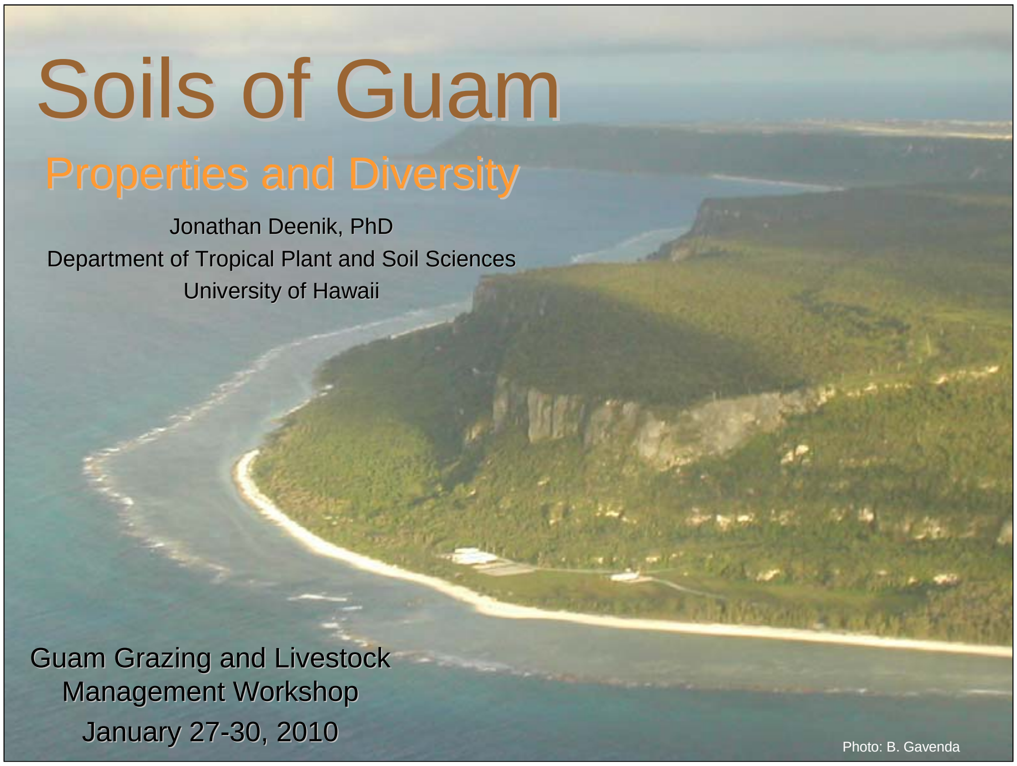
Soils of Guam
Properties and Diversity
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Photo: B. Gavenda

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 Guam

Soil Formation

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

Factors:

PM = parent material (rocks)

Cl = climate (precipitation and temperature)

O = organisms (plants and animals)

R = relief (topography, drainage)

T = time

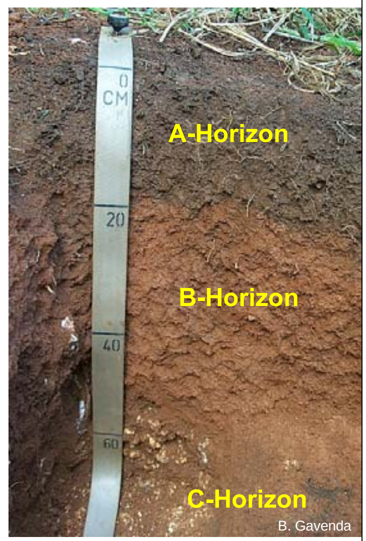
Soils form as a result of the combined effects of climate and biotic activities (microbial, plant, and animal life), modified by landscape relief and position, acting on parent materials over time. Ample rainfall and warm temperatures increase the rate of chemical weathering, which act to transform primary 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 found in south-central Guam (top) that has formed volcanic parent material (basalt 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.

