Soil Research and Soil Mapping History 2

2.1 Traditional Soil Knowledge in Mexico

Traditional folk soil knowledge has a long history in Mexico. Archeological research showed that Pre-Hispanic cultures such as the Aztec, Purepechas, Otomies, and Maya civilizations had a developed system of soil classification. Tovar (1986) reported that the cultures in the southeast of the Republic, such as the Olmec and the Maya, had developed practices of fertilization, irrigation, and drainage systems, including a soil classification, which to date are still being used. The Toltecs and Aztecs had a whole nomenclature to describe the physical and chemical characteristics of soils. Other cultures, such as the Zapotec in Oaxaca and Acolhua in Texcoco, used soil conservation practices through the construction of terraces, and the remains are still possible to see at Monte Alban and the Cerro de Tezcutzingo, respectively. Acolman people, Chalco and Xochimilco, among others, developed the systems of irrigation through the construction and use of artificial islands made of lacustrine mud—chinampas (Laird 1989).

The best documented soil and land classification systems that existed and are still partly preserved among indigenous population of the country have been developed by the Aztecs and Mayas. In the Aztec culture, it was common to show in a single document both land ownership relations and soil productivity and properties. Codices of Santa Maria Asunción and the Vergara have been studied thoroughly by Barbara J. Williams since the early 1970s to date (Williams and Jorge y Jorge 2008). These codices showed the plots of the family leaders, and each plot had in its central part a glyph indicating the type of soil; around 132 glyphs were used, built from 14 graphemes, including elements such as stone, points, backpack, thorn hill, eyes, teeth, manure, maiz, water, and so on (Williams 1976) (Fig. 2.1). The Maya civilization left an extensive land classification based on landscape position and soil properties (Bautista-Zuñiga and Zinc 2010).

Fortunately, the indigenous soil knowledge is relatively well-preserved in Mexico (Ortiz-Solorio et al. 1999), and the country is the world leader in ethnopedological research (Barrera-Bassols and Zink 2000). The very term "ethnopedology" was introduced into the scientific literature in a seminal paper from Mexico (Williams and Ortiz-Solorio 1981). In North America, most folk taxonomic research appear in Mexico, which take the first place in ethnopedological studies in the world. More than 70 publications on folk soil classifications and management practices were published on Mexican material, apart from numerous theses of students of various levels. The abundance of ethnopedological research in Mexico is due to high ethnic and linguistic diversity, relatively well-preserved system of ownership and management practices from pre-Hispanic epoch, and to the existence of several research groups of specialists working in ethnopedology in this country.

The local soil knowledge is studied in Mexico not only as a cultural heritage, but also as an important source of pedological information that may be used for complimenting scientific soil surveys (Williams and Ortiz-Solorio 1981; Ortiz-Solorio et al. 2001; Krasilnikov and Tabor 2003). In more detail, these issues are discussed in the Chap.7 of this book.

2.2 Early Soil Research

Several historical reviews on soil science in Mexico exist, as those published by Laird (1989), Ortiz-Solorio (1993), and Núñez-Escobar (2000). These reviews were based mainly on the books "Biografias de Agronómos y Episodios de la vida de la escuela nacional de agricultura" written by Marte Rodolfo Gómez-Segura (1976a, b). Relevant

P. Krasilnikov et al., *The Soils of Mexico*, World Soils Book Series,
DOI: 10.1007/978-94-007-5660-1_2, © Springer Science+Business Media Dordrecht 2013

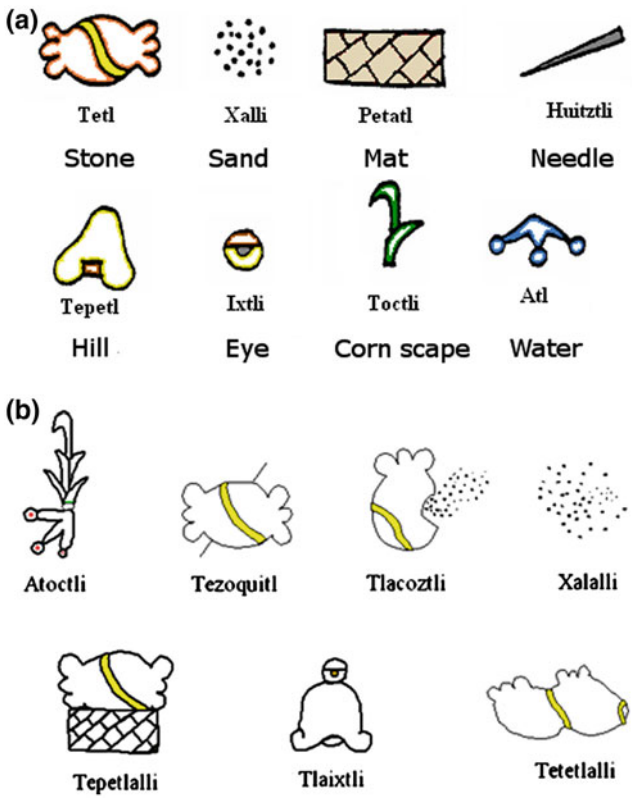

Fig. 2.1 Graphical elements of the glyphs (**a**) and the composite glyphs (**b**) used for soil denomination among Aztecs (glyphs translation after Williams 1976)

Fig. 2.2 Marte Rodolfo Gómez-Segura (1896–1973), the Director of ENA in the epoch of its passage to Chapingo, later the Minister of Agriculture and the Governor of The Tamaulipas State (Gómez-Segura 1976b)

information on the development and evolution of soil studies in Mexico can be found in occasional publications in the Agrociencia and Terra Latinoamericana journals and proceedings of the meetings of the Mexican Society of Soil Science. The historical research of the development of pedology in Mexico was also done with a focus on soil genesis (Gutiérrez-Castorena and Gómez-Diaz 2000) and soil classification (Ortiz-Solorio and Gutiérrez-Castorena 2000). Recently, Palacios-Rangel and Leos-Rodríguez (2011) published a review of the board of the Mexican Society of Soil Science.

The scientific research in the area of agronomy and soil science started its development in the late nineteenth century, when the agronomists extended their interest to the study of chemistry and the geology of soil substrates. One of those was Andres Basurto-Larrainzar who gave the course of agricultural chemistry and was the head of mineralogy section. He wrote a treatise on agriculture that mentioned the importance of physical, chemical, and biological properties of soils, as well as their classification and fertility (Basurto-Larrainzar 1926). The other predecessor of soil science was Alejandro Brambila, who enthusiastically promoted the use of fertilizers since 1892 (Gómez-Segura 1976a). The research activities concentrated mainly in the National School of Agriculture (ENA–Escuela Nacional de Agricultura). The ENA, founded in 1853 in San Jacinto Mexico, D.F, prepared mainly agricultural administrators (*Administradores instruidos* and *Mayordomos inteligentes*) for big land ownerships (*haciendas*). During the early years of the ENA, especially during the government of Porfirio Díaz (1876–1911), the major influence came from France (Cotter and Osborne 1996); one of the most distinguished professors of that period León Fourton taught soils with a focus mainly on agricultural chemistry (Rodríguez-Adame 1984). The first agricultural experimental stations appeared in the country in 1910, and some attention was devoted to soils there.

Fig. 2.3 Charles F. Shaw and Stanley W. Cosby from the University of California at Berkeley, during their travel to the Laguna Salada basin, with Mexican colleagues (the photograph is the courtesy of William Reed; the original provided by Stanley W. Cosby Jr.)

The development of soil research stagnated in the beginning of the twentieth century due to revolutionary events in the country. Only after the revolution did the development of agricultural sciences have a second wind. In 1919, the ENA opened the lines for agricultural engineering and mechanics. The Director of the ENA Marte R. Gómez-Segura (Fig. 2.2) reconstructed the school, and in 1923 invited Alfonso González-Gallardo, who was then recognized as one of the "fathers" of Mexican soil science for the development of agrology. The ENA moved in 1923 to Chapingo, in the State of Mexico, which soon became the center of soil research in the country. In 1929, Jesús Alarcón Moreno presented his bachelor thesis "The study of soils"; this scientist later became the Director of the ENA.

The first agrology college was inaugurated in Villa de Meoqui, Chihuahua, in 1928. One year before engineer Manuel Meza attended the first International Congress of Soil Science in Washington, and the ideas expressed there led him to propose the creation of Soils Specialty in Meoqui. In 1929, the first Mexican scientific meeting, known as "The First Agrological College", was held in Meoqui. This meeting is considered as the first formal activity in the field of soil science in Mexico (Ortiz-Solorio 1993; González 2006). During this Congress, the term *edaphology* was first mentioned, which was defined as the branch of soil science that dealt with soil as a part of nature. This term, as well as in Spain, was used in Mexico as a synonym of *pedology* in English-speaking countries; the meaning was somewhat different from French understanding that limited *edaphology* to the study of soil–plant interactions.

One of the consequences of the formation of the College was the establishment of the Mexican Society of Agrology to promote and disseminate knowledge of soils in Mexico. The first and the only board of this society consisted of Walter E. Packard of CNI (Chair) and Alejandro Brambila Jr. of the General Directorate for Agriculture (Secretary). The society had an ephemeral existence and disappeared soon after establishment.

Later, Manuel Meza together with the Ing. Norberto Aguirre-Palancares, Jesús Alarcón-Moreno, Ramón Fernández, and Escobar brothers presented to the Union Congress the project "Agricultural Education Act", which was approved in 1946 (Aguirre-Palancares 1984). As a result, researchers, technicians, and specialists were trained in order to implement in the field the results of the agricultural science. Therefore this law included education at the highest level, so they proposed the creation of a postgraduate college to award masters and doctoral degrees.

