients for plants. Since the restoration procedures performed by alkaline methods (employing CaO) increase the pH value, it has been observed that some plants cannot develop properly. However, it has also been observed that plant growth is improved by gradually reducing the pH value in the soil, attributing this phenomenon to the fact that CaO is not retained in the structure of the matrix, this phenomenon is presented mostly in soils with a sandy texture and with a low organic matter content (Chávez-García and Siebe, 2019).

On the other hand, when comparing the values of electrical conductivity it was observed that there are differences between T1 and TR1 as well as between T1 and TP1 (HSD > 0.020), but there are no differences between the values of TR1 and TP1(HSD < 0.020);

however, even when it is important to mention that the CE values in TR1 and TP1 are greater than T1; when considering the three samples, the values of this parameter are below the levels of soils with salinity problems (CE < 4 dS m^{-1}) as specified by the Mexican reference standard mentioned above (SEMARNAT, 2002).

There is a similar behavior between the DA, DR, and %Po properties. It was found that the values of T1 show differences with respect to the values of TR1 and TP1 (in DA HSD > 0.122, in DR HSD > 0.1517 and, in %Po HSD > 1.449), whereas TR1 and TP1 did not present differences between them (in DA HSD < 0.122, in DR HSD < 0.1517 and, in %Po HSD < 1.449). The results point out to the fact that these properties do not recover, even after a weathering period; however, it should be noted that the alluvial soils of the study area are reported as associations of Fluvisols, Vertisols, and Gleysols, some of them have a high content of expandable clays which, due to changes in the environmental conditions, present variations throughout the year in apparent and real density, as well as in porosity (Palma-López *et al*., 2017).

Table 3. Characteristics of soils in Zone 1.

Sample	pH	CE	DA	DR	%Po
T1	7.51 ± 0.1	0.12 ± 0.01	1.57 ± 0.02	1.82 ± 0.01	16.48 ± 0.43
TR1	9.45 ± 0.13	0.35 ± 0.02	1.71 ± 0.01	2.15 ± 0.03	20.46 ± 0.77
TP1	7.52 ± 0.20	0.32 ± 0.02	1.72 ± 0.01	2.20 ± 0.02	21.81 ± 0.62
p-value	0.0016	8.05×10^{-8}	0.0159	0.0004	7.01×10^{-5}
HSD	1.028	0.020	0.122	0.1517	1.449

Sample	CC	%MO	Texture		
			%A	%R	%L
T1	23.00 ± 0.90	2.00 ± 0.10	63 ± 0.6	26 ± 0.31	11 ± 0.56
TR1	10.00 ± 0.44	0.50 ± 0.001	95 ± 0.5	0	5 ± 0.10
TP1	20.45 ± 0.91	1.20 ± 0.05	90 ± 0.3	0	10 ± 0.50
p-value	2.33×10^{-7}	2.32×10^{-8}	7.72×10^{-6}	6.12×10^{-10}	3×10^{-7}
HSD	1.3736	0.1012	6.165	1.103	0.6657

Sample	Ca	Mg	K	Na
T1	2532	1425	980	296
TR1	4462	327	99	143
TP1	4450	300	100	140
p-value	2.78×10^{-7}	9.27×10^{-9}	3.20×10^{-10}	2.40×10^{-8}
HSD	220.446	50.420	33.446	12.070

Sample	Pb	Ni	Cr	V	Cd	Fe	Cu	Zn	Mn
T1	0.052	0.090	< LD	< LD	< LD	5.1	0.029	0.024	< LD
TR1	1.990	1.290	91	1.27	< LD	6.8	<LD	<LD	< LD
TP1	2.050	1.250	89	1.25	< LD	6.9	<LD	<LD	< LD
p-value	1.48×10^{-9}	1.97×10^{-9}	1.26×10^{-9}	1.26×10^{-9}	ND	8.21×10^{-6}	1.58×10^{-10}	6.12×10^{-10}	ND
HSD	0.09	0.060	4.300	4.30	ND	0.355	0.001	0.001	ND

TR1 corresponds to the reference values reported by Morales-Bautista *et al.* (2016); TP1 is the problems samples and T1 control sample; for metal, the concentration expressed in mg kg^{-1}, coefficient of variation C.V ≤ 2 and Detection Limit LD = 0.0014; p-value is obtained in ANOVA analysis, HSD is the value obtained in Tukey Test and, ND is undetermined.

Derived from the above, the effects of salinity and compaction by overgrazing about the development of some plant species have been studied and it has been found that plant growth is related to salinity tolerance whereas rooting is related to soil densities (Hassan *et al*., 2019). Due to the conditions presented in the soils analyzed, this kind of problems can occur and therefore it must be done a careful evaluation of the type of plant to be induced in the restored sites, since it has been stated that some forage grasses such as *Brachiaria humidicola* are very tolerant to salinity (Morales-Bautista *et al*., 2011; Zaneti *et al.,* 2019), whereas there are fruit crops that are very sensitive to it, for example, watermelon (*Citrullus lanatus*). Since both species are very common in tropical areas, a careful study about the soil's conditions must be done before the introduction of a proper plant (Stoleru *et al*., 2019; Ulczycka-Walorska *et al*., 2020).

Furthermore, the results of textures presented in Table 3, showed that the values of %A, %R and %L in T1 are different concerning to those of TR1 (in %A HSD > 6.165, in %R HSD > 1.03 and in %L HSD > 0.665), this is similar comparing T1 with TP1, we observe differences between the values of %A and %R, but present differences between themselves in %L (HSD < 0.665); also, when comparing these same parameters between TR1 and TP2, we observe that they are all different from each other TR1 (in %A HSD > 6.165, in %R HSD > 1.03 and, in %L HSD > 0.665); this finding coincides with the reports of some authors such as Adams *et al.* (2014), who found that when adding materials such as CaO to stabilize contaminated soils, the textural properties are lost and densities increase, mainly, the clay content is lost and as a result, the texture changes [in T1 is loam-clay-sand and changed to sandy in TR1 and TP1, according to the texture triangle proposed by Rucks *et al.* (2004)]. Different investigations explain that this phenomenon is due to the deposition of the contaminants or the treating agent on the pores of the clays, which led to the formation of aggregates with the greater mass that usually behaves like sands. These results can also be associated with an increase of densities (Jones *et al.*, 2010; Taboada-Castro *et al*., 2011). The permanence of the textural class after the weathering process may be associated with the stability of these aggregates (Prieto-Méndez *et al*., 2013).

Moreover, it has been reported that the availability and abundance of nutrients, as well as the retention and degradation of pollutants, are directly related to the amount of organic matter and soil texture, for this reason some restoration works add material with these characteristics. For example, when organic material is added, what is sought is either to diminish the concentration of the contaminants to less toxic levels or their degradation to non-toxic reaction products (Gómez-Mellado *et al*., 2020; Kuppusamy *et al*., 2020). In other cases, the addition of inorganic and organic substances is intended to stabilize the contaminant by encapsulation or micellar sequestration (such as the pozzolanic reaction) and, subsequently, organic material with nutrients is added to return some properties to the soil to support planting (Adams *et al.*, 2011; Álvarez-Coronel *et al.*, 2020).

However, for the study area, there was no report of the aggregation of organic material after the treatment; in this sense, when comparing the values of %MO in T1, TR1 and TP1, it was found that all are different from each other (HSD > 0.1012), in general, we note that this value falls from 2% in T1 to 0.5% in TR1, but this recovers to 1.5% after weathering (TP1), this tendency is possibly related to the presence of grass in the restored site (*Brachiaria decumbens*, commonly known as Chontalpo). It was also observed that the variation in organic matter is parallel to the initial decrease of field capacity found in TR1 and the subsequent increase found in TP1 (in this parameter (CC), all the treatments also show differences between each other (HSD > 1.3736)). In terms of the NOM-021-RECNAT-2000 (SEMARNAT, 2002), %MO in T1 is "medium", whereas in TR1 is "very low", but this parameter is recovered after the weathering and the introduction of the grass since in TP1 the classification is "low".

Several works have emphasized the negative effects of low percentages of organic matter and field capacity in plantations with high demand for nutrients and water (Inckot *et al*., 2011; Zanetti *et al*., 2019). Although forage grass was identified as tolerant to salinity and very resistant to moisture changes, it has been reported that it provides a low nutritional value and does not favor the gain of muscle mass by cattle feed with it. Although, it is also recognized that in very affected areas, it is advisable to implement initially tolerant and resistant plants in order to improve soil conditions and, subsequently to induce other species according to the recovered soil properties. This type of restoration is then considered as a long-term technique (Adams *et al*., 2014).

