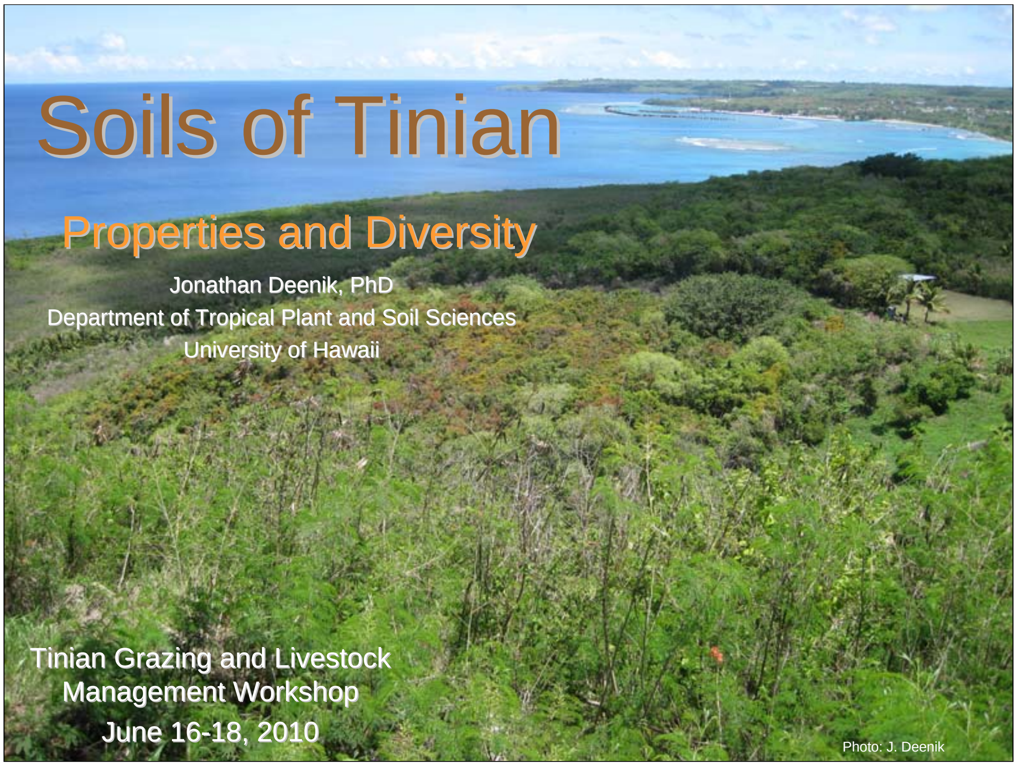
Soils of Tinian
Properties and Diversity
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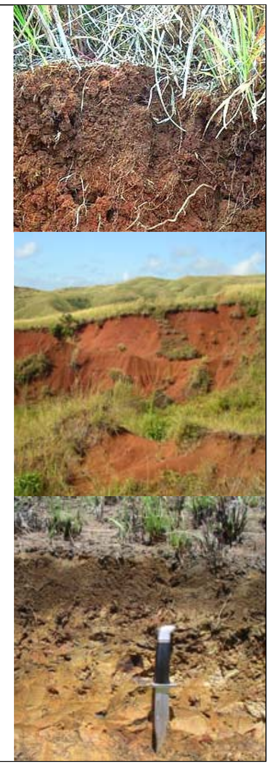
Photo: J. Deenik

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 Tinian



Soil Formation

$$Soil = f(PM, Cl, O, R, T)$$

<u>Factors</u>:

PM = parent material (rocks)

Cl = climate (precipitation and temperature)

O = organisms (plants and animals)

R = relief (topography, drainage)

T = time

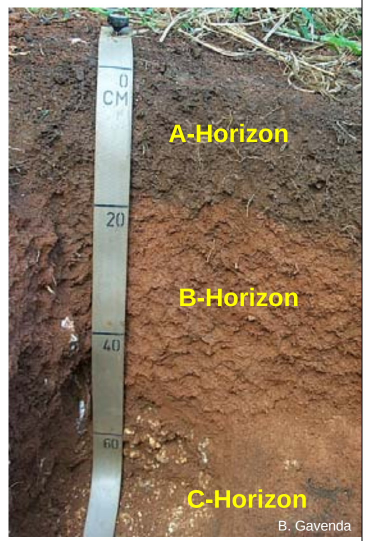
Soils form as a result of the combined effects of climate and biotic activities (microbial, plant, and animal life), modified by landscape relief and position, acting on parent materials over time. Ample rainfall and warm temperatures increase the rate of chemical weathering, which act to transform primary 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.

