

Soils of Rota

Properties and Diversity

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Photo: J. Deenik

Outline

- Soil formation
- Importance of Soil
- Soil Basics
 - Soil composition
 - Texture and clay minerals
 - Soil pH and nutrient availability
 - Soil organic matter
- Soil distribution on Rota



Soil Formation

$$\text{Soil} = f(\text{PM}, \text{CI}, \text{O}, \text{R}, \text{T})$$

Factors:

PM = parent material (rocks)

CI = climate (precipitation and temperature)

O = organisms (plants and animals)

R = relief (topography, drainage)

T = time



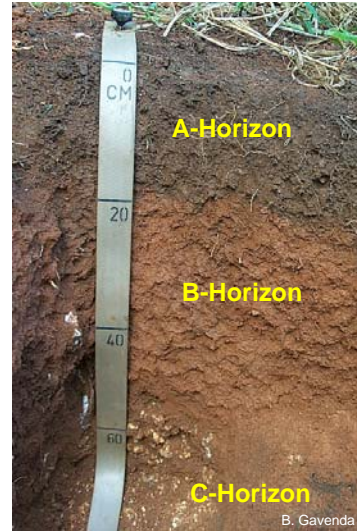
Soils form as a result of the combined effects of climate and biotic activities (microbial, plant, and animal life), modified by landscape relief and position, acting on parent materials over time. Ample rainfall and warm temperatures increase the rate of chemical weathering, which act to transform primary minerals in rocks into secondary minerals such as clays. Plant growth adds organic materials to soils which, in turn, supply carbon and other nutrients fueling microbial growth. Soils on upland landscapes where drainage is rapid tend to lose soluble components more rapidly whereas soils located in bottom lands tend to have poor drainage and soluble compounds accumulate. The nature of the parent also influences the type of soil that is formed. In the pictures above we have an example of an Akina soil widespread in south-central Guam (top) that has formed volcanic parent material (andesitic rock) and a Luta soil on Rota that formed from volcanic ash deposited on top of limestone.

Soils differ one from the other depending on the relative influence of each of the five soil forming factors.

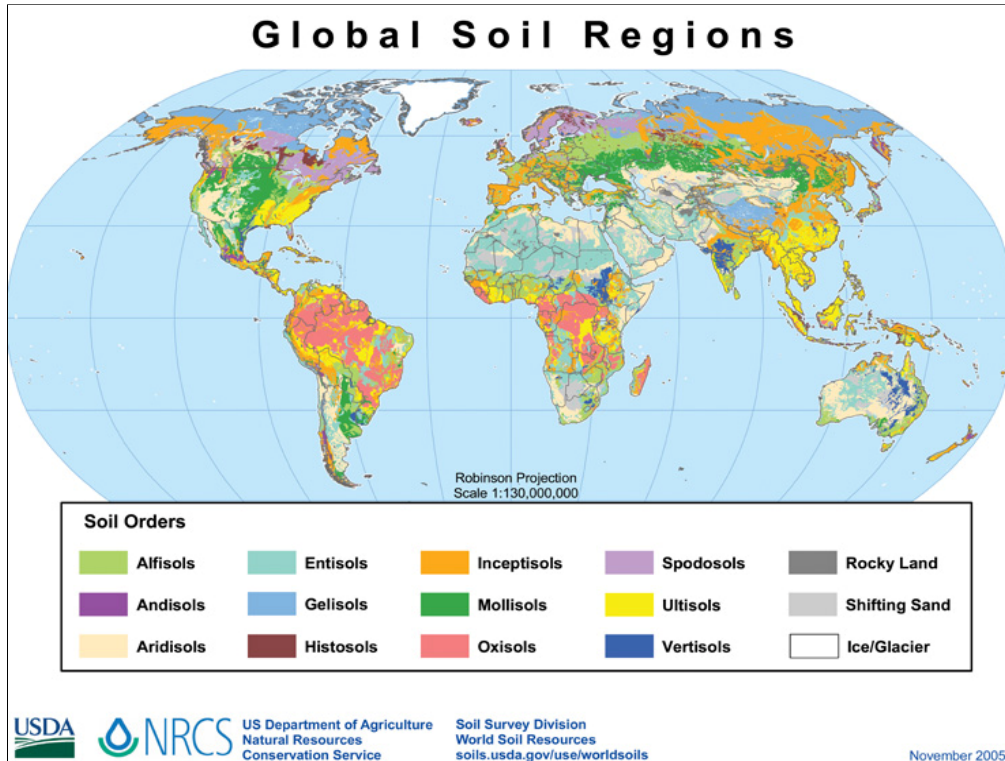
Soil Formation

Processes:

1. Additions
 - Water, organic matter, sediment
2. Losses
 - soluble compounds, erosion
3. Transformations
 - Organic matter to humus
 - Primary minerals to clay minerals
4. Translocations
 - Soluble compounds
 - Clays

