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Soil fertility classification for sugarcane in supply areas of a sugar mill

Salgado-García, Sergio[1]; Salgado-Velázquez, Sergio[1*]; Palma-López, David Jesus[1]; Zavala-Cruz, Joel[1]; Córdova-Sánchez, Samuel[2]; Rincón-Ramírez, Joaquín Alberto[1]; Ortiz-García, Carlos Fredy[1], Hernández-Nataren, Edith[1]

[1] Colegio de Postgraduados-Campus Tabasco, Grupo MASCAÑA, Km. 3.5 Periférico Carlos A. Molina S/N, H. Cárdenas, Tabasco, CP 86500, México.
[2] Universidad Popular de la Chontalpa - División de Académica de Ciencias Básicas e Ingeniería, Cuerpo Académico de Química Verde y Desarrollo Sostenible (CA-QVyDS), Carretera Cárdenas - Huimanguillo, Km. 2.0 Cárdenas, Tabasco, México, CP. 86500.
* Corresponding authors: salgado.sergio@colpos.mx; dapalma@colpos.mx

ABSTRACT

Objective. To prepare the fertility classification for the sugarcane-cultivated soils in the Pujiltic Sugarcane Mill (PSM) supply area in order to improve decision-making.

Design/methodology/approach. The soils were classified according to their fertility (FCC), using a system based on the quantifiable parameters of the upper soil layer and some characteristics of the subsoil directly linked to the growth of sugarcane.

Results. Six factors limited the agricultural potential of the PSM soils: alkalinity, water excess or deficit, clay content, erosion, nutritional deficiencies, and low CEC, which alone or in groups act in detriment of soil fertility.

Limitations/implications. Solving these problems requires a comprehensive analysis that considers crop type, planting season, and technology availability.

Findings/conclusions. The soil fertility classification system enabled the classification of 11 soil subunits of the PSM area.

Key words: Fertility, System, Classification, Sugarcane.

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INTRODUCTION

The Pujiltic Sugarcane Mill is the most important of its kind in the State of Chiapas. It has a cultivated surface of 17,100 ha and uses auxiliary irrigation, with a yield of 90.60 t ha^{-1} of sugarcane and a factory yield of 12.01%, according to the Comité Nacional para el Desarrollo Sustentable de la Caña de Azúcar (CONADESUCA, 2019).

The agricultural production of sugarcane is affected by droughts and a diminished soil fertility. As an alternative, production can be boosted through the increase of the cultivable surface and —according to studies about the yields of sugarcane—, these can be increased through adequate soil fertility management practices and the use of improved

varieties (Pérez *et al.*, 2019). Local experiments have shown that the integration of soil fertility and nutrient management is an advanced approach that serves as a resource to increase or maintain soil fertility throughout time (Salgado-García *et al.*, 2008; Salgado *et al.*, 2013; Salgado-Velázquez *et al.*, 2020). However, a diagnosis is needed in order to identify limitations. Buol *et al.* (1975) developed a system to classify soils according to their fertility (Fertility Capability Classification or FCC), with the aim of closing the gap between the classification and soil fertility subdisciplines. As a technical soil classification system, the FCC has a specific use, derived from natural classification systems such as soil taxonomy (Soil Survey Staff, 2014) or the World Reference Base for Soil Resources (IUSS Working Group WRB, 2014). The FCC's categories indicate the main limitations of the soils according to their fertility, which can be interpreted in relation to the crops of interest. Since its publication in 1975, the FCC has been assessed and applied in several countries. As a result, the definitions of several modifiers have changed and new ones have been therefore included to improve the system (Sánchez *et al.*, 1982). The system is a good starting point to study the suitability of tropical soils. In the Mexican tropic, particularly in the State of Tabasco, this system has only been applied in three regions, resulting in good agronomic management recommendations (Salgado and Palma, 2002; Salgado and Obrador, 2012; Salgado-Velázquez *et al.*, 2017). Knowing the FCC's classes allows us to identify the fertility limitations and —given the importance of sugarcane in the State of Chiapas— generating the said information is necessary. Moreover, a soil study of 33,974.7 ha is available for the Pujiltic Sugar Mill (Salgado-García *et al.*, 2006). Therefore, the objective of this article was to develop the fertility classification of the sugarcane-cultivated soils in the PSM supply area.