During the presidency of Plutarco Elías Calles the National Commission on Irrigation (CNI–Comisión Nacional de Irrigación) was founded, and the Law on Irrigation was passed in January of 1926. In the same year, the CNI invited American soil scientists to train the first agronomists on soil surveys required for the implementation of irrigation of lands. Recently discovered negatives and autochrome glass plates give glimpses into two early soil explorations

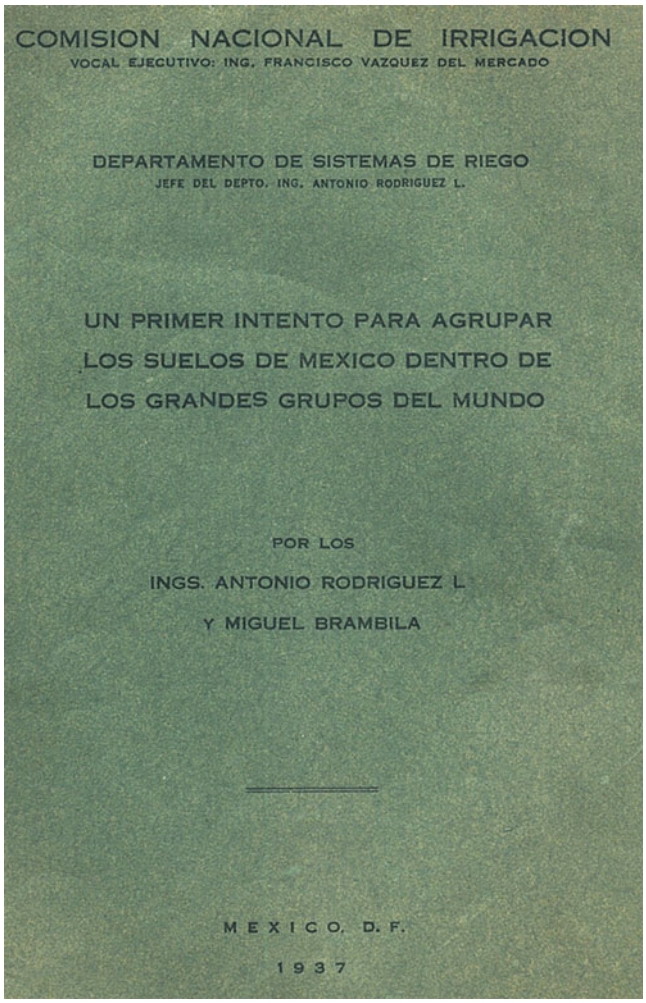

Fig. 2.4 The seminal work of Rodríguez and Brambila (1937)

into the Laguna Salada basin in Baja California, Mexico (Reed 2009). Invited by the CNI, two soil science professors from the University of California at Berkeley, Charles F. Shaw and Stanley W. Cosby, traveled to the Laguna Salada basin to conduct preliminary investigations for the potential for irrigated agriculture and to provide soil survey training for Mexican soil scientists (Fig. 2.3). Walter W. Weir, Drainage Engineer at U.C. Berkeley, was also with the exploration party. As many as 25 people were working together from both nations. The other US specialists invited by the CNI were A. E. Kocher and W. E. Packard. As a result, the soil terminology and methodology in Mexico in that epoch were almost completely borrowed from the USA. The CNI also concentrated outstanding specialists in the area of soil management and irrigation. Since May of 1930 it published a monthly journal "Irrigation in Mexico".

In 1937, the CNI published a seminal book by Antonio Rodríguez and Miguel Brambila entitled "A first attempt to group the soils of Mexico into the World Great Groups" (Rodríguez and Brambila 1937). This book also included the first national small-scale soil map (Fig. 2.4). Also in 1937, the CNI published a translation of the Kellog's Manual of Agrological Studies, translated by Miguel Pérez Espinosa (Kellog 1937b).

The soil science of Mexico integrated gradually into the world scientific community. In 1939, Miguel Brambila published an international paper on the "tepetate" soils of Mexico (Brambila 1940).

The Rockefeller Foundation played an important role in the development of soil science in Mexico. Henry Wallace (Vice-President of the USA) promoted and obtained agreements for American scientists to collaborate with Mexican technicians in 1940 (Aguirre-Palancares 1984). In 1943, a collaborative agreement was signed between the Mexican Department of Agriculture (represented by Gómez-Segura, the Secretary of Agriculture and González-Gallardo, senior officer) and the Rockefeller Foundation. One of the most noteworthy impacts of the Rockefeller Foundation on the development of soil science in Mexico was through an academic exchange (González 2006). Approximately, 300 Mexican technicians obtained graduate-level degrees in the USA (Rodríguez-Adame 1984), and later returned to Mexico to conduct research programs (Ortiz-Solorio 1993; González 2006), mainly in crop production. As a result, the use of fertilizers was implemented and soil fertility developed significantly in Mexico (Ortiz-Solorio 1993). Roberto Núñez-Escobar (CP), Leonel Robles-Gutiérrez (ITESEM), Gildardo Carmona-Ruiz (UANL), Nicolás Sánchez-Durón (Oficina de Estudios Especiales), Martínez Medina (ESAAN), and Rodolfo Plinio Peregrina-Robles (Director del INIA) were some of them. Within the US scientists with expertize in soils were Williams Caldwell, Robert F. Chandler, John B. Pitner, and Reggie J. Laird (Rodríguez-Vallejo 1984); the latter stayed in Mexico and worked as a professor in soil science program in CP. Other researchers were Norman E. Borlaug and Edwin J. Wellhausen who remained in the CIMMYT (Hernández-Xolocotzi 1984).

In the beginning of the 1940s serious progress in pedology was achieved. Alfonso González-Gallardo, mentioned above, published a fundamental book "Introduction to the study of soils" (González-Gallardo 1941) (Fig. 2.5). In 1944, Donaciano Ojeda translated the seminal book of Konstantin Glinka "Great Groups of the Soils of the World and their Development" (Glinka 1944). In fact, this monograph appeared in Spanish in a reduced and modified form: initially, it was a

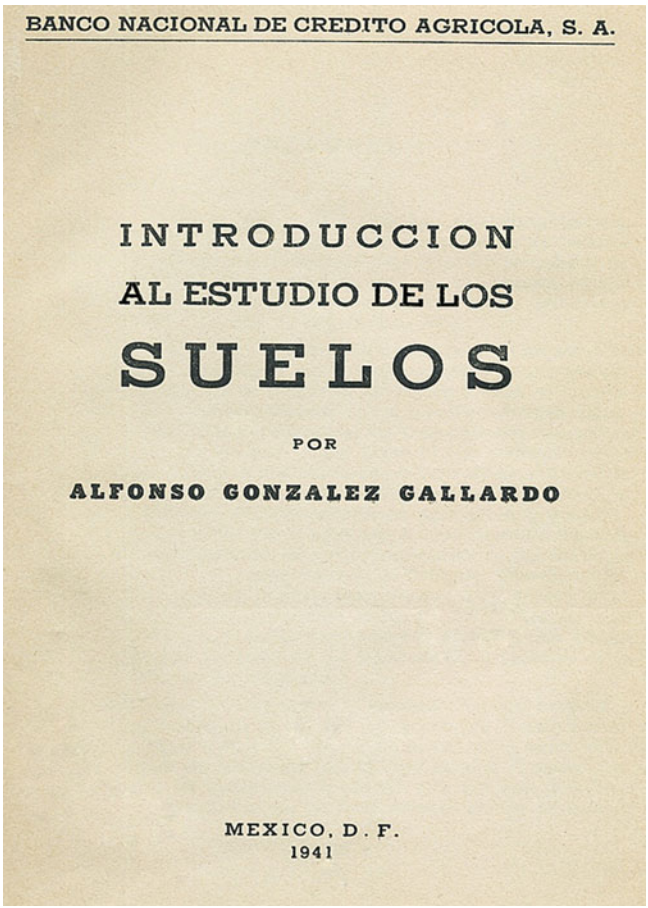

Fig. 2.5 The first Mexican textbook in soil science by A. González-Gallardo

shortened translation from Russian into German by Herman Stremme of the original Glinka's textbook "Soil Science", followed by its translation from German into English by Curtis Marbut, and then from English into Spanish.

In 1946, the CNI was restructured and transformed into a federal-level department named the Secretary of Water Resources (Secretaría de Recursos Hydráulicos–SRH). As a consequence, reduction of experienced soil surveyors occurred during the period of 1947–1966, from 60 to 15 (Ortiz-Solorio 1993). In 1968, the Commission for the Study of National Territory (Comisión de Estudios del Territorio Nacional—CETENAL), was created under a collaborative project with FAO. The CETENAL, which transformed later into the General Directory of Geography (Dirección General de Geografía—DGG) of the National Institute of Statistics and Geography (Instituto Nacional de Estadística y Geografía—INEGI), was the first institution in Mexico that started a systematic study of the soils of the country.

2.3 The Development of National Soil Science Schools in Mexico

The ENA developed as a national center for preparation of human resources in the area of soil sciences. The line of soil science was opened at graduate and postgraduate levels in 1957 and 1959, respectively. In 1959, a Postgraduate College (Colegio de Postgraduados–CP) branched within the ENA; Soil Science department was also founded there. In 1974, the ENA was transformed into the Autonomous University of Chapingo (Universidad Autónoma de Chapingo–UACH) (Fig. 2.6). Until now it is the most important node for scientific research and human resources training in soil science disciplines. In 1979, CP was separated from the ENA to be an independent research body.

The UACH and CP published the most useable textbook on general soil science (Ortiz-Villanueva 1975a) that outstood seven editions (see Ortiz-Villanueva and Ortiz-Solorio 1990). The other important topics covered by the textbooks published in these institutions were soil chemistry (Gavande 1981), soil physics (Gavande 1972), soil fertility (Ortiz-Villanueva 1975b; Salgado-García and Núñez-Escobar 2010), soil conservation (Oropeza-Mota 2011), and fundamental pedology (Ortiz-Solorio et al. 1999). Also the most popular manual for field soil description was published (Cuanalo de la Cerda 1975). The pedological studies are concentrated mainly in the CP, and the researchers there are known for high-quality papers published in international journals (e.g. Gutiérrez Castorena et al. 2005, 2006, 2007; Etchevers et al. 2006; de León-González et al. 2007; Prado et al. 2007; Cruz-Cárdenas et al. 2010). The UACH was a driving force for the organization of the 15th World Congress of Soil Science in Acapulco, Mexico in 1994; Dr. Andrés Aguilar-Santelises of UACH acted as a president of the IUSS during the period of 1990–1994 and chaired the Congress.