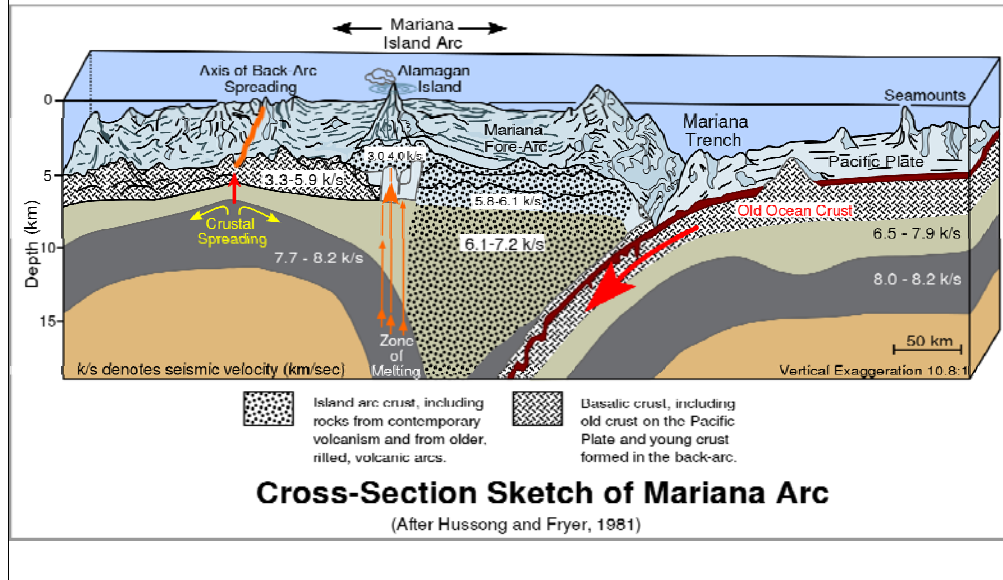


In addition to the five soil forming factors discussed in the previous slide, four soil forming processes interact to differentiate soil horizons or layers. Additions includes inputs to the developing soil profile from outside sources such as organic matter in the form of falling leaves. Sediments transported by erosion may also be an input. Transformations occur when soil constituents (i.e., organic matter and primary minerals) are chemically altered into new components such as the conversion of plant materials into humus during decomposition or the chemical weathering of primary minerals into clay minerals. Losses include the movement of dissolved elements with percolating water out of the soil profile into the water table, erosion due to surface run-off, and removal of surface soil from wind. Soluble compounds including clay minerals and dissolved organic matter can also be translocated between soil horizons.



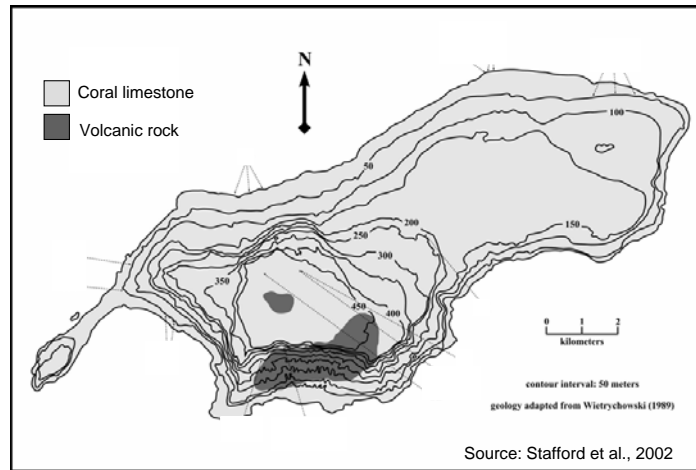
There are twelve soil orders according to the U.S. Soil Taxonomy classification system. Gellisols are the soils of the arctic region, Histosols are organic soils associated with wet cold areas, Aridisols are the soils of the deserts or dry regions of the world, Mollisols are the soils found under grassland vegetation, Alfisols are found under deciduous forest in the temperate climates and savannah in the tropics, Ultisols are typically found in areas of high rainfall with a leaching environment, Oxisols are the weathered, red soils of the tropics, Andisols are recent soils formed from volcanic ash, Spodosols are acid soils of temperate coniferous forest ecosystems, Vertisols are shrink-swell soils of the tropics and sub-tropics, Entisols are young soils with minimal development, and Inceptisols are young soils with little profile with minimal diagnostic horizons.

Island Formation



The Micronesian island group of the Mariana Islands forms a curving chain of 15 main islands located in an extremely tectonically active region of the western Pacific. The Mariana Islands are a classic example of an island arc formation. The islands formed as the Pacific Plate plunged below the Philippine plate resulting in the Marianas Trench. To the west of the subduction zone melting magma resulted in volcanic activity, which has subsequently built the base of the islands and continues to cause volcanic activity in the northern part of the island chain. In the north the islands are geologically young, having been formed within the last 5 million years. Their formation continues today with volcanic activity frequently observed on islands such as Anatahan (2005), Pagan (1993) and Farallon de Pajaros (1967). In the south the islands are older, with Guam being around 30 million years old. The southern islands are composed of volcanic rocks that have been overlain with coral-derived limestone. Subsequent tectonic movements and changing sea levels have raised many of the islands in the south considerable heights above sea level forming terraces and high cliffs. (Source: <http://www.oceandots.com/pacific/mariana/>)

Parent Material on Rota



- Parent material is mostly coral limestone with small exposures of volcanic rock

The island of Rota formed as a result of volcanic activity some 20-40 million years ago. Remnant rocks from the volcano still form the foundation of the island and evidenced by volcanic rock outcrops in the southern portion of the island. Most of the island consists of limestone laid down on top of the old volcano beginning as far back as 5 million years ago proceeding up 12,000 years ago.

Soil Formation on Rota

1. Parent material of Rota soils is predominantly volcanic ash.
2. The source of the ash is still unknown



There are three possible mechanisms explaining the formation of soils found on the limestone plateaus of the Northern Marianas. The first explanation assumes that in the geologic past sediments of volcanic origin were deposited in the submerged lagoonal areas and subsequently incorporated into the coral reef. Following tectonic uplift the exposed limestone plateaus underwent chemical dissolution leaving the impurities behind. It is estimated that the limestone contains 1-3% impurities. The impurities were then altered into the soils we see on the landscape today by chemical weathering processes. If erosion is eliminated it would take about 100 feet of limestone to produce one foot of soil. However, the accumulation rate is unknown. An alternate scenario proposes that soils formed from tropospheric dust from blown over the Pacific from the deserts of Central Asia and deposited by rainfall. The dust formed soil following chemical weathering of the primary minerals into secondary clay minerals. Studies of the Central Pacific Ocean floor shows that this dust accumulates at a rate of 1 mm per 1,000 years. If we assume this rate, then one foot of soil would require at least 300,000 years. Rota appears to be quite different, however. The major soil on Rota, named the Luta series, has formed from volcanic ash deposits overlying the limestone. The ash has weathered into an Andisol. The source of the ash is still not yet known.



Photo of the Luta series on Rota. Most limestone soils in the Mariana Islands are shallow over hard limestone like the soil shown here. There are some areas of deep soils over limestone but these are not extensive.