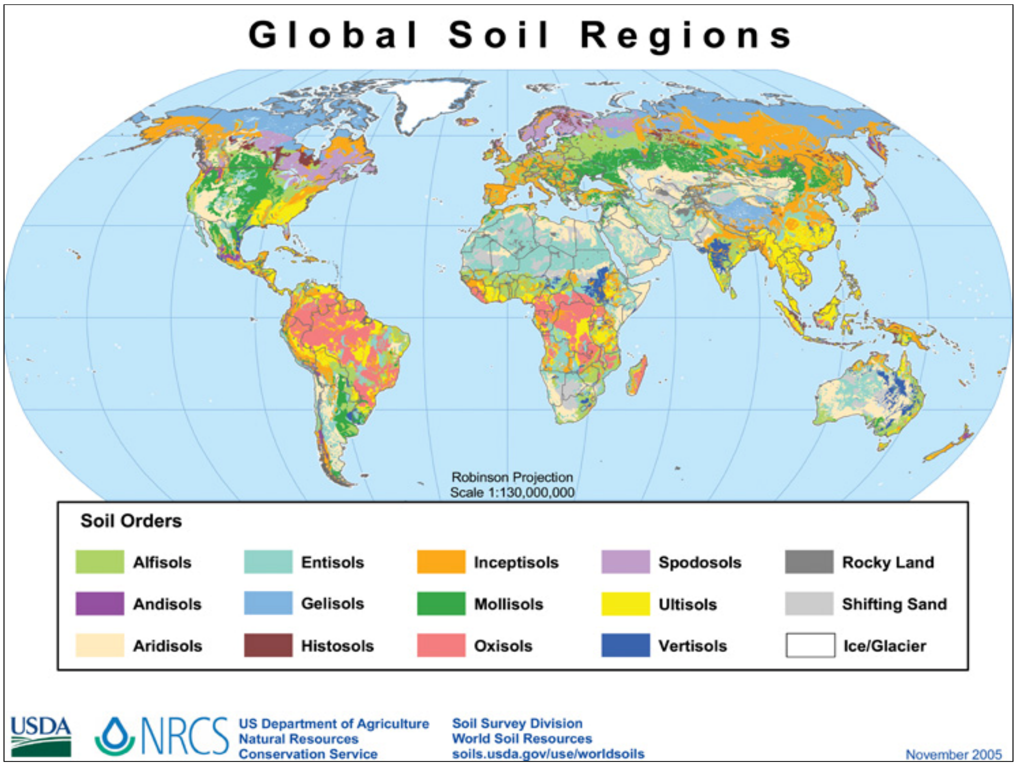
Soil Formation

<u>Processes</u>:

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

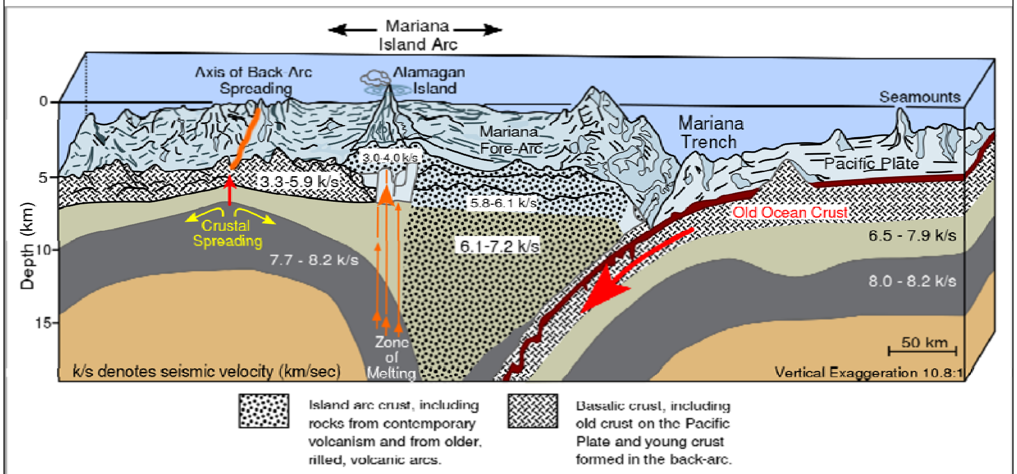


In addition to the five soil forming factors discussed in the previous slide, four soil forming processes interact to differentiate soil horizons or layers. Additions includes inputs to the developing soil profile from outside sources such as organic matter in the form of falling leaves. Sediments transported 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 artic 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 deciduos 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



