Soil Quality and Land Use Change on a Humid Tropical Island – Palau

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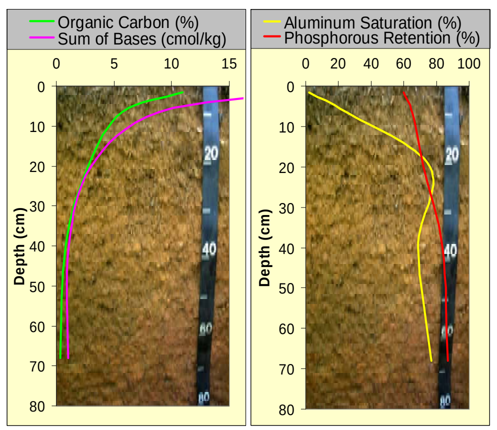
Changes in soil properties as a result of land clearing

- Babeldaob Island, Republic of Palau, is the 2nd largest in Micronesia at 372 km^2 or 144 mi^2
- Increasing development pressure due to improved access from a new road that circles the island
- Development plans on Babeldaob call for significant land clearing for agriculture and housing
- All Palau soils developed in upland volcanic rocks are very infertile ⟶ support sparse vegetation when topsoil is removed

degraded fernland

increasing land degradation

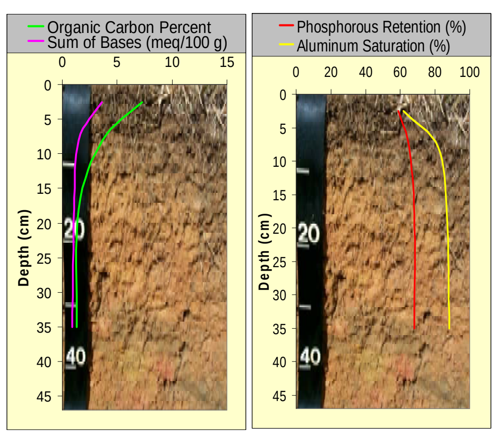
forest



Forest Soils

- Forest topsoils have the highest soil quality in Palau's volcanic uplands
- Active nutrient cycling maintains fertility
- High topsoil carbon results in high amount of bases (plant nutrients)
- Organic acids complex with aluminum and reduce aluminum saturation to 2% in topsoil
- Phosphorus sorption high but lower in topsoil

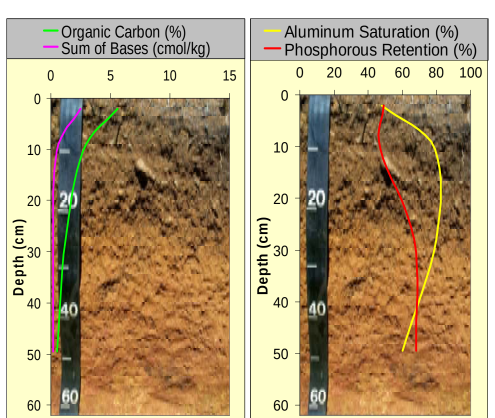
grassland



Grassland Soils

- Grassland soils are degraded forest soils
- Grasslands form through forest clearing and the repeated burnings
- Topsoil has 2/3 the carbon and only 1/5 the bases of forest topsoil
- Aluminum saturation is much higher than the forest topsoil (60% vs. 2%)
- Phosphorus sorption is similar to the forest topsoil but lower in subsoil

fernland



Fernland Soils

- Fernland soils are the most highly degraded soils except for barren ground
- Fernlands form mostly on ridges through repeated burnings of grassland coupled with erosion
- Topsoil has 1/2 the carbon and only 1/10 the bases of forest topsoil
- Aluminum saturation is much higher than the forest topsoil (48% vs. 2%)
- Phosphorus sorption is similar to the forest topsoil but lower in subsoil