Though the environmental impact of metals on soils is a highly studied topic, it is very scarce the research that emphasizes the transfer mechanisms that give rise to bioaccumulation and biomagnification of heavy metals. This tendency may be explained by the complex behavior of the contaminants according to the edaphological properties and environmental conditions. Moreover, there is also a lack of information about the determination of heavy metals in wastewater generated during hydrocarbon production. López-Atamoros *et al.* (2004), mentioned that the presence of such elements is in direct relation with the petroleum asset since the presence of specific minerals depends on the geological characteristics of the extraction site. In Tabasco, Siebe *et al.* (2005) and Madrigal-Díaz *et al.* (2019) reported the presence of Pb, Ni, Zn, Cd, Cu, Cr, Mg, Na, Ca, K, Fe, and V in effluents from petroleum separation batteries (which is where wastewater is produced).

Based on the above, the presence of 13 metals was determined, when comparing the values presented in Table 3 for each sample significant differences were observed between TR1 and TP1 compared to T1 (mean difference above HSD of each metal), but no differences were observed between the values of all the metals in TR1 compared to TP1 (mean difference below HSD of each metal). The heavy metals considered as pollutants: Pb, Ni, Cr and V exhibited concentrations below the allowed limits established in the Mexican norm NOM-147-SEMARNAT/SSA1-2004 (SEMARNAT, 2007), Cd is another heavy metal pollutant that is not considered in the cite norm (it is included in the norm NOM-021-SEMARNAT-2000) and the presence of this metal was below the detection limits of the method employed. The concentration of the following metals Fe, Cu, Zn, Mn, Ca, Mg, K, and Na, are also specified in NOM-021-SEMARNAT-2000 since they are considered with agroecological importance at certain concentrations (SEMARNAT, 2002; Reyes *et al*., 2016).

We also note that the concentrations of Pb and Ni increase in soils after treatment, (even if they remained below the level marked as normal by the aforementioned norm) and although the presence of Cd was not detected, the occurrence of Pb, Ni, V, and Cr, in TR1 and TP1 can be associated with the spillage of congenital waters and it is unlikely that they could be removed by the employed treatment. In these cases, it is highly advisable to carry out long-term evaluations, taking into consideration the types of plant species to be planted to diminish a possible bioaccumulation process (Madera-Parra *et al*., 2014). Likewise, the analysis of the oligo-nutrients showed that both T1 and TR1 and TP1 are deficient in Mn; this is a factor that should be considered since it can occur chlorosis in the plants cultivated in the remediated soils. Moreover, after the treatment and weathering process, significant deficiencies were also found in Cu and Zn, in this sense, Marrero-Coto *et al.* (2012) and Jara-Peña *et al.* (2014) indicate that the deficiency in these metals, concomitant to high pH values, influence the yield of some crops.

An important remark must be added about the behavior of the interchangeable ions: the concentration of Ca almost duplicates its value in both TR1 and TP1 when compared with T1, whereas the concentrations of Mg, K, and Na diminish in TR1 and TP1 concerning to T1. These phenomena are explained by an equilibrium exchange process between this cationic metal (Álvarez-Coronel *et al*., 2020). Furthermore, several studies have identified the relationship between the disposition of interchangeable cations with the pH value, the clay percentage, and the amount of organic matter (Li *et al*., 2016). In this sense, when adding CaO during the remediation procedure, alkaline conditions are generated and although the pH value decreased along the weathering time, it does not reach the original value (Morales-Bautista *et al*., 2011). Additionally, it has been reported that an excess of Ca in the soil inhibits the provision of Mg and K, all of these is consistent with the results observed in the treated and weathering soils: the concentration of these metals decreases between 80% and 90% in TR1 and TP1 when compared to the control. There are known effects of the deficiency of Mg in soils; low levels of this metal affect the development in oil palm crops and forage grasses, the milk quality of cattle can be reduced; also, it has been stated that reducing the amount of K in the soil affects the absorption of CO_2 in vegetables (He *et al*., 2015; Mogollón-Sandoval *et al*., 2015).

The soil remediated by exchange with CaO, there were found properties that are not recovered after the treatment and the weathering process and they are considered important in soils with agricultural vocation such as electrical conductivity, percentage of organic matter, field capacity and texture. There are also important changes in the concentrations of Mg, Ca and K, although the demand for these elements depends on the type of plant, these considerations must be taken into account since most of the agricultural development program correspond to not impacted soils with characteristics similar to those of the control, whereas there is no consideration for the characteristics presented by treated soils. Another factor to be considered with special attention is the possible biomagnification of heavy metals since after the remediation there were still concentrations of some of them. These kind of metals are considered toxic and with an anthropogenic origin, such as the case of V and Cr.

Zone 2

Table 4, presents the results of the determinations performed on treated and control samples of Zone 2.

The ANOVA analysis showed that in DR and %R, there are no differences between the values of the three samples (T2, TR2 and, TP2) ($P > 0.05$), so we deduced that these parameters are not affected during and after the remediation process, in contrast, parameters such as pH, CE, DA, %Po, CC, %MO, %A, %L, Ca, Mg, Na, K, HTP and SARA fractions, we found that at least one treatment is different to others ($P < 0.05$).

Table 4. Physical and chemical properties of soil in Zone 2.

Sample	pH	CE	DA	DR	%Po
T2	6.31 ± 0.18	0.137 ± 0.003	1.18 ± 0.03	2.01 ± 0.10	41.29 ± 1.0
TR2	7.19 ± 0.11	0.243 ± 0.004	1.39 ± 0.02	2.20 ± 0.11	36.81 ± 1.1
TP2	7.00 ± 0.24	0.241 ± 0.002	1.21 ± 0.03	2.09 ± 0.09	42.10 ± 1.9
p-value	0.004	2.66×10-5	0.013	0.165	0.036
HSD	0.503	0.026	0.157		4.982

Sample	CC	%MO	Texture		
			%A	%R	%L
T2	32 ± 1.11	0.728 ± 0.03	4 ± 0.1	56 ± 2	40 ± 1
TR2	25 ± 0.78	0.289 ± 0.01	4 ± 0.1	60 ± 3	36 ± 1
TP2	21 ± 1.01	0.331 ± 0.01	5 ± 0.1	58 ± 2	37 ± 1
p-value	0.000	4.21×10-8	8.97×10-5	0.311	0.010
HSD	3.176	0.0360	0.305		2.772

Sample	Ca	Mg	Na	K
T2	12.01 ± 0.20	17.00 ± 0.32	0.79 ± 0.01	0.25 ± 0.005
TR2	7.33 ± 0.12	12.73 ± 0.22	1.39 ± 0.02	0.17 ± 0.004
TP2	7.24 ± 0.11	13.00 ± 0.23	1.15 ± 0.02	0.16 ± 0.007
p-value	8.41×10-7	2.64×10-5	1.52×10-6	2.42×10-6
HSD	0.672	1.057	0.080	0.015

Sample	HTP	%S	%Arom	%Res	%Asf
T2	0	0	0	0	0
TR2	561 ± 11	14 ± 0.3	36 ± 0.7	13 ± 1.1	37 ± 1.1
TP2	555 ± 13	0	24 ± 0.6	24 ± 0.5	52 ± 2.0
p-value	4.88×10-9	6.12×10-10	3.91×10-9	3.11×10-5	4.16×10-9
HSD	33.498	0.594	1.837	1.159	2.7090

TR2 corresponds to the reference values reported by Morales-Bautista *et al*. (2014); T2 is control spoil, TR2 reference treated soil and TP2 is problem soil; Concentrations of Ca, Na, K, and Mg expressed in $cmol^{+}$ kg^{-1}; the hydrocarbon concentration in mg kg^{-1}; Saturated (%S), Aromatic (%Arom), Polar Resins (%Res), and Asphaltenes (%Asf) fractions, all in % weight; p-value is obtained in ANOVA analysis and HSD is the value obtained in Tukey Test.

It should be noted that in the Tukey Test results, we observed that some parameters were changed by the remediation works and did not recover after this, even after a long period of weathering; for example we observed that the pH value in T2 presents significant differences concerning the values of TR2 and TP2 (HSD > 0.5031), but there were not found significant differences between TR2 and TP2 (HSD < 0.5031), this behavior is similar in CE, %L, Ca, Mg, K and HTP, where the T2 values are different from the TR2 and TP2 treatments (the HSD is above the values expressed in Table 4 corresponding to each parameter). However, the values of the latter (TR2 and TP2), do not present differences between them (HSD is below the values established for each property).

In the case of texture, when comparing the values for %A in T2, no significant differences were observed with respect to TR2 (HSD < 0.3048) but they were found concerning to TR2 (HSD > 0.3048), both treatments (TR2 and TP2), also exhibit differences between each other (HSD > 0.3048); in contrast, when evaluating the values for %L, significant differences were observed between T2 concerning to TR2 and TP2 (HSD > 2.7722), but when comparing both treatments, no significant differences between each (HSD < 2.7722) were observed. However, when adding the percentages to the triangle of textures proposed by Rucks *et al.* (2004), all the samples stayed in the area corresponding to the clayey texture category. In terms of the classification scheme provided by the national reference standard (SEMARNAT, 2002), the pH value of the control soil (T2) was found as moderately acidic, while the treated weathered samples (TR2 and TP2) were neutral. None of the samples presented salinity problems (CE < 4 dS m^{-1}), although it should be noted that the concentration of Na almost duplicated its value after the treatment procedure and remained so even after the weathering period; it should also be noted that although the percentage of organic matter in T2 was low, this parameter decreased even more in TR2 (30% of the control value) and in TP2, it was only recovered to a 45% of the original value.

