Evaluation of Suitable Lands for *Elaeis guineensis* Jacq. Using Geographic Information Systems in the Sierra Region, Tabasco, Mexico

Brindis-Santos, Alfredo I.[1]; Pérez-Roblero, Albina S.[1]; Palma-López, David J.[2*];
Zavala-Cruz, Joel[2]; Sánchez-Hernández, Rufo[3]; Palma-Cancino David J.[4]

[1] Universidad Autónoma de Chiapas, Facultad de Ciencias Agrícolas, Campus IV, Huehuetán, Chiapas, México, C.P. 30660.
[2] Colegio de Postgraduados, Campus Tabasco, Cárdenas, Tabasco, México, C.P. 86500.
[3] Unversidad Juárez Autónoma de Tabasco, División Académica de Ciencias Agropecuarias, La Huasteca, Centro, Tabasco, México, C.P. 86280.
[4] Universidad Popular de la Chontalpa, Cárdenas, Tabasco, Mexico, C.P. 86556.

* Correspondence: dapalma@colpos.mx

ABSTRACT

Objective: The objective of this study was to evaluate the edaphic suitability of *Elaeis guineensis* at a semi-detailed scale (1:50000), in the Plains and Terraces of Tabasco, Mexico (PTT).

Design/Methodology/Approach: The edaphic requirements consisted of a semi-detailed soil map. The evaluation of the edaphic suitability was based on the agroecological zoning methodology proposed by FAO and the final 1:50000 scale map was developed using the algebra mapping tool with the ArcGis® Geographic Information System.

Results: The Gleysols, Fluvisols, Luvisols, and Lixisols groups dominate the PTT, with 65.1, 16.2, 6.3, and 4%, respectively. Most of the soils (79.95%) have zero suitability for oil palm.

Study Limitations/Implications: Oil palm is the eighth most important perennial crop (over cocoa) for the economy of southeastern Mexico. In this scenario, the expansion of plantations in the country is a possibility; therefore, complying with internal regulations and carry is important.

Findings/Conclusions: The internal drainage of Gleysols soils limits the establishment of *E. guineensis* plantations in the plains and terraces of Tabasco, Mexico.

Keywords: Oil palm, Precision Agriculture, Gleysols, Lixisols, Luvisols.

INTRODUCTION

Palm oil is being increasingly used on a large scale, driven by the economic development of countries such as India and China (Murphy, 2014). Palm oil is an enormous world industry with an annual value that exceeds US$50 billion (Paterson and Lima, 2017). Most of the crude palm oil is used to produce food and biodiesel, while palm kernel oil is used

to manufacture detergents, make-up, plastics, and chemical products (Rival, 2017). The large-scale oil palm (*E. guineensis* Jacq.) cultivation has transformed the tropical regions, the lives of people, and the profits of the palm industry. Its high yield, easy establishment, and low costs make this a very profitable crop (Dislich *et al.*, 2017). For example, oil palm is the eight most important perennial crop in southeastern Mexico, surpassing cacao (SIAP, 2021). However, during the last ten years, the fresh fruit bunches (RFF) yield has not increased in Mexico: it remained at 13 t ha^{-1} from 2009 to 2019 (SIAP, 2021). On the contrary, the main producing countries in southeastern Asia report 17 t ha^{-1} RFF yields (FAO, 2021). In response to the growing domestic demands and to the high cost of palm oil imports —for example, in 2019, Mexico imported 478,900 t of palm oil at a cost of US $ 265 million (SIAVI, 2021)—, some South American governments are encouraging national and foreign investors to plant more oil palms (FEMEXPALMA, 2020). Therefore, in view of the potential expansion of these plantations in the country, complying with the domestic regulations and carrying out a sustainable crop management is important to increase local production and to reduce oil imports (Brindis-Santos *et al.*, 2020b).

Evaluating suitable lands availability is necessary to establish crops and to obtain an optimal yield; this information is essential for the development of government policies and for investors (Rhebergen *et al.*, 2016). In this regard, Mexico has made efforts to evaluate land suitability for several crops that have an economic importance for the agricultural sector (Aguilar *et al.*, 2013; González and Hernández, 2016; Ramírez-Sánchez *et al.*, 2019). Specific studies about the establishment of forest species (Aguilar-Rodríguez *et al.*, 2017) and perennial crops (Rivera-Hernández *et al.*, 2012), as well as about alternatives for the production of biofuels (González *et al.*, 2015), have been carried out in Tabasco. Aceves-Navarro *et al.* (2008) zoned areas with high production potential for the cultivation of *E. guineensis*; however, their analysis was carried out more than ten years ago and the evaluation scale (1:250000) was made at reconnaissance level. Consequently, the objective of this research was to carry out a semi-detailed scale (1:50000) evaluation of the edaphic suitability of *Elaeis guineensis* Jacq., in the plains and terraces of Tabasco (PTT), in order to determine potential areas for this crop.

