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CHAPTER 3
SOIL CHARACTERISTICS IN PALAU

Yin Yin Nwe, Christopher Kitalong and Takeshi Watanabe

What is soil?

Soil, pedosphere, is a mixture of solids and pores filled with air and water (Fig.12). The solid components include mineral (stone fragments, sand, silt, and clay), and organic fractions (Fig. 13). It serves four important functions:

- as a medium for plant growth
- as a means of water storage, supply, and purification
- as a modifier of Earth's atmosphere
- as a habitat for organisms

(Moebius-Clune et al., 2017)

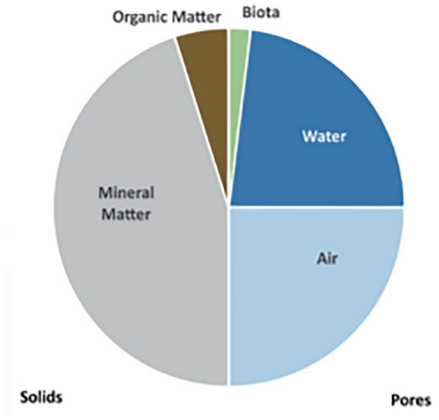

Fig. 12. Distribution of solids and pores in soil. Solids are minerals, organic matter and living organisms, or biota. Pores are filled with water, air, and biota. (Moebius-Clune et al., 2017)

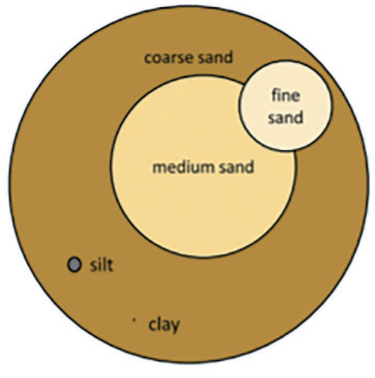

Fig. 13. Relative size of soil particles. (Moebius-Clune et al., 2017)

How is soil formed?

Natural soil formation processes are additions, losses, transformations, and translocations. Soils are generated from parent material, climate, organisms, landscape position, and time. Besides natural processes, human activities work to improve or deteriorate soil fertility.

- Additions mean input of water, organic matter, and sediment to soil.
- Losses mean output of soluble compounds, a part of soil from soil by erosion or some other reasons.
- Transformations mean qualitative changes in soil such as organic matter to humus and primary minerals to clay minerals.
- Translocations mean transfer of soil components such as soluble compounds and clays from one layer to another layer within soil.

How were soils in Palau formed?

Palau is geologically complex. It includes a mixture of older volcanic and metamorphic substrates on the large island of Babeldaob (20 – 40 million years before the present), limestone parent material capping volcanic core material on smaller islands to the south, and hundreds of small islands farther south. Palau also includes atoll islands at its northern and southern extremes. (Giardina et al., 2020).

What is soil health or soil quality?

Soil health or soil quality was defined as “the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health” (Doran and Parkin, 1994).

What soil properties are relevant to plant growth?

Healthy soil (good/ fertile/rich)	→→→	→→→	→→→	Unhealthy soil (bad/infertile/poor)
Texture/Structure: crumbly	→→→	sticky	→→→	compact, dense
Plant Nutrient: large amount	→→→	→→→	→→→	small amount
Organic matter: large amount	→→→	→→→	→→→	small amount
Acidity: low	→→→	→→→	→→→	high
Soluble aluminum: low	→→→	→→→	→→→	high

Fig. 14. Relationship between soil properties and plant growth

- Soil texture/structure are related to tolerance to erosion, water holding capacity, air and water permeability and root penetration (Fig.14). Crumbly soil has high water holding capacity, permeability, and is tolerant to erosion. Subsequently, plant roots can penetrate easily in the soil. On the other hand, compact soil has low water holding capacity, permeability and is sensitive to erosion. Plant roots penetration is limited in the soil.
- Healthy soil can supply plant with the required nutrients such as nitrogen (N), phosphate (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), manganese (Mn), copper (Cu), zinc (Zn), and iron (Fe).