In the case of the interchangeable cations, the concentration of Ca was classified in the high range for the control soil and changed to a medium-range in the treated and weathered soils. On the other hand, although the concentration of Mg decreased in TR2 and TP2 with respect to T2, it is still considered high. That is not the case for K that went from a low classification in T2 to very low in TR2 and TP2. With these results, it is considered that there are permanent impacts on the parameters of pH value, electrical conductivity, percentage of organic matter and the concentrations of Ca, Na, and K. In this regard, Palma-López *et al.* (2017) and Salgado-García *et al.* (2016) have emphasized the importance of these parameters in soils with agricultural use vocation, especially in tropical areas where negative impacts are evident on the development of some plantations, for example in the Plan Chontalpa at Tabasco, Mexico (Adams *et al*., 2014; Akande *et al*., 2018).

In Zone 2, the following crops were identified: banana (*Musa Paradisiaca*), cocoa plantations (*Theobroma Cacao*) as well as grassland of the chontalpo variety (*Brachiaria decumbens*). For the first crop, it is worth mentioning that Ramos Agüero *et al.* (2016) observed that banana cultivation is improved in acidic soils and with contents of K and Ca of 0.9 and 11.9 $cmol^{+}$ kg^{-1} respectively; at the studied site, the remediation and weathering processes changed the pH values to neutral and reduced the content of both K and Ca by about 40%, these factors could have negative developmental effects for this plant and they diminish the quality of its fruits. However, it must be pointed out that soil conditions can be improved by fertilization techniques according to planting needs (Taboada-Castro *et al*., 2011; Cordero-Torres, 2013).

In the case of cocoa crops, several reports have found that the changes in the pH values, the increase in salinity and the decrease in field capacity and the percentage of organic matter could influence the development of cocoa trees, since the growth of this plant is linked to the presence in the soil of microorganisms which provide essential nutrients and their growth is preferably stimulated in soils with acidic conditions, good content of organic matter and high moisture (Sánchez-Hernández *et al*., 2011; Cortés-Patiño *et al*., 2015). Regarding the grasslands, Zavala-Cruz *et al.* (2005) and Adams *et al.* (2016) observed that some brachiarias such as chontalpo and humidícola can be established in low nutrient soils even if they have a high concentration of hydrocarbons, they also mentioned that these grasses are very tolerant to salinity and they grow in soils with pH values in a range from acid to neutral, accordingly, the growth of these brachiarias would not present problems in the conditions found in the study zone.

In regards to the quantification of Total Petroleum Hydrocarbons (HTP), it was found that the control soil (T2) was not contaminated with hydrocarbons and, in the results of Tukey test for this parameter, T2 presents significant differences with respect to TR2 and TP2 (HSD > 33.4983), but no significant differences were observed when comparing the values of TR2 and TP2 (HSD < 33.4983); though, it should be noted that all values are below the MLP of Mexican regulations in matters of the hydrocarbons in soils (SEMARNAT, 2013). In similar studies, Khalladi *et al.* (2009) and Chan-Quijano *et al.* (2015) mentioned that surfactant treatment gave good results for soils contaminated with the light fraction of hydrocarbons. It has also been reported that this process has better selectivity in clay soils without presenting an increment in the formation of aggregates and textures (Li *et al*., 2016); nevertheless, there are some disadvantages for this method: for example, it promotes the removal of organic matter and when cationic surfactants are employed, the salt content is usually increased, if mixed surfactants are used, the dragging of other cations is promoted and the percentage of organic matter is decreased (Mao *et al*., 2015). This explains the increment in electrical conductivity in the treated soils as well as the rise in the Na concentration and the decrease in the concentrations in Ca, Mg, and K as well as the reduction in the percentage of organic matter.

Additionally, Morales-Bautista *et al.* (2016) and Marín-García *et al.* (2016) emphasized the relationship between the presence of polar compounds and water repellency. In this sense, although there are no differences in the concentrations of HTP in TR2 and TP2 (HSD < 33.4983), there are significant differences between the values of TR2 an TR2 for the SARA fractions (in %S HSD > 0.5942, in %Arom HSD > 1.8366, in %Res HSD > 1.1585 and, %Asf HSD > 2.7090); it was also perceived that, in TP2 the fraction of saturated hydrocarbons (%S) completely disappears and the aromatic fraction (%Arom) decreases by 30% with respect to the corresponding values in TR2, in contrast, both polar resins (%Res) and asphaltenes (%Asf) increased their values in TP2 by a proportion close to 80% and 40% respectively, these trends coincide with the results of Peng *et al.* (2011) and Adams *et al.* (2011), who established that low treatment selectivity and environmental conditions allow the deposition of residual hydrocarbons in the porous phase (Gutiérrez-Castorena and Zavala, 2002) where they usually transform towards fractions that are water repellents, such as resins and asphaltenes. Doerr *et al.* (2000) and Marín-García *et al.* (2016) specified that this phenomenon is more recurrent in clayey soils that usually present problems in the hydric potential; these findings were reported in soils with hydrocarbon concentrations greater than 10 000 mg kg^{-1} with a 3% of resin and asphaltene fractions. In this study, the proportion of these fractions are around 76% and this may serve to explain how the increase in the percentage of repellent fractions could be related to the decrease in field capacity in TR2 that drops by 22% and in TP2 that falls in about 45% with respect to T2.

Although in both cases the magnitude of the impact is unknown, similar investigations have stated that the germination process can be affected but it has also been observed that after a while, other plant species manage to establish themselves, although some of them present a reduction in primary productivity (Zavala-Cruz *et al*., 2005; Trujillo-Narcía *et al*., 2012). Many experts agree that, in the case of restorations of soils impacted by hydrocarbons, each particular site has inherent characteristics that differ from others. Due to the amount of hydrocarbons spillage events that have occurred in the state of Tabasco, it is important to establish long-term evaluations in the impacted sites even more if after the treatment they are destined to agricultural or forestry program (Inckot *et al*., 2011). This evaluation will be helpful to size the feasibility of each program to be implemented

In summary, it was found that for a soil remediated by surfactant washing, some of the properties that are considered strategic for soil with an agricultural vocation such as the pH value, the electrical conductivity, the percentage of organic matter and the field capacity have not been recovered after the process of treatment and weathering. There are also significant reductions in the concentrations of Ca and K which can affect the development of the crops that were observed at the site. Although low concentrations of total hydrocarbons were found, there are high contents of polar fractions that may be related to the reduction of hydric potential and can be associated with negative impacts on crop productivity.

Zone 3

Table 5 results of the analysis in soil samples present from Zone 3.

Table 5. Characteristics of soil in an area impacted by activities derived from civil works (Zone 3).

Sample	pH	CE	DA	DR	%Po	CEC
T3	7.12 ± 0.23	0.32 ± 0.01	1.22 ± 0.04	2.10 ± 0.10	41.90 ± 1.2	32.1 ± 1.10
TR3	7.40 ± 0.20	0.12 ± 0.01	1.42 ± 0.02	2.61 ± 0.12	45.59 ± 1.5	5.65 ± 0.21
TP3	7.54 ± 0.19	0.11 ± 0.02	1.49 ± 0.07	2.80 ± 0.13	46.78 ± 1.3	6.11 ± 0. 32
p-value	0.126	1.74 × 10-8	0.000	6.20 × 10-5	0.009	2.35 × 10-9
HSD		0.015	0.097	0.185	3.294	1.405

Sample	CC	%MO	Texture		
			%A	%R	%L
T3	32 ± 1	1.01 ± 0.02	31 ± 1	52 ± 1	17± 0.4
TR3	12 ± 0.5	0.31 ± 0.01	65 ± 2	21 ± 1	14 ± 0.3
TP3	10 ± 0.6	0.34 ± 0.01	72 ± 2	20 ± 1	8 ± 0.2
p-value	5.63 × 10-11	9.95 × 10-9	2.23 × 10-7	6.92 × 10-7	9.69 × 10-7
HSD	0.595	0.045	4.323	4.267	1.679

TR3 corresponds to the reference values reported by Morales-Bautista *et al*. (2017); T3 is a control sample, TR3 is reference treated soil and TP3 is problem soil; p-value is obtained in ANOVA analysis and HSD is the value obtained in Tukey Test.