The CP has seven campuses, which form important centers of agricultural research. Some of them play an important role in the inventory of soil recourses, for example, the Campus Tabasco in Lázaro Cárdenas, Tabasco (see Palma-López et al. 1985).

The other important center of soil research formed is the National Autonomous University of Mexico (Universidad Nacional Autónoma de México–UNAM). Nicolás Aguilera-Herrera (Fig. 2.7) was one of the grantees of the Rockfeller foundation; in 1951, he did postgraduate studies in Wisconsin University with Dr. Marion L. Jackson. Returning to Mexico, initially he worked in several institutions of the country, including the CP, where he organized the line of Soil Science. He started the course of soil science at the

Fig. 2.6 The building of the Autonomous University of Chapingo. It is and original photo made by Carmen Gutiérrez especially for this book

Faculty of Sciences of the UNAM in 1958, and in 1965 founded a Laboratory of Pedology there. Later, he also established a Department of Pedology in the Institute of Geology of the UNAM. Nicolás Aguilera-Herrera was one of co-founders of the Mexican Society of Soil Sciences (Sociedad Mexicana de las Ciencias del Suelo–SMCS) in 1962. He organized annual International Courses in Soil Science, currently the most important short-term educational course in pedology for students and specialists in the Spanish-speaking world and published a soil science textbook for graduate students (Aguilera-Herrera 1989). Actually, the pedologists of the UNAM actively publish papers in international journals (e.g. Solleiro-Rebolledo et al. 2003, 2006, 2007; Bocco et al. 2005; García-Calderón et al. 2005, 2006; Méndez-Linares et al. 2007; Peña-Ramírez et al. 2009).

Regional research developed in many states of Mexico. One of the most important centers of soil-related research in the tropical areas of the country is the College of the Southern Frontier (Colegio Frontera Sur), with five campuses in the states of Chiapas, Quintana Roo, Campeche, and Tabasco. Generally, this research center is focused on the issues of sustainable development, but also has strong research groups of pedologists (Mendoza-Vega et al. 2003; Mendoza-Vega

Fig. 2.7 Maestro Nicolás Aguilera-Herrera, the founder of soil science in the National Autonomous University of Mexico (portrait provided by N.E. García-Calderón)

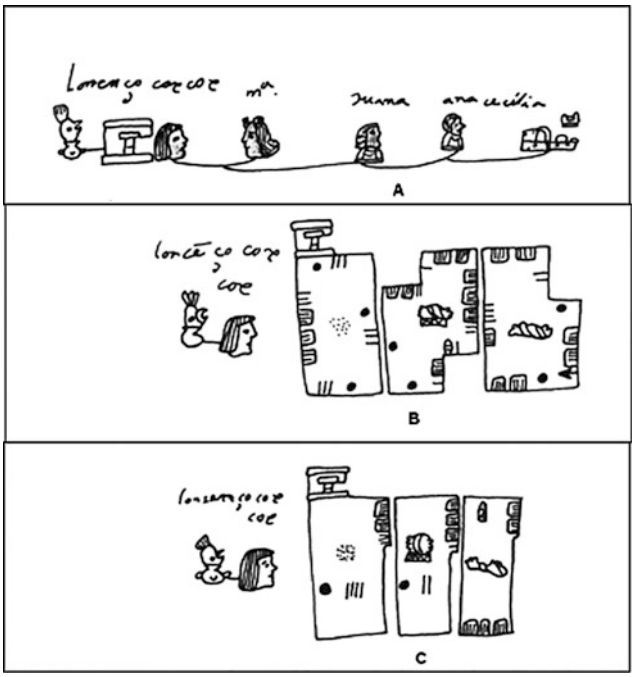

Fig. 2.8 An element of Códice Vergara with representation of the quality of each plot

and Messing 2005; Geissen et al. 2006, 2007, 2009). Important regional settings were described in an extensive monograph about the soils of the Yucatan (Bautista-Zuñiga and Palacio-Álvaro 2005). Some interesting publications were prepared by the researchers in Veracruz State together with Cuban colleagues (Hernández-Jiménez 1991; Ascanio-García and Hernández-Jiménez 2005).

Some recent research activities have been developed in Mexico in collaboration with the US and Canadian colleagues, mostly in the northern part of the country. The majority of these cooperative studies were related to the issues of soil fertility, remediation, and erosion (e.g. Martínez-Gamiño and Walthall 2000; Hudson 2003; Kuhn et al. 2003; Bravo-Garza and Bryan 2005), but several important pedological papers have been also published on the organic matter of volcanic soils (Drijber and Lowe 1990, 1991), the effect of lithology on soil genesis in arid regions (Graham and Franco-Vizcaino 1992), and the formation of calcium carbonate coatings on gravel in extreme arid areas of Baja California (Amundson et al. 1997).

The French scientific school of pedology also actively collaborated with Mexican researchers. The most interesting recent papers include the research of Dubroeucq et al. (1992b) of the dune soil complexes on the coast of the Mexican Gulf, the investigation of the genesis of volcanic soils (Dubroeucq et al. 1992a, 2002; Barois et al. 1998), and the study of the pedogenesis and mineralogy of soils in the Chihuahua desert (Ducloux et al. 1995). A large group headed by Christian Prat conducts a long-term study of the properties and remediation of volcanic soils with cemented layer (tepetate) (Servenay and Prat 2003; Prado et al. 2007).

Currently, many papers are published in international scientific journals by Mexican pedologists alone or together with the colleagues from abroad. However, still a significant part of soil research in Mexico is unavailable for

Fig. 2.9 The first map of the soil Great Groups of Mexico from the book by Rodríguez and Brambila (1937)

international readers: many data are published in "grey" literature or left unpublished in the form of the thesis of various levels. The situation is brightened by the presence of a national scientific journal with free full-text on-line access. The most important journal in the area of soil science was launched in 1983 by the SMCS under the name *Terra*. In 2004 it was renamed into *Terra Latinoamericana*. It is published quarterly in the UACH, Texcoco in Spanish with occasional papers in English. About one-fourth of the volume of the journal is dedicated to pedology and related issues. The other journal that publishes a limited number of papers on soil science is *Agrociencia*. Geological journals, such as *Revista Mexicana de Ciencias Geológicas* and *Boletín de la Sociedad Geológica Mexicana*, also sporadically publish papers on soil science, including special issues.

The Mexican Society of Soil Science (SMCS), founded in 1962, served as a strong organizing force for national soil studies (Palacios-Rangel 2011). Since its foundation, 34 annual and biennial meetings have been organized, and full papers or extended abstracts have been published in a book series « The pedological research in Mexico » . The SMSC has organized several internationals congresses, including VI and XVII Latin American Congresses of Soil Sciences and 15th World Congress of Soil Science in Acapulco (1994). The SMCS has four divisions, namely "Diagnostics,

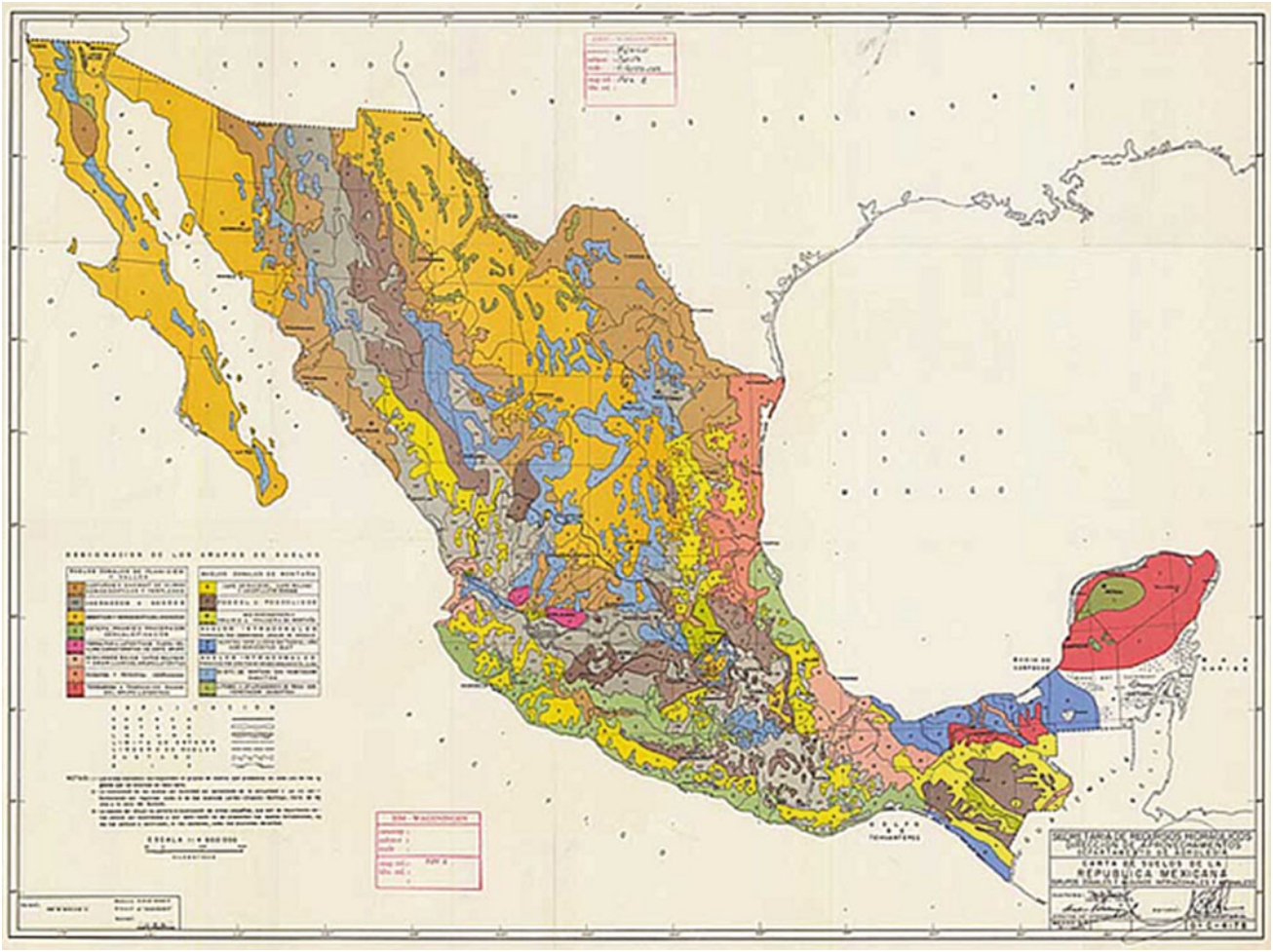

Fig. 2.10 The soil map of Mexico, showing the distribution of "zonal", "intrazonal", and "azonal" soils

methodology and evaluation of soil resources", "Relations between soils, climate and biota", "Use of soil resources", and "Education and technical support" (Palacios-Rangel 2011).