MATERIALS AND METHODS

The study area covered a surface of 33,974.7 ha, divided in 11 soil subunits (Figure 1), all of which are cultivated with sugarcane (Figure 2). The physical and chemical properties data of the first two horizons of each soil subunit in the PSM supply area was taken from the soil study conducted by Salgado-García *et al.* (2006). The system to classify soils according to their fertility (FCC) was used. This system comprises three categories which, in turn, comprise different classes. The combination of these classes makes up the FCC units:

Type. The texture of the plow layer or the top 20 cm, whichever is shallower.

S: Sandy topsoil: loamy sands and sands (Soil Survey Staff, 2014).

L: Loamy topsoil: $<$35% clay, but without loamy sand or sand.

C: Clayey topsoil: $>$35% clay.

O: Organic soils: $>$30% organic matter (OM) up to a depth of 50 cm or more.

Substrata type (subsoil texture). This is only used when there is a marked textural change relative to the surface or if a hard layer hinders root growth up to the first 50 cm of the soil.

S: Sandy subsoil: same as in type; **L**: Loamy subsoil: texture similar to type;

C: Clayey subsoil: texture similar to type; **R**: Rock or another hard layer hindering root development.

Modifiers. When more than one criterion is indicated for each modifier, only one needs to be known. Ideally, the first criterion mentioned should be used if data is available. The following criteria are presented for those cases in which identifying the first one is impossible (Sánchez *et al.*, 1982): **g** (gley), **d** (dry), **e** (low cation exchange capacity), **a** (aluminum toxicity), **h** (acid), **i** (high P-fixation by iron), **x** (short-range-order minerals), **v** (vertisol), **k** (low K reserves), **b** (basic reaction), **s** (salinity), **n** (natric), **c** (cat clay), **'** and **''** (gravel), **%** (slope).

Procedure. Soils are classified according to these parameters by determining if the characteristic is present or not. Most quantitative limits are criteria found in the Soil Taxonomy and the *World Reference Base for Soil Resources* (Soil Survey Staff, 2014; IUSS *et al.*, 2014). FCC units list the type of texture and substrata (if they differ) in capital letters, the modifiers in lowercase, the gravel modifier with a prime symbol ('), and the slope in parentheses, if so wished.

RESULTS AND DISCUSSION

Soil Study

Table 1 presents the chemical and physical properties of the first two horizons of the soil subunits and Figure 1 shows the representative profiles. The FCC classification for each soil subunit is presented below.

Cb. Chernic Chernozem (CHch). This soil subunit has a mollic horizon, it is deep and well structured, has a high base saturation (80% or more), high content of organic matter (2.5% or more), and a high biological activity. These soils have clayey textures in most horizons, with a moderate permeability. The irrigation availability allows yields of up to 116 t ha^{-1} (Salgado *et al.*, 2014).

Lb (12%). Hypocalcic Calcisol (CLccw). This subunit presents a medium infiltration index and a medium water retention capacity; it has secondary carbonate concentrations up to a depth of 100 cm from the soil surface. Its rapid permeability allows a good drainage. The pH is generally considered as moderately alkaline; the electric conductivity (EC) is 0.20 dS m^{-1}, which indicates that no salinity problems are present; the OM is very rich in the plow layer and poor in the last horizons (5.33-1.24%). Given the calcareous nature of these soils, the use of fertilizers derived from phosphate rock or other non-water-soluble phosphates must be avoided. Its iron, boron, and zinc deficiency must be supplemented through chemical or organic fertilization (Salgado *et al.*, 2010).