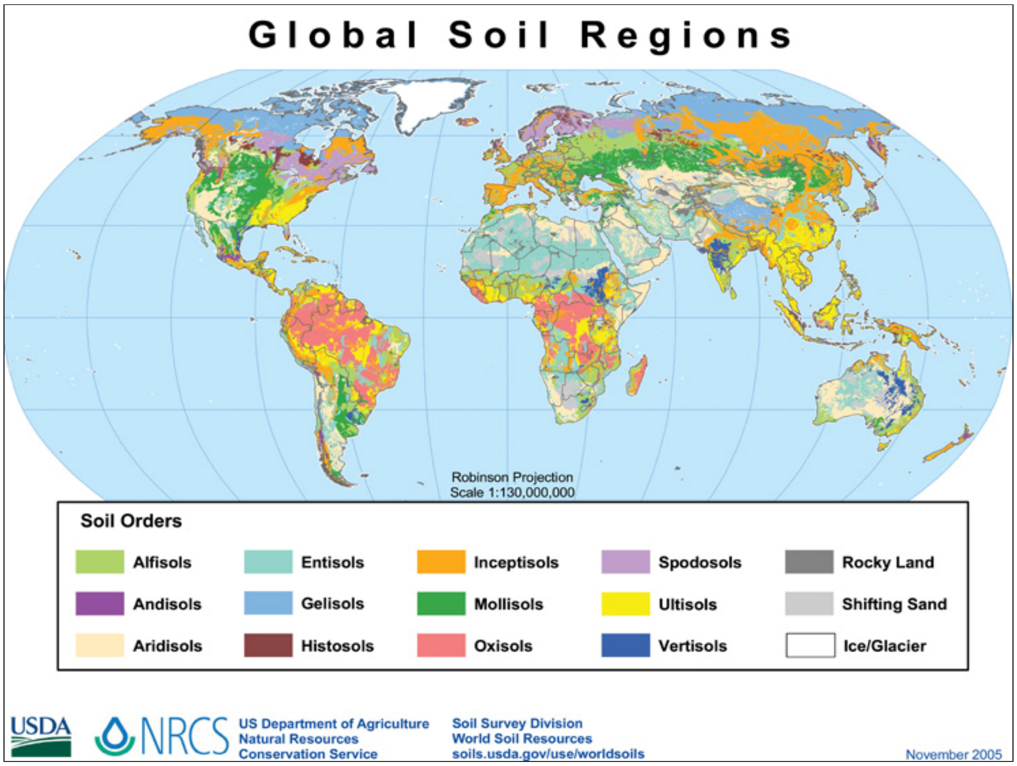
Soil Formation

<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

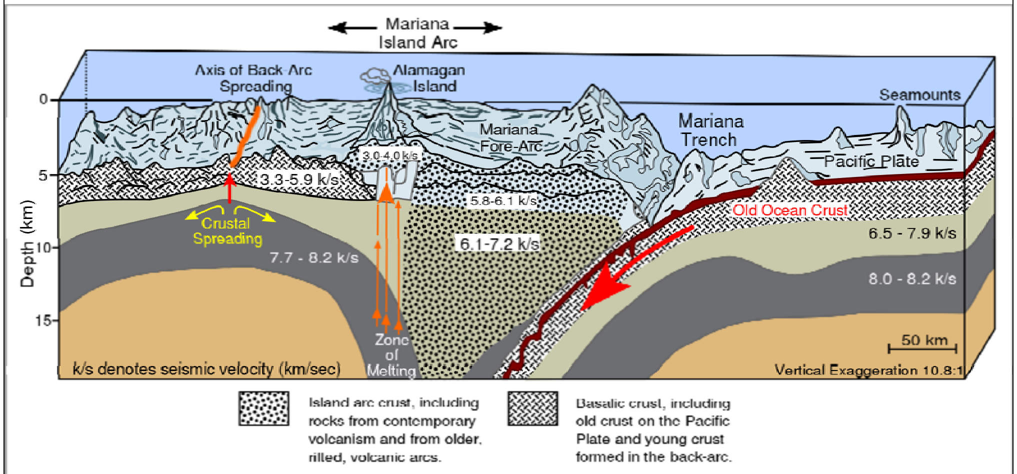


In addition to the five soil forming factors discussed in the previous slide, four soil forming processes interact to differentiate soil horizons or layers. Additions includes inputs to the developing soil profile from outside sources such as organic matter in the form of falling leaves. Sediments transported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



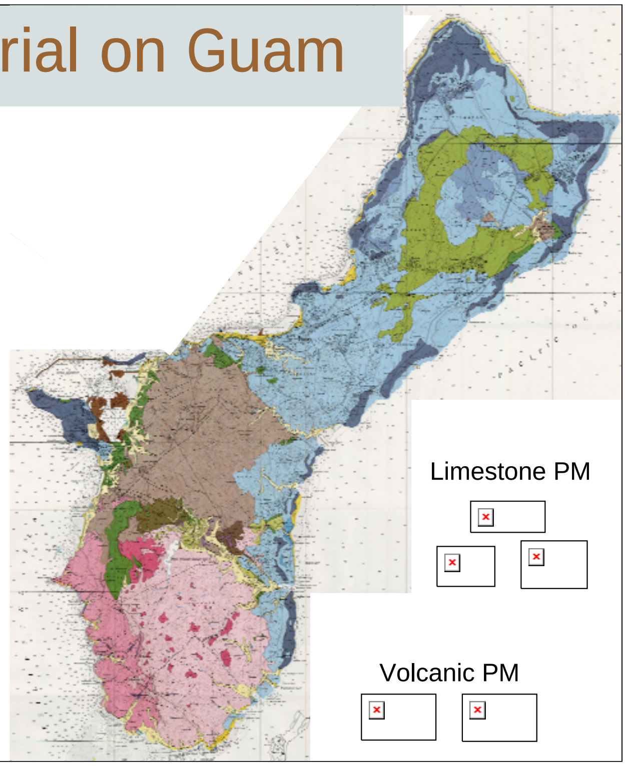
Cross-Section Sketch of Mariana Arc

(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/)

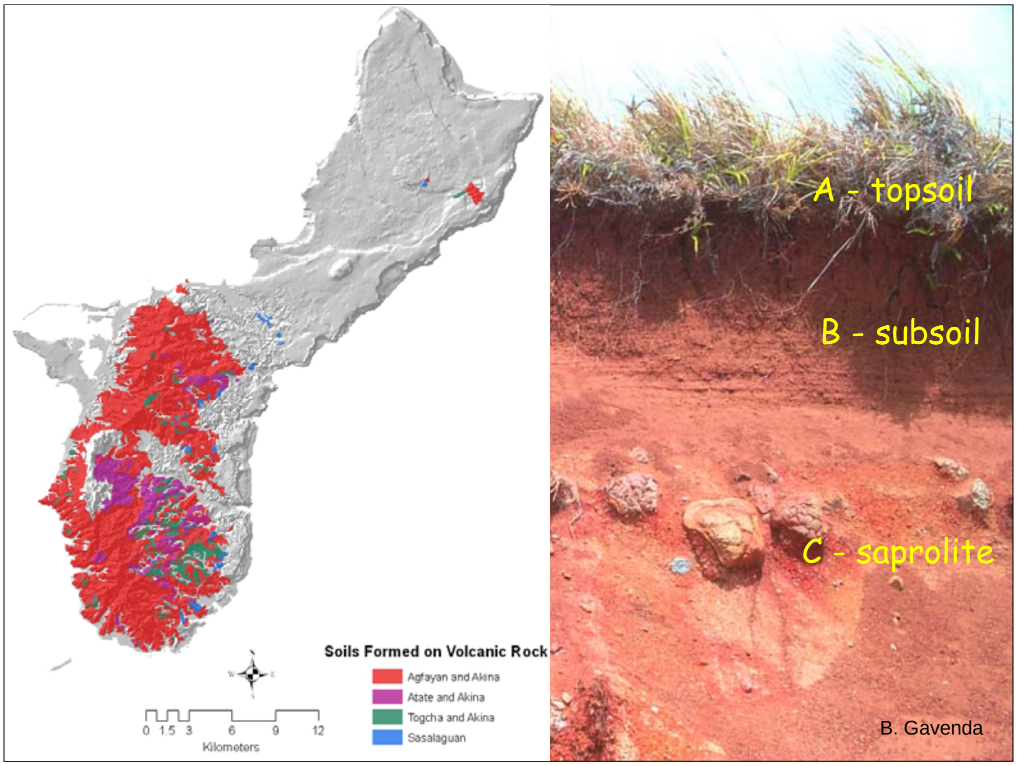
Parent Material on Guam

- Volcanic rock is the foundation of the island
- Southern portion is primarily volcanic rock
- Northern portion is limestone overlying volcanic rock



Source: Gingrich (2003) USGS Report 03-4126

The island of Guam formed as a result of volcanic activity some 35 million years ago. Remnant rocks from the volcano still form the foundation of the island and evidenced by volcanic rock outcrops throughout the southern portion of the island. The northern half 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.



