

2.1 History

The soil survey of Taiwan has been developed for more than 90 years. The soil survey program was started in Taiwan very early; Dr. Shibuya published the reconnaissance soil texture map in 1911 (Fig. 2.1) and the soil reaction map in 1913 (Fig. 2.2). After the reconnaissance soil survey, a series of county soil survey programs were conducted until World War II. The reports focused on soil fertility, land use, and rural infrastructure planning.

After World War II, two major programs on soil survey were conducted, i.e., “Key to the soils of Taiwan” and “A General Study on the Soil Fertility of Taiwan” (Si and Chang 1951) and “County’s soil survey” (1947–1964). The soil classification system followed the 1938 USDA yearbook system of soil classification. Some special purpose soil survey programs were conducted during this period, such as marginal lands land use capability survey (1960) and soil fertility survey of farmlands (1967, 2008), fertility capability classification (1983) for land use planning, and fertilizer management. The aims of most of the programs were concentrated on soil fertility topics due to lack of fertilizers and food security consideration during the period (Guo et al. 2002).

The soil information system can provide information about the pattern of the soil cover and its characteristics for us to analyze and display the topics on soil resources management. Soil information system of plain region and hill lands was constructed by the Taiwan Agricultural Research Institute (TARI) and Soil and Water Conservation Bureau (SWCB) in 1988 and 1990, respectively. The soil information application has become very popular since then. The soil data provided for application in the university and by the government was applied in the fields of environment

protection, land management, nature resources management, and civil engineering application. More than 30 applicants from different institutes ask for soil information every year.

Soil survey has been conducted since the 1920s; some Japanese soil scientists made an approximate soil survey including soil pH and soil texture maps. Below are 19 survey projects that can be listed as important events in the last 50 years since the 1950s.

- Reconnaissance soil survey of Taiwan (1946–1952), conducted by TARI, Council of Agriculture.
- Soil survey and soil fertility evaluation, conducted by Taiwan Fertilizer Company (TFC).
- Soil Survey of Taoyuan County, conducted by TFC.
- Soil survey of Tobacco production of Taiwan, conducted by Department of Agricultural Chemistry, College of Taiwan Provincial Agriculture.
- Soil survey of agricultural farms of Taiwan Sugar Company (TSC), conducted by TSC.
- Soil survey for land use of agriculture and forestry, conducted by TARI.
- Soil survey of Tea production in Kuang-See Township, conducted by the Department of Agricultural Chemistry, National Taiwan University (DAC/NTU).
- Detail survey of Taiwan saline soils, conducted by Department of Agricultural Chemistry, College of Taiwan Provincial Agriculture.
- Soil survey and land use of Lu-Kang region of Chang-hwa County, conducted by TFC.
- Soil survey of saline soil along seashore, conducted by TSC.
- Detailed soil survey of Taiwan rural soils, conducted by National Chung Hsing University (NCHU) from 1962 to 1976 and by TARI from 1974 to 1979.

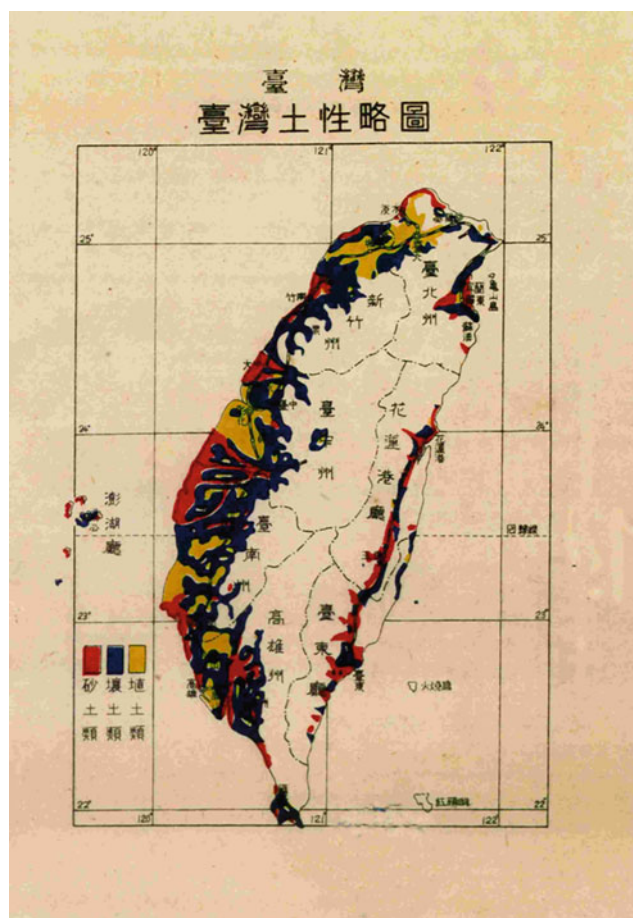


Fig. 2.1 Soil texture map of Taiwan by Dr. Shibuya in 1911. Copyright by Prof. Chen

- Soil survey of Southern region of Taipei Basin, conducted by TFC.
- Reconnaissance soil survey of Taiwan Forest soil, conducted by Forestry Bureau of Taiwan Province.
- Detailed soil survey of Taiwan hill land (1980–1988), conducted by Bureau of Agriculture and Livestock of Hill Land, Taiwan Province.
- Survey of contaminated soils (1984–2000), conducted by NCHU, NTU, Taiwan Agricultural Chemical and Toxic Materials Research Institute (TACTRI), and National Pingtung University of Science and Technology (NPUST).
- Survey of soil productivity grade of upland in Taiwan (1986–1990), conducted by Department of Soil Science, NCHU.
- Detailed soil survey of Taiwan forest soils, which the elevation ranged from 1,000 to 4,000 m (1993–2002), conducted by Taiwan Forestry Research Institute (TFRI), Council of Agriculture.
- Detailed grid soil survey of Taiwan rural soils (2000–2010), conducted by TARI.