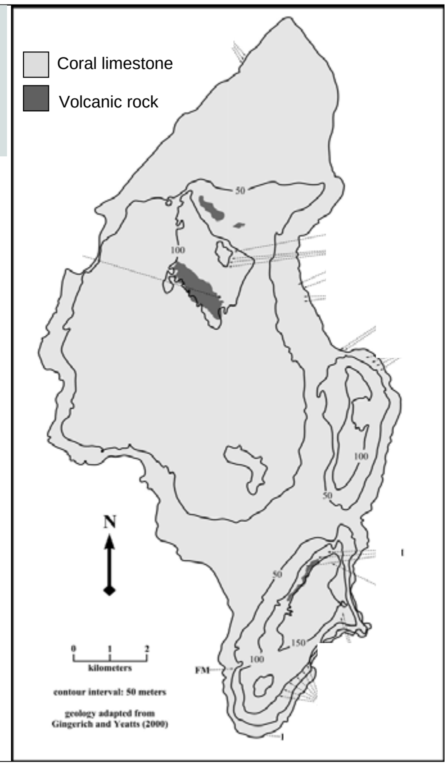
Cross-Section Sketch of Mariana Arc

(After Hussong and Fryer, 1981)

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 Tinian

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



The island of Tinian 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 north central 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

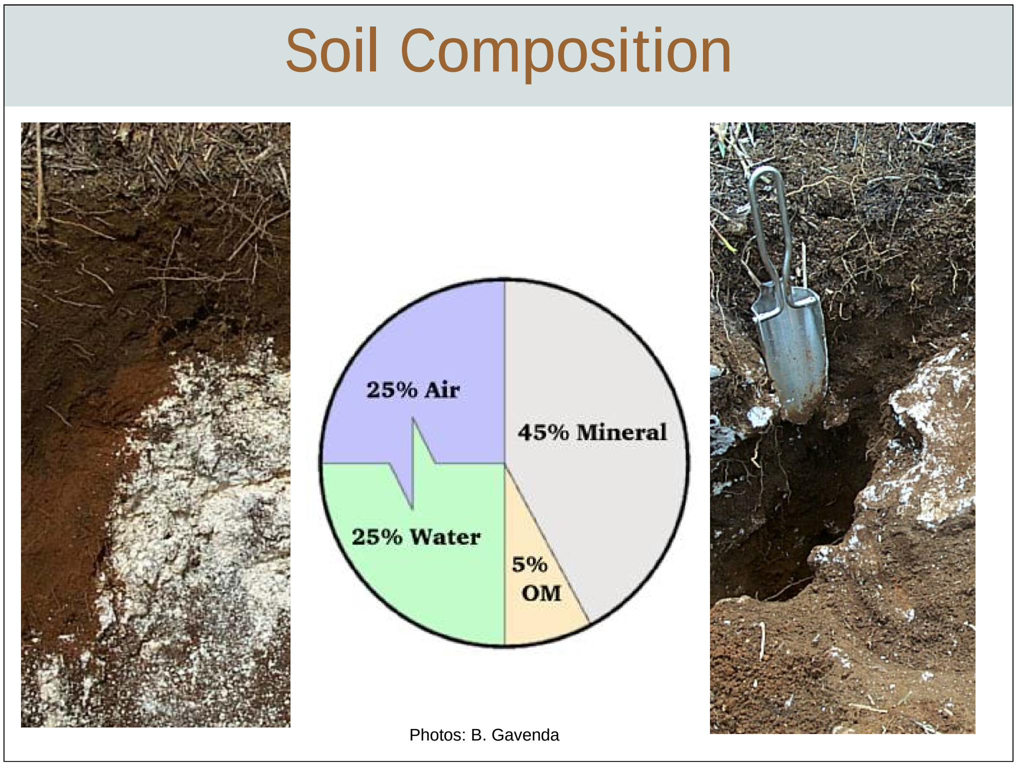
1. Dissolution of $CaCO_3$ limestone, and soil forms from impurities
   - 30-100 ft of limestone to produce 1 ft of soil
2. Deposition of dust blown from Asian deserts, and soils form from weathering of the dust

There are at least two 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.

Photo of the Saipan series which can be found in north central Tinian. 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.

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.