2.4 Soil Mapping in Mexico

According to Hernán Cortés, Mexican indigenous leaders had geographical maps drawn on different materials. These maps reproduced routes and specific areas. Some codices were very similar to cadastral maps; for example, the Codex Santa María Asunción and the Codex Vergara (Gibson 1978; Williams 1976; Williams and Harvey 1988). These codices prepared for Tepetlaoztoc and surrounding communities in the Valley of Mexico, consisted of three parts: one was the census of population housing and household head and the other two were representations of their plots (Fig. 2.8). The striking feature of these codices was that in the middle of each plot there was a glyph, which represented the class of land/soil. Although they were not formally soil maps, they possessed all the elements for soil mapping.

Since colonial times, with the exception of the Tepetlaoztoc Codices, until the completion of the Mexican Revolution, no soil maps of Mexico have been produced.

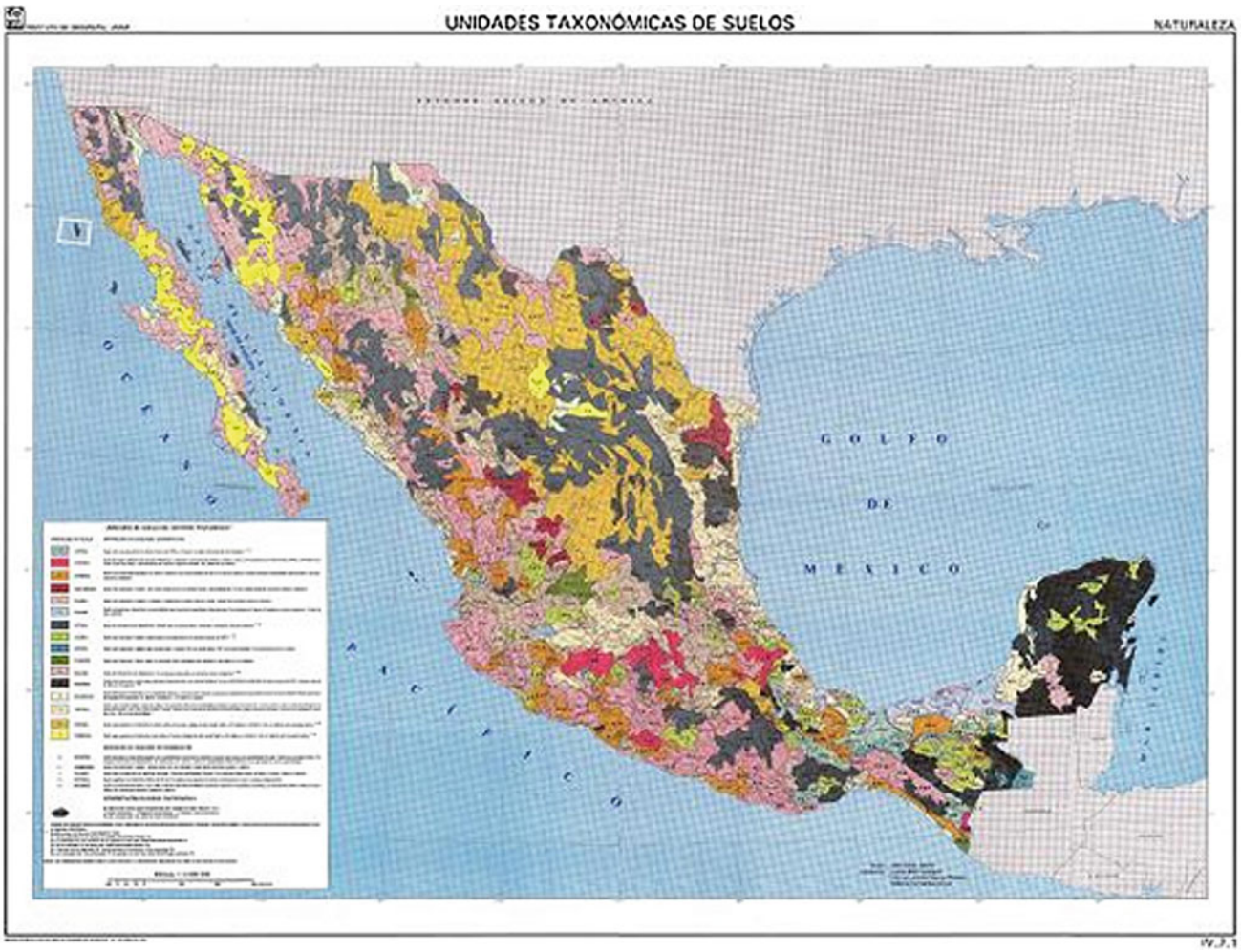

Fig. 2.11 Soil map of Mexico of the scale 1:1,000,000, prepared by the CETENAL using the legend modified after FAO

As mentioned above, the National Irrigation Commission (CNI) was created in 1926, mainly for the construction of large dams in the country. Agriculture Department was established in CNI the same year, and the first Head of the Department from 1926 to 1929 was Walter E. Packard (Baum 1970). The US specialist was hired for that position, because, as President Calles explained, there was a lack of technical experience among Mexicans (Aboites 1998). Agronomy department became the official government agency for conducting soil surveys, a procedure unknown in the country at the time. For unknown reason, the soil surveys were given the name of Agrology. Macías-Villada (1963) indicated that the term 'agrology' was used to characterize the applied part of soil science, mainly in regard to soil mapping and agrologic surveying. Basurto-Larrainzar (1926), in Volume 2 of his Treatise of Agronomy and Agrology, stated that the study of soils belongs to the field of geology, which means that in that epoch pedology was still not considered an independent science in Mexico.

It was the suggestion of the Chief of Agriculture Department to establish the first agrological College in the town of Meoqui in 1928, in order to enlighten young agronomists on developing soil surveys. Meoqui was chosen because of its proximity to the Conchos River, where a big project developed; it seemed convenient to use it as a base for field training (Comisión Nacional de Irrigación 1929).

At that time no aerial photographs were available, soil mapping was done together with topographic survey using a plotting board, and all the maps appeared at the same scale (Ortiz-Solorio 1993). In 1929, Alejandro Brambila Jr. led

Fig. 2.12 Soil map prepared on the basis of the Revised legend of the FAO-UNESCO Soil Map of the World INEGI-SEMARNAP (1999)

the squad that made the agrological map of the State of Morelos, the first federal entity fully studied (Ortiz-Solorio 1993). In 1937, CNI published the first soil map of Mexico as an Annex to the book of Rodríguez and Brambila "First attempt to group the soils of Mexico within the Great Soil Groups of the World" (1937). The map reflected mainly the general concepts of global soil distribution rather than real soil cover of the country (Fig. 2.9). The legend included the Great Groups of soils following the system developed by the USDA Soil Survey (e.g. see Baldwin et al. 1938).

Charles Kellogg published the Soil Survey Manual in the USA (Kellogg 1937a), which was translated into Spanish by Manuel Pérez Espinosa of the CNI with a somewhat erroneous title "Manual de Levantamientos Agrológicos" (Manual for Agrologic Surveys). This document was considered as the standard to follow in soil studies.

The US technical support came to an end in 1930. The CNI was renamed into the Secretary of Water Resources (Secretaría de Recursos Hidráulicos–SRH) in 1946. The staff of Agrology, previously estimated at about 60 technicians, for budgetary problems was reduced to 15 persons. The situation required employment of new methods to achieve speed, accuracy, and economy in agrologic studies, which was implemented by national experts, giving birth in 1958 to the Office of Photogrammetry and Photointerpretation. During the period from 1927 to 1962, the Department of

