Soil Quality Considerations with Agroforestry in Palau

Trees for Improving Sustainability, Resource Conservation, and Profitability on Farms and Ranches

Koror, Palau June 26-27, 2006

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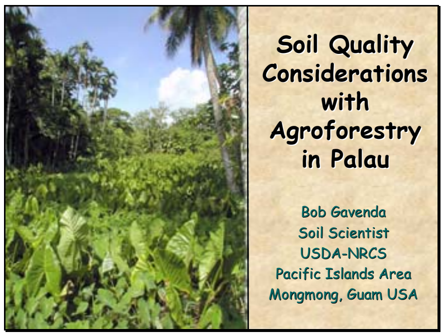
Slide 1



Agroforestry has been successfully practiced in Micronesia for several thousand years. This presentation gives the soils perspective as to why this agricultural system has been sustainable for such a long time.

Slide 2

Slide 3

This is what agriculture is supposed to look like. Well, maybe not. Clean-till agriculture is out of step with natural systems. Steep slopes without vegetative cover are susceptible to water erosion. One good thing here is that the furrows are along the contour. Many farmers in Palau plow up and down the slopes. They supposedly do that to help remove excess water more rapidly.
The system shown here works well if there is no rain, but when the weather moves in . .

Slide 4

And this comes on shore, then . .

Slide 5

This starts to happen. Raindrop impact breaks up soil aggregates, dislodges soil particles and erosion happens.

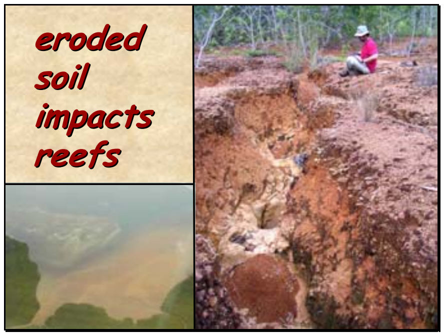
Slide 6

This farm has furrows up and down the slopes. The furrows work well to remove water but the water is removing valuable topsoil. Clean till agriculture on sloping infertile soils is not sustainable in a high intensity rainfall area such as Micronesia. Note that most soils in Micronesia form sand-size stable aggregates of clay. These aggregates are easily eroded from the soil surface.

Slide 7

Planting trees alone without establishing an understory will not prevent further degradation of sites like this. Even these nitrogen-fixing *Acacia* trees have a difficult time surviving on this site. The leaves they drop do not add organic matter to the soil because the leaves, along with soil, are washed away by the rain. Gullying and surface erosion still occur because the soil is still unprotected, which increases runoff and erosion. The watershed for these gullies starts only about 50 meters upslope. Note the poor condition of the *Acacia* trees, which are about 10 years old. The gullies formed after the trees were planted.

Slide 8



The land is connected to the sea. Land degradation adversely affects coral reefs by smothering them with sediment. The sediment alters fish habitat and generally lowers fish populations. The water source for these gullies is rainfall on slopes beginning only 50 meters uphill. Forest clearing followed by grassland maintenance through continued burning starts the downward spiral of land degradation. This situation is more easily prevented than it is solved after gullies start to form.

Slide 9

Agroforestry system in Yap. Multistory cropping offers good protection against raindrop impact. Harvesting different crops in different areas at different times helps ensure that there will always be a fair amount of groundcover to protect the soil from water erosion. There is also the benefit of continuous additions of organic matter. The benefit of cooler soil temperatures and higher soil organic matter are presumed to be more favorable to soil micro-organisms than clean till agriculture systems.

Slide 10

Agroforestry system in Yap. Multistory cropping offers good protection against raindrop impact. Harvesting different crops in different areas at different times helps ensure that there will always be a fair amount of groundcover to protect the soil from water erosion. There is also the benefit of continuous additions of organic matter. The benefit of cooler soil temperatures and higher soil organic matter are presumed to be more favorable to soil micro-organisms than clean till agriculture systems.

Slide 11

Agroforestry system and taro patch in east Koror, Palau. Note vegetative groundcover on steep hillside to prevent erosion.

Slide 12

Agroforestry system and taro patch in the Ngerikiil Watershed, Airai State, Palau. This farmer takes advantage of slight differences in soil moisture conditions (i.e. better drainage on slightly elevated land) to grow a wide variety of crops. Lesson: don’t fight the system with poorly suited crops, choose crops to match soil properties.