Cbv (<5%). Vertic Calcisol (CLvr). This subunit has a vertic horizon up to a depth of 100 cm from the soil surface. These soils present a subsurface clayey horizon, as a result of expansion and contraction. Its slickensides or structural aggregates have 30% more clay throughout its thickness. Most of this soil profile shows >60% clay contents; however, these clay contents and the bulk density (BD) (1 g cm^{-3}) do not cause compaction problems, likely as a result of its high organic matter and calcium contents. Based on field observations, these soils have cutans as a result of the accumulation of carbonates, which react strongly to HCl. Moreover, they have soft, small, cream-colored $CaCO_3$ nodules; the profile presents a good drainage, although permeability goes from moderate to slow, which is attributed to a high clay content (Salgado *et al.*, 2006).

Cb (<1%). Mollic Cambisol (CMmo). This subunit has a low infiltration index and good water retention capacity. Its soils have a high base saturation (>50%) and a high OM content. They have a moderately alkaline pH and no salinity problems (EC<1 dS m^{-1}).

Cbeg (5%). Calcaric Fluvisol (FLca). This subunit has a low infiltration index and good water retention capacity. It is a calcareous soil at least up to a 20-50 cm depth from the soil surface. Based on field observations, the water table was found at a depth of 150 cm; the gleyic processes at this depth gives the soil a grey color. These soils have an average BD of 1 g cm^{-3} and have no compaction problems. They have a moderately alkaline pH and no salinity problems, because their EC ranges from 0.13 to 0.47 dS m^{-1}. The OM has an irregularly arranged profile: it is rich in the first horizon, decreases as the depth increases, and increases again at a still lower depth (3.2-0.4-3.1%), as a result of the continuous alluviation processes. The subunit has a low cation-exchange capacity (CEC), which favors lixiviation, especially in the cases of K, Ca, and Mg. Therefore, we recommend using 10 t ha^{-1} of compost in order not to limit crop development (Salgado *et al.*, 2014). This soil presented a lower K content than Vertisols, contrary to the results reported by Bolio *et al.* (2008) for the sugarcane soils in Chontalpa, Tabasco.

Cbg (<1%). Mollic Gleysol (GLmo). This subunit's soils have high nutrient and organic matter contents; they present loamy textures in the surface that overlie silty clay textures (C horizon). Occasionally, the bottom of the profile may present sandy textures. These soils are deep, although most of the year the water table is found near the surface, causing the sugarcane rooting depth to be less than 60 cm. These soils are predominantly characterized by a clayey texture, grey colors due to gleyzation processes, and poor drainage. Therefore, drainage is necessary to avoid altering the crop's physiology and to allow it to ripen in optimal conditions (Méndez-Adorno *et al.*, 2016). The 1 g cm^{-3} BD does not indicate compaction problems and most horizons maintain a strong reaction to HCl. These soils have a moderately alkaline pH and the EC does not indicate salinity problems (<3 dS m^{-1}). Most of the profile has a very high CEC and, in order to improve the OM content, vinasse and compost must be applied in 150 m^3 and 10 t ha^{-1} doses, respectively (Hernández *et al.*, 2008).

Cb (<.1%). Rendzic Leptosol (LPrz). The main characteristics of these soils are related to their low depth and calcareous rock origins, which provides them with very significant properties such as good OM contents, good nutrient contents, a good infiltration or permeability, a good soil structural development and soil structure stability. However, they have significative problems related to the slope, including: a low radicular volume, a tendency to erosion, a difficult accessibility, and the Ca and Mg saturation. Phosphorus fixation phenomena and iron deficiencies take place when the said saturation reacts to calcium, during the early development stages of the sugarcane crop. The pH is alkaline and the EC does not indicate salinity problems (0.12 dS m^{-1}). The CEC is very high (52.2 cmol(+) kg^{-1}) and the water availability allows the sugarcane crop to achieve yields in excess of 90 t ha^{-1}.