The results of ANOVA analysis showed that for parameters such as pH, there are no significant differences between the three samples ($P < 0.05$), in contrast, for the rest of the properties at least one treatment presents significant differences with respect to the other two ($P > 0.05$). Regarding the Tukey test for the CE analysis, no significant differences were observed between TR3 and TP3 (HSD < 0.152), but comparing these treatments with T3, both show significant differences (HSD > 0.152), this behavior is similar in properties such as DA, %Po, %L, %R, %MO, CEC, since T3 presents significant differences with respect to TR3 and TP3 (it was observed that the result of the mean differences are greater than the HSD presented in Table 5 with respect to each parameter), but when comparing the values of the latter (TR3 and TP3), no significant differences were observed between them (the mean differences are below their HSD for each parameter); likewise, in DR, CC, %A, all treatments show significant differences between them (the differences between the means of T3, TR3 and TP3 are above their respective HSD).

Generally, previous reports have established that most of the area is made up of associations of Vertisols and Gleysol (Palma-López *et al*., 2017), some of the results found in the control sample are in agreement with the properties of these kinds of associations and reports of Morales-Bautista *et al*. (2017) and Gómez-Mellado *et al.* (2020); specifically, the values of T3 exposed in table 7, such as pH (moderately acidic), percentage of clay (> 50%), CEC in the range of 20 to 40 $cmol^+ kg^{-1}$ (in relation to the content of %R and %MO, as exposed for Gutiérrez-Castorena and Zavala, 2002 and, Álvarez-Coronel *et al.*, 2020) and, add to the characteristics observed in the field, such as cracks and orange specks, high phreatic level and high reaction with H_2O_2 in all horizons [that denotes the presence of organic matter in the whole profile (self-plowing) according to Sánchez-Hernández *et al.* (2011) and Salgado-García *et al.* (2016)]; in addition, Capdepont-Ballina and Marín-Olán (2014) reports that for similar soils with high demographics or anthropogenic activities, usually increases the %MO, which may coincide with the value of T3.

For CC, %MO, %A, L and CEC, in general, their variations are comparable with respect to the control sample, the tendency observed is that in both the reference and problem soils there is an increment in the pH values, in real and apparent densities as well as in porosity, whereas there is observed a decrease in the percentage of organic matter, electrical conductivity, and cation exchange capacity. These results are consistent with the reports of Vrščaj *et al.* (2008) and Schindelbeck *et al.* (2008) who stated that to carry out a civil work on urban land, the clay proportion is changed, the soil must be compacted and the amount of organic material should be reduced to avoid displacements or fractures of the infrastructure due to a process of expansion-contracting of the clays; The authors also mentioned that this is an effective measure to avoid moisture problems due to the presence of organic matter and poor compaction; Furthermore, this strategy reduces the formation of saltpeter by the presence of carbonates, sulphates, and silicates of sodium, potassium, and calcium (Pacheco-Bustos *et al*., 2017).

Furthermore, the similarities in the properties determined in the problem and reference soil which are areas affected by constructions are consistent with previous reports that have established that in sites where infrastructure has been developed, most of the removed soil is deposited in neighboring sites, especially when these sites are meant to be destined as green areas; the material in excess derived from the civil work is employed and it is regularly a mixture of sand and concrete although in some cases solid urban waste has been found as reported by Mejía-Restrepo *et al.* (2015). This process explains the textural changes found in soil samples TR3 and TP3 where the percentage of sand increased twice and the clay decreased by approximately 50%. Both TR3 and TP3 are classified as sandy loam soils as reported by Rucks *et al.* (2004).

Additionally, different evaluations have emphasized that the addition of material with a high content of silicates and residues with greater diameter and particle weight concomitant with the work of disassembly, the passage of personnel and the rolling of machinery, contribute to the increase of apparent and real densities as well as the porosity, with a decrease in organic matter (in the studied soils went down from low to very low) and field capacity (which decreased by up to 60%) (Pouyat *et al.*, 2010). It is worth mentioning that according to the characteristics found in TR3 and TP3, they fit into the Class I of Urban Use Capacity in Tabasco according to the classification presented by Zavala-Cruz *et al.* (2016), these findings also coincide with reports in Mexico that have classified the soils affected by human activities as Anthrosols or Technosols (Bautista *et al*., 2015); they can as well be recognized as Uric Regosols, a term that has been established for soils affected by spills of pollutants and industrial use (Palma-López *et al*., 2017). It is important to highlight that The Ecological Management Programme of the State of Tabasco does not include either these types of soils or the areas restored by spills of any pollutant (Rosete *et al.*, 2013; Barba-Macías *et al.*, 2014). This omission is recurring in most of the State of Tabasco Development Plans; Therefore, it is necessary an update which specifies those sites that have been remediated. This information gap must be addressed since currently the Agricultural, Forestry, and Urban Development Plans are based only on satellite and hydrographic studies, which do not consider either the actual situation of specific sites or the physical and chemical parameters of soils.

On the other hand, it is advisable to apply in the studied soil sowing techniques designed for urban and arid areas, for example, double digging or deep seeding, the latter is to leave the root as close to the water table in order to achieve a deeper anchorage and the plant does not have stress for lack of water; this methodology has also been successfully applied to restore underground aquifers and contaminated soils (Rahman and Hasegawa, 2011; Ukiwe *et al*., 2013; Chan-Quijano *et al*., 2015). Regarding the restoration of tropical areas, favorable results have been achieved with the use of plants with a small crown diameter and that can be managed by pruning. Some of the vegetal species that meet these specifications and are recommended in the Development Programme of the state of Tabasco are acacia (*Acacia pennatula*), maculis (*Tabebuia rosea*) and guayacán (*Tabebuia guayacan*) (Burelo and Guadarrama, 2015). It should be noted that these last two species have been successfully applied in the study area (Morales-Bautista *et al*., 2017), the feasibility of using them in urban areas with similar characteristics is high.

CONCLUSIONS

The problem of the impact and remediation of soils by anthropogenic activities is complex, especially since weathering can change conditions after remediation, so long-term evaluation is necessary. Also, it is important to consider factors ranging from the origin of the impact, the remediation process and weathering, the physicochemical properties of the soil and its original vocation, as well as considering whether in the remediation process, the objective is to restore the original vocation of the soil or if an alternative use for the restored soil is contemplated.

In this study, three cases of impacted and remediated soils in the state of Tabasco were analyzed, it was observed that although the remediation processes managed to return some original properties to the soil, others were not like that; return some original properties to the soil, others were not recovered; a recurring point in all areas is that these results depend on the type of treatment applied, but all coincide in the decrease in the amount of organic matter and the cation exchange capacity, on other specific, there are remaining components that provide new properties to soils, such as, changes in density, porosity and field capacity, that can define the type of vegetable species to be planted in the restored areas.

It is concluded that, although the Mexican environmental legislation regulates general aspects, does not focus on particular situations and, as these particular conditions of the impacted areas are found, better strategies can be developed to restore the original vocation of the soils or to allocate them to new vocations of use.

ETHICS STATEMENT

Not applicable.

CONSENTMENT FOR PUBLICATION

Not applicable.

DATA AVAILABILITY

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

CONFLICT OF INTERESTS

The authors declare that they have no competing interests.

FUNDING

Juárez Autonomous University of Tabasco, Autonomous University of Coahuila and the Autonomous University of San Luis Potosí.

AUTHORS' CONTRIBUTION

Conceptualization and methodology: J.C.M.M., N.C.J.P. and C.M.M.B. Software and validation: S.L.M. and I.S.L. Formal analysis, investigation, resources: C.M.M.B., C.E.L.G. and I.S.L. Data curation writing-original: I.M.G.R. and C.E.L.G. Draft preparation, and writing-review and editing: S.A.T.S. and C.M.M.B. Visualization: C.E.L.G. Supervision, project administration and funding acquisition: S.A.T.S., I.M.G.R. and C.M.M.B.

ACKNOWLEDGMENTS

The Mexican Science Council (CONACyT) is thanked for the postgraduate scholarship. Also, to the Juárez Autonomous University of Tabasco, the Autonomous University of Coahuila and the Autonomous University of San Luis Potosí for the use of their scientific infrastructure and support for the financing of this project in collaborative networks of academic groups (CA).

REFERENCES

Adams, R. H., A. L. Álvarez-Ovando, and N. Castañón N. 2016. Effect of hydrocarbon concentration of pasture production (*Brachiaria humidicola*) in Texistepec, Veracruz. Phyton 84: 222-232. doi: https://doi.org/10.32604/phyton.2015.84.222.

Adams, R. H., F. J. Guzmán-Osorio, and V. I. Domínguez-Rodríguez. 2014. Field-scale evaluation of the chemical–biological stabilization process for the remediation of hydrocarbon-contaminated soil. Int. J. Environ. Sci. Technol. 11: 1343-1352. doi: https://doi.org/10.1007/s13762-013-0321-1.

Adams, R. H., K. Kanga-Leyva, F. J. Guzmán-Osorio, and E. Escalante-Espinosa. 2011. Comparison of moisture management methods for the bioremediation of hydrocarbon contaminated soil. Afr. J. Biotechnol. 10: 394-404. doi: https://doi.org/10.4314/AJB.V10I3.