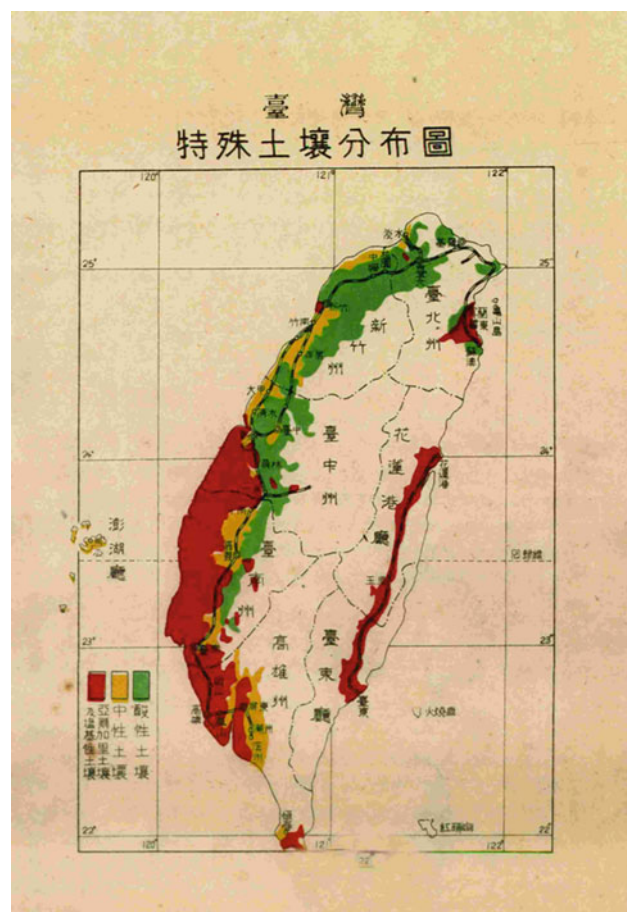


Fig. 2.2 Soil reaction map of Taiwan by Dr. Shibuya in 1913. Copyright by Prof. Chen

- Soil quality monitoring project after different soil management system (1997–2007), conducted by TARI.

2.2 Survey Report and Mapping

Systematic soil surveys of agricultural lands, hill lands, and forest lands on a detailed scale (1:25,000) were implemented in Taiwan in the period 1960–2006. The programs were conducted by NCHU and TARI for farmlands from 1960 to 1978, SWCB was in charge of the hill lands region during 1979–1988, and Taiwan Forestry Research Institute (TFRI) and Bureau of Forestry (BOF) responded for forest region from 1994 to 2006. The soil characteristics of Taiwan were well understood after a 46-year period of soil survey projects. However, different institutes conducted these three stages of soil survey programs, so it takes a lot of time to correlate the soil attributes, map units, and boundaries of soil delineations between these different programs. Unclear soil mapping concepts and techniques in those days also makes soil correlation a problem (Guo et al. 2002).

Eight soil survey projects by 19 teams abovementioned have made valuable and meaningful contribution leading to improvement of human life, such as in agricultural development, designing agricultural policy on agriculture and environment, and education. Especially, the great contribution of soil survey on Taiwan agricultural development is realized as a knowledge infrastructure.

2.2.1 Reconnaissance Soil Survey of Taiwan Province (1946–1952)

This survey was conducted by TARI from 1946 to 1952. Eight volumes of soil survey reports, including eight counties of Taichung, Penghu, Tainan, Kaohsiung, Pingtung, Taoyuan, Hsingchu, and Miaoli, and soil maps on the scale of 1:100,000 have been published. Unfortunately, four counties of soil survey reports were not published owing to limitations in budget. This soil survey followed the soil taxonomy created by USDA in 1938, and soil mapping unit was soil series, soil types, and soil phase for different soils in this stage. The soil survey quality was regarded as a very high soil survey work at that time.

2.2.2 Detailed Soil Survey of Taiwan Rural Soils (1962–1976, 1974–1979)

This survey was conducted over a period of 15 years by the Department of Soil Science, NCHU from 1962 to 1976, with a team of 12 soil surveyors. It was chaired by Professor Min-Kao Wang. Seven volumes of soil survey reports were published for the area of southern Taiwan, including seven counties of Changhwa, Tainan, Pingtung, Chayee, Kaohsiung, Yulin, Taichung, and Nantou, and 90 soil maps on the scale of 1:25,000 were published. There are 342 soil series established by the team of soil survey in this stage.

Then this soil survey was taken over by TARI for 6 years from 1974 to 1979, chaired by Researcher Chun-Chuang Chen. About 10 soil surveyors joined this team. Four volumes of soil survey reports, including four counties of Taoyuan, Miaoli, Hsingchu, Taipei, and Ilan, and 88 soil maps on the scale of 1:25,000 were published. There are 278 soil series established by the team of soil survey in this stage.