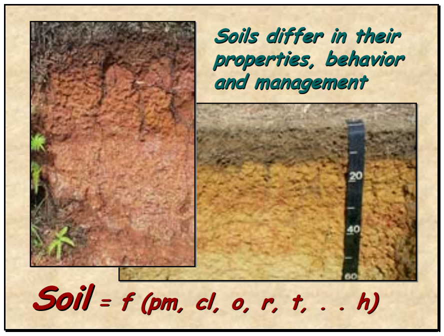
Slide 13

Archeological studies indicate that people introduced agroforestry crops thousands of years ago.

Slide 14

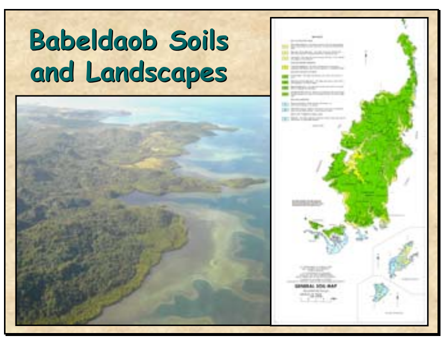
We will look are modern scientific soils data to explain why this system of agriculture is appropriate and successful.

Slide 15



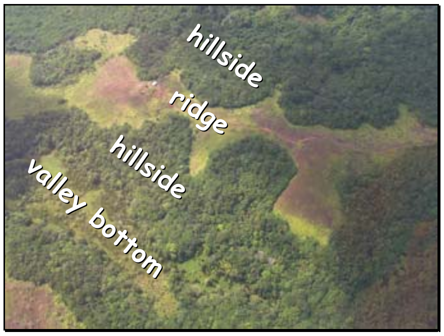
Soils are not randomly distributed across the landscape. Due to differences in the state factors of soil formation (parent material, climate, organisms, relief, time and human influence) there are different soils distributed in a pattern across landscapes. These different soils have different properties that behave differently and therefore respond differently to management.
Reddish Aimeliik-like soil formed in volcanic rock is on the left. Tabecheding soil formed in marine terrace clays is on the right.

Slide 16



We'll look mainly at soils on Babeldaob as that has the greatest land mass in Palau. From the general soil map we can see that the volcanic upland soils (green) are the most extensive soils. Two shades of yellow map units are for marine terrace soils developed in bedded clays and for bottomland soils in alluvium in valley bottoms and corral sand soils and organic soils along the coast. Blue areas are limestone soils. Limestone soils are mostly on steep rugged landscapes and are not farmed. Only Angaur and Peleliu Islands have flat limestone areas suitable for farming.

Slide 17



This is an aerial photo of a typical volcanic upland landscape just north of the airport. Ridge tops have been cleared of forest and then eroded. The vegetation on ridges is usually dominated by ferns, which are tolerant of high soluble aluminum levels. Hillsides are usually covered in forest and savanna. Valley bottom vegetation may be forest, savanna or hydrophytic plants depending on how wet the soils are.

Slide 18

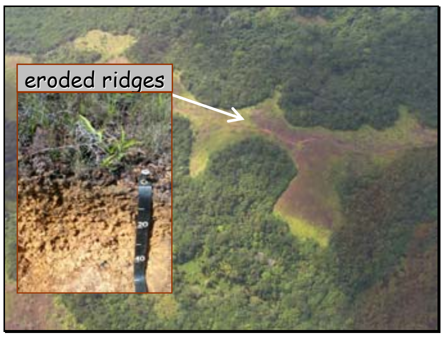


Photo of the Babelthuap series. Note the gravel lag concentrate on the soil surface and the gravelly nature of the soil in general. These are highly infertile soils that formed in volcanic rocks. These soils are considered to be an eroded version of soils that currently occur on forested hillsides.

Slide 19

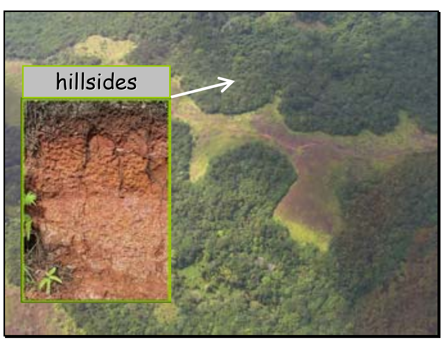


Photo of an Aimeliik series (or at least similar to Aimeliik). Topsoil is only about 4 inches thick. Volcanic saprolite (weathered bedrock with variegated red/white color pattern) occurs about 50 to 100 cm depth. This saprolite can form a root restrictive layer. These soils are infertile, with almost all the soil fertility located in the topsoil.