Akande, F., C. Ogunkunle, and S. Ajayi. 2018. Contamination from petroleum products: Impact on soil seed banks around an oil storage facility in Ibadan, South-West Nigeria. Pollution : 515-525. doi: https://doi.org/10.22059/POLL.2018.249913.375.

Acselrad, H., G. das Neves Bezerra y E. Muñoz Gaviria. 2010. Inserción económica internacional y "resolución negociada" de conflictos ambientales en América Latina. EURE (Santiago) 36: 27-47. doi: http://dx.doi.org/10.4067/S0250-71612010000100002.

Allen, C. D., A. K. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, T. Kitzberger, A. Rigling, D. D. Breshears, E.H. (Ted) Hogg, P. Gonzalez, R. Fensham, Z.

Zhang, J. Castro, N. Deminova, J-H. Lim, G. Allard, S. W. Running, A. Semerci, and N. Conn. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. For. Ecol. Manage. 259: 660-684. doi: https://doi.org/10.1016/j.foreco.2009.09.001.

Álvarez-Coronel, G., V. I. Domínguez-Rodríguez, R. H. Adams, D. J. Palma-López, and J. Zavala-Cruz. 2020. The role of soil clays in mitigating or exacerbating impacts to fertility in crude oil-contaminated sites. J. Trop. Agric. Sci. 43: 119-139.

Angel-Meraz, E. del, L. Veleva y M. Acosta-Alejandro. 2009. Agresividad atmosférica basada en el tiempo de humectación del clima tropical húmedo del estado de Tabasco. Univ. Cienc. 25: 111-120.

Angelopoulou, T., N. Tziolas, A. Balafoutis, G. Zalidis, and D. Bochtis. 2019. Remote sensing techniques for soil organic carbon estimation: A review. Remote Sens. 11: 676-694. doi: https://doi.org/10.3390/rs11060676.

Aprile, S., T. Tuttolomondo, M. C. Gennaro, C. Leto, S. La Bella, and M. Licata. 2020. Effects of plant density and cutting-type on rooting and growth of an extensive green roof of *Sedum sediforme* (Jacq.) Pau in a Mediterranean environment. Sci. Hortic. 262: 109091. doi: https://doi.org/10.1016/j.scienta.2019.109091.

Checa-Artasu, M. C. 2014. Geografía, poder y petróleo en México. Algunos ejemplos. Scripta Nova. Rev. Electrón. Geogr. Cienc. Soc. 18: 1-15.

Asia, I. O., S. I. Jegede, D. A. Jegede, O. K. Ize-Iyamu, and A. E. Bernard. 2007. The effects of petroleum exploration and production operations on the heavy metals contents of soil and groundwater in the Niger Delta. Int. J. Phys. Sci. 2: 271-275.

Asprilla-Lara, Y. y D. M. Castro-Valencia. 2016. Los Planes de Manejo Ambiental (PMA): una herramienta de control a los impactos ambientales que generan la instalación de redes servicios públicos domiciliarios en Colombia. Tecnogestión 13: 37-50.

Azamar Alonso, A. y J. I. Ponce Sánchez. 2015. El neoextractivismo como modelo de crecimiento en América Latina. Econ. Desarrollo 154: 185-198

Barba-Macías, E., F. Valadez-Cruz, M. Á. Pinkus-Rendón y M. J. Pinkus-Rendón. 2014. Revisión de la problemática socioambiental de la Reserva de la Biósfera Pantanos de Centla, Tabasco. Invest. Cienc. 22: 50-57.

Barreda, A. 2018. La guerra de devastación ambiental impuesta a México por el TLCAN y la respuesta popular. El Cotidiano 33: 79-92.

Bautista, F., O. Frausto, T. Ihl y Y. Aguilar. 2015. Actualización del mapa de suelos del Estado de Yucatán México: Enfoque geomorfopedológico y WRB. Ecosist. Recur. Agropec. 2: 303-315.

Beesley, L., E. Moreno-Jiménez, and J. L. Gomez-Eyles. 2010. Effects of biochar and green waste compost amendments on mobility, bioavailability and toxicity of inorganic and organic contaminants in a multi-element polluted soil. Environ. Pollut. 158: 2282-2287. doi: https://doi.org/10.1016/j.envpol.2010.02.003.

Burelo Ramos, C. M. and M. A. Guadarrama Olivera. 2015. Notas etnobotánicas de la familia bignoniaceae en el estado de Tabasco, México. Kuxulkab' 14: 41-43. doi: https://doi.org/10.19136/kuxulkab.a14n26.882.

Capdepont-Ballina, J. L. y P. Marín-Olán. 2014. La economía de Tabasco y su impacto en el crecimiento urbano de la ciudad de Villahermosa (1960-2010). LiminaR 12: 144-160.

Carbajal, E. M., M. C. Zuleta, L. Swayzer, B. M. Schwartz, M. C. Chavarro, A. C. Ballen-Taborda, and S. R. Milla-Lewis. 2019. Development of colchicine induced tetraploid St. Augustinegrass (*Stenotaphrum secundatum)* lines. Plant Breed. 138: 958-966. doi: https://doi.org/10.1111/pbr.12742.

Chan-Quijano, J. G., A. Jarquín-Sánchez, S. Ochoa-Gaona, P. Martínez-Zurimendi, L. N. López-Jiménez y A. Lázaro-Vázquez. 2015. Directrices para la remediación de suelos contaminados con hidrocarburos. Teoría y Praxis 17: 123-144. doi: https://doi.org/10.22403/UQROOMX/TYP17/05.

Chávez-García, E. and C. Siebe. 2019. Rehabilitation of a highly saline-sodic soil using a rubble barrier and organic amendments. Soil Tillage Res. 189: 176-188. doi: https://doi.org/10.1016/j.still.2019.01.003.

Chávez León, G., L. M. Tapia Vargas, M. Bravo Espinoza, J. Sáenz Reyes, H. J. Muñoz Flores, I. Vidales Fernández, A. Larios Guzmán, J. Bautista Rentería, F. J. Villaseñor Ramírez, J. L. Sánchez Pérez, J. J. Alcántar Rocillo y M. Mendoza Cantú. 2012. Impacto de cambio de uso de suelo forestal a huertos de aguacate. INIFAP. México, D. F. ISBN: 978-607-425-825-7.

Cordero-Torres, J. M. 2013. Análisis del programa especial concurrente para el desarrollo rural sustentable en México. Desarr. Local Sost. 6: 1-19.

Córdova-Ávalos, V., M. Sánchez-Hernández, N. G. Estrella-Chulím, A. Macías-Layalle, E. Sandoval-Castro, T. Martínez-Saldaña y C. F. Ortiz-García. 2018. Factores que afectan la producción de cacao (*Theobroma cacao* L.) en el ejido Francisco I. Madero del Plan Chontalpa, Tabasco, México. Univ. Cienc. 17: 93-99.

Cortés-Patiño, S. L., N. P. Vesga-Ayala, A. K. Sigarroa-Rieche, L. Moreno-Rozo y D. Cárdenas-Caro. 2015. Sustratos inoculados con microorganismos para el desarrollo de plantas de cacao (*Theobroma cacao* L.) en etapa de vivero. Bioagro 27: 151-158.

Cuevas, A., M. Febrero, and R. Fraiman. 2004. An ANOVA test for functional data. Comput. Stat. Data Anal. 47: 111-122. doi: https://doi.org/10.1016/j.csda.2003.10.021.

Cui, S., Z. Zhang, Q. Fu, R. Hough, K. Yates, M. Osprey, G. Yakowa, and M. Coull. 2020. Long-term spatial and temporal patterns of polycyclic aromatic hydrocarbons (PAHs) in Scottish soils over 20 years (1990–2009): A national picture. Geoderma 361: 114135. doi: https://doi.org/10.1016/j.geoderma.2019.114135.

Damian, J. M., O. H. D. C. Pias, M. R. Cherubin, A. Z. Fonseca, E. Z. Fornari, and A. L. Santi. 2020. Applying the NDVI from satellite images in delimiting management zones for annual crops. Sci. Agric. 77: e20180055. doi: https://doi.org/10.1590/1678-992x-2018-0055.

Daza-Torres, M. C., F. Hernández-Florez y F. Alba-Triana. 2014. Efecto del uso del suelo en la capacidad de almacenamiento hídrico en el páramo de Sumapaz-Colombia. Rev. Fac. Nac. Agron. Medellín 67: 7189-7200. doi: https://doi.org/10.15446/rfnam.v67n1.42642.

De la Barrera, F., S. Reyes-Paecke, and E. Banzhaf. 2016. Indicators for green spaces in contrasting urban settings. Ecol. Indicat. 62: 212-219. doi: https://doi.org/10.1016/j.ecolind.2015.10.027.

Gutiérrez-Castorena, M. C. y J. Zavala. 2002. Rasgos hidromórficos de suelos tropicales contaminados con hidrocarburos. Terra Latinoamericana 20: 101-111.