This is probably a Togcha soil series from Southern Guam. This soil has formed in place from the volcanic basalt parent material.

Soil Formation on Limestone

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

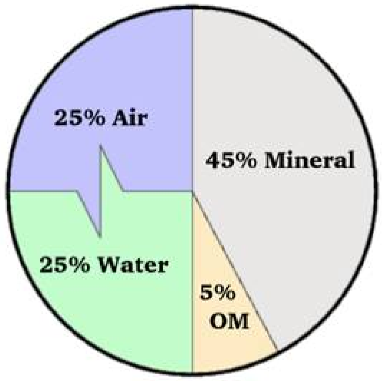
There are at least two possible mechanisms explaining the formation of soils found on the limestone plateaus of Northern Guam. The first explanation assumes that in the geologic past sediments of volcanic origin were deposited in the submerged lagoonal areas and subsequently incorporated into the coral 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.

Example of the Saipan soil series located in the Yona area of east central Guam.

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

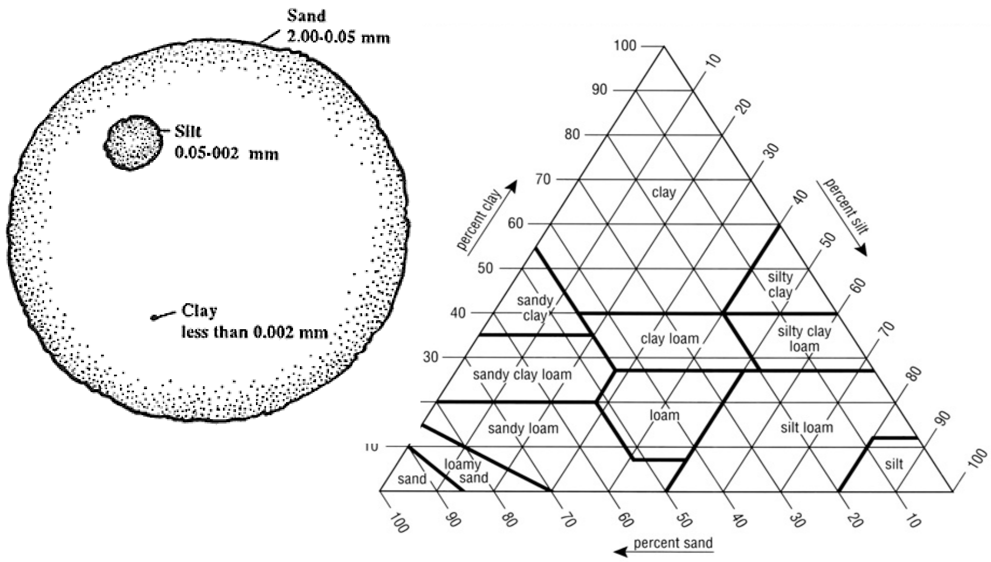


Photos: B. Gavenda

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

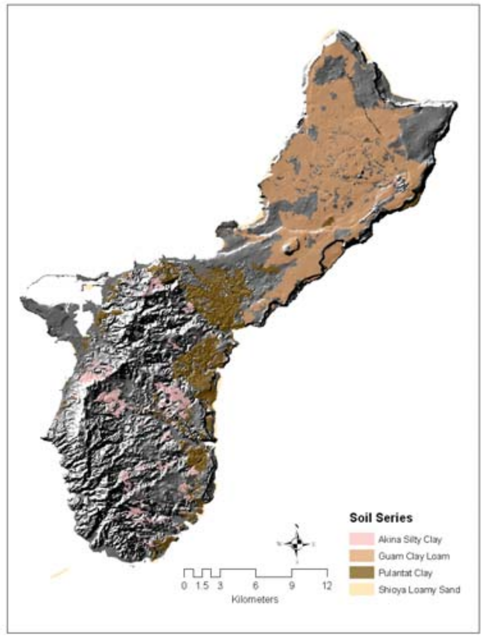
Sand: 2.0 mm -0.05 mm, gritty feel. Sand is visible to the naked eye, consists of particles with low surface area, low nutrient holding capacity, and permits excessive drainage.

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.

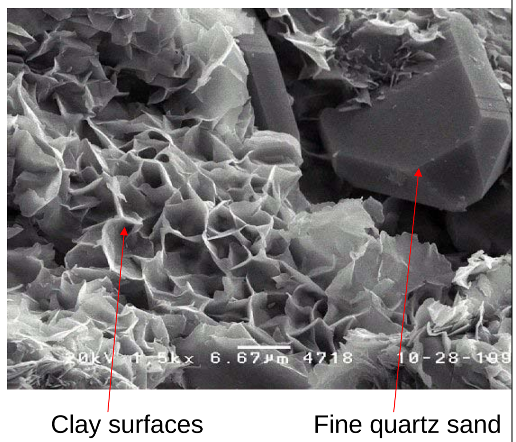
Sandy soils are prone to drought, are typically infertile, and require intensive management to promote good plant growth. The Shioya series is a loamy sand soil found along the coasts of north-western and south eastern Guam.