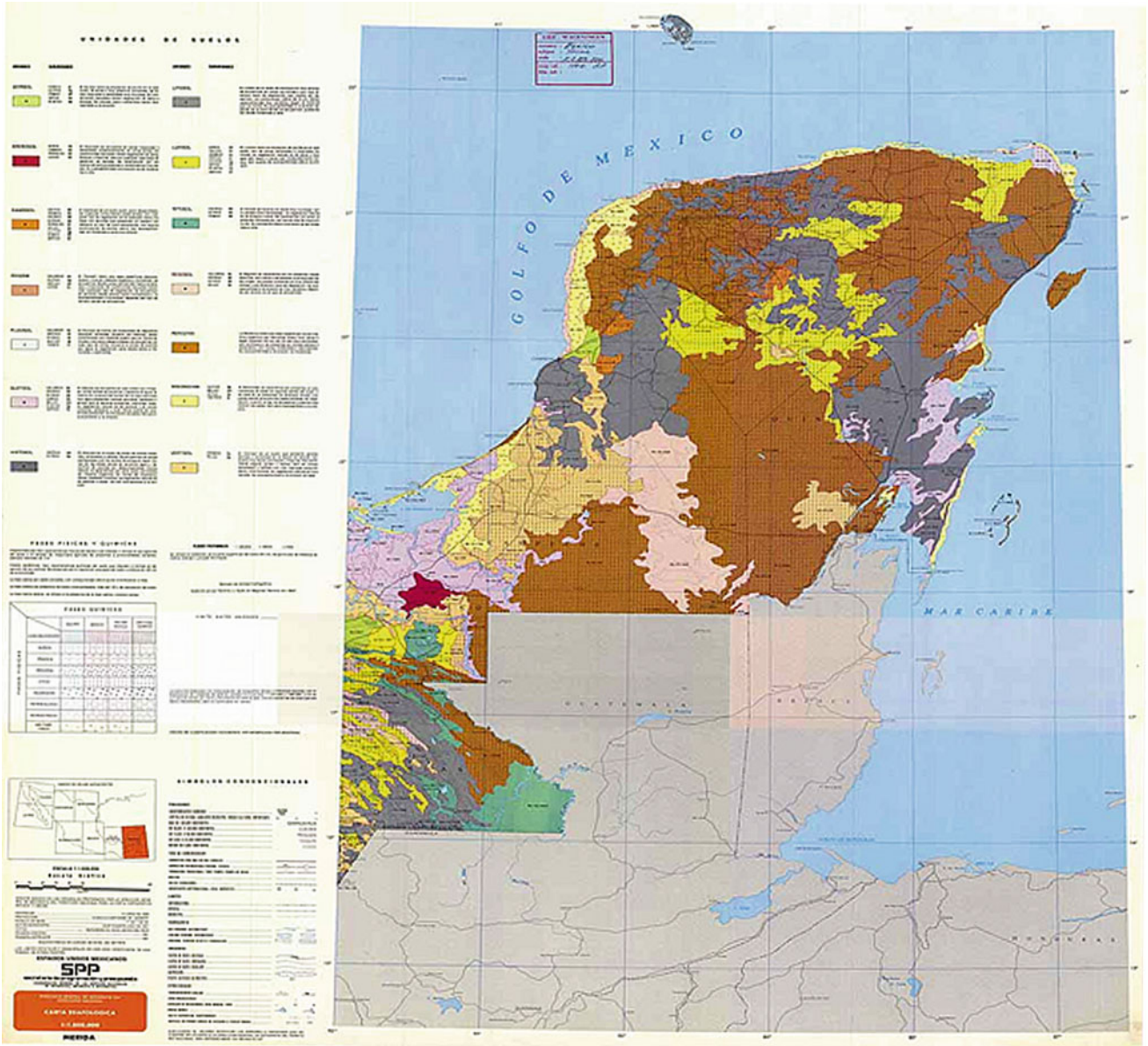

Fig. 2.13 An example of the map of the scale 1:250,000 developed by INEGI

Agrology studied soils at different levels for 17 % of the territory of Mexico, i.e., at 36 million ha (Macías-Villada 1963). As a part of these activities, the SRH published a soil map, stressing the distribution of "zonal", "intrazonal", and "azonal" soils in the country (Fig. 2.10).

The soils mapping in Mexico have been detonated by the project of the World Soil Map of the scale 1:5,000,000 by the Food and Agricultural Organization of the United Nations (FAO). This project has been developed during the period of 1961–1978, and implied close cooperation of the national experts with the international soil science community. In the decade of the 1970s, the Department of Agrology under the leadership of Gaudencio Flores Mata and in collaboration with experts from FAO integrated the available information on the soils of Mexico to World Soil Map of the FAO (1974). The information about the soils of the country was not very precise in that epoch, and the FAO soil map for Mexico had numerous errors. Generally, the

Fig. 2.14 The distribution of reference soil profiles used by INEGI for developing the soil map of the country

map had the same mistakes as the map prepared by the Secretary of Hydraulics: the systematic study of the soils of Mexico had not yet started, and large gaps in the knowledge existed, especially for arduous areas.

Apart from these efforts, some Mexican pedologists developed their own soil maps. A schematic map of soil Great Groups was published by Aguilera-Herrera (1969); it was one of the early attempts to use the American soil taxonomy for mapping Mexican soils.

The other early product of national-scale soil mapping in Mexico was the soil map of the scale 1:1,000,000, prepared during 1978–1980 by the CETENAL, which transformed later into INEGI (see Fig. 2.11). This institution, founded in 1968, later played a major role in the development of soil mapping in the country. There was a discussion on soil classification to be used for the map. Finally, the legend was based on the legend of the FAO-UNESCO Soil Map of the World (FAO-UNESCO 1968), modified by CETENAL (1970). The main reason for the selection of classification was that it could be used with minimal data on soil chemistry, while the classification used in the USA (Soil Survey Staff 1960) required extensive analytical support.

The other example of small-scale soil map was the map of dominant soils of the Mexican republic developed by the National Commission for the Study and Use of Biodiversity (CONABIO–Comisión Nacional para el Conocimiento y Uso de la Biodiversidad) of the scale 1:1,000,000 by generalization of the soil maps of INEGI and updating the legend using the new version of classification proposed by FAO (FAO-UNESCO-ISRIC 1988).

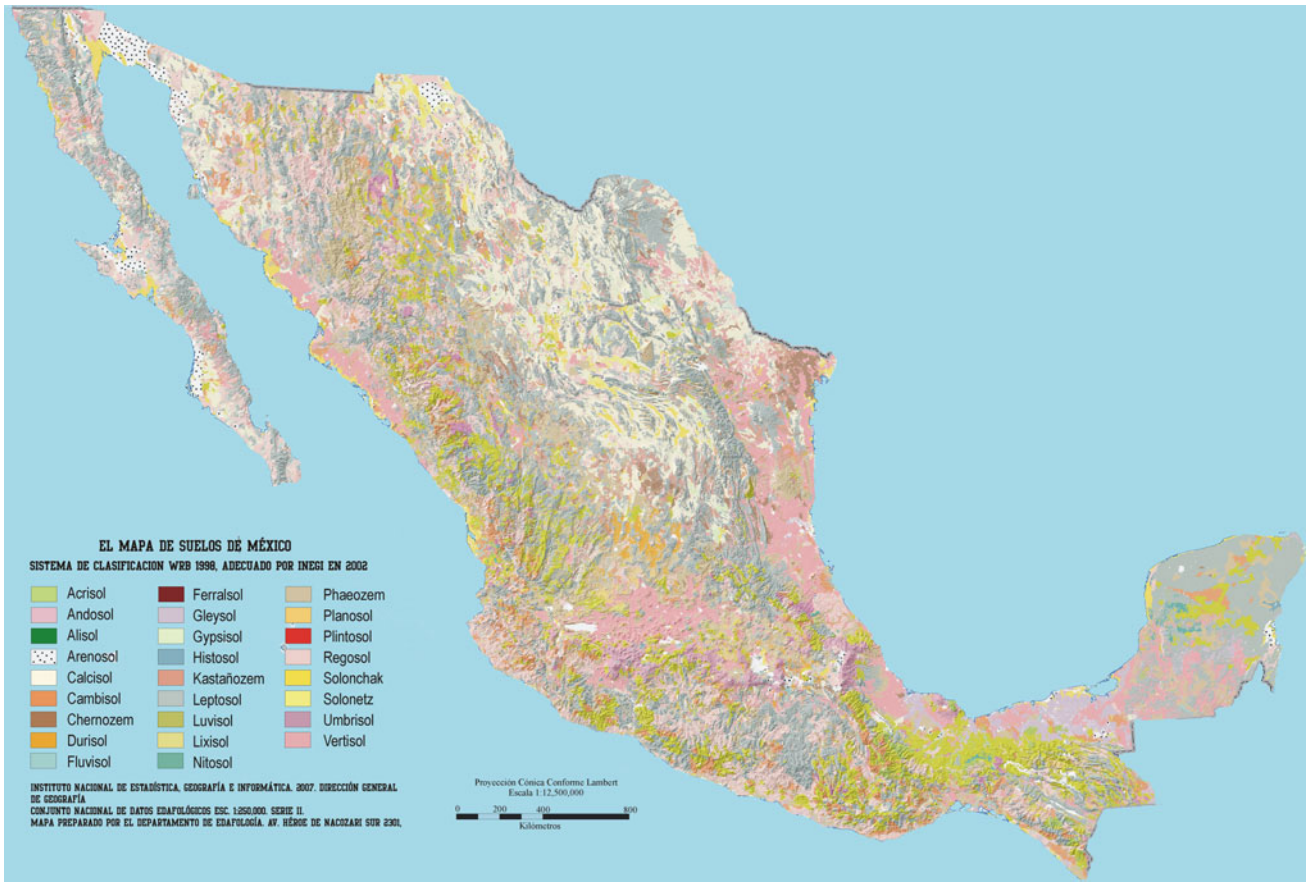

Fig. 2.15 The soil map of Mexico prepared by INEGI in 2006 using the WRB classification as a legend (FAO-ISRIC-ISSS, 1998)

The second version of this map was developed by three Mexican institutions: the Secretary of Environment, Natural Resources and Fishery (Secretaría del Medio Ambiente, Recursos Naturales y Pesca–SEMARNAP), the CP, and the INEGI. One of the aims of this map was to update the nomenclature of the soil maps, using the Revised Legend of the World Soil Map of FAO/UNESCO/ISRIC (1988). The process of updating the information consisted of a translation of names, and where possible keep to the original boundaries of soils, taking into account that such abundant in Mexico units as Xerosols and Yermosols have been deleted from the legend (Ortiz-Solorio et al. 1994). The map also included a general description of the main soil groups of the country (Fig. 2.12).

The development of medium- and large-scale soil mapping started in 1980s in Mexico. In 1968, the INEGI started work on preparation of soil maps of the scale 1:50,000. Each sheet of these maps had a size of 15 min of latitude per 20 min of longitude, thus covering an area of about 1,000 km^2. The total coverage of these maps, elaborated during the period of 1968–1982, was 762 sheets, or about 30 % of the whole territory of the country. The maps used Mercator Universal Transversal Projection (UTM) and Datum NAD27 as cartographic bases. The maps have been prepared both by field surveys and by interpreting stereoscopic pairs of black-and-white aerial photographs of the scale 1:50,000 and 1:75,000. The disadvantage of these maps was that the density of the survey was insufficient for the declared scale, and real resolution of the maps corresponded to a smaller scale.