MATERIAL AND METHODS

Study Area. The PTT are located at 17° 31' 57" and 17° 47' 44" N and 92° 42' 55" and 92° 54' 22" W, in a geographical area of 138,143 ha, located in the Llanura Costera del Golfo Sur geomorphological province, in the municipalities of Jalapa and Tacotalpa, in southeastern Tabasco, Mexico (INEGI, 2016). The study zone has three geomorphological landscapes: active alluvial plains (PFA), detrital coastal terraces (TCD), and soft sloping volcanic hills (LSIV). The prevailing landscape is PFA; it covers 82% of the total area; it is a flat area located in the lowest topographic position, over fluvial sediments and marshes from the Quaternary period (Holocene). The remaining 18% of the region consists of terraces and low hills landscapes, over detrital sedimentary rocks and andesite rifts from the Tertiary (Paleocene) and Quaternary (Pleistocene) periods, at an altitude of 7-70 m (Zavala-Cruz *et al.*, 2016). The climates are humid-warm —with abundant rainfall in summer (Am (f))— and humid-warm —with rainfall all year round

(Af(m)). The average temperature is 25 °C and the annual average precipitation is 2,500-4,000 mm (García, 2004).

Elaeis guineensis Suitability Requirements (Climate, Topography, and Soil). Seven edaphic properties of soil were analyzed to determine land suitability: pH, depth, texture, cation exchange capacity (CIC), electric conductivity (CE), base saturation percentage (PSB), and drainage. There are four significant climate and relief variables: temperature, precipitation, height above sea level, and slope. The requirements of the values used to define suitability ranges were based on Ecocrop (2014) and Corley and Tinker (2016); the types of drainage were based on Cuanalo (1990) and Parmananthan (2003). The pH, CIC, CE, and PSB ranges were based on NOM-021-RECNAT (2000) and IUSS Working Group WRB (2015). The lower limits were defined taking into account the information provided by Corley and Tinker (2016), who pointed out that 80% of the E. guineensis roots can be found at a depth of 0-50 cm.

Edaphic, Climatic, and Relief Data. The soil units' map (1:50000 scale) and the physical and chemical data were obtained from Brindis-Santos *et al.* (2020a). The precipitation and temperature data were obtained from the cartography of INEGI (2021) (1:250,000 scale); the format was changed from vectors to raster. The relief and slope map was generated based on a LIDAR model, using the ArcGis® 9.2 software (ESRI, 2004).

Zonification of the Elaeis guineensis Edaphic Suitability

The *E. guineensis* edaphic suitability was evaluated based on FAO's Agro-Ecological Zoning guidelines (1997). The suitability types were grouped in the following categories: 1) high suitability (*i.e.*, the values of the variables found in the optimal range); 2) medium suitability (which gathers the values of the variables found in the absolute suitability range); and 3) zero suitability (which is defined by the variables whose values are lower than those reported as absolute minimum by Aguilar-Rodríguez *et al.* (2017)). Using the map algebra tool —which executes all the spatial analysis operators and functions, adding two or more maps to obtain a polygon mix of the original maps' variables (Rivera-Hernández *et al.*, 2012)—, an edaphic suitability map of *E. guineensis* was generated (1:50000 scale).

RESULTS AND DISCUSSION

Table 1 shows the variables required to determine the suitability of E. guineensis: soil, climate, and relief.

Physical and Chemical Characteristic of the Soils in the Sierra Region of Tabasco

Soils from the Gleysols (GL), Fluvisols (FL), Luvisols (LV), and Lixisols (LX) groups prevail in 65.1, 16.2, 6.3, and 4%, respectively, of the Plains and Terraces of Tabasco (PTT) —which were the subject of this study. GL were formed in zones with reducing conditions; FL, in natural levees and meander banks; and LV and LX, in low hills and terraces. The following representative soil units were found: GL- st.eu- lo.oh (50%), GL-hi.oy.eu- cen. lop.hu (12.7%), FL- fve.gl.eu- hu.lo (12.5%), LV-gl- ct.hu-je.lo.qv (3.6%), and LX-ab.cr-ct. df.cen.lop.je.pn (3.8%) (Figure 1).