Soil Series	Textural Class
Agfayan	Clay
Akina	Silty Clay
Atate	Clay
Chacha	Clay
Guam	Clay Loam
Inarajan	Clay
Kagman	Clay
Pulantat	Clay
Ritidian	Clay Loam
Sasalaguan	Clay
Shioya	Loamy Sand
Togcha	Silty Clay
Yigo	Silty Clay
Ylig	Clay



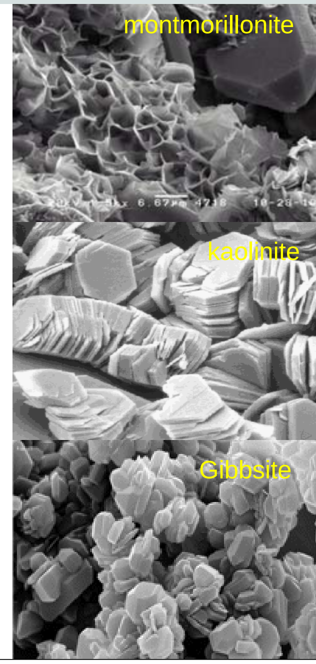
Properties and Importance of Clay

- 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)



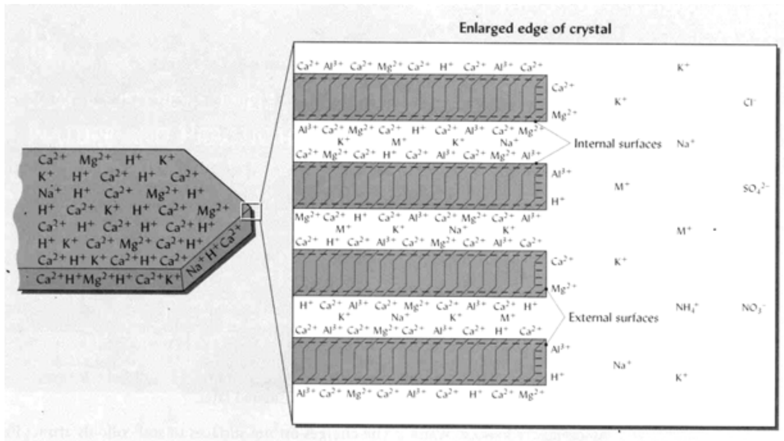
Clay Type is Important

- Montmorillonite (high activity clay)
  - Shrink-swell clay (unstable)
  - High fertility clay (high cation exchange capacity)
- Kaolinite (low activity clay)
  - Non-expanding clay (stable)
  - Low fertility clay (low cation exchange capacity)
- Fe & Al oxides (low activity clay)
  - Goethite, gibbsite
  - Non-expanding clay (stable)
  - Very low fertility (no cation exchange capacity)

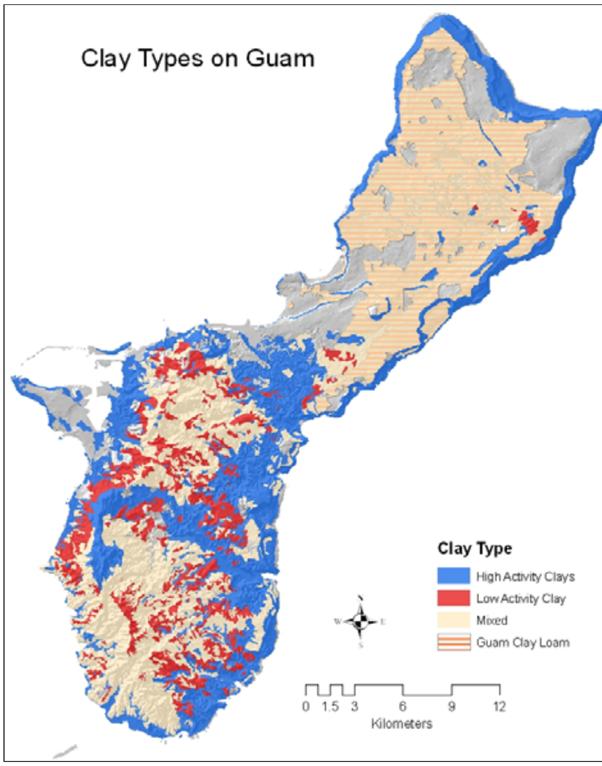


The effects of chemical weathering of primary minerals produce clay minerals. Variations in weathering intensity produce different clay minerals with different physical and chemical properties. Clay mineralogy is closely related to soil fertility. Differences in clay mineralogy cause great differences in soil fertility. For instance, under moderate weathering conditions, montmorillonite clays are dominant. Montmorillonite is a clay that swells when it is wet and shrinks or cracks when it dries out. It has very high surface area with abundant negative charge. These negatively charged surfaces have the ability to adsorb important plant nutrients like calcium (Ca2+), magnesium (Mg2+) and potassium (K+). This ability to adsorb cations (positively charged ions) is called cation exchange capacity or CEC for short. As weathering intensity increases, kaolinite clays form. Kaolinite is a non-expanding clay with much less surface area than montmorillonite and a low capacity to adsorb cations. Although soils containing kaolinite are much less fertile than montmorillonitic soils, they have good physical properties making them relatively easy to cultivate. Some soils contain a mixture of both montmorillonite and kaolinite clays. Under intense weathering conditions gibbsite forms. Gibbsite is an oxide of aluminum that has very low CEC

Cation Exchange Capacity (CEC)



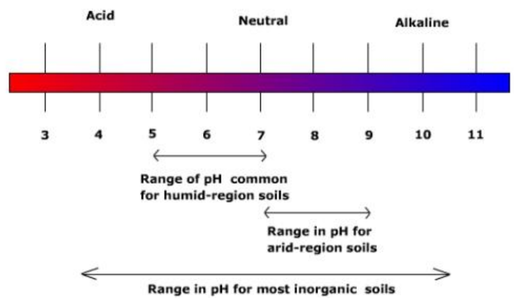
Negatively charged sites that adsorb cations:
Ca^{2+}, Mg^{2+}, K^{+}, NH^{4+}



- Guam Clay Loam contains high Al-oxides (low activity clay) with good physical properties
- But has high CEC, a property associated with high activity clay