The next stage was to make soil maps of the scale 1:250,000 for the whole national territory (Fig. 2.13). Each sheet had an extension of 1° of latitude per 2° of longitude; the cartographic bases were UTM and Datum NAD27. Field soil survey was strengthened by the use of remote sensing data, mainly Landsat MSS satellite images of the bands 4, 5, 6, and 7. During the period of 1980–1998, the mapping plan for the whole territory of Mexico, excepting isles, have been completed in the scale 1:250,000. The legends of the maps of the scales 1:50,000 and 1:250,000 were based on the

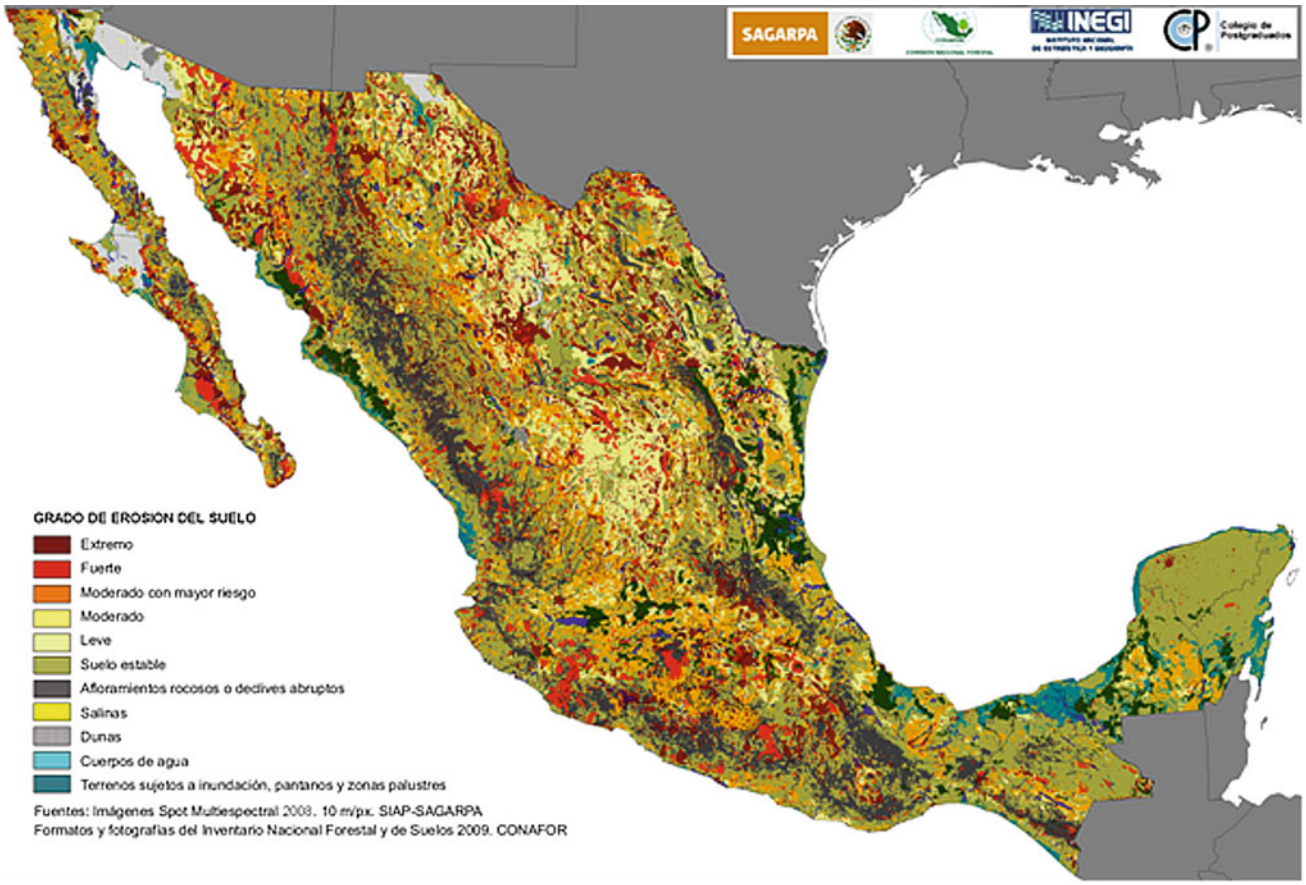

Fig. 2.16 The map of the development of soil erosional processes in Mexico, prepared by SAGARPA

classification system of FAO World soil map, modified by CETENAL (1970).

In 2001, it was decided that the maps at the scale 1:250,000 for the first round of soil survey needed certain improvement (Guerrero-Eufracio and Cruz-Gaistardo 2011). During the period of 2002–2007, the INEGI conducted the second round of soil survey that included excavation of new profiles, the revision of legacy data, and reshaping the polygons using available remote sensing data. The legend was based on the World Reference Base for Soil Resources–WRB (FAO-ISRIC-ISSS 1998). The advantage of the improved maps was that the classification was much more detailed than in the previous version, and that the staff of the Pedology Department had more professional skill than during the previous inventory (Cruz-Gaistardo et al. 2006). The maps exist in GIS format and are linked with a database that includes 9,549 soil profiles (in fact, more than 30,000 profiles are potentially available for including in the database). The distribution of soil profiles is shown at Fig. 2.14. The second round allowed developing a new small-scale soil map of Mexico with strikingly higher detail than the previous versions (Fig. 2.15).

The maps produced by INEGI received certain criticism, mostly because many users had unjustified expectations that small-scaled soil maps (1:250,000 and 1:1,000,000) might give precise information for development site-specific practical recommendations. Also the methodology applied by INEGI overstated the use of interpretation of aerial photographs and satellite images; the number of observations in the field was low '(about 1 observation per 50 cm^2 map), and the state of soil information should be still regarded as insufficient.

A number of maps have been developed on the basis of the data recently obtained by INEGI and other institutions of Mexico. A map for estimating soil erosion was developed by the Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA–Secretaria de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentacion) mainly on the basis of interpretation of satellite images (Fig. 2.16). A set of auxiliary data, the use

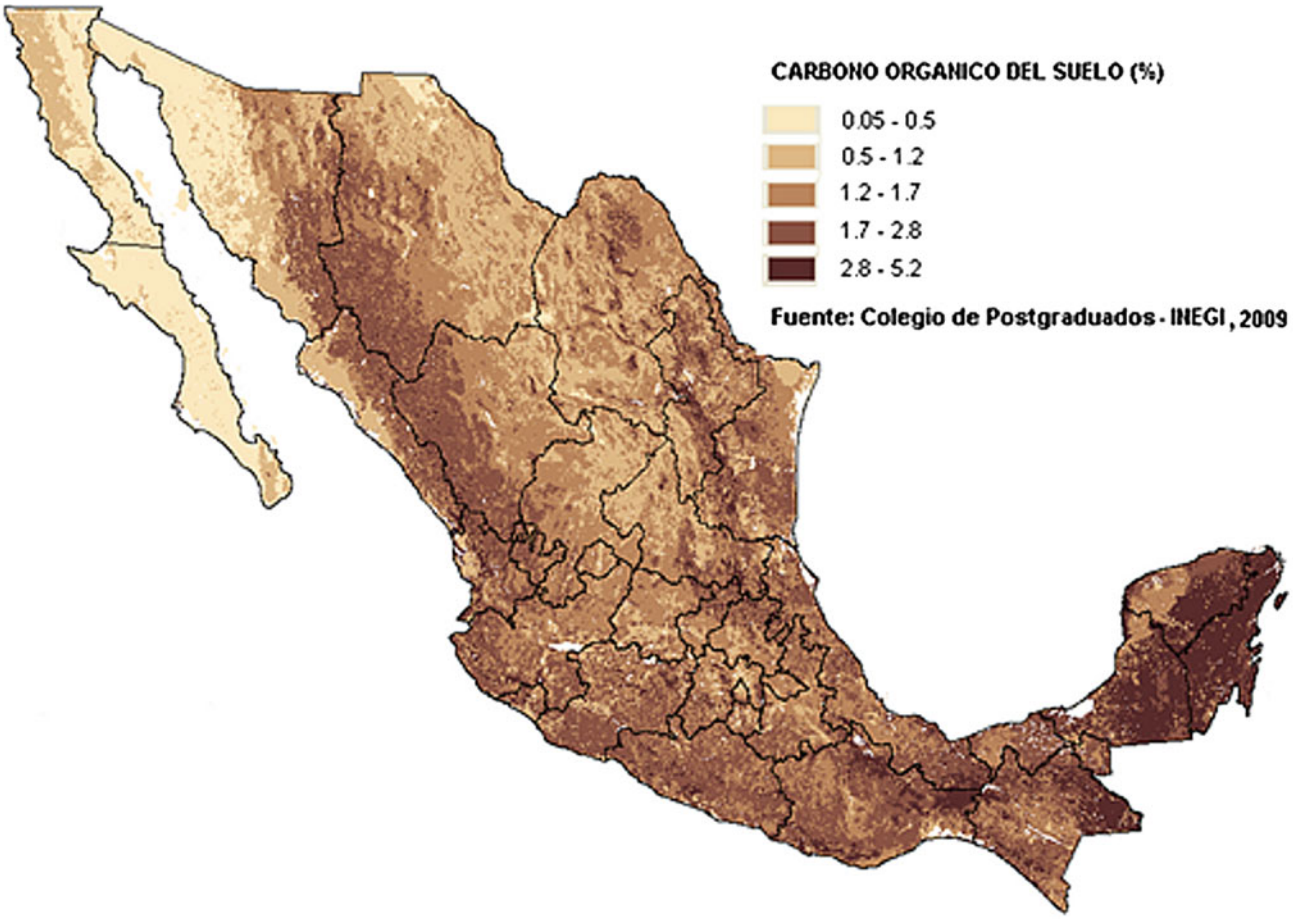

Fig. 2.17 The map of the reserves of soil organic carbon in Mexico prepared by C.O Cruz-Gaistardo

of conventional and nonparametric methods for modeling, and certain field verification makes the map a reliable tool for assessing soil degradation. The interpretation of the map showed that most of the heavily eroded soils (24.6 million ha) were erodible soils subjected to intense changes in land use, specifically deforestation, overgrazing, or poorly planned agriculture.