Slide 20

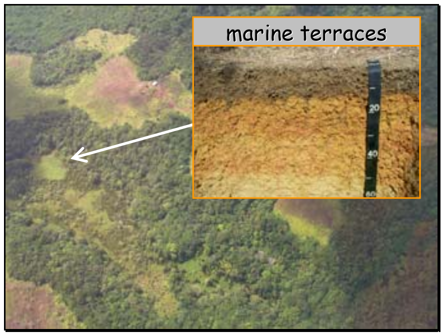


Photo of the Ngatpang or Tabecheding series near the Nekken Experiment Station, Palau. The water table is often within 16 inches of the soil surface. Note the reddish bands of oxidized iron that indicate a fluctuating water table. These soils formed in bedded clays that percolate very slowly. The soils are infertile and usually have high levels of soluble aluminum. These soils occur mostly in the area around Ngeremeduu Bay and in scattered areas in Airai State, Palau.

Slide 21

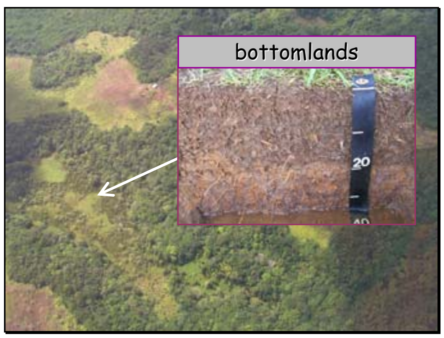
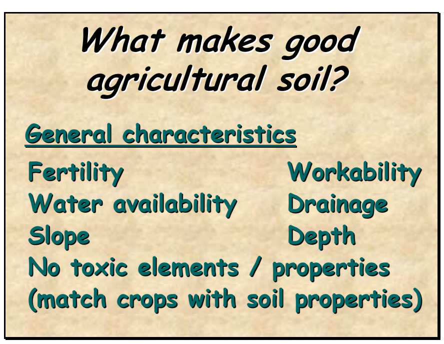


Photo of the Dechel series in the Ngerikiil Valley, Airai State, Palau. These soils formed in alluvial (i.e. water-deposited) sediment in broad valley bottoms. Note the high water table and grey and orange colors that indicate wetness. These soils are relatively fertile and are well suited for taro cultivation.

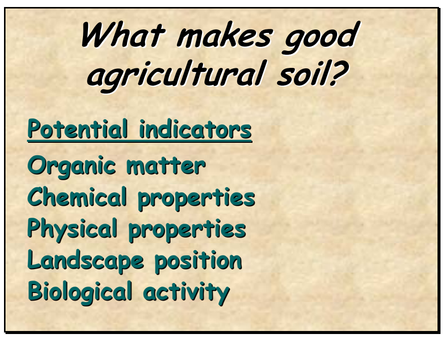
Slide 22



Keep in mind that these general characteristics need to be further refined depending on the type of agriculture being considered. For example, a soil that is good for lowland rice or taro is likely completely unsuited for potatoes. The type of agriculture also makes a big difference. Some of the most desirable soils for mechanized plantation agriculture are valued for their physical properties even though they generally have low soil fertility.

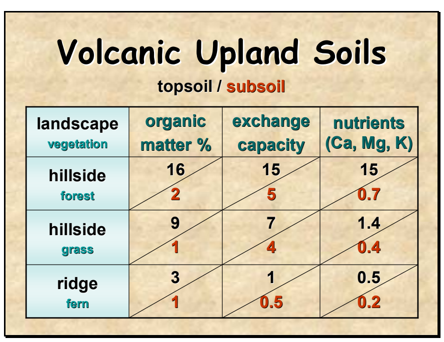
One of the biggest difficulties in looking at soil quality is identifying appropriate (and measurable) indicators (next slide) that will help us get a handle on the more general and intuitive characteristics shown in this slide.

Slide 23



Look at and/or measures these indicators to get a handle on whether a soil is “good” or not for the desired use.

Slide 24



landscape vegetation	organic matter %	exchange capacity	nutrients (Ca, Mg, K)
hillside forest	16 / 2	15 / 5	15 / 0.7
hillside grass	9 / 1	7 / 4	1.4 / 0.4
ridge fern	3 / 1	1 / 0.5	0.5 / 0.2

Table is for topsoil (upper 4 inches or 10 cm) / subsoil (4 to 40 inches or 10 cm to 100 cm) for three main volcanic upland soils on Babeldaob, Palau. Forest = Aimeliik series. Grass = Palau series. Fern = Babelthuap series. Pictures of the soils discussed here were presented earlier in the slideshow. Landscapes and associated vegetation are in the far left column. Table examines topsoil and subsoil properties of soil organic matter, cation exchange capacity and amount of nutrients.
We measure organic carbon and then convert to percent organic matter by multiplying by 1.724, which assumes that organic matter is generally about 58% carbon. This is called the Van Bemmelen Factor. Aimeliik series with it’s intact forest has the highest soil organic matter (SOM) content; Palau

series under grass has a little more than half as much SOM and Babelthuap under ferns has only about a fifth as much. All three subsoils have similar SOM around 1-2%.