What are the problems of acidic soil?

Soil pH is considered a master variable in soils as it affects many chemical processes. It specifically affects plant nutrient availability by controlling the chemical forms of the different nutrients and influencing the chemical reactions they undergo. The optimum pH range for most plants is between 5.5 and 7.5, however, many plants have adapted to thrive at pH values outside this range.

Soil pH is an expression of acidity. In strongly acidic soils (pH<5), availability of many nutrients such as P, K, Ca, Mg tends to be low (Fig. 15).

In extremely acidic soil (pH<4.5) aluminum solubility becomes high (Fig. 16).

Soluble aluminum in soil has toxicity for plant growth. High soil aluminum causes root damage (Fig. 17).

Historically, the acidic, infertile Oxisols of Babeldaob uplands were forested and not cultivated. These soils’ acidity and excessive concentrations of soluble Al limit their use for agriculture.

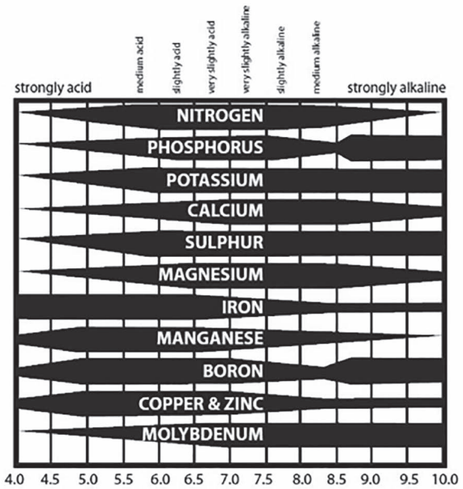

Fig. 15. Nutrient availability and soil pH (Deenik, 2011).

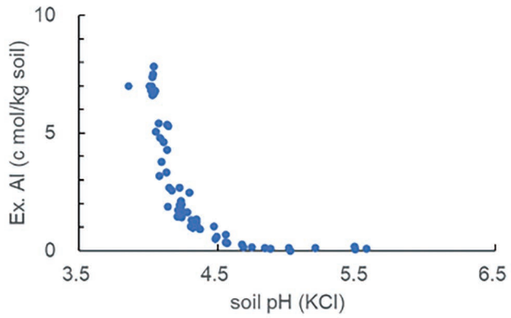

Fig. 16. Soil pH (KCl) and exchangeable Al concentration of soils in Palau.

Fig. 17. High soil Aluminum causes root damage in plants (Deenik, 2011).

Functions of soil organic matter:

Soil organic matter (SOM) promotes a healthy soil environment for beneficial organisms.

- SOM allows the soil to hold on to and recycle nutrients (i.e. SOM acts as a slow-release fertilizer so nutrients do not leach out of soil too fast).
- SOM improves soil aggregation and structure that contributes to better permeability and leads to lower erosion. SOM improves water holding capacity.
- SOM binds aluminum so that it detoxifies soluble aluminum in soil.

These functions are very important in many soils of Palau. In soils on volcanic uplands, SOM concentration in the surface soil layer is one of most decisive for soil fertility. The minimal fertility of upland soils (Oxisols) in Palau resides in the organic matter-rich surface layer, and loss of this important layer leaves behind a severely degraded soil. The increasing incidence of wildfires across Babeldaob has played a strong role in baring forested uplands, causing topsoil loss to erosion and the creation of severely degraded soils that have difficult reforestation. The Hisosol, on the other hand, are base cation-rich
organic soils that have been continuously planted to wetland taro for as long as 1,000 years. Adjacent, poorly drained organic matter rich Inceptisols are also important agricultural soils. (Giardina et al., 2020)

Soils and landscapes in Palau

As landscape (topography, drainage) is an important factor for soil formation, each soil can be seen in a particular landscape in many cases (Fig. 18 and Table 1). Soils in Palau are categorized into the 10 soil groups (USDA general soil map units) based on landscapes where each group appears (Table 2). Brief explanations for the soils on typical landscapes are as follows.