Soil Organic Matter (SOM) vs. Synthetic Fertilizers

- SOM promotes healthy soil environment for beneficial organisms
- SOM allows the soil to hold on to and recycle nutrients
- SOM improves soil aggregation and structure ⟶ better permeability ⟶ lower erosion
- SOM improves water holding capacity
- SOM complexes with aluminum so that it does not interfere with plant growth
- SOM acts as slow-release fertilizer so nutrients do not leach out of soil too fast
- Fertilizers can help plants after soil organic matter is built up to increase the soil exchange capacity
- Fertilizers can be a quick fix for nutrient deficiencies if the soil can hold on to the nutrients
- Fertilizers can be easily over-applied and be a source of pollution
- Fertilizers *do not* have the other beneficial effects of SOM

Aluminum Saturation and Liming

- A number of important agricultural crops suffer from aluminum toxicity symptoms and reduced productivity when the Al saturation is greater than 10%
- Some plants (e.g. cassava, sweet potato, native trees) tolerate high levels of soluble aluminum
- Aluminum stunts root growth thereby limiting the amount of soil the plant can exploit for nutrients
- Stunted roots limit water uptake, potentially exposing plants to water deficiency stress
- When liming soils with high soluble aluminum the rule of thumb is to add 1.5 tons of $CaCO_3$ per acre for every miliequivalent of extractable aluminum
- Soil pH needs to be raised to about 5.5 to eliminate the harmful effects of high soluble aluminum
- Liming the soil increases the cation exchange capacity in these pH-dependent variable charge soils and adds calcium as a plant nutrient
- Crushed coral can be used for liming but the finer the coral particles are the more effective they will be as liming material
- High soluble aluminum and low calcium inhibit beneficial soil organisms

Phosphorus Retention

- Phosphorus retention capacity measures the ability of soil to retain phosphorous
- P-sorption is pronounced in soils dominated by kaolin minerals and iron and aluminum oxides
- Volcanic soils in Palau sorb 60 – 95 % of applied phosphorus fertilizer, which is only slowly released and available for plant uptake
- Phosphorus fertilizer is best applied in bands close to plant roots rather than broadcast application
- Phosphorus fertilizer applied in contact with lime forms insoluble calcium phosphate
- Eroded soils with sorbed phosphorus can impact eutrophication of coastal waters

Reclaiming Degraded Lands with Nitrogen-fixing Trees

Acacia w/ & w/o mulch, lime, fertilizer

- N-fixing *Acacia* trees were thought to be able to restore degraded lands on Babeldaob
- Many *Acacia* were planted 10 - 15 years ago but barely survive today on highly infertile soils
- N-fixing ability of the trees probably compromised by low calcium and high soluble aluminum in the soils
- Additions of mulch, lime and fertilizer have revived trees in only 5 months
- Reclaiming large areas of degraded land requires high inputs of time, money, resources and energy
- *Acacia* alone without groundcover does not stabilize sites and can lead to gully formation

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Republic of Palau
7° 35' N latitude
134° E longitude
3,700 mm rainfall
27° C air temperature

Introduction

- Study examines soil quality and land cover changes on Babeldaob Island
- Mostly highly weathered soils (Oxisols) with very low fertility and high levels of soluble aluminum (Al toxicity)
- Soils: highly sensitive to disturbance and low resilience for recovery
- Increasing pressure to clear forest for housing and agriculture
- Clean-till agriculture is not sustainable, agroforestry is sustainable

Objectives

- Examine soil quality changes linked with land use change
- Examine conservation strategies to maintain soil quality

Methods

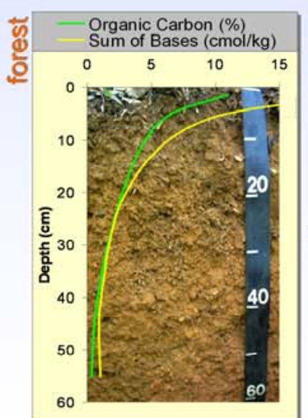
- Soil data from forest and fernland are compared
- Standard USDA soil analyses conducted to determine values for soil quality parameters
- Empirical observations