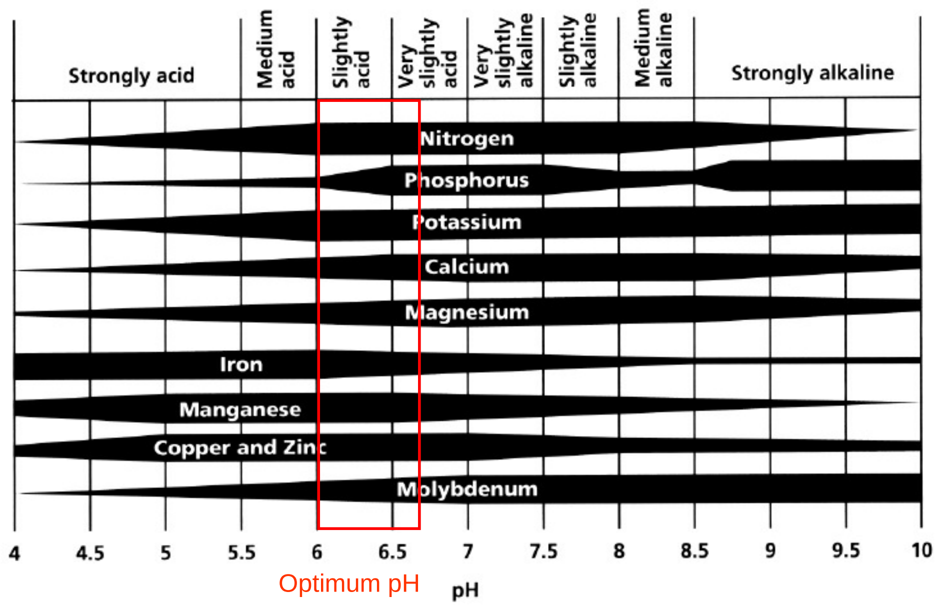
The Guam series, which is extensive on the limestone plateau of northern Guam, is an unusual soil. Based upon mineralogical analysis in the laboratory it contains a high amount of gibbsite (Al-oxide clay mineral) – a low activity clay with very low CEC. The high CEC in this soil can be attributed to high amounts of organic matter in the surface horizon.

The pH Scale

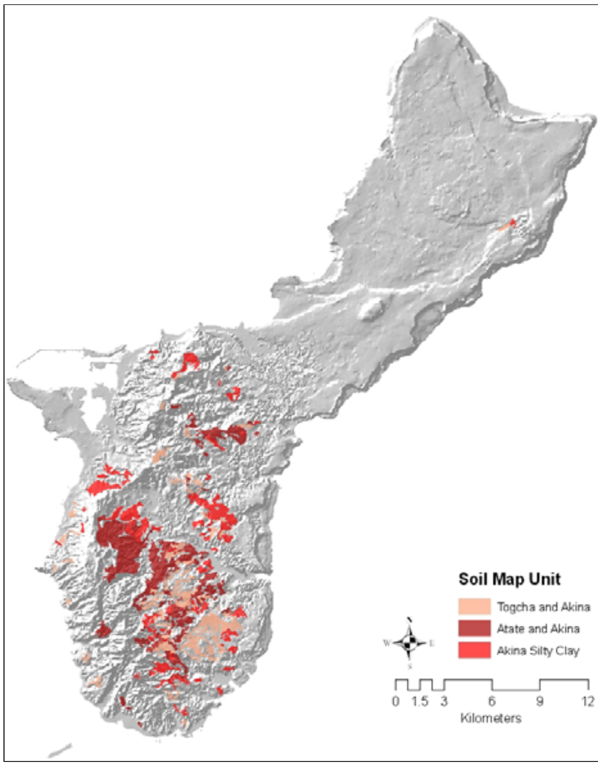


pH is a scale we use to describe the concentration of H+ ions in water. Below pH = 7.0 we have acid conditions where [H+] is higher than [OH-]. At pH = 7.0 [H+] = [OH-] and at pH > 7.0 we have alkaline conditions where [OH-] > [H+]. pH in soil is important because it controls the solubility and availability 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.

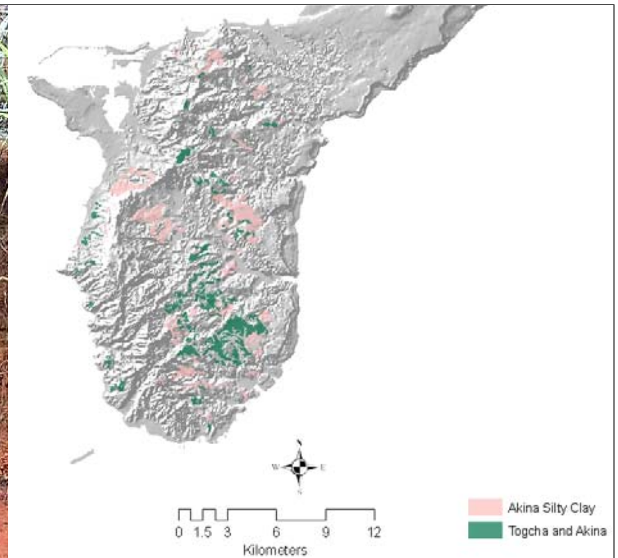
Soil Acidity and Nutrient Availability



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.



- Soils typically acid to strongly acid
- Aluminum toxicity especially severe in Akina subsoil

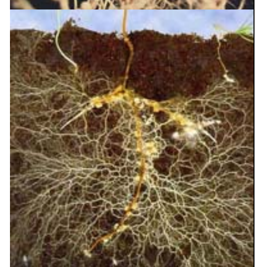


Depth (cm)	OM	pH	CEC	$Base_{sat}$	Al_{sat}
	%		$cmol_c\ kg^{-1}$	%	
0-10	5	5.0	12.4	85	15
20-10	2.8	4.9	8.4	49	51