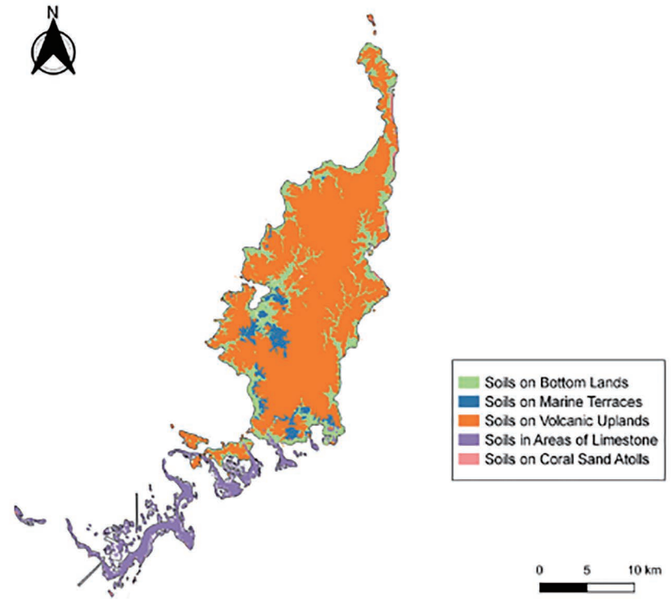

Fig. 18. Soils on typical landscape in Palau (Northern part of Palau) (Kikuchi, unpublished data).

Table 1. Area and share of the soils on typical landscape in Palau (Northern part of Palau shown in Figure 6)

Unit	Area (ha)	%
Soils on bottom lands	7677	16.7
Soils on marine terraces	1758	3.8
Soils on volcanic uplands	26397	61.8
Aimeliik-Palau	22540	49.1
Babeldoab-Ngardmau-Uforthents*	3618	7.9
Soils in areas of limestone	6532	14.2
Soils on coral atolls	1553	3.4

*Except for typic Udorthents complex, mined

Table 2. Soils on typical landscape and general soil map units in Palau

Soils on typical landscape	General soil map units
Soils on bottom lands	Mesei-Dechel-Ngesuul Odesangel Ilachetomel-Naniak-Chia
Soils on marine terraces	Tabecheding-Ngatpang-Dystrudepts
Soils on volcanic uplands	Aimeliik-Palau Babedoab-Ngardmau-Udordepts Udorthents-urban land Ollei-Nekken
Soils in areas of limestone	Peleliu-Chelbacheb
Soils on coral atolls	Ngedebus-Majuro

1. Soils of bottom lands

This group of soils shares about 16.7 % of Palau. This group consists of 3 general soil map units: Mesei-Dechel-Ngersuul, Odesangel, and Ilachetomel-Naniak-Chia. These soils are very deep, very poorly drainage or somewhat poorly drained soils in areas of swamps, flood plains on valley floors on volcanic islands. These soils were formed in alluvial sediments or organic material. So, these soils have thick surface layers (often around 200 cm) that are rich in organic matter. This thick surface layer has low aluminum saturation (almost zero). These soils support swamp forests (Fig. 19). Mesei-Dechel-Ngersulul soils and Odesangel soils are used for wetland taro cultivation (Fig. 20).

2. Soils on marine terraces

This group of soil shares about 3.8 % of Palau. This group consists of a general soil map unit: Tabecheding-Ngatpang-Dystrudepts. These soils are very deep, somewhat poorly drained or moderately well drained soils on dissected fluviomarine terraces on volcanic islands. The soils were formed in inter-bedded clays, silty clays, and lignite from marine deposits derived from volcanic rock. The Tabecheding soils have surface layers that have relatively low concentrations of organic matter (3 - 5% or more) and medium to high aluminum saturation (36 – 70%). The soils support lowland forests and wet savannah plant communities (Fig. 21). The Ngatpang soils have surface layers that have low concentrations of organic matter (2 - 4% or more) and medium aluminum saturation (30 – 45%). The soils support lowland forests and wet savannah plant communities.