Soils have electrical charge and can hold on to both positively and negatively charged ions. Most soils have much more negative charge than positive charge and therefore hold more positively charged ions. This is expressed as Cation Exchange Capacity or CEC. There is also Anion Exchange Capacity (AEC), which may be important in Palau's highly weathered soils.

There are various ways to express exchange capacity, all related to the pH of the system. CEC can be determined at pH 8.2, 7 or at the field pH. The Effective CEC at field pH is presented here. Raising the pH (as in determining CEC at pH7 in Palau's acid soils) will give an artificially high CEC value but it will give some indication of how the soil's charge can be manipulated by liming. Units are in miliequivalents per 100g soil. Emphasize the relative differences among soils. Before discussing exchange capacity look at the following slide that shows the different sources of exchange capacity.

Data are from: Properties and Management Considerations of Some Acid Soils on the Islands of Palau. 1988. Christopher Smith and Neil Babik. USDA Soil Conservation Service. In Proceedings of the Third International Soil Management Workshop on the Management and Utilization of Acid Soils of Oceania. Feb 2-6, 1987. Koror, Palau. Data are also available at http://soils.usda.gov

Slide 25

Volcanic Upland Soils

topsoil / subsoil

landscape (vegetation)	organic matter %	exchange capacity	nutrients (Ca, Mg, K)
hillside (forest)	16 / 2	15 / 5	15 / 0.7
hillside (grass)	9 / 1	7 / 4	1.4 / 0.4
ridge (fern)	3 / 1	1 / 0.5	0.5 / 0.2

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Slide 26

Cation Exchange Capacity

Component	meq/100g soil
organic matter	200-400
montmorillonite	60-100
kaolinite	2-16
halloysite	5-10
Fe and Al oxides	0

Cations are positively charged ions. The mineral components of most volcanic soils in the Mariana Islands are kaolinite, halloysite, and iron and aluminum oxides. Organic matter is obviously important in providing cation exchange capacity (CEC) in these soils. Oxides mostly provide anion exchange capacity (AEC). There is some montmorillonite in alluvial soils. The amount of negative charge on organic matter, kaolinite, halloysite, and oxides depends on the pH of the soil. Higher pH (i.e. less acidity) creates more negative charge with which to hold on to positively charged nutrients (cations). Montmorillonite has mostly permanent charge not affected by pH.
Source: Soil Survey Laboratory Information Manual. 1995. USDA NRCS National Soil Survey Center, Soil Survey Laboratory. Soil Survey Investigations Report No. 45 Version 1.0

Slide 27

Volcanic Upland Soils

topsoil / subsoil

landscape (vegetation)	organic matter %	exchange capacity	nutrients (Ca, Mg, K)
hillside (forest)	16 / 2	15 / 5	15 / 0.7
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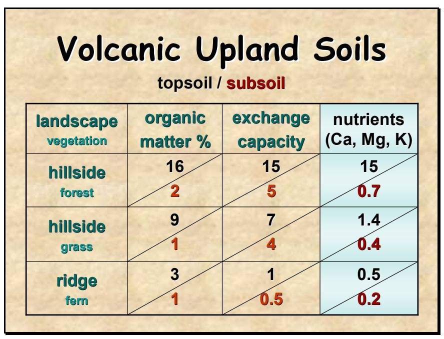

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Slide 29

Volcanic Upland Soils

topsoil / subsoil

landscape vegetation	organic matter %	pH	aluminum saturation
hillside forest	16 / 2	5.3 / 5.1	1 / 85
hillside grass	9 / 1	4.9 / 5.2	80 / 90
ridge fern	3 / 1	4.9 / 5.3	60 / 80

This slide shows the same soils/landscapes as the previous slides and the organic matter column is the same as the last slide. The columns for pH (acidity) and aluminum saturation (%) are new.

All soils have similar pH (the smaller the pH the greater the acidity) in the 4.9 to 5.3 range. Aluminum generally becomes more soluble at pH 5.2 and lower.

The next slide shows what happens with soluble aluminum on the exchange complex.

Slide 30

Volcanic Upland Soils

topsoil / subsoil

landscape (vegetation)	organic matter %	pH	aluminum saturation
hillside (forest)	16 / 2	5.3 / 5.1	1 / 85
hillside (grass)	9 / 1	4.9 / 5.2	80 / 90
ridge (fern)	3 / 1	4.9 / 5.3	60 / 80

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All soils have similar pH (the smaller the pH the greater the acidity) in the 4.9 to 5.3 range. Aluminum generally becomes more soluble at pH 5.2 and lower.