Cb. Pachich Leptic Phaeozem (PHphle). Similar to the Rendzic Leptozol (LPrz), this soil achieves its best yield in the Mex 79-431 cultivar, using the fertilizer dose recommended by the SIRDF (*Integrated System for Recommending Fertilization Rates in Sugar Cane*): 120-60-60 kg ha^{-1} of N, P_2O_5, and K_2O, 92.01 t ha^{-1} (Pérez *et al.*, 2019).

Lbe. Calcaric Regosol (RGca). These Regosols have calcareous properties at least between 20 and 50 cm from the soil surface. They have good permeability and drainage. They show a strong reaction to HCl in all their horizons and are also very rocky soils, with pebbles and gravel throughout the profile. The BD does not reflect compaction problems (1 g cm^{-3}); these soils have a moderately alkaline pH and there are no salinity-related effects (average EC of 0.2 dS m^{-1}). The superficial horizon of these soils is rich in OM, which diminishes along with the depth of the profile (6.6-1.1%). These Regosols present a low CEC, which favors lixiviation, particularly in the cases of K, Ca, and Mg.

Cbev. Eutric Vertisol (VReu). This subunit has a >35% clay layer which covers the whole profile. It has a high-water table that remains flooded during rainy season, causing the stems to die, as a consequence of the saturation of the pores of the soil. Since these soils present denitrification problems due to an anaerobic subsoil, a superficial drainage is recommended. It has a moderately alkaline pH and no salinity problems, as a result of its ECof <2 dS m^{-1}. These soils have a low CEC that favors lixiviation, particularly in the cases of K, Ca, and Mg. During the sugarcane cultivation, the soil did not accumulate potassium, as indicated by Bolio *et al.* (2008) for Vertisols in Chontalpa, Tabasco. Low K contents —compared with the high Ca and Mg contents (Table 1)— account for the foliar deficiency of K (<1.0% in leaf 4) in the sugarcane crops of the Pujiltic region. This phenomenon took place in spite of the application of the fertilizer dose recommended by SIRDF and/or 10 t ha^{-1} of compost, which allows a yield of 60-101.8 t ha^{-1} (Salgado *et al.*, 2014).

Cbve (3%). Pellic Calcic Vertisol (VRpecc). Similar to Eutric Vertisol (VReu).

CONCLUSIONS AND RECOMMENDATIONS

Six factors limit the potential production rate of soils in the area where sugarcane used in the PSM is cultivated: soil alkalinity, water excess or deficit, clay content, erosion, nutrient deficiencies, and a low cation exchange capacity. These factors, alone or grouped together, act in detriment of soil fertility.

Knowledge about the relation between soils, plants, and atmosphere allows us to consider agricultural drainage, irrigation, and fertilization with macro- and micronutrients as agronomic practices that would improve the conditions of Gleysol, Vertisol, Fluvisol, and Cambisol units.

LITERATURE

Bolio-López, G.I., Salgado-García, S., Palma-López, D.J., Lagunes-Espinoza, L.C., Castelán-Estrada, M. y Etchevers-Barra, J.D. (2008). Dinámica de potasio en suelos cañeros. *Terra Latinoamericana* 26(3): 252-263. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0187-57792008000300007&lng=es&tlng=es.

Buol, S.W., Sánchez, P.A., Cate., Jr R.B., and Granger, M.A. (1975). Soil fertility capability classification: a technical soil classification system for fertility management. *In*: E. Bornemisza and A. Alvarado (eds.) *Soil Management in Tropical America*. N.C. State University, Raleigh, N.C. Pp.126-145.