Fig. 19. Swamp forests on the soils of bottom lands (Ilachetomel-Naniak-Chia and Tabecheding-Ngatpang soil map units).

Fig. 20. Wetland taro field on the soils of bottom lands (Ilachetomel-Naniak-Chia soil map units).

Fig. 21. Wet savannah on the soils on marine terraces on the soils of marine terraces *(Photo by Hiromi Ito)*

3. Soils on volcanic uplands

This group of soil shares about 61.8 % of Palau. This group consists of 4 general soil map units: *Aimeliik-Palau, Babeldaob-Ngardmau-Udorthents, Udorthents-Urban Land and Ollei-Nekken.*

Aimeliik-Palau are very deep, well drained soils in all hill slope positions on hills and on ancient anthropogenic terraces of volcanic islands. The soils were formed in saprolite derived from volcanic rock. The Aimeliik soils have surface layers that have high concentrations of organic matter (9 - 17% or more) and low aluminum saturation (2 – 22%). Because of this, Aimeliik soils are more fertile than Palau soils and other soils on volcanic uplands and support more vegetation such as mixed-upland forest (Fig. 22). The Palau soils have surface layers that have medium concentrations of organic matter (9 – 12%) but very high aluminum saturation (75 – 85%). The Palau soils typically have grassland-pandanus forest (Fig. 23). These soil map units share 49.1 of Palau.

Babeldaob-Ngardmau-Udorthents are very deep, well drained soils on erosional hills on volcanic islands. The soils were formed in saprolite driven from volcanic rock. The Babelthuap soils and Ngardmau soils have surface layers that have low concentration of organic matter (1 – 4%) and high aluminum saturation (55 – 75%). About 70 – 80 % of the surface is covered by gravel consisting of petroferric fragments, ironstone, and gibbsite concretions. Because of these reasons, fertility of these soils is very low and these soils support fern-land plant communities (Fig. 24). This soil map unit shares 7.9 % of Palau.

Udorthents-Urban Land are soils in built-up areas, quarries, bauxite surface mines.

Ollei-Nekken are moderately deep or shallow, well drained soils on coastal benches and ridges on hills on volcanic islands. The soils were formed in residuum derived from volcanic rock. The typical vegetation is Ollei-Nekken-outcrop forest. An obvious indicator of this forest type is *Heterospathe elata var. palauensis* (demailei).

Fig. 22. Mixed-upland forest on Aimeliik soil map units

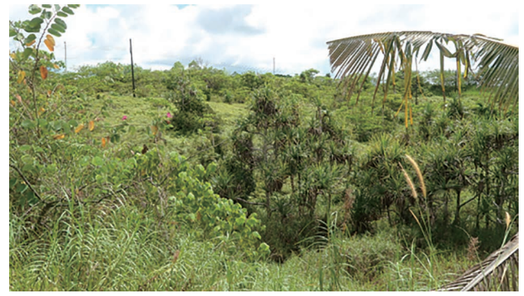

Fig. 23. Grasslands-pandanus forest on Palau soil map units

Fig. 24. Fern-land on Babelthuap-Ngardmau-Udorthents soil

4. Soils in Areas of Limestone

This group consists of a general soil map unit: Peleliu-Chelbacheb. This group of soil shares about 14.2 % of Palau. These soils are shallow, well drained soils on karst islands. The soils were formed in coralline colluvium or organic material over residuum weathered from limestone. The Peleliu soils and Chelbacheb soils have surface layers that have very high concentrations of organic matter (12 - 30% or more) and these soils are free from aluminum toxicity. Typical vegetation is broadleaf-evergreen limestone forests (Fig. 25).