Table 1. *Elaeis guineensis* Jacq. edaphic requirements in Tabasco, Mexico (Ac=clay; An=sand; F=loam; L=silt).

Factor	Variable	Aptitude		
		High	**Average**	**None**
Weather	Type: Tropical	X	X	
	Mean Temperature (°C)	20-35[1]	12-20 y 35-38 1	<12 y >38[1]
	Precipitation (mm)	1500-3000[1]	1000-1500 y 3000-8000 1,2	<1000 y >8000 1
Soil characteristics	pH	4.5-7.5 1,3	3.2-4.5 y 7.5-8 1,3,4	<3.2 y >8 1,3,4
	Depth (m)	>1.5[1]	0.5-1.5[1]	<0.5[1]
	Texture *	L, LC, LSt, LCSt 1,2,3	LCSd, SdL, SdL, CSd[2]	Sd, C, St, gravel 1,2,3
	Cation-exchange capacity (Cmol (+) (kg^{-1})	>24	14-24[7]	<14
	Salinity by electric conductivity (dS/m^{-1})	<4[1]	<4[1]	>4[12]
	Exchangeable bases, %	>50	20-50	<20
	Drainage	Good to average 1,2	Good to excesive, poor, slow, easy to drain 1,2,4	Poor, hard to drain[4]
Topographical relief	Altitude (meters above sea level)	0-500[5]	500-1300[1]	>1300
	Slope	<12 2,4	12-23 2,4	>23[4]

GL and FL have slow permeability (in horizon A) and very slow permeability (in underlying horizons C); they have loamy and loamy clayey textures (FL) and clayey texture (GL). Their pH ranges from moderately acid to neutral. A and C horizons have contrasting organic matter (OM) contents (rich to very poor); nutrients range from high to low (both with assimilated P and CIC), with over 50% with PSB. These highly-fertile soils are suitable for intensive agriculture; however, water excess causes anaerobiosis and oxide-reduction processes in these soils (Palma-López *et al.*, 2017; Brindis-Santos *et al.*, 2020a) (Figure 1). LV and LX share the following characteristics: loamy clay, silty clay, and clayey texture; Bt horizon formed through the accumulation of clay; good to imperfect drainage; rich to poor organic matter content; high to low nutrients with P; cation exchange capacity (CIC); base saturation percentage (PSB); and moderately to strongly acid pH. These conditions limit agricultural capacity (Zavala-Cruz *et al.*, 2016).