Hernández, M.G.I., Salgado, G.S., Palma-López, D.J., Lagunes, E.L.C., Castelán, E.M., y Ruiz, R.O. (2008). Vinaza y composta de cachaza como fuente de nutrientes en caña de azúcar en un Gleysol

Table 1. Physical and chemical properties of the superficial horizons of the soil subunits cultivated with sugarcane in the Pujiltic Sugarcane Mill, Chiapas.

Subunit	Horizons (cm)	pH (H_2O) rel. 1:2	EC ($\mu S\ m^{-1}$)	OM %	P ($mg\ kg^{-1}$)	K	Ca	Mg	Na	CEC	Da ($g\ cm^{-3}$)	Clay	Silt	sand	Texture
						(cm)					(%)				
		7.70	0.59	9.55	37.18	0.76	64.2	10.86	0.97	55.3	1.03	63	13	24	Clayey
	A2 (25-62)	7.51	0.43	4.25	2.54	0.44	36.7	6.91	0.77	55.3	1.02	83	5	13	Clayey
CLccw	Ap (0-26)	7.96	0.23	5.32	7.04	0.29	22.3	7.88	0.11	17.2	1.02	27	40	32	Loamy
	A2 (26-43)	8.02	0.22	4.23	2.89	0.22	20.5	7.88	0.04	14.7	1.2	31	41	28	Clayey Loam
CLvr	AP (0-20)	7.59	0.51	4.11	5.35	0.55	53.6	11.35	0.74	45.1	1.01	57	17	27	Clayey
	A2 (20-56)	7.52	1.88	2.12	3.66	0.41	85.7	8.39	1.31	40.6	1.15	79	3	18	Clayey
CMmo	Ap (0-13)	7.22	0.75	3.28	18.87	0.67	29.0	6.41	0.53	29.9	1.04	35	23	43	Clayey Loam
	A2 (13-55)	7.24	0.32	3.85	2.54	0.23	38.2	4.11	0.30	26.9	1.01	40	17	43	Clayey
FLca	Ap (0–20)	8.06	0.47	3.2	5.44	0.19	20.1	10.67	0.33	13.2	1.02	29	55	16	Silty Clay Loam
	A2 (20.40)	8.11	0.39	2.33	2.49	0.10	18.6	7.88	0.39	11.2	1.01	29	54	17	Silty Clay Loam
GLmo	Ap (0-22)	7.77	0.57	6.50	7.75	0.48	69.1	14.31	0.37	52.7	1.03	67	19	14	Clayey
	A2 (22-42)	7.64	2.55	2.92	1.83	0.32	82.3	18.91	1.41	45.1	1.02	67	19	14	Clayey
LPrz	Ap (0-37)	6.75	0.12	8.7	1.97	0.47	49.7	3.52	0.06	52.2	1.02	69	15	16	Clayey
PHphle	Ap (0-22)	7.42	0.45	6.90	2.39	0.43	51.6	9.70	0.76	54.3	1.24	81	9	10	Clayey
	A2 (22-62)	7.49	0.56	8.89	16.06	0.83	54.9	10.69	0.90	59.3	1.02	63	17	21	Clayey
RGca	Ap (0-31)	7.94	0.26	6.63	34.65	0.15	38.9	3.22	0.13	12.2	1.01	30.7	31.4	37.9	Clayey Loam
	C (31-65)	8.02	0.24	1.39	4.37	0.05	31.2	1.02	0.05	2.0	1.01	24.7	24.7	50.6	Sandy Clay Loam
VReu	Ap (0-21)	8.10	0.21	4.73	8.71	0.27	60.5	13.47	0.26	8.6	1.02	55	36	9	Clayey
	A2 (21-44)	8.10	0.29	2.53	0.28	0.09	71.2	13.63	0.41	16.2	1.01	55	36	9	Clayey
VRpecc	Ap (0-20)	8.07	0.19	3.60	3.80	0.17	31.9	13.4	0.14	24.3	1.02	41	27	40	Clayey
	A2 (20-49)	8.02	0.33	1.33	2.68	0.18	61.8	16.92	0.26	23.8	1.01	43	28	29	Clayey