Fig. 25. Broadleaf-evergreen limestone forests on soils of limestone. *(Photo by Hiromi Ito)*

5. Soils on Coral Sand Atolls

This group of soil shares about 3.4 % of Palau. These soils are very deep, somewhat excessively drained soils on beach terraces in areas of atolls, karst, and volcanic islands. The soils were formed in water- and wind-deposited coralline sandy material. Typical vegetation is casuarina and atoll forest (Fig. 26).

Fig. 26. Casuarina and atoll forest on soils on coral sand atolls (Ngedebus-Majuro soil map unit).

Soil types

Table 3 describes the basic soil types of Palau (United States Department of Agriculture, 2009) and provides a brief description—the full descriptive table can be found in the 1983 USGS Soil Survey. A color-coded map with soil numbers corresponding to the USGS Soil Survey is located in the appendices and shows that the limestone rock islands have a relatively homogeneous substrate.

As mentioned earlier in this chapter, most Palau soils have low levels of fertility; the majority of large-scale agricultural and mining activity during foreign occupation was done on the large island of Babeldaob, with the exception of phosphate/bauxite mining on the southern island of Angaur. The mining and agriculture covered vast areas of land, carving away at the natural landscape.

Table 3. General description Soil Types of Palau(United States Department of Agriculture, 2009).

I. Soils on Bottom Lands

These soils make up about 17 percent of the survey area

1. Mesei-Dechel-Ngersuul

Very deep, very poorly drained and somewhat poorly drained soils in areas of swamps and flood plains on valley floors on volcanic islands; formed in alluvial sediments or organic material over alluvial sediments derived from volcanic rock

2. Odesangel

Very deep, very poorly drained soils in swamp areas of atolls and karst islands that retain fresh or brackish water; formed in deposits of organic material overlying coralline sand and/or limestone

3. Ilachetomel-Naniak-Chia

Very deep, very poorly drained in the intertidal zone of mangrove swamps adjacent to volcanic or karst islands; formed in organic deposits and alluvium derived from volcanic material or limestone

II. Soils on Marine Terraces

These soils make up about 4 percent of the survey area

4. Tabecheding-Ngatpang-Dystrudepts

Very deep, somewhat poorly drained or moderately well drained soils on dissected fluviomarine terraces on volcanic islands; formed in interbedded clays, silty clays, and lignite from marine deposits derived from volcanic rock

III. Soils on Volcanic Uplands

These soils make up about 62 percent of the survey area

5. Aimeliik-Palau

Very deep, well drained soils in all hillslope positions on hills and on ancient anthropogenic terraces of volcanic islands; formed in saprolite derived from volcanic rock

6. Babelthuap-Ngardmau-Udorthents

Very deep, well drained soils on erosional hills on volcanic islands; formed in saprolite derived from volcanic rock

6. Udorthents-Urban Land

Built-up areas, quarries, bauxite surface mines, and nearly level to very steep, very deep, well drained soils consisting of bauxite, human-transported material, or coral fill over saprolite derived from volcanic rock

7. Ollei-Nekken

Moderately deep or shallow, well drained soils on coastal benches and ridges on hills on volcanic islands; formed in residuum derived from volcanic rock

IV. Soils in Areas of Limestone

These soils make up about 14 percent of the survey area.

8. Peleliu-Chelbacheb

Shallow, well drained soils on karst islands; formed in coralline colluvium or organic material over residuum weathered from limestone

V. Soils on Coral Sand Atolls

These soils make up about 3 percent of the survey area.

9. Ngedebus-Majuro

Very deep, somewhat excessively drained soils on beach terraces in areas of atolls, karst, and volcanic islands; formed in water- and wind-deposited coralline sandy material

Major soil types in Palau according to soil taxonomy

According to soil taxonomy that differentiates between mineral soils and organic soils, major soil types in Palau belong to Entisols, Histosols, Inceptisols, Oxisols, and Ultisols (Fig. 27).