The most important contribution of this detailed soil survey is to establish 620 basic soil series of Taiwan rural soils and to publish 177 soil maps on a scale of 1:25,000 for soil management and fertilization recommendation. The soil series was identified by the differences in parent materials, drainage classes, texture changes through the profile, and

soil reaction in some cases. The soil survey system was followed by the Soil Taxonomy system created by USDA in 1949, and soil mapping unit is the soil type for rural soils. This soil survey work was regarded as the most important contribution for agricultural production and development in Taiwan.

2.2.3 Detailed Soil Survey of Taiwan Hill Land (1980–1988)

This survey was conducted by the Bureau of Agriculture and livestock of hill land (reorganized as SWCB later), Taiwan, from 1980 to 1988. This soil survey was chaired by Researcher Chun-Chuang Chen, who was working at TARI. About 12 soil surveyors joined this team. The survey area of hill land is the elevation lower than 1,000 m except the rural soils surveyed before 1980. A total of 13 volumes of soil survey reports of Taiwan hill lands and 215 soil maps on the scale of 1:25,000 were published. There are 432 soil series established by the team of soil survey in this stage, in about 10 years (1980–1988).

The soil series was also identified by the differences in parent materials, drainage classes, texture changes of the profile, and soil reaction in some cases. The soil survey system was followed by the approximate Soil Taxonomy created by USDA revised in 1960, and the soil mapping unit is soil phase including surface soil textures and slope. This soil survey work was regarded as the most important contribution for Taiwan agricultural production and development.

2.2.4 Soil Survey of Productivity Grade of Taiwan Upland (1986–1990)

This survey was conducted for 5 years by the Department of Soil Science, NCHU from 1986 to 1990. This soil survey was chaired by Professor Chur-Chung Yang, who was working at the Department of Soil Science, NCHU. About 10 students joined this team. Four classes of soil productivities were established depending on the existence of texture changes of soil profile and gray mottles formed at different soil depths, such as 40–60, 60–90, 90–150 cm, and lower than 150 cm from soil surface. Finally, 168 soil maps of soil productivity classes of Taiwan upland on a scale of 1:25,000 were published. The conclusion is that the worst soil productivity corresponds to the occurrence of gray mottle which was produced in the surface 40–60 cm depth, while the best soil productivity is the gray mottle in soil deeper than 150 cm.

2.2.5 Soil Survey of Contaminated Soils (1984–2000)

This survey of contaminated soils in Taiwan was conducted for 10 years by NCHU, NTU, Taiwan Agricultural Chemical and Toxic Materials Research Institute (TACTRI), and National Pingtung University of Science and Technology (NPUST). This soil survey was chaired by Professor Yin-Po Wang, who worked at the Department of Soil Science, NCHU. About two researchers from government agencies, five professors of universities, and 10 students and research assistants joined this team. Owing to the serious soil contamination found around the discharged area of 90 industrial parks in Taiwan, Taiwan Environmental Protection Administration (Taiwan/EPA) started the soil survey of contaminated rural soil by heavy metals from 1984 to now, including As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn.

More than 10,000 soil sampling locations, 150 potential polluted sites, and five seriously polluted sites in Taiwan were included into this GIS system, hence we can make an evaluation of the status of contaminated sites to identify the relationships between the contamination soil status and contaminated resources, and also to request the best remediation techniques to be applied in the remediation projects in the future.

2.2.6 Detailed Soil Survey of Taiwan Forest Soils in Mountains (1993–2002)

This detailed forest soil survey was conducted for 10 years by Taiwan Forestry Research Institute (TFRI) from 1993 to 2002. This soil survey was chaired by Mr. Kuang-Chin Lin, who was working at the Department of Silviculture, Taiwan Forest Research Institute, Council of Agriculture (TFRI). About 16 soil surveyors joined this team for 10 years. Until now, more than 10 volumes of soil survey reports, and more than 200 soil maps on a scale of 1:50,000 were published. More reports and soil maps will be continuously published in the next few years. The soil data and soil maps can be retrieved from the Internet (<http://ims.tfri.gov.tw/tfri1/main.aspx/>) (TFRI 2005).

The soil classification of this survey was based on *Keys to Soil Taxonomy* (Soil Survey Staff 1998), and soil mapping unit is soil phase including surface soil textures and slope. This soil survey work was regarded as the most important contribution for Taiwan forestry production and development in the next decade. All the published reports and soil maps were combined into the Taiwan National Soil Information System in the website of TARI (http://www.tari.gov.tw/index_in.htm) (Guo et al. 2005), shown in Chinese, not included English version.

[tw/index_in.htm](http://www.tari.gov.tw/index_in.htm)) (Guo et al. 2005), shown in Chinese, not included English version.