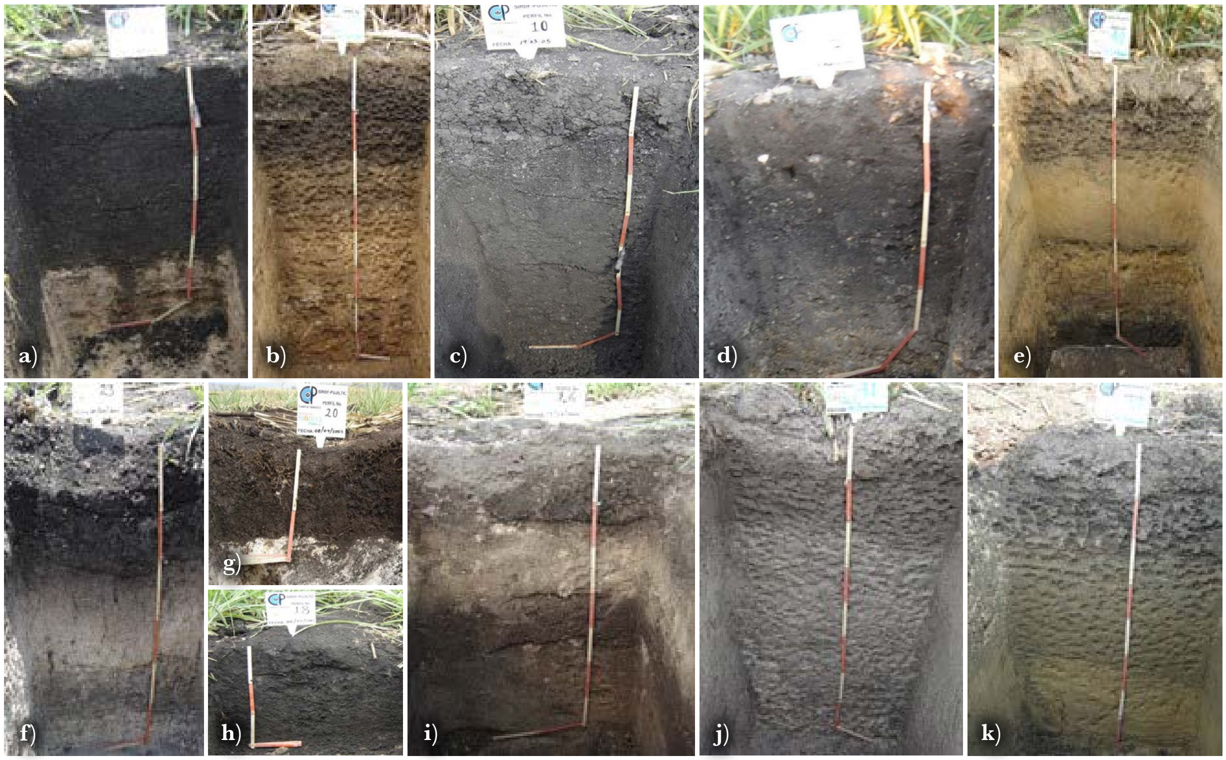

Figure 1. Details of the profiles of sugarcane-cultivated soils at the Pujiltic Sugar Mill: a) Chch, b) CLccw, c) CLvr, d) CMmo, e) FLca, f) GLmo, g) LPrz, h) PHphle, i) RGca, j) VReu, and k) Vrpecc.