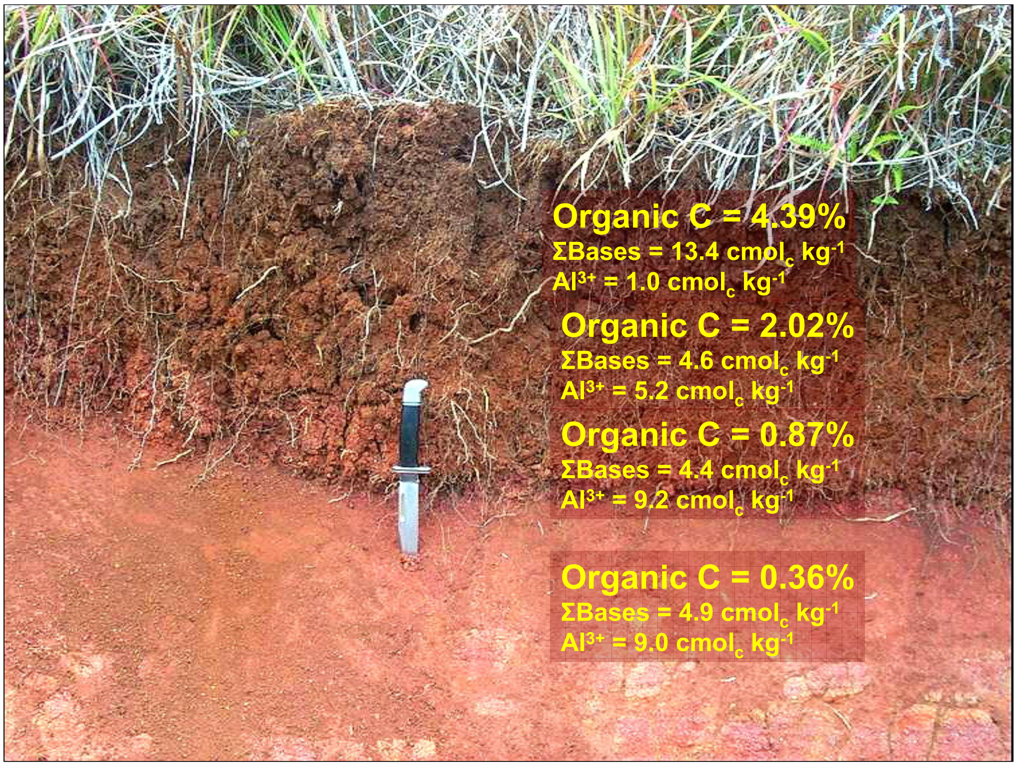
Akina soil series is found in southern Guam. It also occurs in close association with the Agfayan and Atate soils. The Akina soil is a very acid soil with a shallow A and B horizon overlying weathered saprolite. Aluminum toxicity is common in this soil and liming with calcium carbonate improves its fertility. This soil is susceptible to erosion.

Role of Organic Matter in Soil

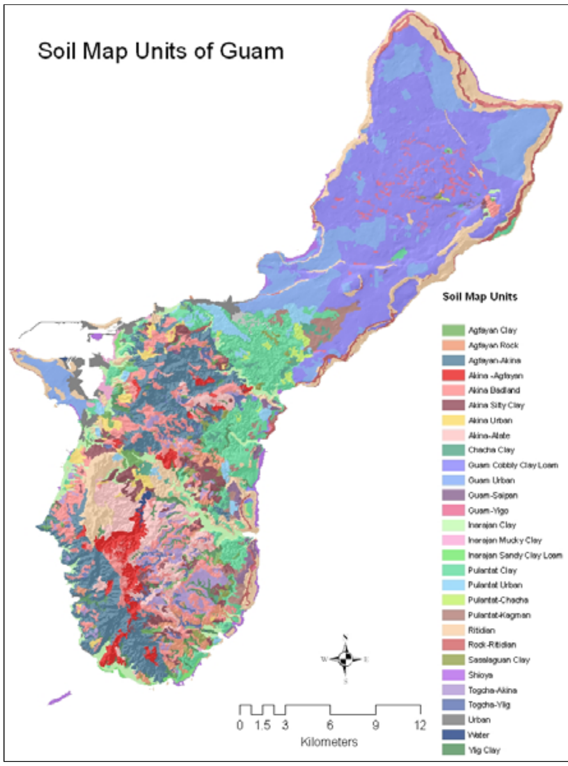
- **Physical**
  - Improves soil structure
  - Increases water retention
- **Chemical**
  - Increases nutrient availability (N & P cycling, solubility)
  - Increases nutrient retention (CEC)
  - Detoxifies Al
- **Biological**
  - Increases microbial diversity
  - N fixation (rhizobia), P availability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



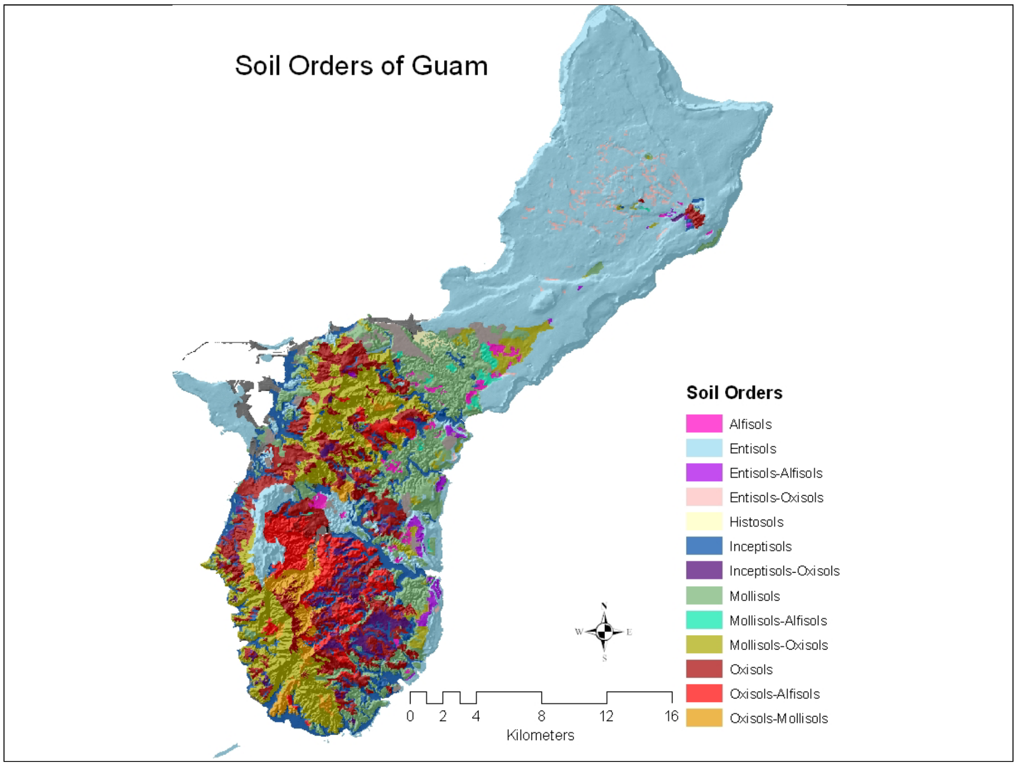
Soil organic matter (SOM) includes: living organisms (soil biomass), the remains of microorganisms that once inhabited the soil, the remains of plants and animals, organic compounds that have been decomposed within the soil over thousands of years and reduced to complex and relatively stable substances 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.