2.2.7 Detailed Grid Soil Survey of Taiwan Rural Soils (2000–2010)

Taiwan Agricultural Research Institute (TARI) began to conduct a detailed grid soil survey project from 2000 to 2010. This soil survey was chaired by Mr. Horng-Yu Guo (HYGuo@wufen.tari.gov.tw), who is working at the Department of Agricultural Chemistry, Taiwan Agricultural Research Institute, Council of Agriculture (TARI/COA) (Guo et al. 2000). One representative soil profile was sampled in every 250 m based on the air photo pictures on a scale of 1:5,000. This means there is one representative soil profile data that was sampled in 6.25 ha by soil auger from soil surface to 150 cm depth, including six samples in one profile at 0–15, 15–30, 30–60, 60–90, 90–120, and 120–150 cm depth from soil surface. The soil samples showed the soil morphological characteristics, and also the basic physical, chemical, and biological properties in the laboratory of TARI.

More than 5,000 soil profiles (or 30,000 soil samples) were sampled in one county, and more than 90,000 soil profiles (or 540,000 soil samples) database in the whole of Taiwan were included in the GIS system of National Soil Information System of Taiwan. From this valuable database, many item maps were produced and published by TARI for soil interpretation, land planning, and soil management, especially for fertilizer recommendation for different crops production (http://www.tari.gov.tw/index_in.htm). Until now, this website is shown in Chinese, not in English version. These maps are also demonstrated in many workshops of reasonable fertilization workshop on high economic fruits in Taiwan, especially for rice, corn, sorghum, citrus, wax apples, mango, watermelon, apple, and vegetables. The soil item maps are listed as follows:

- Maps of soil pH values of surface soils
- Maps of soil texture classes of surface soils
- Maps of soil organic matter content of surface soil
- Maps of soil drainage classes
- Maps of soil erosion prediction
- Maps of crop suitability classes for 300 crops and economic fruits
- Maps of soil moisture regimes
- Maps of soil temperature regimes
- Maps of Soil Orders based on Soil Taxonomy (Soil Survey Staff 1999)
- Maps of soil available nutrients including N, P, K, Na, Ca, Mg, Fe, Mn, Cu, and Zn

- Maps of soil management groups
- Maps of bioavailable heavy metals (extracted by 0.1 M HCl).

2.2.8 Soil Quality Monitoring Project After Different Soil Management System (1997–2007)

The Taiwan Agricultural Research Institute (TARI) conducted a soil quality monitoring project from 1998 to 2008. This soil quality monitoring project was chaired by Mr. Horng-Yu Guo (HYGuo@wufen.tari.gov.tw), working at the Department of Agricultural Chemistry, Taiwan Agricultural Research Institute, Council of Agriculture (TARI/COA) (Guo et al. 2003). One hundred and fifty rural soil sites were selected from different environmental conditions including different soils, crops, and climates conditions, for monitoring the changes in soil quality in each site. The area of each representative site is 1 ha. Thirty soil samples were sampled in this 1 ha site and soil characteristics are also analyzed for evaluation of changes in soil quality.

This monitoring project was conducted in the second round of 150 sites in Taiwan (first round in 1997–2002 and second round in 2002–2007). They have selected some soil indicators to evaluate the change in soil quality, including soil texture, pH, organic C, total N, exchangeable K, Na, Ca, Mg, and Mn (extracted by 0.1 M sodium acetate at pH 7), soluble Fe, Mn, Cu, Zn, Cd, Pb, Cr, and Ni (extracted by 0.1 M HCl), and available P, K, Ca, Mg, Na, B, Cu, Zn, Fe, and Mn (extracted by Mehlich #3 solution). Unfortunately, no data of biological soil indicators were included into their database. After 5 years' monitoring, the results indicate that the soil-available phosphorus content is much higher than the need for crops and soil-available K is still not enough for crop production. We need more workshops to train farmers to have better soil and fertilizer management in the future.

2.3 Soil Information System (Application and Education)

Soil information was applied on several fields by TARI, such as: the soil productivity classification of paddy fields (1986), soil productivity promotion planning (1993), soil management grouping (1998), assessment of susceptibility of soil liquefaction (1999), assessment of the susceptibility of nitrogen fertilizer (2000), and soil quality monitoring (2001). An agricultural environmental management expert system (rice) is in progress; the system includes climate data, soil data, and soil testing data, cadastral data, and crop

management of knowledge base provides recommendations for cultivation process for each farmer.

There are 15 attributes data for each map unit in this system that include: parent material, soil morphology (color or special feature), soil formation, soil drainage class, slope class, soil reaction, soil calcareous properties, soil type, four layers of different depth of soil texture class of the representative profile, and soil phases (salinity, stoniness and gravelly). The attributes of soil units except soil reaction are qualitative, i.e., by grades or classes classification. TARI has applied these soil databases of Taiwan farmlands to recognize the distribution and to assess the grade of low-productivity croplands.

However, the basic soil attribute data that soil survey reports provided could not be satisfied with the requirement of intensified farming system operation and rapid-changing soil quality (Guo et al. 1992). A soil fertility project, which concerns plant nutrients and heavy metals contained in soil is in progress. These attribute data will be as compensation for the soil survey data shortage of the management of soil nutrients and food safety protection. This chapter provides experiences of providing information for the management of low-productivity and degraded soils that we have done in Taiwan.

2.3.1 Soil Information Apply to Low Productivity Land Assessment

By the concept of FAO land qualities, the low-productivity soils assessment chose several land qualities that criteria could link with the soil information system of Taiwan farmland, such as shallowness, stoniness, workability, salinity, acidity, water logging, droughty (moisture availability), nutrients deficiency. The low-productivity soils criteria inferred from the soil survey reports, research reports, and derived soil quality and fields experience. The soil database was evoked in relation with criteria to assess and map the distribution of the low-productivity soils.