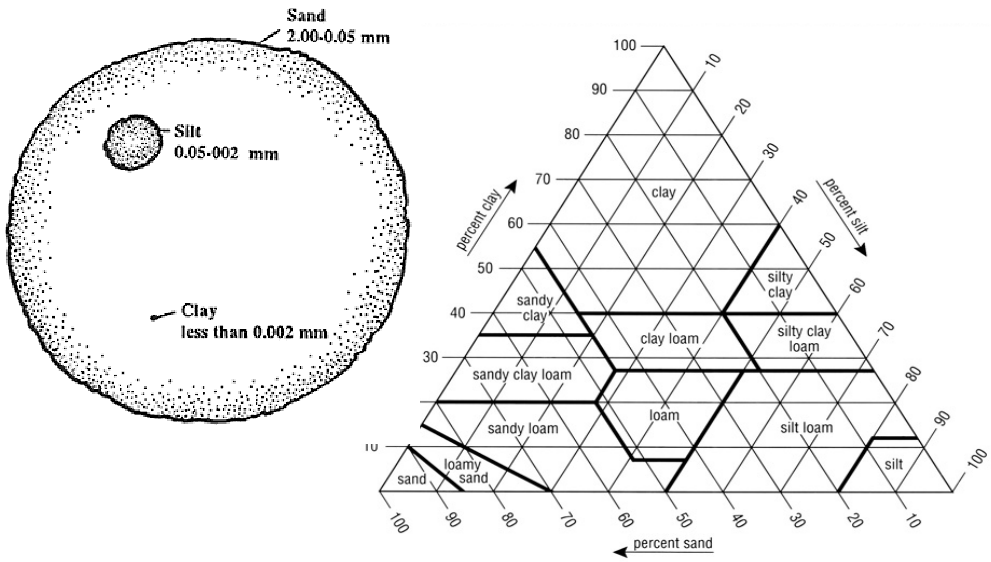
There are 12 essential elements which plants obtain from the soil that are commonly managed by growers. In addition, plants require carbon, hydrogen, and oxygen to grow. What makes an element *essential* to plant growth? An element is essential if the plant cannot complete its life cycle without the 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 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

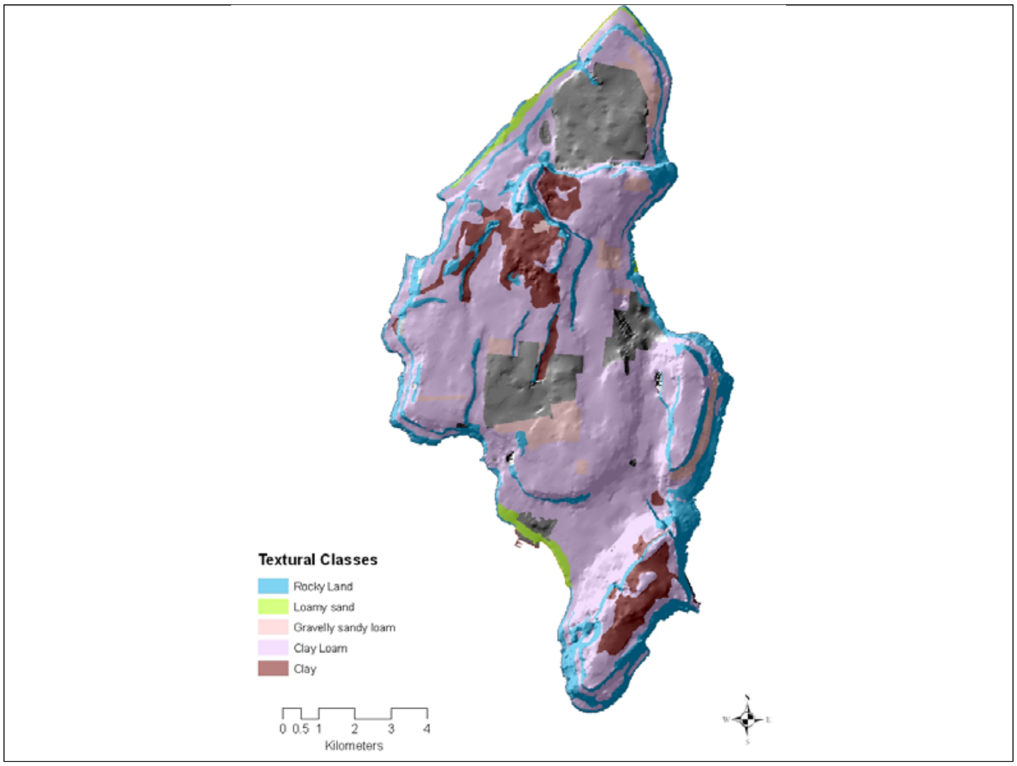


Soil Texture

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.

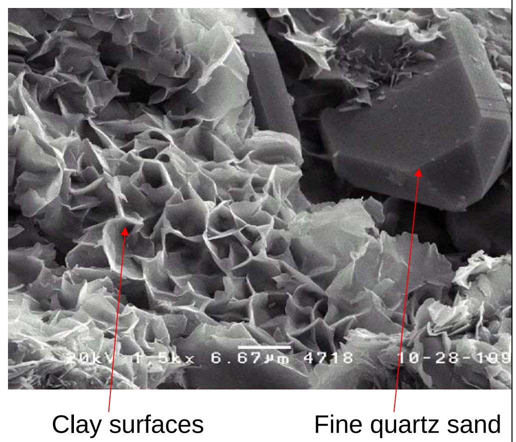
Clay< 0.002 mm, sticky feel. Clay has a high surface area, high water holding capacity, many small pores, and possesses charged surfaces to attract and hold nutrients.