Díaz-Ramírez, I. J., E. Escalante-Espinosa, E. Favela-Torres, M. Gutiérrez-Rojas, and H. Ramírez-Saad. 2008. Design of bacterial defined mixed cultures for biodegradation of specific crude oil fractions, using population dynamics analysis by DGGE. Int. Biodeter. Biodegr. 62: 21-30. doi: https://doi.org/10.1016/j.ibiod.2007.11.001.

Dissanayake, D. M. S. L. B., T. Morimoto, M. Ranagalage, and Y. Murayama. 2019. Land-use/land-cover changes and their impact on surface urban heat islands: Case study of Kandy City, Sri Lanka. Climate 7: 99-118. doi: https://doi.org/10.3390/cli7080099.

Doerr, S. H., R. A. Shakesby, and R. Walsh. 2000. Soil water repellency: its causes, characteristics and hydro-geomorphological significance. Earth-Sci. Rev. 51: 33-65. doi: https://doi.org/10.1016/S0012-8252(00)00011-8.

Donaldson, G. H. and E. M. João. 2019. Using green infrastructure to add value and assist place-making in public realm developments. Impact Assess. Proj. Appr. 37: 1-15. doi: https://doi.org/10.1080/14615517.2019.1648731.

Domínguez R., I. y N. Aguilera H. 1989. Metodología de análisis físico-químicos de suelos. Facultad de Ciencias, UNAM. México, D. F.

Domínguez-Rodríguez, V. I., R. H. Adams, M. Vargas-Almeida, J. Zavala-Cruz, and E. Romero-Frasca. 2020. Fertility deterioration in a remediated petroleum-contaminated soil. Int. J. Environ. Res. Public Health 17: 382-403. doi: https://doi.org/10.3390/ijerph17020382.

Ellison, J. C. 2015. Vulnerability assessment of mangroves to climate change and sea-level rise impacts. Wetlands Ecol. Manage. 23: 115-137. doi: https://doi.org/10.1007/s11273-014-9397-8.

Fett, A. K. J., L. J. Lemmers-Jansen, and L. Krabbendam. 2019. Psychosis and urbanicity: a review of the recent literature from epidemiology to neurourbanism. Curr. Opin. Psy. 32: 232-241. doi: https://doi.org/10.1097/yco.0000000000000486.

Gama, L., M. A. Ortiz-Pérez, E. Moguel-Ordoñez, R. Collado-Torres, H. Díaz-López, C. Villanueva-García, and M. E. Macías-Valadez. 2011. Flood risk assessment in Tabasco, Mexico. WIT Trans. Ecol. Environ. 145: 631-639. doi: https://doi.org/10.2495/WRM110561.

Gómez-Mellado, A. Y., C. M. Morales-Bautista, I. M. De la Garza-Rodríguez, S. A. Torres-Sánchez, S. A., and I. Sánchez-Lombardo. 2020. Evaluation of two remediation techniques applied to a site impacted by petroleum production waters. Terra Latinoamericana 38: 77-89. doi: https://doi.org/10.28940/terra.v38i1.564.

Guzmán Luna, A., B. G. Ferguson, O. Giraldo, B. Schmook, and E. M. Aldasoro Maya. 2019. Agroecology and restoration ecology: fertile ground for Mexican peasant territoriality? Agroecol. Sust. Food Syst. 43: 1174-1200. doi: https://doi.org/10.1080/21683565.2019.1624284.

Hassan, D. F., A. A. Jafaar, and R. J. Mohamm. 2019. Effect of irrigation water salinity and tillage systems on some physical soil properties. Iraqi J. Agric. Sci. 50: 42-47.

Hatch Kuri, G. 2018. Fracking en el acuífero transfronterizo Edwards-Trinity-El Burro: implicaciones y daños ambientales transfronterizos. Invest. Geogr. 96: 1-20. doi: http://dx.doi.org/10.14350/rig.59570.

He, Z., J. Shentu, X. Yang, V. C. Baligar, T. Zhang, and P. J. Stoffella. 2015. Heavy metal contamination of soils: sources, indicators and assessment. J. Environ. Indicat. 9: 17-18.

Hernández-García, M. A., C. M. Morales-Bautista, C. Méndez-Olán y R. Adams-Schoreder. 2016. Extracción de hidrocarburo pesado en suelo Acrisol. J. Basic Sci. 2: 18-23. doi: https://doi.org/10.19136/jobs.a2n5.1478.

Hernández Melchor, G. I., A. S. Sánchez, O. Ruíz Rosado, J. I. Valdez Hernández, J. C. López Collado y J. L. Reta Mendiola. 2016. Diagnóstico del proceso de reforestación en manglares de la costa de Tabasco. Rev. Mex. Cienc. Agríc. 14: 2883-2894.

Higuera Zimbrón, A. y M. Á. Rubio Toledo. 2011. La vivienda de interés social: sostenibilidad, reglamentos internacionales y su relación en México. Quivera 13: 193-208.

Inckot, R. C., G. de Oliveira Santos, L. A. De Souza, and C. Bona. 2011. Germination and development of *Mimosa pilulifera* in petroleum-contaminated soil and bioremediated soil. Flora-Morphol. Distribut. Funct. Ecol. Plants 206: 261-266. doi: https://doi.org/10.1016/j.flora.2010.09.005.

Jara-Peña, E., J. Gómez, H. Montoya, M. Chanco, M. Mariano y N. Cano. 2014. Capacidad fitorremediadora de cinco especies altoandinas de suelos contaminados con metales pesados. Rev. Peruana Biol. 21: 145-154. doi: https://doi.org/10.15381/rpb.v21i2.9817.

Jones, B. E. H., R. J. Haynes, and I. R. Phillips. 2010. Effect of amendment of bauxite processing sand with organic materials on its chemical, physical and microbial properties. J. Environ. Manage. 91: 2281-2288. doi: https://doi.org/10.1016/j.jenvman.2010.06.013.

Khalladi, R., O. Benhabiles, F. Bentahar, and N. Moulai-Mostefa. 2009. Surfactant remediation of diesel fuel polluted soil. J. Hazardous Mat. 164: 1179-1184. doi: https://doi.org/10.1016/j.jhazmat.2008.09.024.

Kharrat, A. M., J. Zacharia, V. J. Cherian, and A. Anyatonwu. 2007. Issues with comparing SARA methodologies. Ener. Fuels 21: 3618-3621. https://doi.org/10.1021/ef700393a.

Kiani, M., G. Hernandez-Ramirez, and S. A. Quideau. 2020. Spatial variation of soil quality indicators as a function of land use and topography. Can. J. Soil Sci. 100: 1-16. doi: https://doi.org/10.1139/cjss-2019-0163.

Kjellstrom, T., A. J. Butler, R. M. Lucas, and R. Bonita. 2010. Public health impact of global heating due to climate change: potential effects on chronic non-communicable diseases. Int. J. Publ. Health 55: 97-103. doi: https://doi.org/10.1007/s00038-009-0090-2.

Kolb, M. and L. Galicia. 2018. Scenarios and story lines: drivers of land use change in southern Mexico. Environ. Dev. Sust. 20: 681-702.

Kuppusamy, S., N. R. Maddela, M. Megharaj, and K. Venkateswarlu. 2020. Regulatory guidelines for total Petroleum Hydrocarbon contamination. pp. 207-224. *In*: Total petroleum hydrocarbons. Springer Nature. Berlin. doi: https://doi.org/10.1007/978-3-030-24035-6_8.

Li, G., S. Guo, and J. Hu. 2016. The influence of clay minerals and surfactants on hydrocarbon removal during the washing of petroleum-contaminated soil. Chem. Engin. J. 286: 191-197. doi: https://doi.org/10.1016/j.cej.2015.10.006.

López-Atamoros, L. G., G. Fernández-Villagómez y M. J. Cruz-Gómez. 2010. Integración de una Base Nacional de Datos de Accidentes durante el Transporte de Gas LP (BNDAT@GLP) 1998-2009: Sustento para un estudio de evaluación de riesgo. Tecnol. Cienc. Educ. (IMIQ) 25: 99-112.

López-Hernández, E. S. y A. R. Rodríguez-Luna. 2014. Intervenciones en educación ambiental con niños y niñas: Los pijijes. Comalcalco, Tabasco. Horiz. Sanit. 7: 29-45. doi: https://doi.org/10.19136/hs.a7n1.210.

Macías, V. B., J. S. Ramírez, Y. M. Delgado, M. Córdoba, M., and A. O. Rubio. 2018. 84 years of Mexico's land use planning: reflections for biodiversity conservation. Nova Sci. 10: 592-629. doi: https://doi.org/10.21640/ns.v10i20.1177.

Madera-Parra, C. A., E. J. Peña-Salamanca, and J. A. Solarte-Soto. 2014. Efecto de la concentración de metales pesados en la respuesta fisiológica y capacidad de acumulación de metales de tres especies vegetales tropicales empleadas en la fitorremediación de lixiviados provenientes de rellenos sanitarios. Ing. Competit. 16: 179-188. doi: https://doi.org/10.25100/iyc.v16i2.3693.