The Akina soil pictured above, is a good example of how SOM plays a key role in the fertility of many tropical soils. In the A-horizon organic carbon (C), which is a laboratory measure of organic matter (we multiply % organic C by 1.72 to get % organic matter), is high relative to the B and C-horizons. The high organic C in the A-horizon acts to retain the base cations (Ca, Mg, K), which are important plant nutrients. These nutrients are high in the organic rich A-horizon because the organic matter supplies CEC. At the same time, the high organic matter in the A-horizon reduces Al3+ toxicity, but as the organic matter decreases in the slower horizons, Al^{3+} toxicity becomes a serious obstacle to plant growth.



- 53 map units on the soil survey
- Map unit name provides no information on soil properties
- Soil Taxonomy is a classification system used to group soils based on measurable properties



The island of Guam consists of four soil orders with Entisols dominating the limestone plateau of Northern Guam and a mixture of Oxisols, Mollisols and Alfisols on the volcanic parent material of Southern Guam. Inceptisols are found in the bottom lands of southern Guam.

Entisols are weakly developed soils without B horizons. On Guam they are typically very shallow soils where depth to limestone bedrock ranges between 5 to 41 cm. They are moderately suited to grazing, but their rocky nature and susceptibility to drought can be problematic for pasture maintenance.

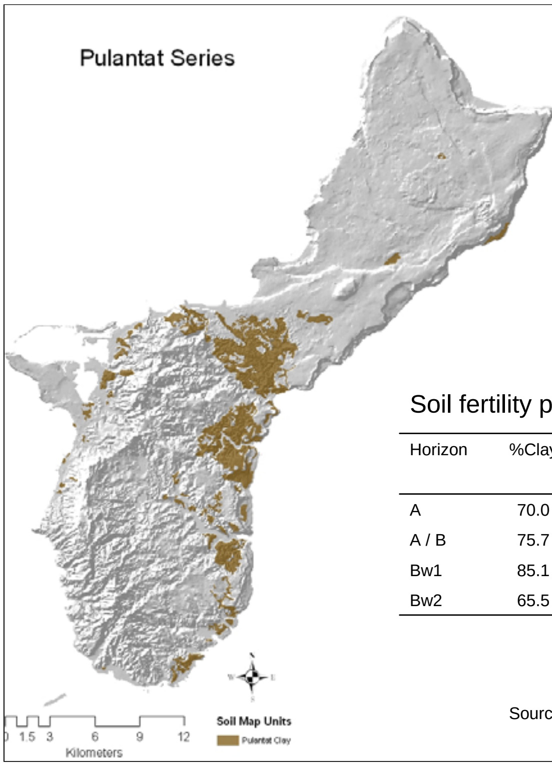
Mollisols are fertile soils rich in organic matter and non-acid cations that develop under grassland landscapes. They are typically rich in montmorillonite clays and their pH ranges from 6.5 to 7.0. These are classified as very productive soils.

Alfisols are moderately fertile soils that typically develop under savanna landscapes. They are characterized by clay accumulation in the B horizon, and moderate amounts of non-acid cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}). These soils are moderately acidic with pH ranging from 5.5 to 6.5.

Oxisols are highly weathered soils with low fertility that have developed from volcanic parent material in southern Guam. They 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 typically found in the bottom lands of southern Guam and they are formed from alluvial materials. They are typically relatively fertile soils with slightly acidic pH. However, when they occur in association with Oxisols on steep lands they are usually acid and infertile.

From the map, it is clear that soils developed on the limestone plateau of northern Guam are uniform, but the soils developed on the volcanic parent material of southern Guam are more diverse and variable on the landscape.



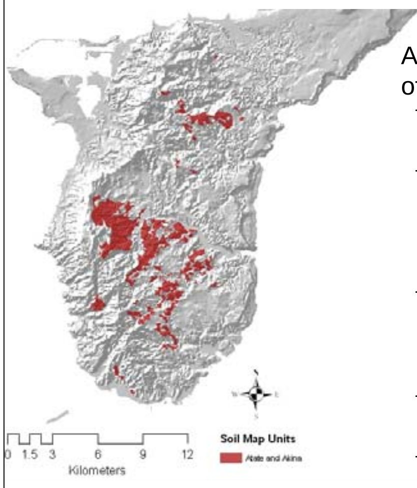
Soil fertility properties

Horizon	%Clay	pH	% C	Ca	Mg	Na	K
				cmol$_c$ kg^{-1}			
A	70.0	6.5	5.09	62.8	10.8	0.4	0.6
A / B	75.7	6.6	2.28	51.2	8.5	0.3	0.4
Bw1	85.1	7.5	1.47	65.3	5.6	0.2	0.4
Bw2	65.5	8.0	1.05	91.2	3.0	0.3	0.3

Source: NRCS soil characterization data

The Pulantat series is common to central and south-eastern Guam. It is a very fertile soil with a slightly acidic surface horizon that becomes alkaline in the sub-soil due to the influence of the limestone parent material. It has high levels of organic matter in the surface horizons, and it is rich in Ca throughout the profile. It shows very high CEC and there are no fertility constraints in this soil.