Note the high aluminum saturation (in percent of the exchange complex) for all topsoils and subsoils (except the forested Aimeliik topsoil). Some agricultural crops suffer from aluminum toxicity when the Al saturation is only 10%. Aluminum interferes with the photosynthetic cycle by complexing with phosphate, so with high soluble aluminum the plant is starved for phosphate. Al-toxicity also stunts root growth thereby limiting the amount of soil the plant can exploit for nutrients. Stunted roots can also limit water uptake and can cause plants to wilt with only a few days without water. Some plants (e.g. cassava) have high tolerance to high levels of soluble aluminum. On the Babelthuap series ferns that are highly tolerant to aluminum can make up nearly 100% of the plant community in places. High soluble Al and acidity may adversely affect soil health by inhibiting beneficial organisms.

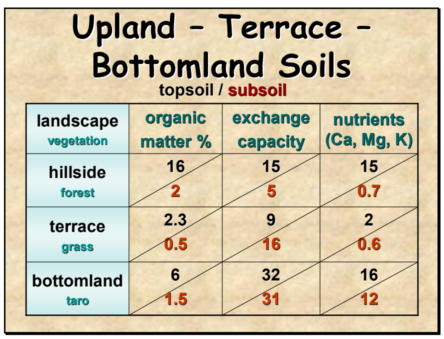
When liming soils with high soluble aluminum the rule of thumb is to add 1.5 tons of $CaCO_3$ per acre for every miliequivalents of soluble aluminum. The pH only needs to be raised to about 5.5 to eliminate the harmful effects of high soluble aluminum.

Why is the forested Aimeliik topsoil so different from the other soils in terms of aluminum saturation?

Why do the forested topsoil and the fern subsoil have the same pH but vastly different amounts of soluble aluminum?

The reason is that the forested Aimeliik soil has much more SOM, which complexes with soluble aluminum and takes it out of solution. This is another benefit SOM provides to highly weathered soils.

Slide 31

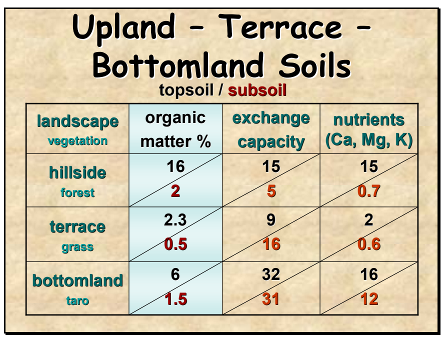


This slide is in similar format as the previous slides showing data but it compares the Aimeliik series (forested volcanic hillside; same data as previous slides) with a Tabecheding series (marine terrace soil) and a Dechel series (wet alluvial bottomland soil). The forested hillside data (the most fertile of the volcanic upland soils) are there for comparison.

The forested hillside soil has higher SOM content than either the marine terrace or the bottomland soil. The exchange capacity of the marine terrace soil increases with depth, possibly because the clays are less weathered at depth. Even though the SOM of the bottomland soil is 2-3 times less than the forest soil its exchange capacity is double that of the forest topsoil. This is because the soil minerals that form in this environment have an inherently greater capacity to hold on to cations. The nutrient levels in the marine terrace soil are quite low, comparable to the grassed hillside soil data in previous

slides. The bottomland soil has a relatively high nutrient level, comparable to the forest topsoil, but differs in also having high nutrient levels in the subsoil too. This is one of the most productive soils in Palau, well suited for wetland taro agriculture.

Slide 32



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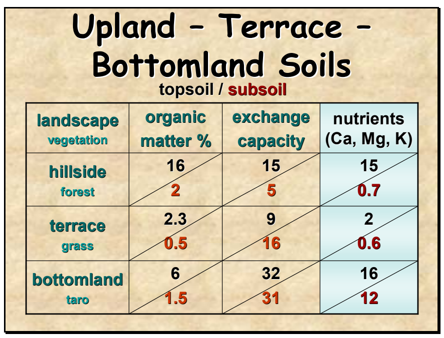

landscape (vegetation)	organic matter %	exchange capacity	nutrients (Ca, Mg, K)
hillside (forest)	16 / 2	15 / 5	15 / 0.7
terrace (grass)	2.3 / 0.5	9 / 16	2 / 0.6
bottomland (taro)	6 / 1.5	32 / 31	16 / 12