The soil organic carbon map provides data estimates of the C content in the soil, and serves as background for recording the C loss or acquisition in the future. The information will enable management to formulate policies that positively impact the reserves of CO_2 in ecosystems (Fig. 2.17).

References

Aboites L (1998) El Agua de la nación, Una historia política de México (1888–1946). CIESAS, México

Aguilera-Herrero N (1969) Mapa y distribución de los Grandes Grupos de Suelos. Atlas de la República Mexicana, Porrá, México.

Aguilera-Herrero N (1989) Tratado de edafología de México, Tomo I, Facultad de Ciencias, UNAM, México

Aguirre-Palancares N (1984) Las Ciencias Agrícolas y sus protagonistas vol. 1. Colegio de Postgraduados, Chapingo, México

Amundson R, Graham RC, Franco-Vizcaino E (1997) Orientation of carbonate laminations in gravelly soils along a winter/summer precipitation gradient in Baja California, Mexico. Soil Sci 162: 940–952

Ascanio-García MO, Hernández-Jiménez A (2005) Los suelos de los agrosistemas cañeros de Veracruz y Oaxaca: cambios globales y medio ambiente. Editorial Veracruzana, Ver, México

Baldwin M, Kellog CE, Thorp J (1938) Soil classification. In United States department of agriculture, Soils and men: Yearbook of agriculture 1938. US Government Printing Office, Washington

Barois I, Dubroeucq D, Rojas P, Lavelle P (1998) Andosol-forming process linked with soil fauna under the perennial grass Mulhembergia macroura. Geoderma 86:241–260

Barrera-Bassols N, Zinck JA (2000) Ethnopedology in a worldwide perspective: an annotated bibliography. ITC Publication No. **77**. International Institute for Aerospace Survey and Earth Sciences (ITC), The Netherlands

Basurto-Larrainzar A (1926) Tratado de Agronomía. Tomo II, México, Dirección de Estudios Geográficos y Climatológicos

Baum WK (1970) Land and power development in California, Greece, and Latin America. Interview with Packard W E. The University of California in Berkley

Bautista-Zuñiga F, Palacio-Álvaro G (eds) (2005) Caracterización y manejo de los suelos de la Península de Yucatán: Implicaciones agropecuarias, forestales y ambientales. UAC–UAY–INE, Yucatán, México

Bautista-Zuñiga F, Zinck AJ (2010) Construction of an Yucatec Maya soil classification and comparison with the WRB framework. J Ethnobiol Ethnomed 6:7. doi:10.1186/1746-4269-6-7

Bocco G, Velázquez A, Siebe C (2005) Using geomorphologic mapping to strengthen natural resource management in developing countries. The case of rural indigenous communities in Michoacan, Mexico. Catena 60:239–253

Brambila MR (1940) The tepetate soils of Mexico. In: Proceedings of the sixth Pacific science congress vol 4, pp 869–871

Bravo-Garza MR, Bryan RB (2005) Soil properties along cultivation and fallow time sequences on Vertisols in Northeastern Mexico. Soil Sci Soc Am J 69:473–481

CETENAL (1970) Modificaciones al Sistema de Clasificación FAO/UNESCO 1968, una opción ante el problema de clasificación de suelos para México. México DF

Comisión Nacional de Irrigación (1929) Memorias del 1er colegio agrológico. Villa de Meoqui, Chihuahua. México, DF

Cotter J, Osborne MA (1996) Agronomía afranceada: The French contribution to Mexican agronomy, 1880–1940. Sci Technol Soc 1:25–49

Cruz-Cárdenas G, Ortiz-Solorio CA, Ojeda-Trejo E, Martínez-Montoya JF, Sotelo-Ruiz ED, Licona-Vargas AL (2010) Evaluation of four digital classifiers for automated cartography of local soil classes based on reflectance and elevation in Mexico. Intern J Remote Sens 31:665–679

Cruz-Gaistardo CO, García-Calderón NE, Krasilnikov P (2006) Avances en la cartografía de México con WRB. In: Memorias del X congreso nacional y II internacional de la ciencia del suelo "Suelo, Seguridad Alimentaria y Pobreza", 6–10 de, Lima, Perú. pp 193–196

Cuanalo de la Cerda H (1975) Manual para la descripción de perfiles de suelos en el campo. Colegio de Posgraduados, Chapingo, México

De León-González F, Gutiérrez-Castorena Ma del C, González-Chávez MCA, Castillo-Juárez H (2007) Root-aggregation in a pumiceous sandy soil. Geoderma 142:308–317

Drijber RA, Lowe LE (1990) Nature of humus in Andosols under differing vegetation in the Sierra Nevada, Mexico. Geoderma 47:221–231

Drijber RA, Lowe LE (1991) Bound phenolic acids in humus fractions of andosols under varying vegetation in the Sierra Nevada, Mexico. Geoderma 48:431–442

Dubroeucq D, Campos A, Geissert D (1992a) Comportamiento de los andosoles negros con respecto al agua en el volcán Cofre de Perote. Terra 10:51–58

Dubroeucq D, Geissert D, Moreno P, Millot G (1992b) Soil evolution and plant communities in coastal dunes near Veracruz, Mexico. Cah Orstrom, sér Pédol 37:237–250

Dubroeucq D, Geissert D, Barois I, Ledru M-P (2002) Biological and mineralogical features of Andisols in the Mexican volcanic highlands. Catena 49:183–202

Ducloux J, Delhoume JP, Petit S, Decarreau A (1995) Clay differentiation in Aridisols of northern Mexico. Soil Sci Soc Am J 59:269–276

Etchevers-Barra JD, Masera O, Balbontín C, Gómez D, Monterroso A, Martínez R, Acosta M, Martínez M, Ortiz C (2006) Soil carbon sequestration in Mexico and Central America. In Cerri C, Lal R (eds), CRC Press, Boca Raton

FAO (1968) Definitions of the soil units for the soil map of the world. World Soil Resources Report 33. FAO, Rome

FAO (1974) FAO-UNESCO Soil map of the world. vol 1. Legend. UNESCO, Paris

FAO-ISRIC-ISSS (1998) World reference base for soil resources. Soil Resources Report 84, FAO, Rome

FAO-UNESCO-ISRIC 1988. Soil map of the world, revised legend. World Soil Resources Report 60. FAO, Rome

Garcia-Calderón NE, Krasilnikov PV, Ibañez-Huerta A, Alvarez-Arteaga G, Fuentes-Romero E, Marín-Castro BE (2005) WRB classification of some polygenetic soils of Sierra Sur de Oaxaca, Mexico. Euras Soil Sci 38:S27–S34

Garcia-Calderón NE, Ibañez-Huerta A, Alvarez-Arteaga G, Krasilnikov PV, Hernández-Jiménez A (2006) Soil diversity and properties in mountainous subtropical areas, in sierra sur de oaxaca, Mexico. Can J Soil Sci 86:64–72

Gavande SA (1972) Física de suelos. Principio y aplicaciones. Editorial Limusa, México

Geissen V, Casasola-Hernández I, Sepúlveda-Lozada A (2006) Effect of open ditch draining on sediment and soil properties in cultivated areas in southeast Mexico. Geoderma 136:401–410

Geissen V, Kampichler C, López de Llergo-Juárez JJ, Galindo-Acántara A (2007) Superficial and subterranean soil erosion in tabasco, tropical Mexico: Development of a decision tree modeling approach. Geoderma 139:277–287

Geissen V, Sánchez-Hernández R, Kampichler C, Ramos-Reyes R, Sepulveda-Lozada A, Ochoa-Goana S, de Jong BHJ, Huerta-Lwanga E, Hernández-Daumas S (2009) Effects of land-use change on some properties of tropical soils—An example from Southeast Mexico. Geoderma 151:87–97

Gibson C (1978) Los Aztecas bajo el dominio Español, 1519–1810. Siglo 21 editores. México, DF

Glinka KD (1944) Los grandes grupos de suelos del mundo y su desarrollo. Traducido por GF Marbut y D Ojeda, ingenieros agrónomos de la comisión nacional de irrigación, México, DF

Gómez-Díaz. JD, Gutiérrez-Castorena Ma del C (2000) Los estudios de génesis de suelos en México. In Quintero-Lizaola R, Reyna-Trujillo T, Corlay-Chee I, Ibáñez-Huerta A, García Calderón NE (eds) La edafología y sus perspectivas al siglo 21, 1ª edición. Tomo I. CP-UNAM-UACH

Gómez-Segura MR (1976a) Episodios de la escuela nacional de agricultura. Centro de economía agrícola. Colegio de Postgraduados. Escuela Nacional de Agricultura. Chapingo, México

Gómez-Segura MR (1976b) Biografía de Agronómos. Centro de economía agrícola. Colegio de Postgraduados. Escuela Nacional de Agricultura. Chapingo, México

González JM (2006) History and development of soil science in Mexico. Abstr 18 World Congress of Soil Science, Philadelphia, pp 9–15

González-Gallardo A (1941) Introducción al estudio de los suelos. Banco nacional de crédito agrícola, México

Graham RC, Franco-Vizcaino E (1992) Soils on igneous and metavolcanic rocks in the Sonorian Desert of Baja California, Mexico. Geoderma 54:1–21

Guerrero-Eufracio EG, Cruz-Gaistardo CO (2011) Cartografía edáfica y mapas edáficos en México. In: Krasilnikov P, Reyna-Trujillo T, Jiménez-Nava FJ, García-Calderón NE (eds) Geografía de suelos de México. UNAM, Facultad de Ciencias, México