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**Functions
of Soil**

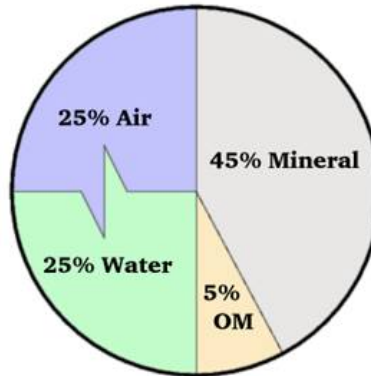
Like water and air, soils are crucial to life on earth. Soils have five key functions in supporting life: 1) they are a medium for plant growth by providing physical support to anchor plant roots, and supply of water, air, and nutrients for growth; 2) they regulate water supply through their capacity to store and transmit water; 3) they recycle organic matter to form humus and play a key role in the earth's geochemical cycles; 4) they are a habitat for a myriad of organisms from the microscopic bacteria to the ubiquitous earthworm; and 5) they are an engineering medium and vary dramatically in physical properties and stability. Given these five crucial functions, maintaining a healthy planet requires an understanding of soil.



- Animal health begins with good nutrition
- Grasses and other plants are the source of nutrients
- Soils supply nutrients and store water for plant growth

There are 12 essential elements which plants obtain from the soil that are commonly managed by growers. In addition, plants require carbon, hydrogen, and oxygen to grow. What makes an element *essential* to plant growth? An element is essential if the plant cannot complete its life cycle without the element. It is essential if the element is directly or indirectly involved in the metabolic processes of the plant (i.e. photosynthesis or respiration). A deficiency in an essential nutrient will result in the development of a characteristic, visual symptom. The essential plant nutrients are: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn), molybdenum (Mo), boron (B), copper (Cu).

Soil Composition

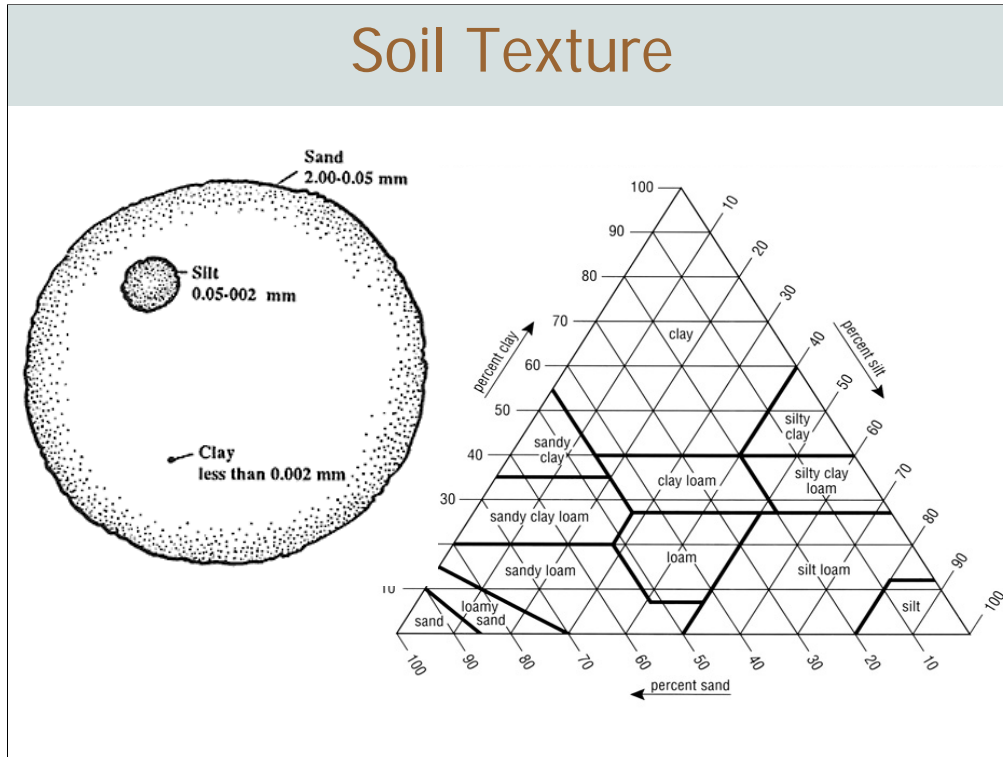


Photos: B. Gavenda

Soil composition is an important aspect of nutrient management. While soil minerals and organic matter hold and store nutrients, soil water is what readily provides nutrients for plant uptake. Soil air, too, plays an integral role since many of the microorganisms that live in the soil need air to undergo the biological processes that release additional nutrients into the soil.

The basic components of soil are minerals, organic matter, water and air. The typical soil consists of approximately 45% mineral, 5% organic matter, 20-30% water, and 20-30% air. These percentages are only generalizations at best. In reality, the soil is very complex and dynamic. The composition of the soil can fluctuate on a daily basis, depending on numerous factors such as water supply, cultivation practices, and/or soil type.