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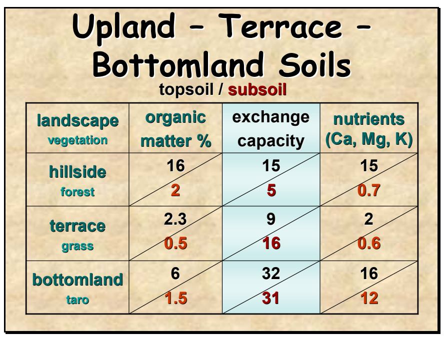


landscape (vegetation)	organic matter %	exchange capacity	nutrients (Ca, Mg, K)
hillside (forest)	16 / 2	15 / 5	15 / 0.7
terrace (grass)	2.3 / 0.5	9 / 16	2 / 0.6
bottomland (taro)	6 / 1.5	32 / 31	16 / 12

This slide is in similar format as the previous slides showing data but it compares the Aimeliik series (forested volcanic hillside; same data as previous slides) with a Tabecheding series (marine terrace soil) and a Dechel series (wet alluvial bottomland soil). The forested hillside data (the most fertile of the volcanic upland soils) are there for comparison.

The forested hillside soil has higher SOM content than either the marine terrace or the bottomland soil. The exchange capacity of the marine terrace soil increases with depth, possibly because the clays are less weathered at depth. Even though the SOM of the bottomland soil is 2-3 times less than the forest soil its exchange capacity is double that of the forest topsoil. This is because the soil minerals that form in this environment have an inherently greater capacity to hold on to cations. The nutrient levels in the marine terrace soil are quite low, comparable to the grassed hillside soil data in previous

slides. The bottomland soil has a relatively high nutrient level, comparable to the forest topsoil, but differs in also having high nutrient levels in the subsoil too. This is one of the most productive soils in Palau, well suited for wetland taro agriculture.

Slide 35

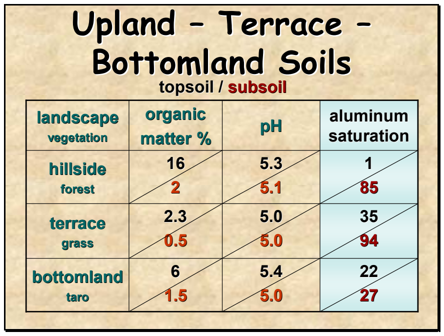
Upland – Terrace – Bottomland Soils

topsoil / subsoil

landscape (vegetation)	organic matter %	pH	aluminum saturation
hillside (forest)	16 / 2	5.3 / 5.1	1 / 85
terrace (grass)	2.3 / 0.5	5.0 / 5.0	35 / 94
bottomland (taro)	6 / 1.5	5.4 / 5.0	22 / 27

This slide shows the same soils/landscapes as the previous slides and the organic matter column is the same as the last slide. The columns for pH (acidity) and aluminum saturation (%) are new.
The acidity (pH) levels of all the soils are fairly similar, all hovering around the critical pH 5.2 level, below which aluminum becomes much more soluble. The forested hillside soil was discussed previously.
Complexing of aluminum with SOM in the marine terrace topsoil is presumably the reason why the topsoil value is lower than the subsoil. The aluminum level in the alluvial bottomland soil is surprisingly high given that the pH is 5.4 and there is a fair amount of SOM, but at only 22% the level is below the critical level that adversely affects production of many agricultural crops grown in Micronesia.

Slide 36



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Slide 37

Slide 38

Key role of OM

- ✓OM is the key to soil quality in Micronesian agriculture
- ✓Practices that improve organic matter content will nearly always improve soil quality

Slide 39

Key role of OM

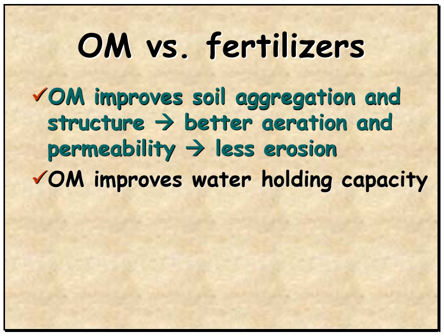
- ✓OM is the key to soil quality in Micronesian agriculture
- ✓Practices that improve organic matter content will nearly always improve soil quality
- ✓Practices that degrade organic matter content will nearly always reduce soil quality

Slide 40

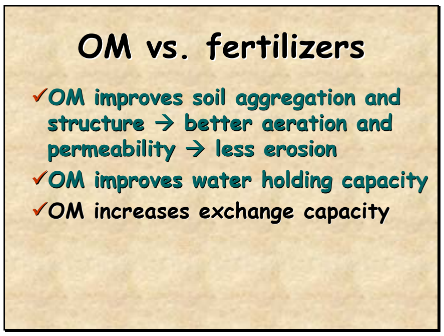
OM vs. fertilizers

- ✓OM improves soil aggregation and structure → better aeration and permeability → less erosion