Climatic and Relief Characteristics of Tabasco's Sierra Region. Am(f) climate prevails in the center, north, and northeast; while Af(m) prevails in the South and Southeast of the PTT; the average temperature is 25 °C. Fifty-seven percent of the area is suitable for *E. guineensis*, as a result of the average (2000-3000 mm) and moderate (43%; 3000-4000 mm) annual precipitation in southern Tacotalpa. These findings match those reported by Paramananthan (2003), who argues that *E. guineensis* grows better with a 2000-2500 mm year^{-1} precipitation, evenly distributed throughout the year (no month with <100 mm of rain). Relief and slope intervals have the following characteristics: a) flat to gentle, 0-12% (97% of the PTT); b) moderate to steep, 12-24% (2.5% of the PTT), to the South and Northeast; and c) very steep, >25% (0.07% of the PTT), to the Southwest. Altitude ranges from 7 to 70 masl (Figure 2).
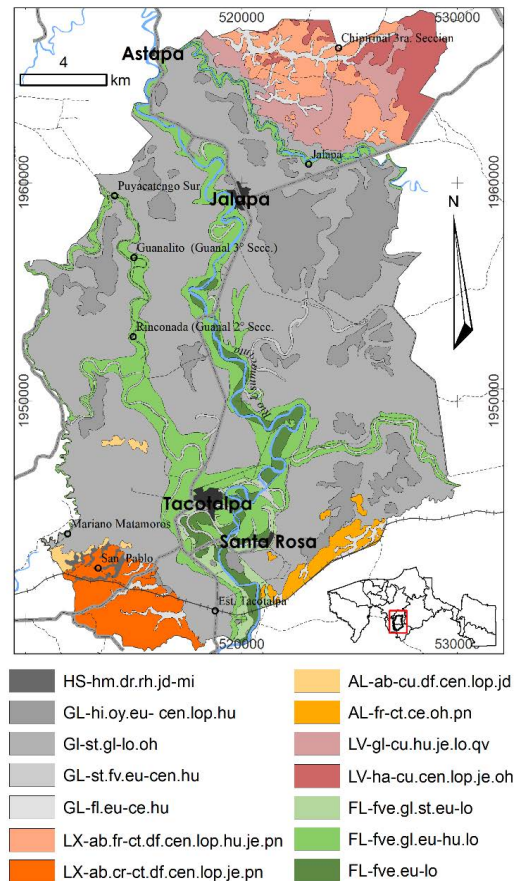
Figure 1. Soil survey in La Sierra, Tabasco, Mexico (Brindis-Santos *et al.*, 2020a). meaning of abbreviations: GL-st.fl.eu-ce.hu/ Eutric Fluvic Stagnic Gleysol (Clayic, Humic), FL.fve.gl.st.eu-lo/ Eutric Stagnic Gleyic Pantofluvic Fluvisol (Loamic), FL-fve.gl.eu-hu.lo/ Eutric Gleyic Pantofluvic Fluvisol (Humic, Loamic), FL-fve.eu-lo/ Eutric Pantofluvic Fluvisol (Loamic), GL-st.eu-lo.oh/Eutric Stagnic Gleysol (Loamic, Ochric), GL-hi.oy.eu-cen.lop.hu/ Eutric Oxigleyic Histic Gleysol (Endoclayic, Epiloamic, Humic), GL-fv.eu-ce.hu/Eutric Fluvic Gleysol (Clayic, Humic) LV-gl-ct.hu.je.lo.qv/ Gleyic Luvisol (Cutanic, Humic, Hypereutric, Loamic, Protovertic), LX-ab.fr-ct.df.cen.lop.hu.je.pn/ Ferric Abruptic Lixisol (Cutanic, Differentic, Endoclayic, Epiloamic, Humic, Hypereutric, Profondic) AL-fe-ct.ce.oh.pn/ Ferric Alisol (Cutanic, Clayic, Ochric, Profondic), LV-ha-cu.cen.lop.je.oh/ Haplic Luvisol (Cutanic, Endoclayic, Epiloamic, Hipereutric, Ochric), HS-hm.dr.rh.jd-mi/Hyperdystric Rheic Drainic Hemic Histosol (Mineralic), LX-ap.cr-ct.df.cen.lop.je.pn/ Chromic Abruptic Lixisol (Cutanic, Differentic, Endoclayic, Epiloamic, Hipereutric, Profondic), AL-ab-cu.df.cen.lop.jd/ Abruptic Alisol (Cutanic, Differentic, Endoclayic, Epiloamic, Hyperdistric).