Soil Texture

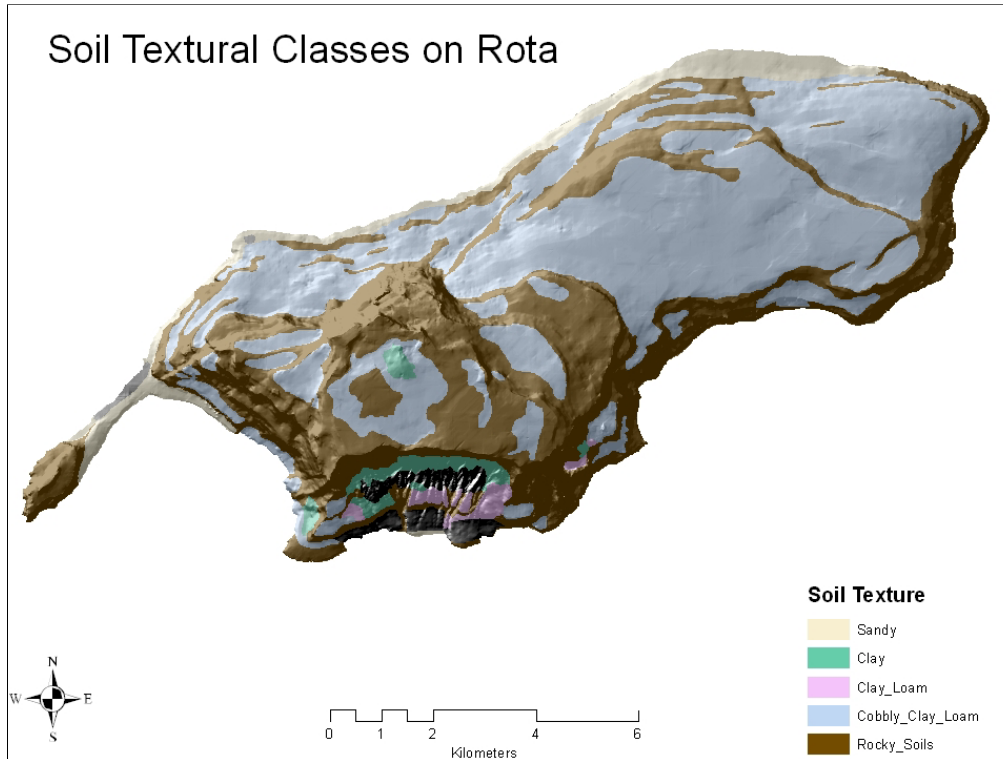


Soil Texture

Sand: 2.0 mm -0.05 mm, gritty feel. Sand is visible to the naked eye, consists of particles with low surface area, low nutrient holding capacity, and permits excessive drainage.

Silt: 0.05 mm - 0.002 mm, buttery feel. Silt is not visible to the naked eye and increases the water holding capacity of soil.

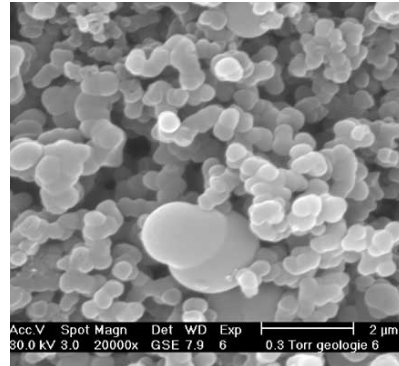
Clay< 0.002 mm, sticky feel. Clay has a high surface area, high water holding capacity, many small pores, and possesses charged surfaces to attract and hold nutrients.



Rocky and cobbly soils dominate the limestone plateau of Rota. Clay rich soils have formed on the volcanic parent material at the summit and along the southern flank of Mt. Sahana. Sandy soils occur on the coastal strand of northern Rota.

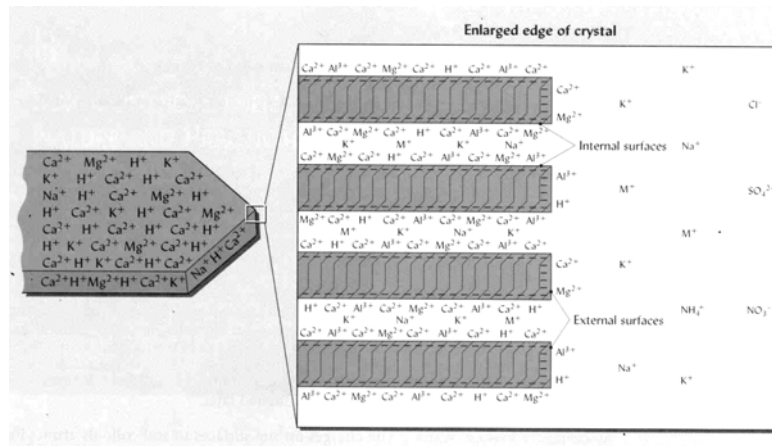
Properties and Importance of Clay

- Properties
 - High surface area
 - 1 gram = 10 to 1,200 m²
 - Charged surfaces
 - Usually negatively charged
- Importance
 - High water holding capacity
 - Clay minerals in Rota soils fix phosphorus into insoluble forms



The luta series is an Andisol with amorphous clay minerals. These clays have very high surface area (1,200 m²/g) and a high capacity to fix phosphorus resulting in P deficiency.

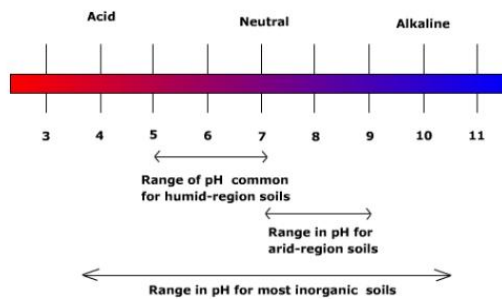
Cation Exchange Capacity (CEC)