The soil properties and soil fertility in Taiwan are not of good quality; however, many crops have good yields; intensive fertilizer application and soil management are the reasons for the results. Though improved management and ameliorative measures have been intensively studied to solve these low productivity soils, the problems of economical feasibility and social requirement prohibit the program of soil reclamation proceeding.

Soil information and soil management system provide a clear understanding of low productivity soils and degradation soils in Taiwan farmlands (Table 2.1). It provides an overview of the relative extent of physical resource limitations to agriculture and other forms of land use in the whole

Table 2.1 The soil attributes of soil information applied on the assessment of low productivity soils in Taiwan

Low-productivity soils	Attributes used for assessment	Acreages (ha)
Shallowness	Soil types; profile depth; soil phase	137,610
Stoniness	Soil phase	28,390
Tillage practice and soil workability	Soil type; profile texture; drainage class	107,010
Salinity	Soil salinity; drainage class	62,970
Acidity	Soil formation and pH	190,830
Water logging	Soil type; drainage class	47,480
Droughty	Profile texture; drainage class	55,970
Nutrients deficiency	Parent materials; pH; calcareous materials	268,980

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country; highlight the area which calls for the treatment or management of specific land resources constraints, so the regional or national action plans can be better focused on specific problems; indicates the limitations of the data and the amelioration methods, and hence the priority needs for improved information and research.

2.3.2 Soil Information Apply to Soil Liquefaction Assessment

Soil liquefaction has been observed in many places after the 921 Taiwan Chichi Earthquake mentioned in Chap. 1. Soil liquefaction resulted in disastrous effects such as tilted buildings, foundation failure, and sand volcanoes or sand boils in the fields. Because liquefaction only occurs in saturated soil, its effects are most commonly observed in low-lying areas near water bodies such as rivers, lakes, bays, and oceans. Parts of Taichung, Nantou, Changhua and Yunlin's Plain regions belong to these kinds of landscapes. The Tzo-Sui Alluvial Fan covers the most area in this region. The Tzo-Sui River had changed its waterway several times in the past 200 years, so many abandoned channels spread around this region. Taichung, Changhua, and Yunlin plains are also near the seashores, these lands have high potential of soil liquefaction.

Sands were considered to be the only type of soil susceptible to liquefaction, but liquefaction has also been observed in gravel and silt. So different soil textures are of different sensitivity to soil liquefaction. Soil drainage classes can indicate the different levels of soil water contents, which can be also used to evaluate the sensitivity of soil liquefaction. We evaluated, classified, and mapped the susceptibility of soil liquefaction in disastrous regions based on three categories in soil information. The map further verified the

reliability in earthquake areas. Most of the boundaries of the soil liquefaction susceptibility units match the soil liquefaction regions. The reliability of the assessment of soil liquefaction susceptibility is very high. The information provided here could be very helpful in the developing plan for evading soil liquefaction hazard.

2.3.3 Soil Information Apply to Food Safety

The quality of food (rice) has become a social-economic issue of concern in Taiwan due to soil pollution. New insight into the relationship between soil quality and the quality of food should be used by soil environmental scientists around the world to improve scientific methods to provide tools to estimate risks, set soil standards, and reduce the uptake of heavy metals by rice. To assess the risk of the metals in these soils, soil quality guidelines standards have been developed in many countries, including Taiwan. Such soil quality standards are based on the total heavy metal content although research results from the last decade clearly indicate that the risk of heavy metals in soils does not depend on the total metal content only. In fact, a part of the total metal content can be considered nonreactive.

At 16 sites, 12 different cultivars of rice were used, including the ones most commonly grown at present in Taiwan. This includes japonica type, *indica* type, and sticky rice which are the three major rice varieties. It was found that the heavy metal uptake rate differs among the rice varieties: uptake by *indica* varieties is higher compared to *japonica* varieties, which is especially true for cadmium in brown rice. It was commonly observed that although the soil cadmium concentration was below the standard level of monitoring, the cadmium concentration in the brown rice of several *indica* varieties exceeded the rice safety regulation for cadmium. A detailed report can be referred from Guo et al. (2007). The regression equations to predict cadmium uptake by brown rice from soil properties according to equation are calculated. The results indicate that the prediction of brown rice of cadmium concentration is by considering soil pH, organic carbon, and CEC.

Experimentally derived models were used to calculate the so-called risk map for rice cropping. This was done by calculating the critical levels of cadmium in the soil above which the rice cadmium content exceeds the food quality standard. The soil database from Taiwan was used to compare this critical level with the actual measured values across the country. The results indicate that areas exist where the quality of *indica* species will be insufficient (i.e., cadmium in the rice will exceed the standard of 0.2 or 0.4 mg kg⁻¹). Such areas include soils derived from marine sediments as well as contaminated soils. One of the options that are rather easy to implement by farmers is to grow *japonica* genotype rice in these regions.

2.3.4 Soil Museum for Soil Function Education

The international level of national soil museums were established and opened in 2005 at TARI for service to students, farmers, teachers, and government officials (http://www.tari.gov.tw/index_in.htm) (Fig. 2.3). More than 200 soil monoliths were displayed in this museum (Fig. 2.4).