Madrigal-Díaz, S. C., C. M. Morales-Bautista y I. M. de la Garza-Rodríguez. 2019. Evaluación de los cambios físicos y químicos de dos suelos contaminados con agua congénita en el estado de Tabasco. J. Ener. Engin. Opt. Sust. 3: 37-46. doi: https://doi.org/10.19136/jeeos.a3n1.3280.

Maiolo, M., B. Pirouz, R. Bruno, S. A. Palermo, N. Arcuri, and P. Piro. 2020. The role of the extensive green roofs on decreasing building energy consumption in the Mediterranean climate. Sustainability 12: 359-371. doi: https://doi.org/10.3390/su12010359.

Mao, X., R. Jiang, W. Xiao, and J. Yu. 2015. Use of surfactants for the remediation of contaminated soils: a review. J. Hazardous Mat. 285: 419-435. doi: https://doi.org/10.1016/j.jhazmat.2014.12.009.

Marín-García, D. C., R. H. Adams, and R. Hernández-Barajas. 2016. Effect of crude petroleum on water repellency in a clayey alluvial soil. Int. J. Environ. Sci. Technol. 13: 55-64. doi: https://doi.org/10.1007/s13762-015-0838-6.

Marrero-Coto, J., I. Amores-Sánchez y O. Coto-Pérez. 2012. Fitorremediación, una tecnología que involucra a plantas y microorganismos en el saneamiento ambiental. Rev. ICIDCA 46: 52-61.

Martínez-Zurimendi, P., M. Domínguez-Domínguez, A. Juárez-García, L. M. López-López, V. de-la-Cruz-Arias y J. Álvarez-Martínez. 2015. Índice de sitio y producción maderable en plantaciones forestales de *Gmelina arborea* en Tabasco, México. Rev. Fitotec. Mex. 38: 415-425.

Mejía-Restrepo, E., L. Osorno-Bedoya y N. W. Osorio-Vega. 2015. Residuos de la construcción: una opción para la recuperación de suelos. Rev. EIA Esc. Ing. Antioq. 1: 55-60. doi: https://doi.org/10.24050/reia.v1i1.706.

Mogollón-Sandoval, J. P., A. E. Martínez y D. G. Torres. 2015. Efecto de la aplicación de un vermicompost en las propiedades químicas de un suelo salino-sódico del semiárido venezolano. Acta Agron. 64: 315-320. doi: https://doi.org/10.15446/acag.v64n4.47115.

Morales-Bautista, C. M., V. Domínguez-Rodríguez y R. H. Adams. 2011. Estudio cinético del intercambio catiónico con Ca(OH)2 y evaluación de la fertilidad en un suelo arcilloso contaminado con aguas congénitas. Bioagro 23: 129-134.

Morales-Bautista, C. M., C. E. Lobato-García y J. Flores-Jiménez. 2014. Efectos en las características físicas de un suelo contaminado con diésel y tratado con lavado. pp. 223-227. *In*: M. Bernal-González, M. C. Durán-Domínguez-de-Bazúa, R. S. García-Gómez y L. Ramírez-Burgos (eds.). Libro electrónico de trabajos selectos: Memorias del Minisimposium internacional sobre remoción de contaminantes de aguas, atmósfera y suelos RACAM (Red para el Análisis de la Calidad Ambiental en México). México, D. F.

Morales-Bautista, C. M., C. E. Lobato-García, C. Méndez-Olán y M. J. Alor-Chávez. 2016. Evaluación del tratamiento del intercambio catiónico en dos suelos aluviales contaminados con aguas congénitas. Interciencia 41: 696-702.

Morales-Bautista, C. M., C. E. Lobato-García y M. J. Alor-Chávez. 2017. Evaluación de impactos causado por cambios en la vocación de uso de suelo: estudios preliminares en un programa de reforestación. Kuxulkab' 23: 11-20. doi: https://doi.org/10.19136/kuxulkab.a23n45.2070.

Morales-Bautista, C. M., C. Méndez-Olán, S. López-Martínez, and M. Ojeda-Morales. 2020. Design of experiments to optimize soxhlet-HTP method to establish environmental diagnostics of polluted soil: Optimization of the soxhlet-HTP method by DOE. pp. 33-52. *In*: E. G. Carrillo-Cedillo, J. A. Rodríguez-Avila, K. C. Arredondo-Soto and J. M. Cornejo-Bravo (eds.). Design of experiments for chemical, pharmaceutical, food, and industrial applications. IGI Global. México. doi: https://doi.org/10.4018/978-1-7998-1518-1.ch002.

Ocampo, O. 2011. El cambio climático y su impacto en el agro. Rev. Ingeniería 33: 115-123.

Oldoni, H., V. S. Silva Terra, L. C. Timm, C. R. Júnior, and A. B. Monteiro. 2019. Delineation of management zones in a peach orchard using multivariate and geostatistical analyses. Soil Tillage Res. 191: 1-10.

Olmos Martínez E., M. E. González Ávila y M. R. Contreras Loera. 2013. Percepción de la población frente al cambio climático en áreas naturales protegidas de Baja California Sur, México. Polis 35: 459-481. doi: https://doi.org/10.4067/S0718-65682013000200020.

Pacheco Bustos, C. A., L. G. Fuentes Pumarejo, E. H. Sánchez Cotte y H. Rondón Quintana. 2017. Residuos de construcción y demolición (RCD), una perspectiva de aprovechamiento para la ciudad de Barranquilla desde su modelo de gestión. Rev. Cient. Ing. Desarr. 35: 533-555.

Palma-López, D. J., R. Jiménez-Ramírez, J. Zavala-Cruz, F. Bautista-Zúñiga, F. Gavi-Reyes y D. Y. Palma-Cancino. 2017. Actualización de la clasificación de suelos de Tabasco, México. Agro Productividad 10: 29-35.

Pannecoucke, L., M. Le Coz, X. Freulon, and C. de Fouquet. 2020. Combining geostatistics and simulations of flow and transport to characterize contamination within the unsaturated zone. Sci. Total Environ. 699: 134216. doi: https://doi.org/10.1016/j.scitotenv.2019.134216.

Peng, S., W. Wu, and J. Chen. 2011. Removal of PAHs with surfactant-enhanced soil washing: influencing factors and removal effectiveness. Chemosphere 82: 1173-1177. doi: https://doi.org/10.1016/j.chemosphere.2010.11.076.

Perevochtchikova, M. and J. L. Lezama de la Torre. 2010. Causas de un desastre: Inundaciones del 2007 en Tabasco, México. J. Latin Am. Geogr. 9: 73-98.

Pérez-Hernández, I., S. Ochoa-Gaona, R. Adams-Schroeder, M. C. Rivera-Cruz, and V. Geissen. 2013. Tolerance of four tropical tree species to heavy petroleum contamination. Water Air Soil Pollut. 224: 1637-1649. doi: https://doi.org/10.1007/s11270-013-1637-7.

Pérez-Medina, S. e I. López-Falfán. 2015. Áreas verdes y arbolado en Mérida, Yucatán. Hacia una sostenibilidad urbana. Econ. Soc. Territ. 15: 01-33.

Pérez-Vidal, H., M. A. Lunagómez-Rocha y L. Acosta-Pérez. 2010. Análisis de partículas suspendidas totales (PST) y partículas fracción respirable (PM10), en Cunduacán, Tabasco. Univ. Cienc. 26: 151-162.

Pons-Jiménez, M., A. Guerrero-Peña, J. Zavala-Cruz y A. Alarcón. 2011. Extracción de hidrocarburos y compuestos derivados del petróleo en suelos con características físicas y químicas diferentes. Univ. Cienc. 27: 1-15

Pouyat, R. V., K. Szlavecz, I. D. Yesilonis, P. M. Groffman, and K. Schwarz. 2010. Chemical, physical, and biological characteristics of urban soils. pp. 119-152. *In:* J. Aitkenhead-Peterson and A. Volder (eds.). Urban ecosystem ecology. Urban agronomy monographs 55. American Society of Agronomy. Madison, WI, USA.

Prieto-Méndez, J., F. Prieto-García, O. A. Acevedo-Sandoval y M. A. Méndez-Marzo. 2013. Indicadores e índices de calidad de los suelos (ICS) cebaderos del sur del estado de Hidalgo, México. Agron. Mesoam. 24: 83-91.

Rahman, M. A. and H. Hasegawa. 2011. Aquatic arsenic: Phytoremediation using floating macrophytes. Chemosphere 83: 633-646. doi: https://doi.org/10.1016/j.chemosphere.2011.02.045.

Ramos Agüero, D., E. Terry Alfonso, F. Soto Carreño, A. Cabrera Rodríguez, G. M. Martín Alonso y L. Fernández Chuaerey. 2016. Respuesta del cultivo del plátano a diferentes proporciones de suelo y Bocashi, complementadas con fertilizante mineral en etapa de vivero. Cult. Trop. 37: 165-174.