Negatively charged sites that adsorb cations:
 Ca^{2+} , Mg^{2+} , K^+ , NH_4^+

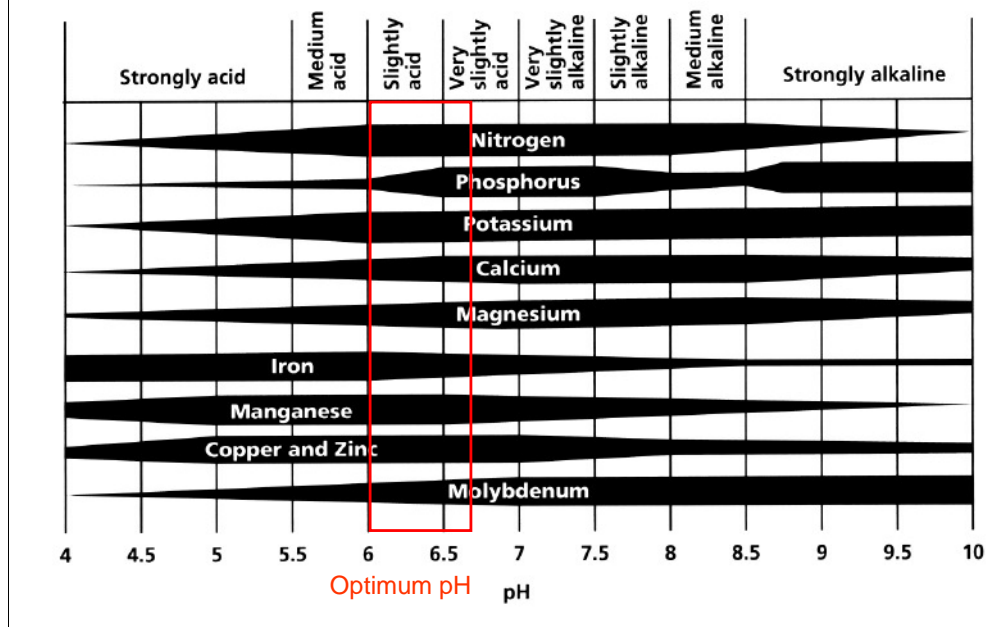
Cation exchange capacity (CEC) is defined as the ability of negatively charged colloid surfaces (clays and humus) to attract and retain positively charged nutrient cations. Fertile soils typically have a high CEC and thus a large reservoir of plant nutrients. Sandy soils typically have low CEC because sand grains do not carry a charge.

The pH Scale

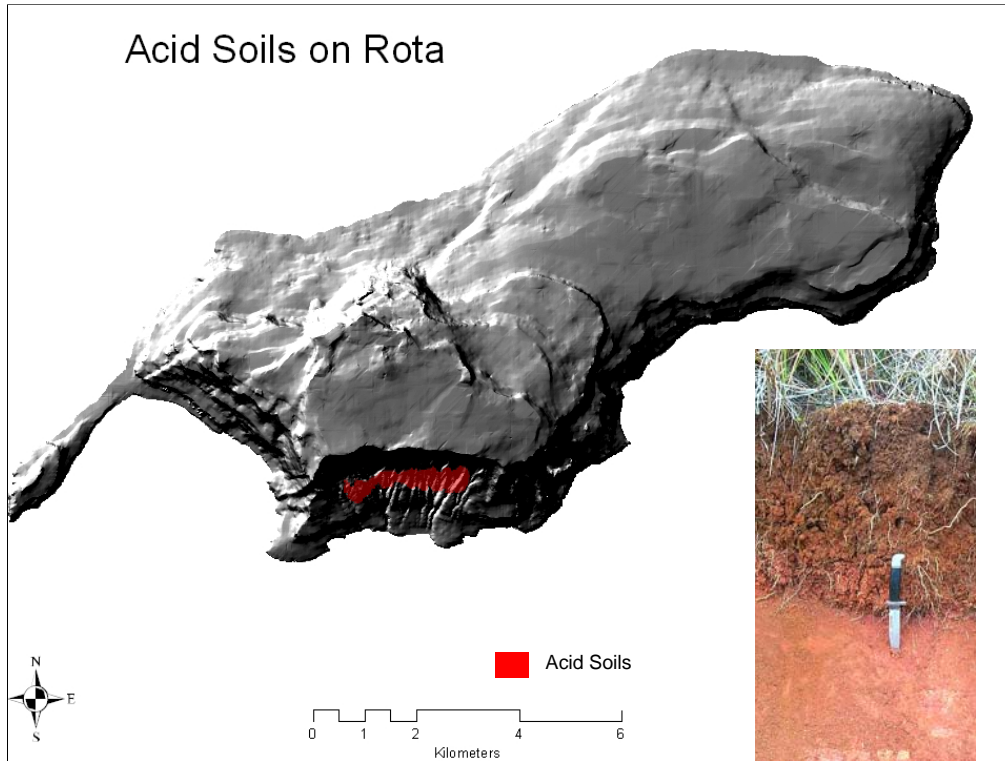


pH is a scale we use to describe the concentration of H^+ ions in water. Below $pH = 7.0$ we have acid conditions where $[H^+]$ is higher than $[OH^-]$. At $pH = 7.0$ $[H^+] = [OH^-]$ and at $pH > 7.0$ we have alkaline conditions where $[OH^-] > [H^+]$. pH in soil is important because it controls the solubility and availability of many of the essential plant nutrients. Most soils have pH that ranges between 3 on the very acid end to 11 on the very alkaline side.

Soil Acidity and Nutrient Availability



Soil pH is an important soil property, because it affects the chemical, biological, and physical processes of the soil. Thus, pH is often considered the “master variable” of soil. Its importance in nutrient management cannot be understated. Soil pH controls the availability of essential plant nutrients. As pH drops below 5.5, the availability of nitrogen, phosphorus, sulfur, calcium, magnesium, potassium, and molybdenum is limited and plants often show deficiency symptoms. On the other end of the spectrum, as pH increases above 7.0 the solubility of phosphorus, iron, manganese, copper, zinc, and boron decreases and plants become deficient in these nutrients. Phosphorus shows only a small pH window between 6.5 and 7.5 where it is available for plant uptake. As pH decreases below 5.5 Al toxicity becomes a severe constraint limiting plant growth to those plants adapted to acidic soil conditions. Many forage species do not grow well on strongly acidic soils. Soil pH for nutrient availability is optimal between 6.0 and 6.5.