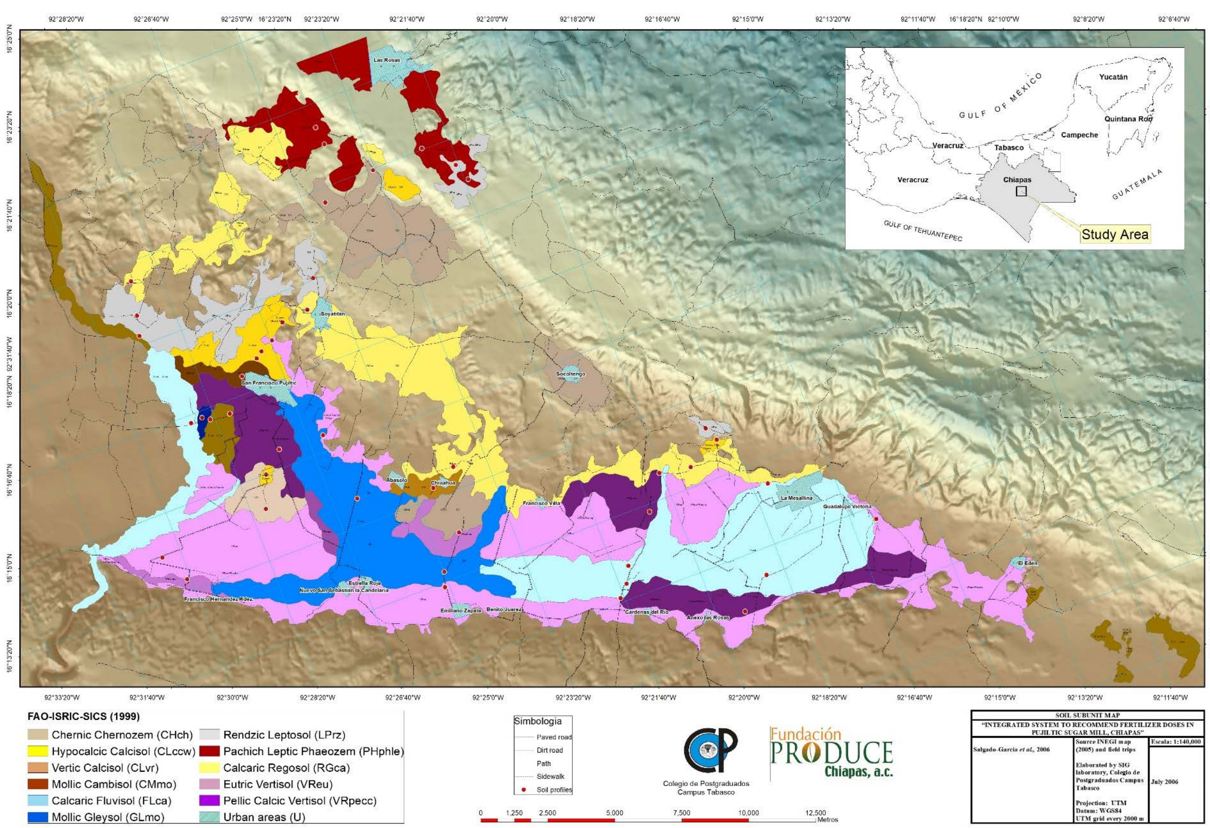

Figure 2. Map of soil subunits at the Pujiltic Sugar Mill, Chiapas.

Mólico de Chiapas, México. *Interciencia 33*(11): 855-860. http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0378-18442008001100016&lng=es.

IUSS Working Group WRB. (2014). *World Reference Base for Soil Resources 2014*. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome. 203 p. http://www.fao.org/3/i3794en/I3794en.pdf

Méndez-Adorno, J.M., Salgado-García, S., Lagunes-Espinoza, L.C., Mendoza-Hernández, J.R.H. Castelán-Estrada, M., Córdova-Sánchez, S. y Hidalgo-Moreno, C.I. (2016). Relación entre parámetros fisiológicos de caña de azúcar sometida a suspensión de riego previo a la cosecha. *Agroproductividad 9*(3): 15-20. http://revista-agroproductividad.org/index.php/agroproductividad/article/view/729/596