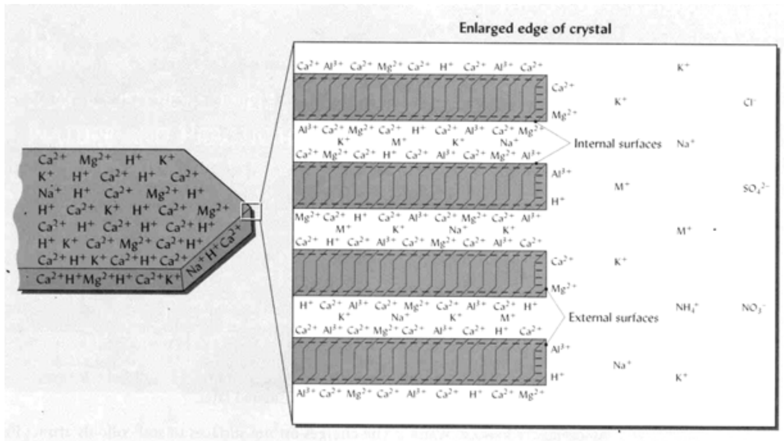
Most of the soils on Tinian are clay loams. Clay soils are associated with volcanic parent material in the north central region and the uplands in the south. Sandy soils occupy the coastal areas of northern and southern Tinian.

Properties and Importance of Clay

- Properties
  - High surface area
    - 1 gram = 10 to 800 m^2
  - Charged surfaces
    - Usually negatively charged, but highly weathered oxide clays have + charge
- Importance
  - High water holding capacity
  - High nutrient retention capacity (cation exchange capacity, CEC)



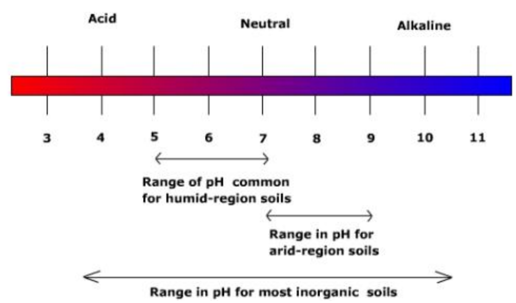
Cation Exchange Capacity (CEC)



Negatively charged sites that adsorb cations:
Ca^{2+}, Mg^{2+}, K^{+}, NH^{4+}

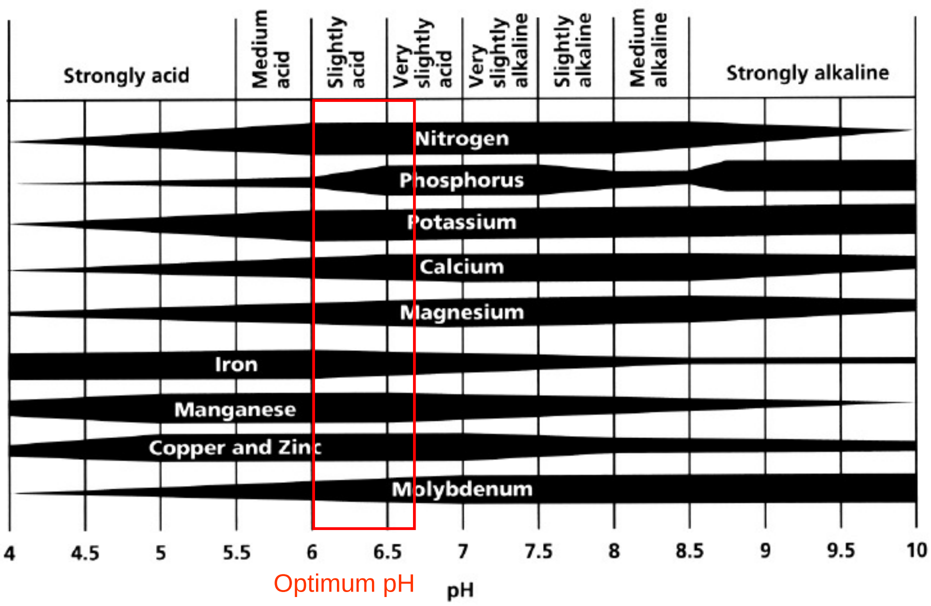
Cation exchange capacity (CEC) is defined as the ability of negatively charged colloid surfaces (clays and humus) to attract and retain positively charged nutrient cations. Fertile soils typically have a high CEC and thus a large reservoir of plant nutrients. Sandy soils typically have low CEC because 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.