Gutiérrez-Castorena Ma del C, Gómez-Díaz JD (2000) Los estudios de génesis de suelos en Mexico. In Quintero-Lizaola R, Reyna-Trujillo T, Corlay-Chee I, Ibáñez-Huerta A, García Calderón NE

(eds) La edafología y sus perspectivas al siglo XXI, 1ª edición. Tomo I. CP-UNAM-UACH

Gutiérrez-Castorena Ma del C, Stoops G, Ortiz-Solorio CA, López-Avila G (2005) Amorphous silica materials in soils and sediments of the Ex-Lago de Texcoco, Mexico: An explanation for its subsidence. Catena 60:205–226

Gutiérrez-Castorena Ma del C, Stoops G, Ortiz-Solorio CA, Sánchez-Guzmán P (2006) Micromorphology of opaline features in soils on the sediments of the ex-Lago de Texcoco, México. Geoderma 132:89–104

Gutiérrez-Castorena Ma del C, Ortiz-Solorio CA, Sánchez-Guzmán P (2007) Clay coatings formation in tepetates from Texcoco, Mexico. Catena 71:411–424

Hernández-Jiménez A (1991) Informe sobre los suelos y sus factores limitantes para la caña de azucar en el Central Motzorongo, Veracruz, México. SUCROMER, Veracruz, México

Hernández-Xolocotzi E (1984) Las Ciencias Agrícolas y sus protagonistas. Colegio de Postgraduados, Chapingo, México. vol 1, 205–240

Hudson PF (2003) Event sequence and sediment exhaustion in the lower Panuco Basin, Mexico. Catena 52:57–76

INEGI-SEMARNAP (1999) Mapas de suelos dominantes, FAO/UNESCO/ISRIC, 1988, primera aproximación. SEMARNAP-CP-INEGI. Estadísticas ambientales, México

Kellogg CE (1937a) Soil survey manual. US Dept Agric Misc Publ 274

Kellog CE (1937b) Manual de levantamientos agrológicos. Se traduce por Miguel Pérez-Espinosa. Memorandum Técnico nu. 2. Comisión Nacional de Irrigación, México

Krasilnikov PV, Tabor JA (2003) Perspectives on utilitarian ethnopedology. Geoderma 111:197–215

Kuhn NJ, Bryan RB, Navar J (2003) Seal formation and interrill erosion on a smectite-rich Kastanozem from NE-Mexico. Catena 52:149–169

Laird RJ (1989) Evolución de la ciencia del suelo en México y los desafios para el futuro. TERRA 7:173–189

Macías-Villada (1963) Los suelos de la República Mexicana. Secretaría de Recursos Hidráulicos. Dirección de Agrología, México, DF

Martínez-Gamiño MA, Walthall PM (2000) Propiedades físicas, químicas y mineralógicas en el encostramiento de suelos de México y Louisiana, EU. TERRA 18:179–185

Méndez-Linares AP, López-Portillo J, Hernández-Santana JR, Ortiz-Pérez MA, Oropeza-Orozco O (2007) The mangrove communities in the arroyo seco deltaic fan, Jalisco, Mexico, and their relation with the geomorphic and physical- geographic zonation. Catena 70:127–142

Mendoza-Vega J, Karltun E, Olsson M (2003) Estimation of amounts of soil organic carbon and fine root carbon in land use and land cover classes, and soil types of Chiapas highlands, Mexico. Forest Ecology Manag 177:191–206

Mendoza-Vega J, Messing I (2005) The influence of land use and fallow period on the properties of two calcareous soils in the humid tropics of southern Mexico. Catena 60:279–292

Núñez-Escobar R (2000) Academia de ciencias agrícolas en el Colegio de Postgraduados. Evolución de la investigación y la educación en suelos. Programa de Edafologia, Colegio de Postgraduados, Montecillo, Texcoco, México

Oropeza-Mota JL (2011) Conservación del suelo y de agua. Introducción general y antecedentes. Especialidad de Hidrociencias, Colegio de Postgraduados. Montecillo, Texcoco, México

Ortega-Torres E (1981) Química de Suelos. Departamento de Suelos. Universidad Autónoma Chapingo. Texcoco, México

Ortiz-Solorio CA (1993) Evolución de la ciencia del suelo en México. Ciencia Special Issue:23–32

Ortiz-Solorio CA, Gutiérrez-Castorena Ma del C (1999) Evaluación taxonómica de sistemas locales de clasificación de tierras. TERRA 17:277–286

Ortiz-Solorio CA, Gutiérrez-Castorena Ma del C (2000) Situación actual y perspectivas de la clasificación de suelos en México. In Quintero-Lizaola R, Reyna-Trujillo T, Corlay-Chee I, Ibáñez-Huerta A, García Calderón NE (eds) La edafología y sus perspectivas al siglo XXI, 1ª edición. Tomo I. CP-UNAM-UACH

Ortiz-Solorio CA, Gutiérrez-Castorena Ma del C (2001) Mexican Ethonopedology: The experience in soil mapping roots and wings for development. Royal Academy of Overseas Sciences and UNESCO, pp 107–136

Ortiz-Solorio CA, Pajaro D, Gutiérrez-Castorena Ma del C (1994) Introduccion a la leyenda del mapa mundial de suelos FAO-UNESCO, version 1988. Colegio de Postgraduados, Texcoco, México

Ortiz-Villanueva B (1975) Edafología. Escuela Nacional de Agricultura. Chapingo, Texcoco, México

Ortiz-Villanueva B (1975) Fertilidad de suelos. Escuela Nacional de Agricultura. Chapingo, Texcoco, México

Ortiz-Villanueva B, Ortiz-Solorio C (1990) Edafología. 7a ed. Universidad autónoma de chapingo, México

Palacios-Rangel Ma I (2011) Apuntes de la historia de la Sociedad Mexicana de la Ciencia del Suelo. In Leos-Rodríguez JA, Ledezma-Ocampo J, Palacios-Rangel Ma I, Reyes-Canchola R (eds). Sociedad Mexicana de la ciencia del suelo: tenacidad de una construcción. UACH. Chapingo, México

Palacios Rangel Ma I, Leos-Rodríguez JA (2011) La Sociedad Mexicana de la Ciencia del Suelo, una historia de identidad compartida. Colegio de Posgraduados, México

Palma-López DJ, Cisneros OJ, Trujillo NA, Granados AN, Serrano BJ (1985) Caracterización de los suelos de Tabasco (uso actual, potencial y taxonomía). DESIC-SECUR, Gobierno del Estado de Tabasco. Villahermosa, Tab. México

Peña-Ramírez VM, Vázquez-Selem L, Siebe C (2009) Soil organic carbon stocks and forest productivity in volcanic ash soils of different age (1835–30,500 years B.P.) in Mexico. Geoderma 149:224–234

Prado B, Duwig C, Hidalgo C, Gómez D, Yee H, Prat C, Esteves M, Etchevers JD (2007) Characterization, functioning and classification of two volcanic soil profiles under different land uses in Central Mexico. Geoderma 139:300–313

Reed WR (2009) Historical views of soil explorations in the Laguna Salada basin, Baja California, Mexico. Soil Geography: New Horizons, Abstr Intern Conf Huatulco, Mexico, pp 16–20

Rodrigo-Vallejo J (1984) Las ciencias agricolas y su protagonistas, vol1, Colegio de Postgraduados, Chapingo, México

Rodríguez A, Brambila M (1937) Un primer intento para agrupar los suelos de México dentro de los grandes grupos del mundo, Comisión Nacional de Irrigación, Departamento de Sistemas de Riego, México

Rodríguez-Adame J (1984) Las Ciencias Agrícolas y sus protagonistas, vol 1. Colegio de Postgraduados, Chapingo, México

Salgado-García S, Núñez-Escobar R (2010) Manejo de fertilizantes químicos y orgánico. MundiPrensa, México, S.A. de C.V. México, p 146

Segura-Castruita MA, Sánchez-Guzmán P, Ortiz-Solorio CA, Gutiérrez-Castorena Ma del C (2005) Carbono organico de los suelos de México. Terra Latinoamericana 2:21–28

Servenay A, Prat C (2003) Erosion extension of indurated volcanic soils of Mexico by aerial photographs and remote sensing analysis. Geoderma 117:367–375

Soil Survey Staff (1960) Soil classification, a comprehensive system, 7th approximation. US Government Printing Office, Washington

Solleiro-Rebolledo E, Sedov S, Gama-Castro J, Flores-Román D, Escamilla-Sarabia G (2003) Paleosol-sedimentary sequences of the Glacis de Buenavista, Central Mexico: interaction of Late Quaternary pedogenesis and volcanic sedimentation. Quatern Intern 106–107:185–201

Solleiro-Rebolledo E, Sedov S, McClung de Tapia E, Cabadas H, Gama-Castro J, Vallejo-Gómez E (2006) Spatial variability of environment change in the Teotihuacan valley during the Late Quaternary: paleopedological inferences. Quatern Intern 156–157: 13–31

Solleiro-Rebolledo E, Sedov S, Macías JL, Pi T (2007) Late Holocene paleopedological records contained in tephra from El Chichón volcano, Chiapas, Mexico. Catena 71:444–455

Tovar JL (1986) El departamento de suelos de la Universidad Autónoma Chapingo. UACH, Chapingo, México

Williams BJ (1976) Nahuatl soil glyphs from Códice de Santa María Asunción. Actes du XLII congres internacional des americanistes, Paris II:27–37

Williams BJ, Harvey HR (1988) Content, providence, and significance of the Codex Vergara and Codice de Santa María Asunción. Am Antiq 53:337–351

Williams BJ, Jorge y Jorge Ma del C (2008) Aztec arithmetic revised: land-area algorithms and acolhua congruence arithmetic. Science 320:72–77

Williams BJ, Ortiz-Solorio CA (1981) Middle American folk soil taxonomy. Ann Assoc Am Geogr 71:335–358