Atate-Akina Map Unit



Atate series (Alfisol) covers approximately 60% of the map unit

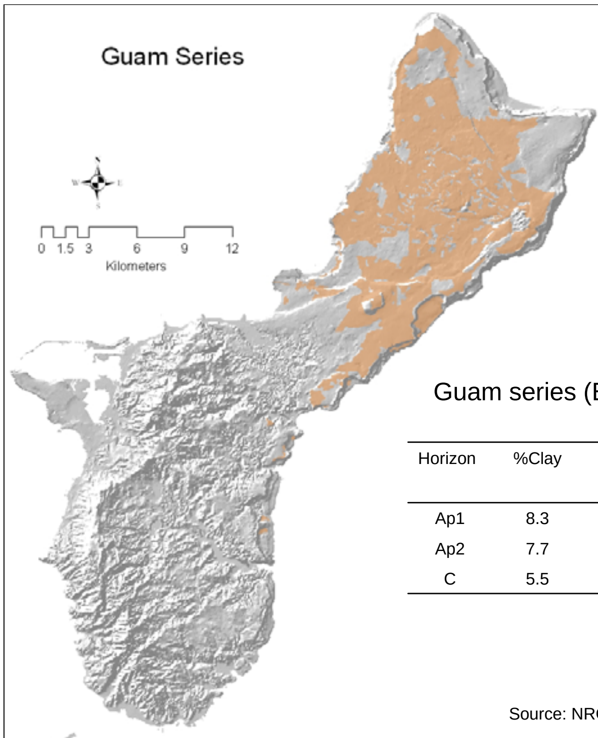
Horizon	%Clay	pH	% C	Ca	Mg	Na	K
					$cmol_c\ kg^{-1}$		
A1	42.8	5.5	3.86	6.2	4.7	0.2	0.8
A2	53.6	6.2	1.85	2.6	2.7	0.2	0.1
Bo1	74.4	5.8	0.91	2.3	4.3	0.2	0.1
Bo2	56.8	5.9	0.53	3.4	6.9	0.3	0.3

Akina series (Oxisol)

Horizon	%Clay	pH	% C	Ca	Mg	Na	K
					$cmol_c\ kg^{-1}$		
A	65.5	5.0	5.04	3.4	6.6	tr	0.5
Bo1	68.9	4.9	2.81	1.4	2.7	tr	tr
Bo2	62.1	5.0	1.53	1.1	2.6	tr	--
Bw	50.5	5.1	0.63	1.0	2.8	tr	--

Source: NRCS soil characterization data

The Atate series is an Alfisol with intermediate fertility. It has much lower Ca than the Pulantat, but not as Ca depleted as the Akina series. The Akina series is the least fertile soil on Guam. It is very acidic, very low in plant nutrients, and prone to Al toxicity.

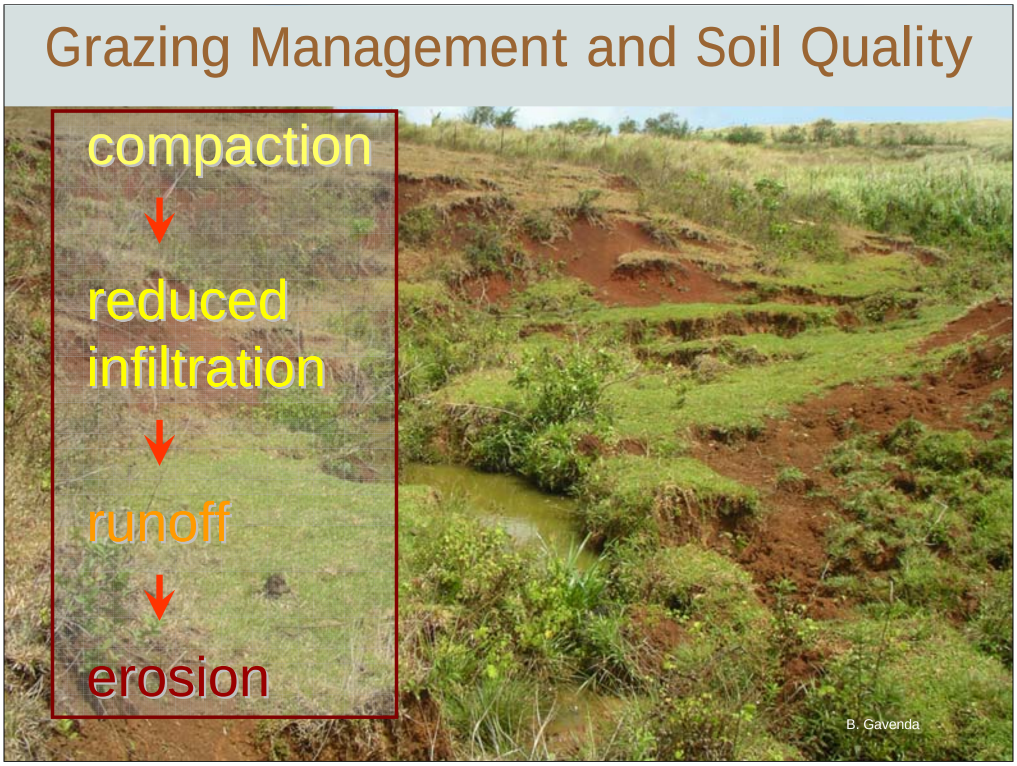


Guam series (Entisol)

Horizon	%Clay	pH	% C	Ca	Mg	Na	K
					cmol$_c$ kg^{-1}		
Ap1	8.3	7.6	6.8	84.4	4.1	0.1	0.3
Ap2	7.7	7.8	5.9	79.9	2.1	tr	0.1
C	5.5	8	2.8	71.9	0.7	tr	tr

Source: NRCS soil characterization data

The Guam series is the dominant soil type on northern Guam. It is a shallow soil overlying coral limestone. The soil pH is high, which can cause deficiencies in micronutrients such as iron and zinc. Clay content varies depending on depth to the limestone bedrock. The shallower soils like the example above (20 cm deep) have very low clay content and are prone to drought. On the other hand, in some areas where the soil is deeper (>1 m), clay content can be as high as 60-70%.



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