The small scale of university level soil museum was established and opened in 2005 at National Taiwan University (NTU Soil Museum) (<http://Lab.ac.ntu.edu.tw/soilsc/>) (Figs. 2.5, 2.6 and 2.7), which provided more than 100 soil monoliths to show the typical soil morphological characteristics and valuable posters to display the soil properties and to use these characteristics for more interpretation in soil

Fig. 2.3 Opening ceremony of Taiwan Soil Museum in 2005. Copyright by Prof. Chen



Fig. 2.4 The display of soil monoliths in the Taiwan Soil Museum. Copyright by Prof. Chen



Fig. 2.5 The display of soil monoliths in NTU Soil Museum. Copyright by Prof. Chen



Fig. 2.6 Soil education for new generations in Taiwan (the standing lecturer is the primary author of this book in the Taiwan Soil Museum). Copyright by Prof. Chen

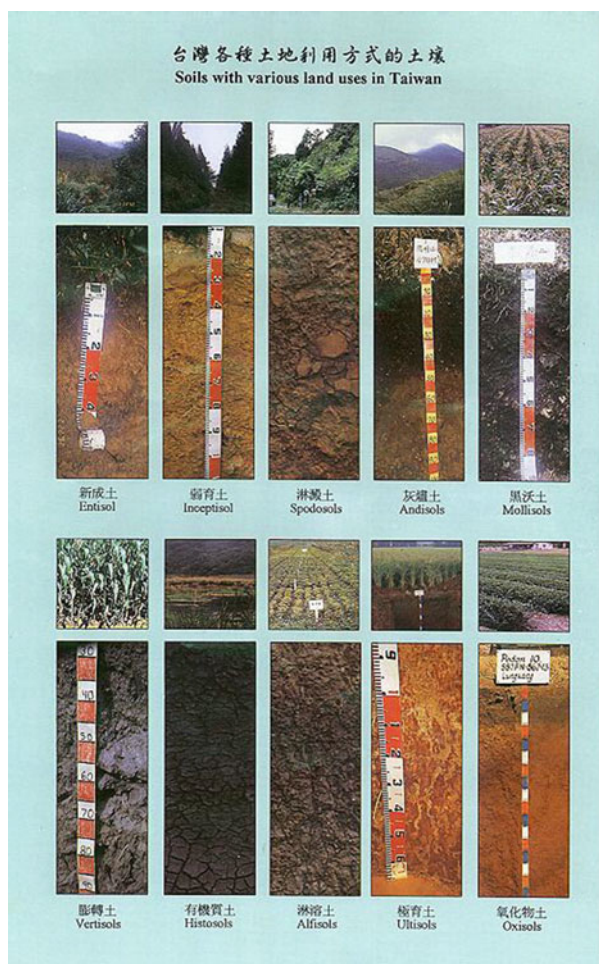


Fig. 2.7 Ten major soil orders of Taiwan soils are one of the typical posters shown in the Soil Museum of National Taiwan University. Copyright by Prof. Chen

management and soil quality, crop quality, and environmental quality in the future (Chen 1998; Chen et al. 1999a, b; Lee et al. 2006).

2.4 Pedology Studies in Taiwan

2.4.1 The Soil Characteristics and Genesis of Soils Derived from Different Parent Materials (1960–1975)

The basic research in soil morphological characteristics, clay mineralogy, and pedogenic processes of different representative soils derived from parent materials were conducted by Prof. Chang working at National Taiwan University (Chang 1962, 1964, 1966, 1969, 1971, 1972, 1974, 1975). The basic database of the representative “major Soil Groups” of Taiwan provided valuable soil information during the 1960s and made great contribution toward the agricultural development of Taiwan. These soil groups included sandstone alluvial soils, slate alluvial soils, schist alluvial soils, brown forest soils, Podzolic soils, volcanic ash soils, and red soils in the terrace of Taiwan.

2.4.2 The Soil Characteristics and Genesis of Rice-Growing Soils of Ultisols (1980–2005)

This series of studies was conducted for 10 years by colleagues from National Taiwan University from 1980 to 2005, especially for Ultisols with plinthites. Till date, more

than 10 scientific papers have been discussed and published in international journals, such as Soil Science Society of America Journal and Soil Science, and related local journals in Taiwan (Chang and Chen 1982; Chang et al. 1983; Chen 1984; Chen and Chang 1984, 1985; Chiang et al. 1997; Hseu and Chen 1994, 1995, 1996, 1997, 1999, 2000, 2001; Hseu et al. 2000; Jien et al. 2004).

2.4.3 The Soil Characteristics and Genesis of Podzolic Soils (1988–2005)

These series studies of Podzolic soils in Taiwan are conducted since the 1960s. There are significant albic horizons formed in subalpine and alpine forest soils in the central ridge of Taiwan, including Mountains of Alishan, Taipingshan, Chusahn, where the elevation is always higher than 2,500 m above sea level, with high precipitation (>4,500 mm/year and low annual air temperature, <15 °C). The second stage of these series studies was conducted by colleagues from the National Taiwan University from 1988 till the present. Four typical Podzolic soils in Taiwan were proposed (Chen and Tsai 2000), including Spodosols, Ultisols, and Inceptisols with or without placic horizon based on the Soil Taxonomy (Soil Survey Staff 1999, 2003; Hseu et al. 1999b).