typical volcanic upland landscape

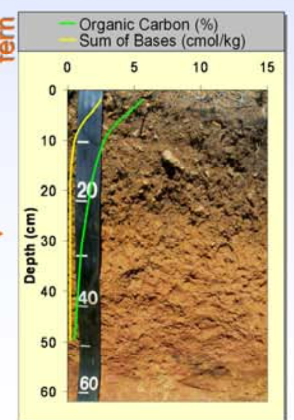
Key Soil Quality Parameters

- Land clearing via fire converts forest to grassland and fernland ⟶ affects soil properties
- Soil property changes mostly affect topsoil; all subsoils have similar properties
- Organic carbon (not soil minerals) provides nearly all nutrient exchange capacity
- Plant nutrients (sum of bases) are very low
- Soil fertility linked to topsoil organic matter
- Converting forest to fernland reduces carbon content and the capacity to hold plant nutrients

forest

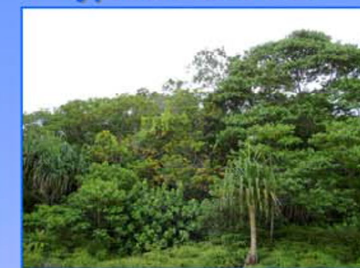


fern



Typical Land Use

increasing land degradation



Forest

- About 80% of Babeldaob forested
- Intact active nutrient biocycling
- Biocycling of organic matter essential for forest health
- Relatively fertile topsoil but infertile subsoil
- Highest quality soil health

Agroforestry

- Maintains soil organic matter through mulching, reduced tillage
- Harvest different crops in different areas at different times to ensure groundcover protection from rainfall impact and water erosion
- Proven sustainability

Clean-till Agriculture

- High intensity rainfall erodes bare topsoil, especially on slopes
- Lowered carbon: oxidation, erosion
- High input of synthetic fertilizers, low input of organic matter
- Sediment and chemical pollution
- Low return on investment
- Not sustainable

Homesite Development

- Highly infertile subsoils exposed
- Inability to revegetate and stabilize sites due to very low soil fertility
- High intensity rainfall erodes bare soil, especially on slopes

Recommended Conservation Practices

agroforestry multi-story cropping

hillside ditches and vegetative barriers

groundcover prevents erosion

→

trees without groundcover

mulching prevents erosion and adds organic matter to the soil

→

Acacia with and without mulch, lime and fertilizer

Upland Volcanic Soils and Land Use - Conclusions

- ✓ Volcanic upland soils are highly sensitive to disturbance and have low resilience for recovery
- ✓ Managing for high soil organic matter levels is key for maintaining soil quality and productivity in the humid tropics on low fertility soils
- ✓ Clearing forest and repeated burning causes topsoil erosion and loss of soil organic matter, which holds nearly all the soil fertility
- ✓ Agroforestry uses sustainable organic matter management
- ✓ Organic mulch improves soil fertility, prevents erosion
- ✓ Clean-till agriculture reduces soil organic matter, accelerates erosion and is not sustainable

Abstract

The Republic of Palau lies in the high rainfall (3800 mm/yr) zone of the tropical western Pacific Ocean. Babeldaob Island accounts for three quarters of Palau's landmass and has nearly eighty percent forest cover and about twenty percent grasslands. The soils developed on volcanic rocks are predominately Haploperox, which are highly infertile and have low resilience to disturbance.

Change in land cover from forest to orchard or clean-till agriculture has severe impacts on soil properties. From initial forested conditions topsoil organic matter decreases by about fifty percent under grass. Soil organic matter (SOM) provides the majority of the cation exchange capacity (CEC) as the low activity clays have little capacity to hold nutrients. All soils have high soluble aluminum (60 to 90 percent) except for the forest topsoil, which has only one percent aluminum but sixteen percent SOM. The amount of SOM appears to lower the soluble aluminum level. SOM also appears to interfere with phosphorus sorption. Topsoils generally have twenty to thirty percent less P-sorption than subsoils with lower SOM contents.

In these soils nearly all soil fertility resides in the topsoil. Lowering of SOM leads to a downward spiral of land degradation that is difficult to recover from. Land use conversion from forest to agriculture needs to emphasize retention of SOM. Without high SOM the soils have little capacity to retain synthetic fertilizers. Additions of carbon to the soil are the means to sustaining soil health and productivity.