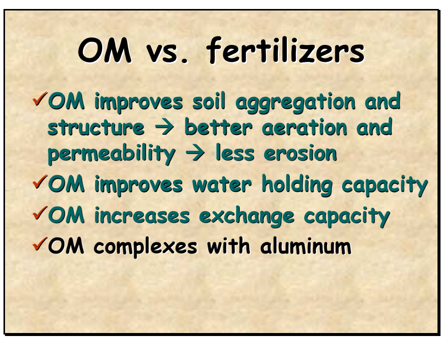
Slide 41



Slide 42



Slide 43



Slide 44

OM vs. fertilizers

- ✓OM improves soil aggregation and structure → better aeration and permeability → less erosion
- ✓OM improves water holding capacity
- ✓OM increases exchange capacity
- ✓OM complexes with aluminum
- ✓OM acts as slow-release fertilizer

Slide 45

OM vs. fertilizers

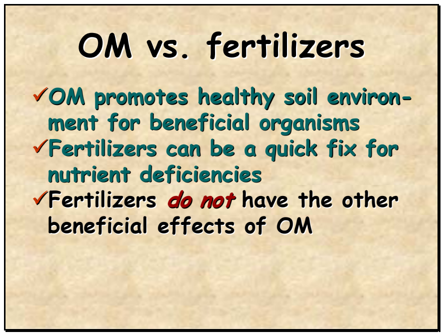
- ✓OM promotes healthy soil environment for beneficial organisms

Slide 46

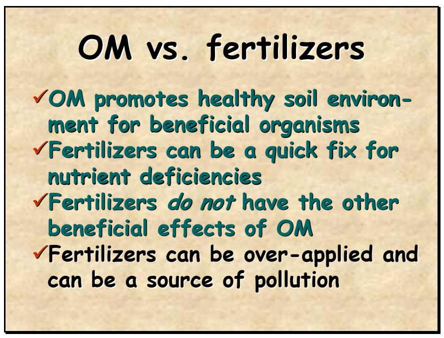
OM vs. fertilizers

- ✓OM promotes healthy soil environment for beneficial organisms
- ✓Fertilizers can be a quick fix for nutrient deficiencies

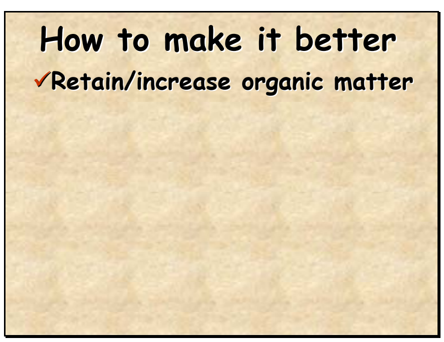
Slide 47



Slide 48



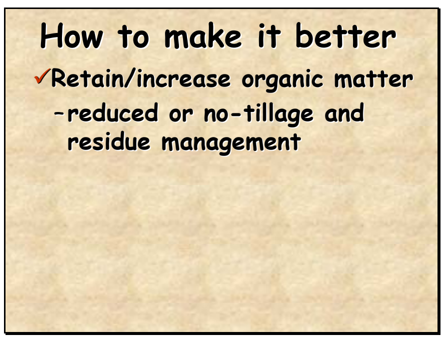
Slide 49



Compost and mulch from off-site can help maintain high SOM. Note that mulch is OM applied to the surface and compost can be either added to the surface or incorporated into the soil. The difference is that compost has decomposed OM with a low C:N (carbon:nitrogen) ratio similar to what is already in the soil (usually 10-15). Mulch is usually undecomposed and has a high C:N (sawdust, for example, is about 400). If a high C:N material is mixed into the soil the micro-organisms have a virtually unlimited supply of carbon and

they will utilize all the nitrogen that is released through organic matter competition, leaving no nitrogen for the plants.
These points are the principles of traditional Micronesian agroforestry and account for its long-term sustainability.

Slide 50



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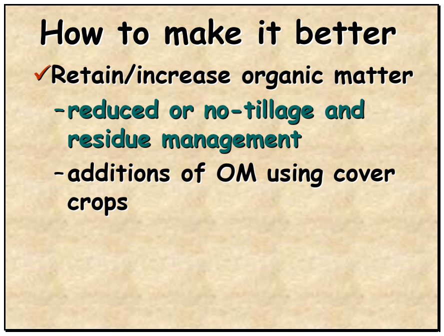