Until now, more than 10 scientific papers have been discussed and published in international journals such as Soil Science Society of America Journal, Soil Science, Geoderma, and related local journals of Taiwan (Chen et al. 1989, 1995; Chen and Tsai 2000; Hseu et al. 1999, 2004; Li et al. 1998a, b; Lin et al. 1988, 2002; Liu and Chen 1990, 1991, 1998, 2004; Liu et al. 1998; Wu and Chen 2005). The most significant soil characteristics of these Spodosols, Ultisols, or Inceptisols, are loamy soil texture in the Spodic horizon or Spodic morphological horizon, whose clay content ranged from 250 to 350 g/kg. The other characteristics are that the soils have high precipitation, especially it is higher than 4,500 mm/year in the summer. These special characteristics are different compared with other countries which have the distribution of Spodosols.

2.4.4 The Soil Characteristics and Genesis of Volcanic Soils (1990–2005)

The first stage study of volcanic ash soils in Taiwan was conducted in the 1970s by Prof. Chang working at National Taiwan University (Chang 1972, 1974, 1975). Some basic research can be compared with the reports from Japan volcanic soils (Saigusa et al. 1991; Shoji et al. 1982, 1993). After 15 years, the second stage study was conducted for another 15 years by colleagues from National Taiwan University from the 1990s till the present, especially for non-

allophanic soils. Until now, more than 15 scientific papers have been discussed and published in international journals such as Soil Science and related local journals of Taiwan (Asio and Chen 1998; Asio et al. 2000; Chen and Huang 1991; Chen et al. 2001; Huang and Chen 1990, 1992; Huang et al. 1988, 1993, 1994).

Until now, 86 soil pedons have been studied in whole National park, major distributed in Mountains of Samao, Chishing, and Tatung. The soils were collected from different transects including Andisols (Hapludand, Fulvudand or in terms of Allophanic Andisols) and Inceptisols (Dystrudept, or in terms of nonallophanic Andisols) are formed in different regions of the park. The Inceptisols are distributed in the lower elevation and sharp landscape of the study area, about 60 % of the total area and the Andisols are distributed in the higher elevation and stable landscape of the study area, about only 15 % of the total area. The relationship between volcanic soil genesis and environmental factors is difficult to recognize in this area. We estimated that the interaction within climate, landscape, and vegetation would be variable with time and reduced the effect of landscape on the volcanic soil genesis.

Soil pedons selecting from Mt. Tatung to lower terrace were collected to understand the pedogenic process of volcanic soils and to identify the soil indicators of transition soils from Andisols to Ultisols under the same parent materials. The results of this study suggest that six pedogenesis indices may be useful to identify the transitional soils among Andisols, Inceptisols, and Ultisols, including soil texture, soil consistence, bulk density, phosphate retention, and amorphous material content of $A_{lo} + 1/2Fe_o$ (%), and S_{io} (%) (Tsai and Chen 2006; Tsai et al. 2006).

Volcanic activities occurred from about 0.5 to 0.8 million years ago, leaving various signs of post-volcanic activity that we can see today. The Pleistocene volcanic activities are most important in the geologic evolution of Taiwan. The most typical characteristics of Taiwan volcanic soils were collected from different transects including Andisols (Hapludand and Fulvudand or in terms of Allophanic Andisols) and Inceptisols (major with Dystrudept or in terms of non-allophanic Andisols) are formed in different regions of the park.

2.4.5 The Soil Genesis and Geomorphology on River and Marine Terraces (2005–Present)

Most soil properties are time-dependent variables, which can be used as indicators of the duration of pedogenesis. The island of Taiwan has experienced mountain building since about 5 Ma, and is still active until the present time (Ho 1988). River terrace is one of the most prominent

geomorphic features on the land surface serving as geomorphic marker to gauge the differential or absolute surface deformation. However, such use of river terrace is often hampered by the absence of well-documented ages for deformed or partially preserved surfaces (Tsai and Sung 2003).

The Pakua tableland defines a deformation front of the fold-and-thrust belt in central Taiwan due to tectonic compression (Lee et al. 1996; Delcaillau et al. 1998). There is a series of widely unpaired river terraces developed in the south of the tableland. They are divided into as many as six altitudinal levels. A soil chronosequence consists of genetically-related suites of soils of varying age that evolved under similar conditions of vegetation, topography, and climate (Harden 1982). The surface deposits of these river terraces may form a soil chronosequence since they have comparable soil-forming factors except the age of the deposit. However, the identification of a particular set of soil properties that are consistently indicative of soil development is needed. Therefore, Tsai et al. (2006) and Tsai et al. (2007a) used six representative soil pedons from the six levels of terraces on the tableland (from the highest pedon PK-1 to lowest pedon PK-6) to characterize the soil properties in a chronosequence, and to relate the pedogenic processes in the major terraces to the formation and evolution of the landscape. The soil morphological, physical, and chemical properties as well as the clay mineral variation showed that pedogenic intensity is strongly dependent on the terrace levels with varying formation age. Based on the crystallinity ratios of free iron, the soils give an estimated age of 40–400 ka for the river terraces of the tableland. The soils can be divided into three domains as Kandiodult for pedon PK-1, Paleudult (or Hapludult) for pedons PK-2, -3, -4, and -5 and Dystrudept for pedon PK-6, based on *Soil Taxonomy*. The degree of soil development increases with altitude in a sequence from PK-1 to PK-6 forming a post-incisive type of soil chronosequence in accord with the evolution of the geomorphic surface by successive river incision in the study area.