Entisols: Entisols recently formed soils that lack well-developed horizons and found in low-lying coastal areas.

Histosols: Histosols are organic soils.

Inceptisols: Inceptisols are young soils that have subsurface horizon formation but show little eluviation and illuviation. These soils range from very poorly drained to excessively drained. Inceptisols commonly occur on landscapes that are relatively active, such as mountain slopes, where erosional processes are actively on.

Oxisols: They are heavily weathered, are rich in iron and aluminum oxides but low in silica. They have only trace nutrients due to heavy tropical rainfall and high temperatures and low CEC of the remaining clays. The very acidic, red colored Oxisols are the dominant soil type in Palau. Oxisols are weathered soils that are extremely infertile, reservation of plant nutrients is not good. The natural vegetation ranges from tropical rain forests to desert savannas.

Ultisols: They are acid soils in the humid tropics and subtropics, which are depleted in calcium, magnesium and potassium (important plant nutrients). They are highly weathered, but not as weathered as Oxisols. Cultivation, therefore, is a shifting cultivation unless soil amendments are applied. Extractable aluminum normally is high.

Fig. 27. Major soil types in Palau (USDA)

Glossary

Acid soil: Any soil with pH of <6.5

Aggregate soil: Many fine particles held in a single mass or cluster. Natural soil aggregates, such as granules, brocks or prisms, are called peds

Alkaline soil: Soil with pH over 7

Alluvium: Material, such as sand, silt or clay, deposited on land by stream

Aluminum saturation: The amount of KCl-extractable Al divided by extractable bases (extracted by ammonium acetate) plus the KCl-extractable Al. It is expressed as a percent. If there is more that 50% Al saturation, Al problems in the soil are likely

Anthropogenic: Caused or produced by humans

Bauxite: A residual rock-weathering product consisting of hydrated aluminum oxides, the principal commercial source of aluminum

Bottom land: The normal flood plain of a stream, subject to flooding

Casuarina: Australian pine tree or whistling pine tree

Erosion: The action of surface processes (such as water flow or wind) that removes soil, rock, or dissolved material from one location on the Earth's crust, and then transports it to another location

Fluviomarine terraces: Constructional coastal strip, sloping gently seaward and /or down valley, veneered or completely composed unconsolidated sediments (typically clay silt, sand and fine gravel). Sediments were deposited by both marine and fluvial processes, resulting from sea level fluctuations and/or stream migration

Karst (topography): The relief an area underlain by limestone that dissolves in differing degrees, thus forming numerous depressions or small basins

Lignite: Lignite, often referred to as brown coal, is a soft, brown, combustible, sedimentary rock formed from naturally compressed peat

Marine terrace: See Fluviomarine terrace

Metamorphic: Relating to rock that has undergone transformation by heat, pressure, or other natural agencies

Neutral soil: Soil with pH 6.5 to 7.5

Organic matter: Plant and animal residue in the soil in various stages of decomposition

Parent material: The unconsolidated organic and mineral material in which soil forms

Pedosphere: The outermost layer of the Earth that is composed of soil and subject to soil formation processes

Petroferric: Ferruginous or ferromanganiferous nodules or concretions

Saprolite: Soft, disintegrated, usually more or less decomposed rock remaining in its original place

Soil pH: Soil pH is a measure of the acidity or alkalinity of the soil

Swamp: An area of low, saturated ground, intermittently or permanently covered with water and vegetated dominantly by shrubs and trees, with or without the accumulation of peat

Volcanic: Relating to, or made by a volcano (= a mountain with a hole at the top through which hot liquid rock is or has been forced out)

Water holding capacity: The amount of water that a given soil can hold for crop use

Index of Genera and Species

Scientific	Common	Palauan
Pandanus odoratissimus L.f.	pandanus, screw pine	ongorrake

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