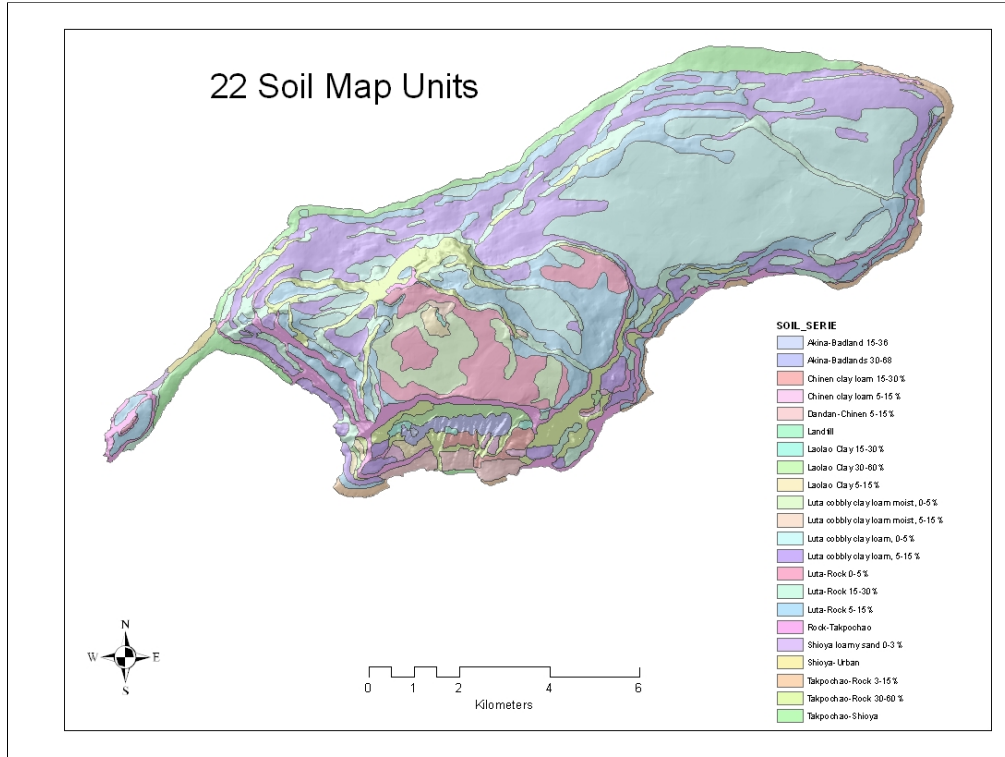
The Akina soil is an acid soil formed from volcanic outcrops along the southern flanks of Mt Sahana.

Role of Organic Matter in Soil

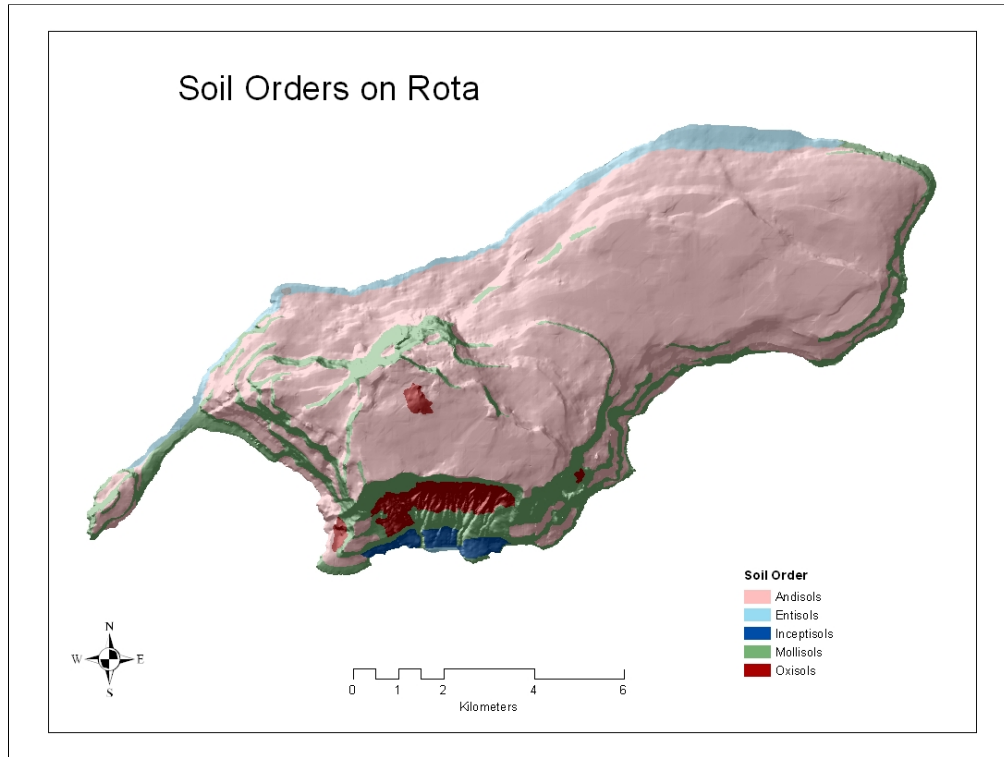
- **Physical**
 - Improves soil structure
 - Increases water retention
- **Chemical**
 - Increases nutrient availability (N & P cycling, solubility)
 - Increases nutrient retention (CEC)
 - Detoxifies Al
- **Biological**
 - Increases microbial diversity
 - N fixation (rhizobia), P availability (mycorrhiza)
 - Increases pathogen suppression



Soil organic matter (SOM) includes: living organisms (soil biomass), the remains of microorganisms that once inhabited the soil, the remains of plants and animals, organic compounds that have been decomposed within the soil over thousands of years and reduced to complex and relatively stable substances commonly called humus. Although surface soils usually contain only 1-6 % organic matter, SOM performs very important functions in the soil including the following: SOM acts as a binding agent for mineral particles, which produces friable (easily crumbled) surface soils, SOM increases the amount of water that a soil can hold for plant use, SOM provides food for organisms that inhabit the soil, SOM is a source essential plant nutrients, and the humus in SOM has cation exchange capacity (CEC), which acts as a nutrient reservoir.



According to soil survey, the island of Rota has 22 map units identified by a soil series name and different slope characteristics. The map unit provides information on textural class and slope, but gives no further information to help interpret soil behavior. Fortunately higher levels of U.S. Soil Taxonomy (the classification systems for organizing soils) help us interpret and predict soil behavior.



The island of Rota consists of four soil orders with Andisols dominating the limestone plateau, Oxisols that have developed on the volcanic parent material of the southern escarpment, Mollisols on the limestone parent material on the steep lands along the perimeter of the island, Inceptisols on the bottom lands of southern Rota, and entisols on the low-lying coastal strand .