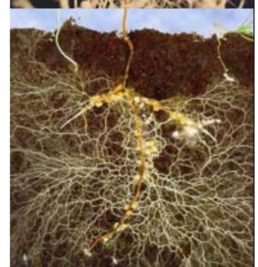
Soil Acidity and Nutrient Availability



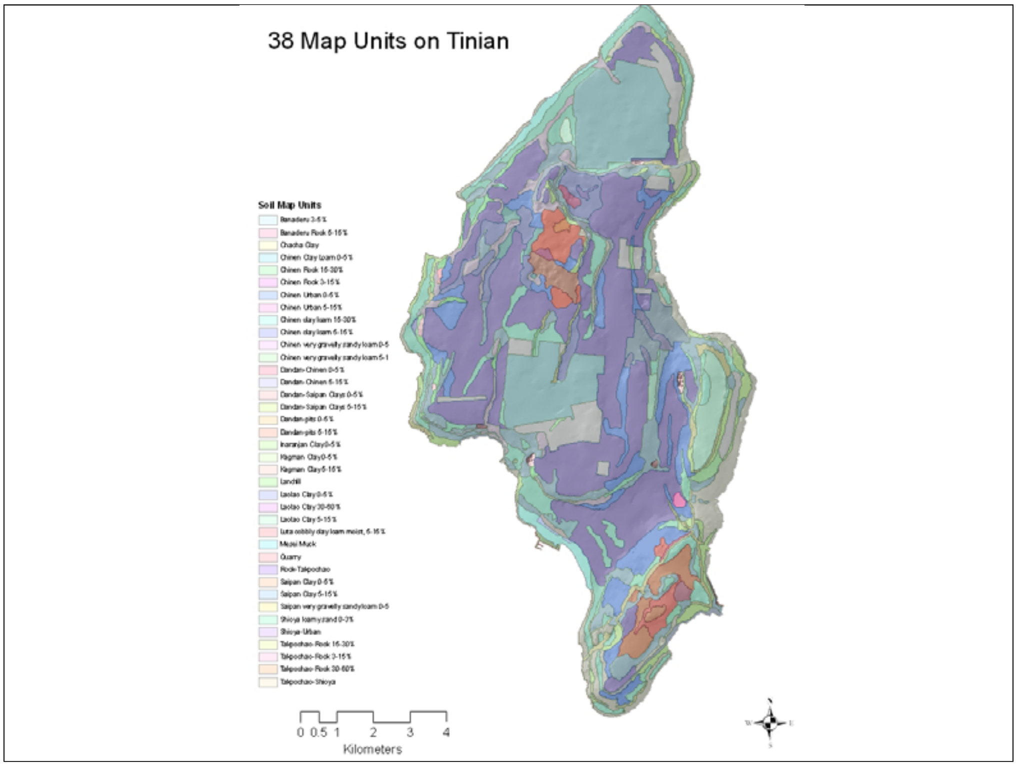
Soil pH is an important soil property, because it affects the chemical, biological, and physical processes of the soil. Thus, pH is often considered the "master variable" of soil. Its importance in nutrient management cannot be understated. Soil pH controls the availability of essential plant nutrients. 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.