Edaphic suitability for *Elaeis guineensis* in the Sierra Region of Tabasco. The PTT has 1532.26 ha that are ideal for oil palms (3.75% of the total surface area). Lands with at least one limiting condition comprised 7875.09 ha (19.29%). It has been determined that this area is non-suitable for the production of *E. guineensis*, as a result of its CIC, interchangeable bases, drainage, and topography. This area comprises 31 414.50 ha. The FL-fve.eu.lo unit has high suitability for *E. guineensis* (Figure 3): it has a deep soil (>100 cm); its surface layer (0-50 cm) has loamy, silty loam, and clayey loamy silt textures; it has a good internal drainage at a depth of 100 cm; it does not have salinity problems; and it has over 50% PSB.
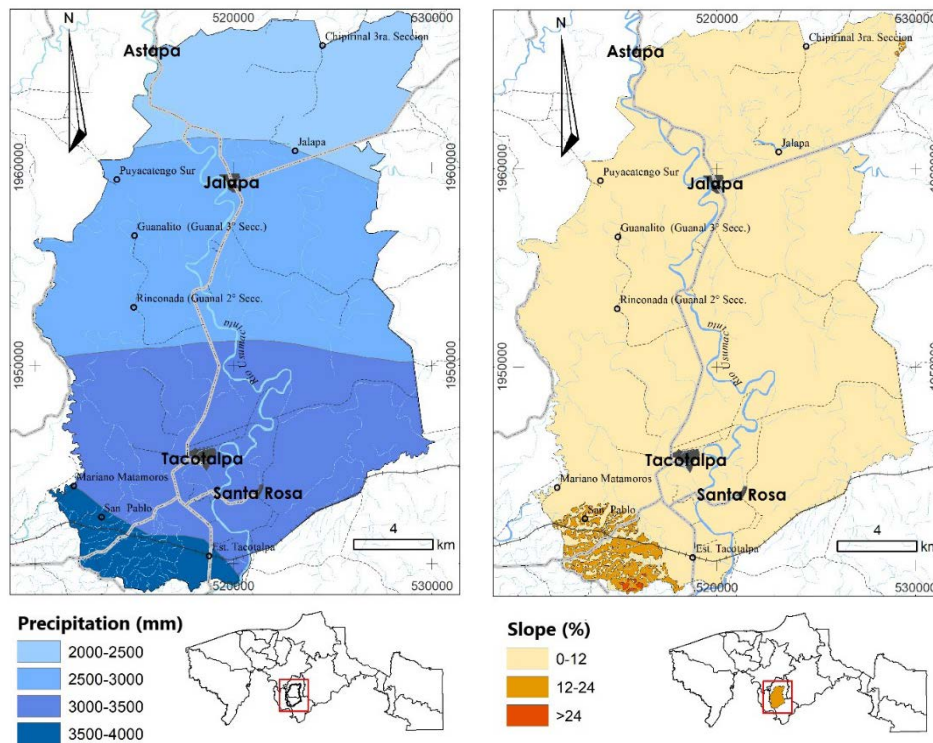
Figure 2. Precipitation and topography in La Sierra, Tabasco, Mexico.
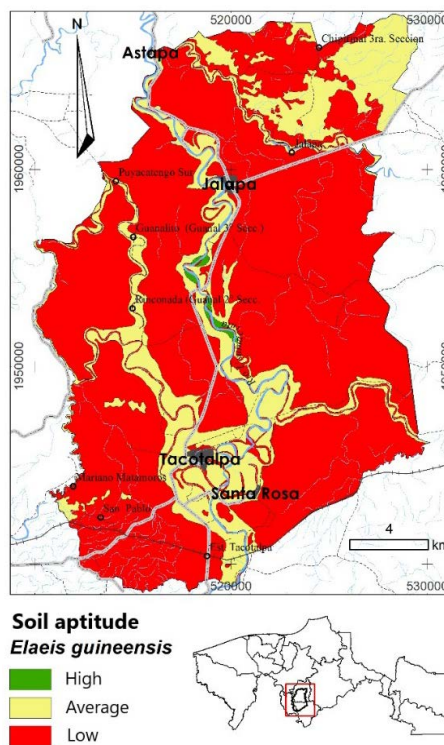

Figure 3. Soil aptitude for *Elaeis guineensis* in La Sierra región, Tabasco, Mexico.

These properties match those of other soils suitable for *E. guineensis* in other tropical regions (Paramananthan, 2003; Corley and Tinker, 2016). Meanwhile, Rhebergen *et al*. (2016) maintain that the soil's physical properties —which control the soil's capacity to provide water for the crops— are more important than its chemical properties —which cannot be easily changed through handling. The soils in the study area have variables with optimum values to expand the surface in which the crop is grown. Low fertility is the edaphic variable that causes an average suitability for *E. guineesis* in the PTT's Lixisols (except in Luvisols with poor drainage). Nutrient availability is not a major limiting factor for the evaluation of land suitability, since handling can be carried out adding nutrients and returning residues to the soil. However, correcting the poor to slow drainage that limits this perennial crop is a difficult task (Rhebergen *et al*., 2016; Harahap *et al*., 2018).

Gleysols (GL) with various qualifiers dominate relieves with low topographical position. This zone shows reducing conditions, a gley color pattern, and a 7-150 cm depth, as a result of the high-water table and the water stagnation associated with medium and fine textures (Brindis-Santos *et al*., 2020a).

GLs with zero suitability for *E. guineensis* cover most of the study area surface (76.95% of the PTT); these soils show slow permeability in horizon A (which is associated with a clayey texture) and moderate permeability in underlying Cg horizons (as a result of the decrease in the clay content). The area has stagnic properties, as a consequence of its high-water table. These soil color reducing conditions can be found on the first 50 cm of depth —as seen in the dominance of grey and deep grey colors. According to their geographical position, these characteristics are divided into decantation basins, floodplains, and cumulative valleys (Zavala-Cruz *et al*., 2016). However, this unfavorable physical soil conditions limit root growth and function —leading to plants with inadequate growth (Ogunkunle, 1993)— and, even when fertilizers are applied, they reduce nutrient and water absorption —inhibiting microbial growth (Goh *et al*., 2016).

CONCLUSION

The poor internal drainage of Gleysols in most of the plains and terraces of Tabasco, Mexico, limits the establishment of *E. guineensis* in those areas. Land suitability in the study area is ideal (3.75%), medium (19.29%), and zero (76.95%). Climatic suitability ranges from medium-high to medium as a result of the relief (<70-masl heights and 30% slopes).

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