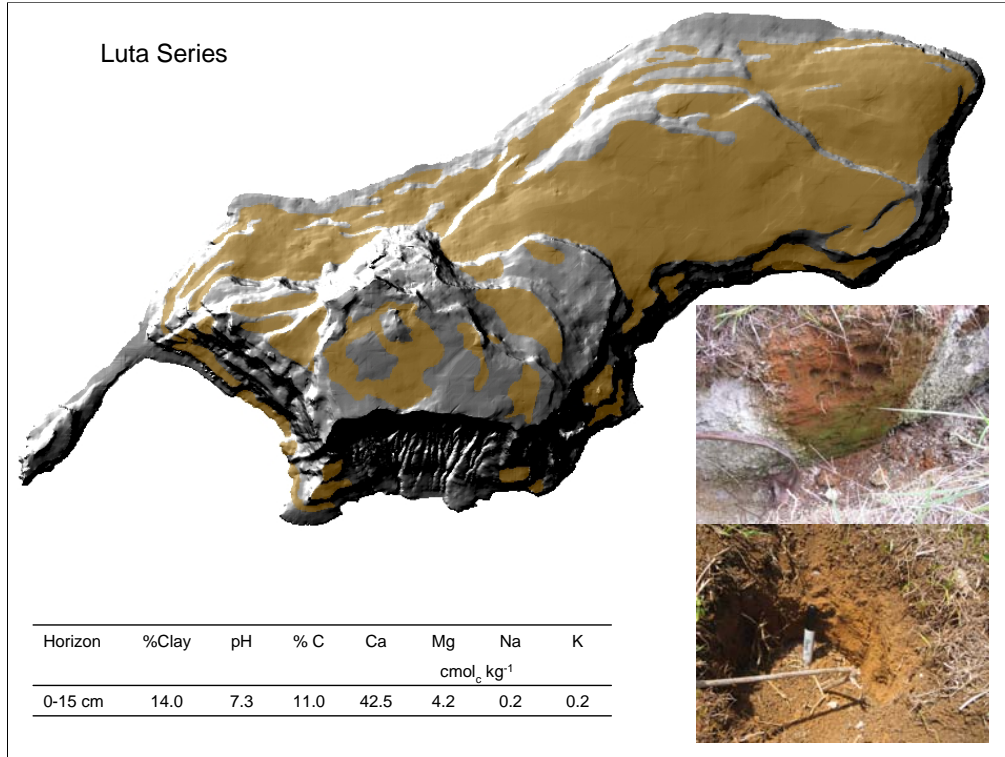
Andisols are the dominant soil order on Rota covering the limestone plateau. They are shallow, well-drained soils rich in organic matter. They have formed in volcanic ash deposits overlying the limestone. These soils are well suited to pasture, but can suffer from phosphorus deficiency and insufficient moisture during the dry season.

Entisols are weakly developed soils without B horizons. On Rota they are deep, excessively drained, sandy soils on coastal strands. They are not suited to grazing.

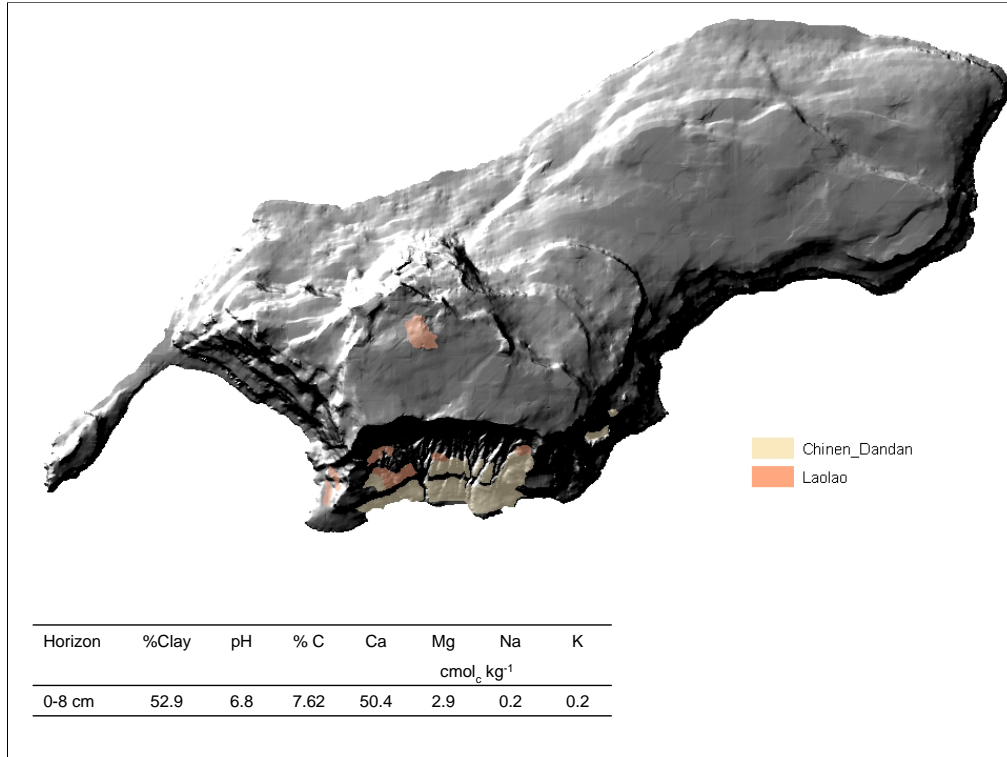
Mollisols are typically fertile soils associated with grasslands, but the Mollisols on Rota are rocky soils located on the steep escarpments. On Rota, these soils are not suitable for grazing.

Oxisols are highly weathered soils with low fertility that have developed from volcanic parent material in southern Rota. They are typically acid to very acid with high soluble aluminum in the subsoil. These soils have a low capacity to supply key plant nutrients such as Ca, K, and P. Lime is often required to raise the soil pH.