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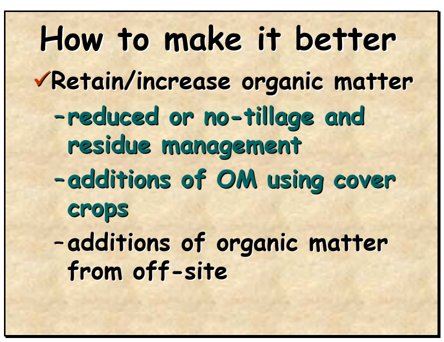

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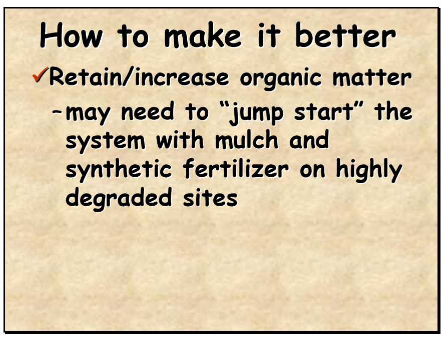
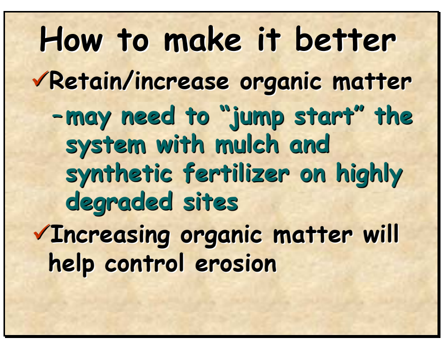
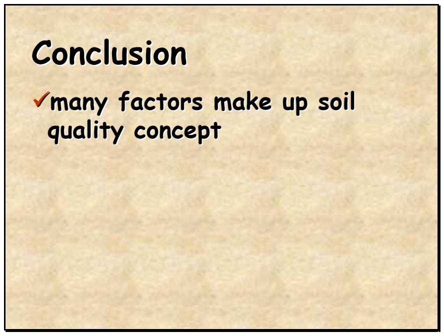


Slide 54

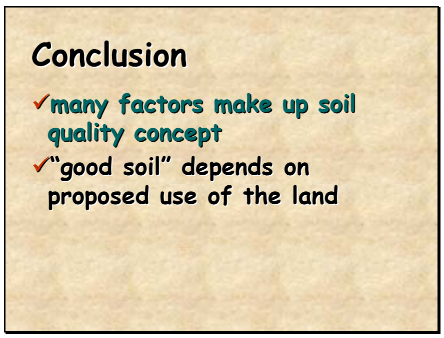


Protection from erosion is just a natural byproduct of practices that increase soil organic matter.

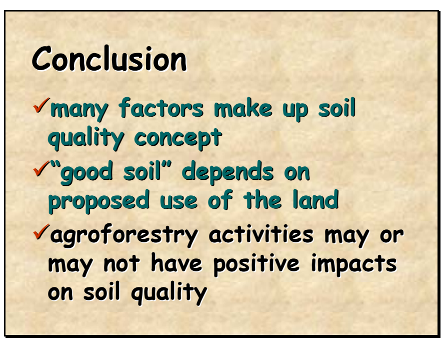
Slide 55



Slide 56



Slide 57



But the way agroforestry is practiced in Micronesia it usually has positive impacts on the soil.

Slide 58

Conclusion

- ✓agroforestry practices can improve the soil quality on highly degraded soils

Slide 59

Conclusion

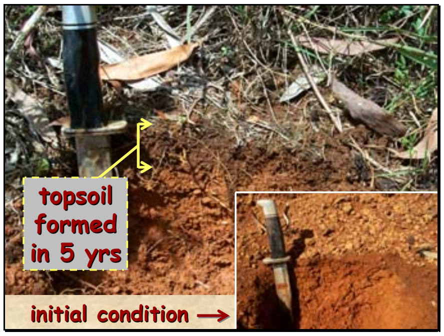
- ✓agroforestry practices can improve the soil quality on highly degraded soils
- ✓trees can't do the job alone, may need mulch and fertilizer to establish ground cover

Slide 60

Conclusion

- ✓Significant improvements in several soil quality indicators can be seen in a relatively short time (5 years)

Slide 61



Additions of mulch and some synthetic fertilizer have been demonstrated to produce an inch of topsoil in less than 5 years in Palau. Point out morphological differences between topsoil within and outside of plot (“initial condition”). Although this is a promising result, it would be difficult to reclaim large areas in this way. The best path to follow is to ensure that topsoil is not degraded or lost.

Slide 62

Modern soils data can explain why traditional agroforestry management is appropriate and sustainable.

Slide 63

USDA-NRCS soils data and much more soils information of all kinds are available on the internet.

Slide 64

USDA - NRCS

Palau Field Office

488-5843

Contact your local NRCS office for assistance.

Slide 65

Questions?

Slide 66

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