Tsai et al. (2007b) further explored the lateritic river terraces on the Pakua, Chushan, and Touliau tablelands in central Taiwan whose geomorphic features are inadequate for regional terrace correlation. They used an alternative pedogenic scheme based on the weighted mean profile development index (WPDI). Four soil pedons from the Chushan and Touliau terraces are classified as Inceptisol and Ultisol in *Soil Taxonomy*. By citing another six soil pedons (PK-1 to -6) of the Pakua terraces in the previous study (Tsai et al. 2006), the WPDI values of all the total 10 soil pedons suggest a chronological order for the terrace correlation. The correlation suggests the Chushan and Touliau terraces likely belong to one anticline as a whole, and is separated by the

Chinshui River. This anticline represents the southern extension of the Pakua anticline resulted from the frontal thrusting of the Changhua Fault.

Placing a time or age constraint on soil development has become one of the most important factors in the disciplines of soil science and fluvial geomorphology. The radiocarbon (^{14}C) method is unable to date old terraces or soils, but the longer half-life of cosmogenic beryllium-10 (^{10}Be) permits this isotope to be useful to determine soil ages and rates of formation. Red soils (redder than 7.5YR) are commonly distributed on old, high altitude river terraces throughout Taiwan. Tsai et al. (2008) used three pedons of alluvium-related red soils were sampled from the Taoyang (TY-YM), Pakua (PK-1), and Chiayi terraces (CY-1), respectively located in northern, central, and southern Taiwan. Meteoric ^{10}Be dating shows ages of ≥ 261 ka for TY-YM, ≥ 124 ka for PK-1, and ≥ 386 ka for CY-1. However, the trend of these ages does not agree with the degree of soil development. The former two ages are likely underestimated through loss of ^{10}Be due to strong leaching and considerable erosion. The age obtained from CY-1 may represent the minimum time required for soils develop into Oxisols in Taiwan.

The Tadu tableland is located at the deformation front of the Western Foothills in central Taiwan (Fig. 1.3). Previous geomorphic studies suggested a fluvial terrace landform developed on the surfaces of the tableland. However, other suggestions have been proposed in recent years. Tsai et al. (2010) solved the argument by examining the pedogenesis of surface deposits. Five soil pedons were sampled to the depths of C horizons in the surface deposits of the tableland. These soils were classified as Paleudult and Kandiodult of Ultisols according to *Soil Taxonomy*. In addition, their morphological characteristics were further quantified in terms of soil development by the horizon index and WPDI. The WPDI values of 0.64–0.73 for the soils of the Tadu tableland agree with those of Ultisols developed on the Pakua tableland. Both qualification and quantification assessments indicate all soils of the Tadu tableland are equivalent in terms of degree of pedogenesis. As a result, all the geomorphic surfaces on the tableland probably developed at the same time, which rules out the interpretation of fluvial terraces developing on the tableland. The pedogenic evidence supports the recently proposed kinematic model for the development of the Tadu tableland. Moreover, relative dating based on regional pedogenic correlation suggests the folding activities of the Tadu tableland occurred more recently than those of the Pakua tableland did.

Vertisols, Mollisols, and Entisols are generally found on different levels of marine terrace herein, but no detailed investigations in soil chronosequence have been conducted by integrating field morphology, physiochemical characterization, micromorphology, and mass balance interpretations.

Tsai et al. (2007c) found that strongly developed angular blocky structures, pressure faces, and slickensides are more common in higher terrace soils than in lower terrace soils. In their studies, including depth to C horizon, solum thickness, and thickness of the clay-enriched zone show increase with relative terrace age. Although only one to two profiles per terrace were characterized, the following soil analytical characterizations increase with time: the degree of sand grains weathering, pH (H₂O), organic carbon, CEC, contents of Fe_d, Fe_o, and Mn_d. Soils on all terraces have a mixed mineralogy. Mica, smectite, and kaolinite have slightly increased with increasing terrace age. Furthermore, the dominant processes identified with mass-balance analysis include loss of bases (Ca and Mg), iron, and clay with time. The soil properties, including analytical and mineralogical characterizations, which do not have notable changes with time are primarily due to relatively young soil age (<20 ka). Moreover, Huang et al. (2010) indicated that the relatively weaker degree of soil development on the oldest terrace at the southern part of Hua-tung marine terrace supports the conclusion that uplift rates in the southern area are greater than at middle and northern parts of Hua-tung marine terraces in eastern Taiwan (Fig. 7.2).

2.5 Work Needs in the Future

Soil mapping quality should be improved for more and more public requirements. The present soil database preferred chemical properties, but important physical properties like bulk density and hydraulic conductivity need to be collected for further application. The basic soil attributes data in soil survey reports could not be satisfied with the requirement of intensified farming system operation and rapid-changing soil quality. Therefore, we need to develop new strategies of soil survey for the future. The major items will be discussed, including the development of new soil survey techniques to identify the boundary of contaminated soils, improvement in soil properties due to the land use changes from paddy soils, use of national soil information system for more soil interpretation, and continuous education in soil function.

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