Role of Organic Matter in Soil

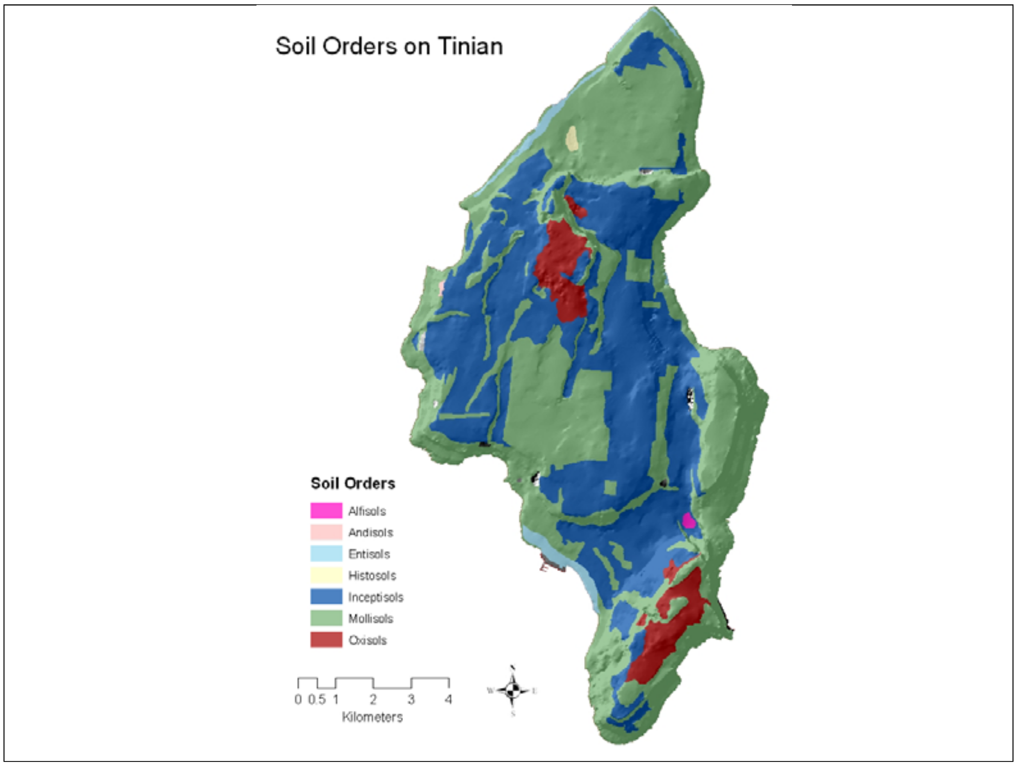
- **Physical**
  - Improves soil structure
  - Increases water retention
- **Chemical**
  - Increases nutrient availability (N & P cycling, solubility)
  - Increases nutrient retention (CEC)
  - Detoxifies Al
- **Biological**
  - Increases microbial diversity
  - N fixation (rhizobia), P availability (myccorhiza)
  - 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 Tinian has 38 map units identified by a soil series name and different slope characteristics. The map unit can provide 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.



Soils on the island of Tinian are predominantly Mollisols and Inceptisols that formed on limestone. There are smaller areas of Oxisols and Alfisols that developed on volcanic outcrops and Entisols are found on the coastlines of parts of western Tinian. Isolated patches of Histosols and Andisols are located in western and northern Tinian.

Mollisols are typically fertile soils associated with grasslands. On Tinian they occur on the elevated limestone plateaus and prime pasture lands.

Inceptisols on Tinian are similar in properties to the Mollisols and tend occur together on the landscape, except that they are higher in oxide clay content and tend to have slightly acidic pH (6.0-6.5). They are fertile soils that are also suited to pasture.

Entisols on Tinian are sandy and located along the coast. They are excessively drained and vulnerable to drought.

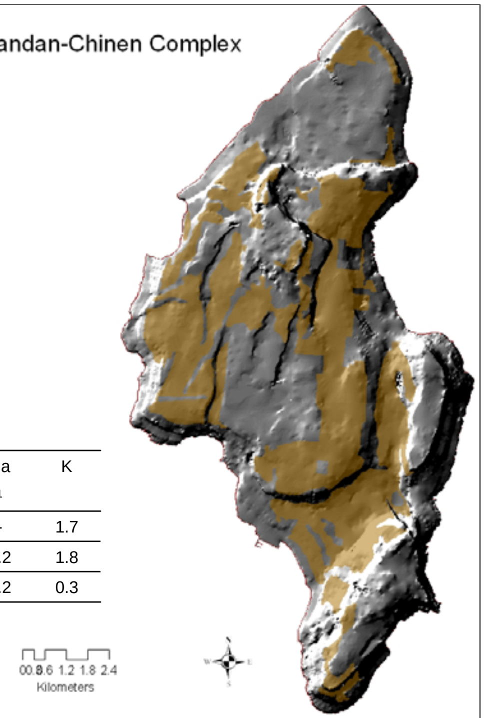
Oxisols are highly weathered soils with low fertility that have developed from exposed volcanic parent material. They are typically acid and have a low capacity to supply key plant nutrients such as Ca, K, and P. Lime is often required to raise the soil pH.

Andisols are soils from volcanic ash parent material. They are typically fertile soils.