Pérez, B.E.A., Gordillo, L.I., Salgado-Garcia, S., Islas, R.S., and Córdova, S.S. (2019). Fertilization Alternatives for Sugarcane (*Saccharum officinarum* L.) Crop in Pujiltic Sugarcane Mill, Chiapas, Mexico. *Sugar Tech. 21*(5): 756-764: https://doi.org/10.1007/s12355-018-0692-1

Salgado, G.S. y Palma–López, D.J. (2002). *Clasificación de los suelos de Tabasco de acuerdo a su fertilidad*. *In*: Palma-López, D.J. y A. Triano S. (eds). Plan de uso sustentable de los suelos de Tabasco. II. Colegio de Postgraduados Campus Tabasco-ISPROTAB. Villahermosa, Tabasco. Pp. 57-76.

Salgado, G.S., Núñez, E.R. y Lagunes, E.L.C. (2010). Micronutrimentos. *In*: Salgado, G.S. y Núñez, E.R. (Ed). *Manejo de fertilizantes químicos y orgánicos*. Edit. Mundi Prensa-Colegio de Postgraduados. México, D.F. 183 p.

Salgado, G.S. y Obrador, O.J.J. (2012). Clasificación de suelos de la cuenca baja del río Tonala por fertilidad. *In*: *Suelo y vegetación de la Cuenca Baja del Río Tonalá, Tabasco*. Zavala Cruz, J., García-López E (Eds). Publicación especial del Colegio de Postgraduados, Campus Tabasco. H. Cárdenas, Tabasco, México. Pp.63-82.

Salgado, G.S., Castelán, E. M., Aranda, I.E.M., Ortiz, G.C.F., Ortiz, L.H., Lagunes, E.L.C., Mendoza, H.J.R.H., Córdova, S.S. (2014). Validación de dosis generadas por el sistema de fertilización SIRDF para caña de azúcar (*Sacharum officinarun* L). *Agroproductividad 7*(2): 47-54. http://revista-agroproductividad.org/index.php/agroproductividad/article/view/514/394

Salgado-García, S, Palma-López, D.J., Zavala-Cruz, J., Lagunes-Espinoza, L.C. Castelán-Estrada, M., Ortiz-García, C.F., Juárez-López, J.F. (2006). *Sistema integrado para recomendar dosis de fertilizantes en caña de azúcar (SIRDF): Ingenio Pujiltic*. Colegio de Postgraduados, Campus Tabasco. H. Cárdenas, Tabasco, México. 103 p.

Salgado-Velázquez, S., Salgado-García, S., Palma-López, D.J., Zavala-Cruz, J., Córdova-Sánchez, S. y Rincón-Ramírez, J.A. (2017). Clasificación de los suelos por fertilidad de la Subregión Ríos de Tabasco, México. *Agroproductividad 10*(12): 9-16. http://revista-agroproductividad.org/index.php/agroproductividad/article/view/106/91

Salgado-Velázquez, S., Salgado-García, S., Rincón-Ramírez, J. A., Rodrigues, F.A., Palma-López, D. J., Córdova-Sánchez, S., & López-Castañeda, A. (2020). Spatial Variability of Soil Physicochemical Properties in Agricultural Fields Cultivated with Sugarcane (*Saccharum officinarum* L.) in Southeastern Mexico. *Sugar Tech 22*(1): 65-75. https://doi.org/10.1007/s12355-019-00742-9

Sánchez, P.A., Couto, W., and Buol, S.W. (1982). The fertility capability soil classification system: Interpretation, applicability and modification. *Geoderma 27*(4): 283-309. https://doi.org/10.1016/0016-7061(82)90019-2

Soil Survey Staff. (2014). *Keys to Soil Taxonomy*, 12th ed. USDA-Natural Resources Conservation Service, Washington, DC. 372 p. file:///C:/Users/84688/Downloads/2014_Keys_to_Soil_Taxonomy.pdf