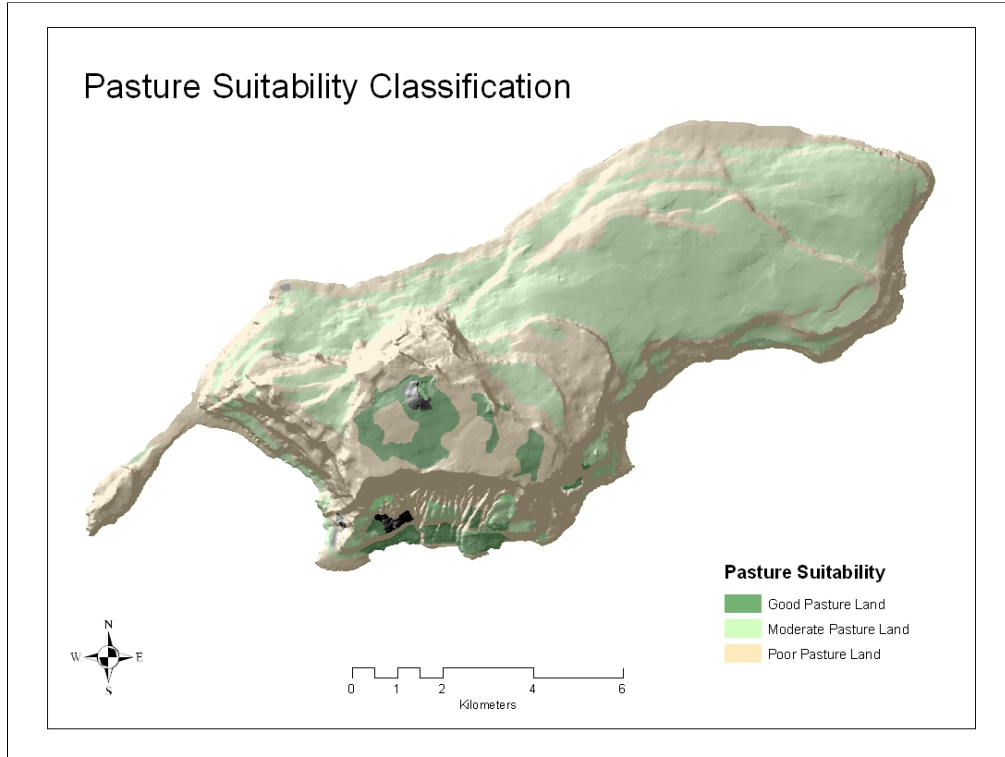
Inceptisols are found in the bottom lands of southern Rota and they are formed from alluvial materials. They are typically relatively fertile soils with slightly acidic pH.



The Luta series is the most common soil on Rota. It is a shallow soil, but it can be deep depending upon the underlying coral limestone. It has high organic matter content and it is typically neutral to alkaline with high levels of Ca and Mg. This soil has a strong capacity to fix phosphorus increasing the likelihood of P deficiency.

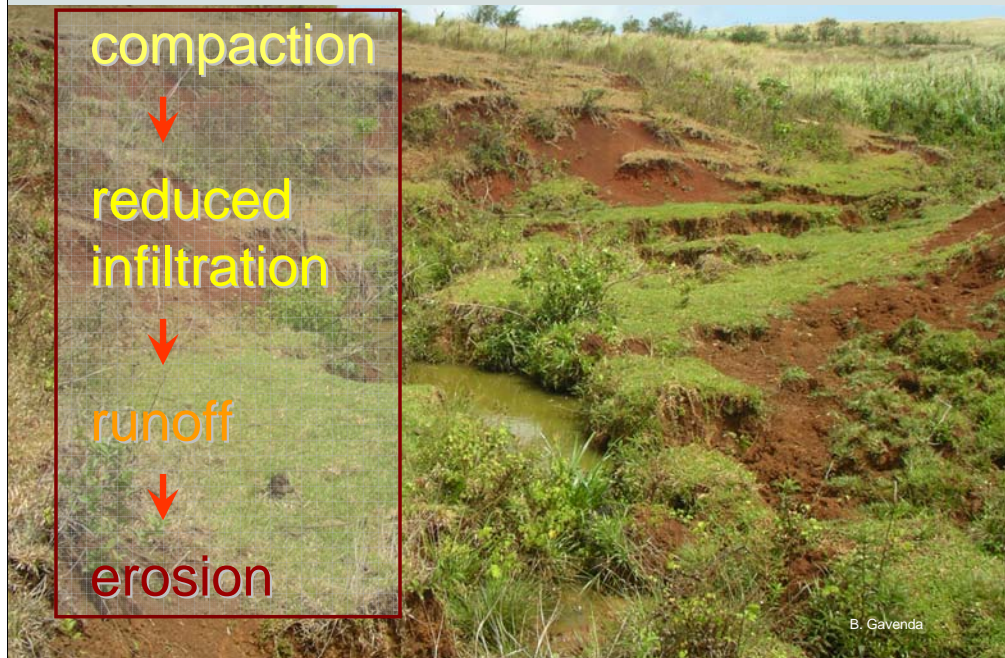


The Chinen series is found on the lower southern slopes of Rota. It is a shallow soil high in organic matter content and it is typically neutral to alkaline with high levels of Ca and Mg. This is a fertile soil.



Soil map units were grouped into either good, moderate or poor pasture land categories based upon suitability classification found in “Soil Survey of the Islands of Aguijan, Rota, Saipan, and Tinian, Commonwealth of the Northern Marianas” USDA, Soil Conservation Service 1989.

Grazing Management and Soil Quality



Compaction leading to reduced infiltration, more runoff and consequent erosion is common in pastures where over-grazing and poor cow management has occurred.

Grazing Management and Soil Quality



Effects of overgrazing in southern Guam. Once the soil is scarred like this it is very hard for it to recover. It's difficult to revegetate denuded soil because of the low soil fertility and relatively high amount of soluble aluminum in the subsoil. Volcanic soils are especially difficult to revegetate because of very low soil fertility and elevated levels of soluble aluminum. Note the headwall erosion even on these gentle slopes. Planting trees is not effective in controlling erosion; establishing a grass cover will stabilize this landscape.



Soils are non-renewable!

B. Gavenda