Reyes, Y., I. Vergara, O. Torres, M. Díaz-Lagos y E. E. González-Jiménez. 2016. Contaminación por metales pesados: Implicaciones en salud, ambiente y seguridad alimentaria. Ing. Invest. Desarr. 16: 66-77. doi: https://doi.org/10.19053/1900771X.v16.n2.2016.5447.

Rodríguez-Jiménez, C., N. Méndez de los Santos, M. Wade-Alejo y J. R. Laines-Canepa. 2014. Casas VIETAB: construcción verde y azul. Kuxulkab' 18: 71-77. doi: https://doi.org/10.19136/kuxulkab.a18n35.262.

Rosete Vergés, F. A., G. Enríquez Hernández y E. Aguirre von Wobeser. 2013. El componente del riesgo en el ordenamiento ecológico del territorio: el caso del ordenamiento ecológico regional y marino del Golfo de México y Mar Caribe. Invest. Geogr. 80: 07-20. doi: https://doi.org/10.14350/rig.36393.

Rucks, L., F. García, A. Kaplán, J. Ponce de León J y M. Hill. 2004. Propiedades físicas del suelo. Universidad de la República, Facultad de Agronomía. Montevideo, Uruguay.

Ruiz-Luna, A., R. Bautista Bautista, R. Hernández-Guzmán, and V. Camacho-Valdez. 2019. Uneven distribution of urban green spaces in a coastal city in northwest Mexico. Local Environ. 24: 458-472. doi: https://doi.org/10.1080/13549839.2019.1590324.

Salgado-García, S., D. J. Palma-López. J. Zavala-Cruz, S. Córdova-Sánchez, M. Castelán-Estrada, L. C. Lagunes-Espinoza, C. F. Ortiz-García, M. C. Rivera-Cruz, F. Ventura-Ulloa, A. Marín-Aguilar, E. Moreno-Cáliz y J. A. Rincón-Ramírez. 2016. Programa de fertilización sustentable para plantaciones de cítricos en Tabasco, México. Ecosist. Recur. Agropec. 3: 345-356.

Sánchez-Hernández, R., R. Ramos-Reyes, V. Geissen, J. D. Mendoza-Palacios, E. de la Cruz-Lázaro, E. Salcedo-Pérez y D. J. Palma-López. 2011. Contenido de carbono en suelos con diferentes usos agropecuarios en el trópico mexicano. Terra Latinoamericana 29: 211-219.

Sastry, K. S., B. Mandal, J. Hammond, S. W. Scott, and R. W. Briddon. 2019. *Stenotaphrum secundatum* (St. Augustine grass). pp. 2504-2505. *In:* K. S. Sastry, B. Mandal, J. Hammond, S. W. Scott, R. W. Briddon (eds.). Encyclopedia of plant viruses and viroids. Springer Nature. New Delhi. doi: https://doi.org/10.1007/978-81-322-3912-3_908. Print ISBN: 978-81-322-3911-6.

Schindelbeck, R. R., H. M. van Es, G. S. Abawi, D. W. Wolfe, T. L. Whitlow, B. K. Gugino, O. J. Idowu, and B. N. Moebius-Clune. 2008. Comprehensive assessment of soil quality for landscape and urban management. Landsc. Urban Plann. 88: 73-80. https://doi.org/10.1016/j.landurbplan.2008.08.006.

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. SEMARNAT. México, D. F.

SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales). 2007. Norma Oficial Mexicana NOM-147-SEMARNAT/SSA1-2004. Que establece criterios para determinar las concentraciones de remediación de suelos contaminados por arsénico, bario, berilio, cadmio, cromo hexavalente, mercurio, níquel, plata, plomo, selenio, talio y/o vanadio. Diario Oficial de la Federación. México. SEMARNAT. México, D. F.

SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales). 2013. Norma Oficial Mexicana NOM-138-SEMARNAT/SSA1-2012 que establece los límites máximos permisibles de hidrocarburos en suelos y lineamientos para el muestreo en la caracterización y especificaciones para la remediación. Diario Oficial de la Federación. México, D. F.

Shahsavari, E., A. Schwarz, A. Aburto-Medina, and A. S. Ball. 2019. Biological degradation of polycyclic aromatic compounds (PAHs) in soil: A current perspective. Curr. Pollut. Rep. 5: 84-92. doi: https://doi.org/10.1007/s40726-019-00113-8.

Siebe, C., S. Cram, A. Herré and N. Fernández-Buces. 2005. Distribución de metales pesados en los suelos de la llanura aluvial baja del Activo Cinco Presidentes, Tabasco. pp. 431-450. *In*: A. V. Botello, J. Rendón-von Osten, G. Gold-Bouchot, and C. Agraz-Hernández (eds.). Golfo de México: contaminación e impacto ambiental: diagnóstico y tendencias. UNACAR-UNAM. México, D. F. ISBN: 968-5722-37-4.

Stoleru, V., C. Slabu, M. Vitanescu, C. Peres, A. Cojocaru, M. Covasa, and G. Mihalache. 2019. Tolerance of three Quinoa cultivars (*Chenopodium quinoa* Willd.) to salinity and alkalinity stress during germination stage. Agronomy 9: 287-300. doi: https://doi.org/10.3390/agronomy9060287.

Taboada-Castro, M. M., M. L. Rodríguez-Blanco, M. T. Taboada-Castro y J. L. Oropeza-Mota. 2011. Vulnerabilidad estructural en suelos de textura gruesa bajo cultivo y huerta. Terra Latinoamericana 29: 11-21.

Terkenli, T. S., S. Bell, O. Tošković, J. Dubljević-Tomićević, T. Panagopoulos, I. Straupe, K. Kristianova, L. Straigyte, L. O'Brieni, and I. Živojinović. 2020. Tourist perceptions and uses of urban green infrastructure: An exploratory cross-cultural investigation. Urban For. Urban Green. 49: 126624. doi: https://doi.org/10.1016/j.ufug.2020.126624.

Trujillo-Kanga, M. Y. 2015. La reforma energética de 2013 y sus implicaciones en la cultura laboral de Petróleos Mexicanos. Ecos Soc. 3: 30-36.

Trujillo-Narcía, A., M. C. Rivera-Cruz, L. C. Lagunes-Espinoza, D. J. Palma-López, S. Soto-Sánchez y G. Ramírez-Valverde. 2012. Efecto de la restauración de un fluvisol contaminado con petróleo crudo. Rev. Int. Contam. Ambient. 28: 360-374.

Ukiwe, L., U. Egereonu, P. Njoku, C. Nwoko, and J. Allinor. 2013. Polycyclic aromatic hydrocarbons degradation techniques: A review. Int. J. Chem. 5: 43-55. doi: http://dx.doi.org/10.5539/ijc.v5n4p43.

Ulczycka-Walorska, M., A. Krzymińska, H. Bandurska, and J. Bocianowski. 2020. Response of *Hyacinthus orientalis* L. to salinity caused by increased concentrations of sodium chloride in the soil. Not. Bot. Horti Agrobot. Cluj-Napoca 48: 398-405. doi: https://doi.org/10.15835/nbha48111748.

Vargas-Garzón, B. y L. F. Molina-Prieto. 2010. Cinco árboles urbanos que causan daños severos en las ciudades. Rev. Nodo 5: 115-126.

Vargas, R. 2015. La reforma energética: a 20 años del TLCAN. Probl. Desarr. 46: 103-128.

Vrščaj, B., L. Poggio, and F. A. Marsan. 2008. A method for soil environmental quality evaluation for management and planning in urban areas. Landsc. Urban Plann. 88: 81-94. doi: https://doi.org/10.1016/j.landurbplan.2008.08.005.

Zanetti, F., W. Zegada-Lizarazu, C. Lambertini, and A. Monti. 2019. Salinity effects on germination, seedlings and full-grown plants of upland and lowland switchgrass cultivars. Biom. Bioener. 120: 273-280. doi: https://doi.org/10.1016/j.biombioe.2018.11.031.

Zavala-Cruz, J., F. Gavi-Reyes, R. H. Adams-Schroeder, R. Ferrera-Cerrato, D. J. Palma-López H. Vaquera-Huerta y J. M. Domínguez-Esquivel. 2005. Derrames de petróleo en suelos y adaptación de pastos tropicales en el activo Cinco Presidentes, Tabasco, México. Terra Latinoamericana 23: 293-302.

Zavala-Cruz, J., S. Salgado García, A. Marín Aguilar, D. J. Palma López, M. Castelán Estrada y R. Ramos Reyes. 2014. Transecto de suelos en terrazas con plantaciones de cítricos en Tabasco. Ecosist. Recur. Agropec. 1: 123-137.

Zavala-Cruz, J., M. A. Morales-Garduza, L. M. Vargas-Villamil, D. J. Palma-López y C. A. Ortiz-Solorio. 2016. Capacidad de uso del suelo urbano en planicies fluviales costeras: el caso de Villahermosa, Tabasco, México. Interciencia 41: 296-304.