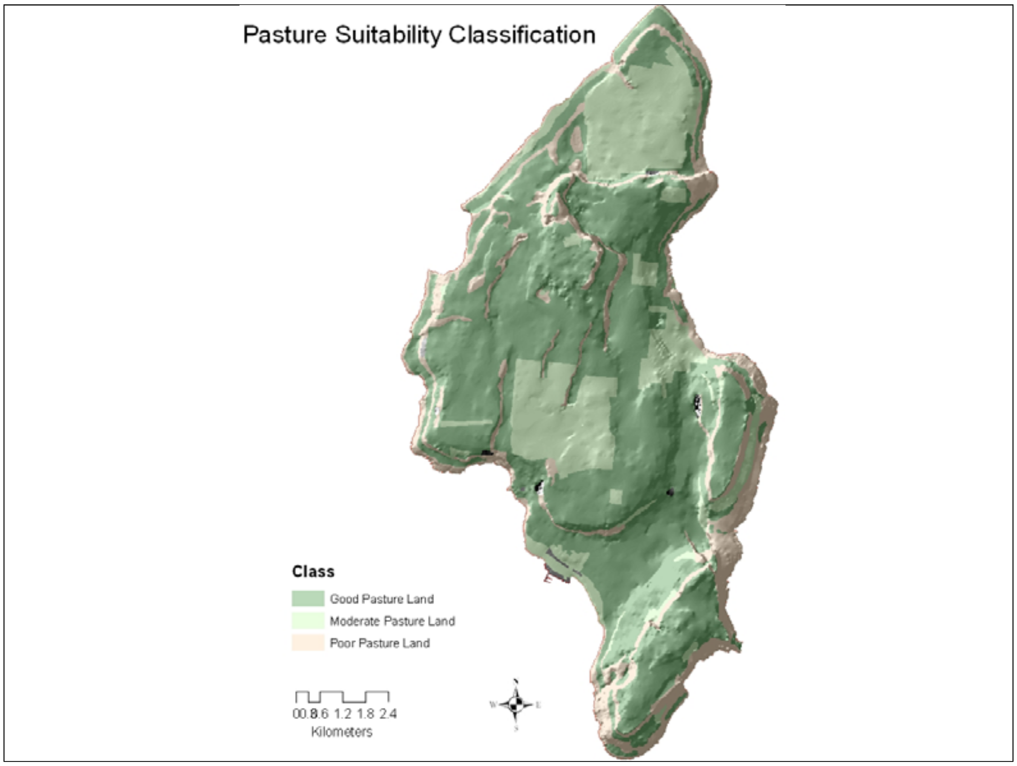
Histosols form in depressions where organic matter has accumulated and drainage is poor. They are typically associated with poorly drained sites such as wetlands.

Dandan-Chinen Complex

Horizon	%Clay	pH	% C	Ca	Mg	Na	K
cm					cmol$_c$ kg^{-1}		
0-11	82.0		4.69	48.3	14.5	-	1.7
11-22	53.2		2.87	28.7	5.0	0.2	1.8
22-45	77.2		1.17	22.3	12.2	0.2	0.3

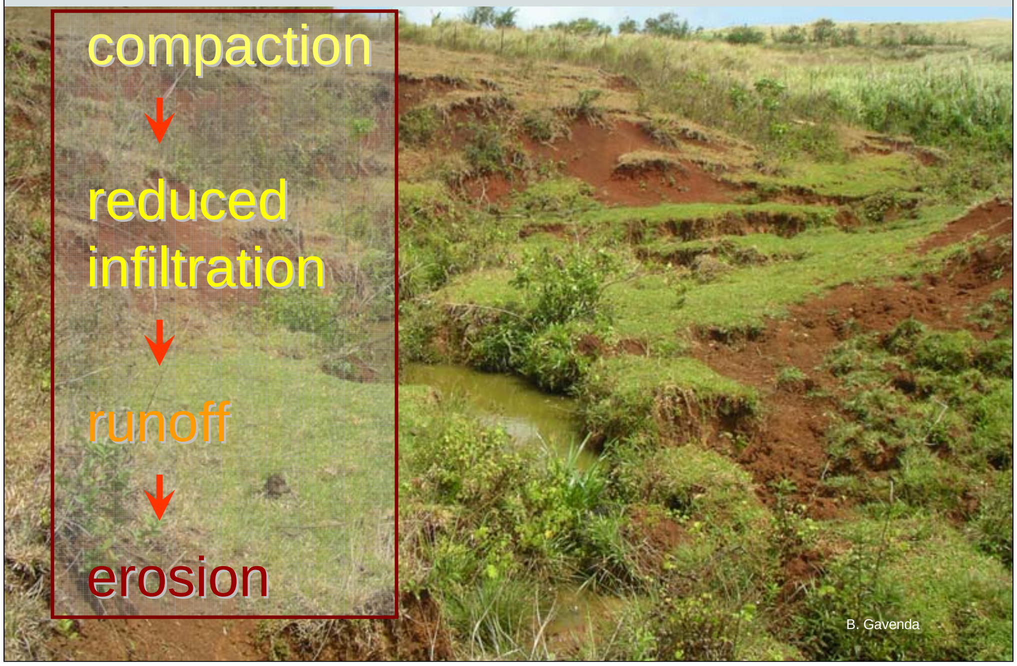


The Dandan-Chinen complex is a common soil association on Tinian. The Dandan is an Inceptisol and the Chinen is a Mollisol. Data in the table is from a Dandan soil sampled in central Tinian.



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.

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