Soil Fertility and Nutrient Management for Guam and the Northern Mariana Islands

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2011
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Introduction: The purpose of this publication is to bring together the role of soil fertility and nutrient management in plant health and disease suppression as they relate to Guam and the CNMI (Commonwealth of the Northern Mariana Islands). The topics are presented in discrete chapters and sections that can be duplicated for educational purposes. Complexities of diagnosing nutrient deficiencies and developing fertilizer recommendations for crops grown in the Mariana Islands are discussed. This publication brings together information from various regional sources including extension and research publications and personal communications from local extension agents, growers and research scientists. It is comprehensive in nature and intended as a resource for local university students and agriculture professionals.

Acknowledgements: This guide was made possible by the collaborative efforts of the Agriculture and Natural Resources Unit of the Guam Cooperative and Extension Service, the Western Pacific Tropical Research Center, and the University of Florida. This publication is derived from training materials developed for classroom and field instruction of agriculture professionals, which was directly funded through the Western SARE (Sustainable Agriculture Research & Education) Professional Development Program (PDP). SARE is a USDA competitive grants program that supports agricultural systems that are economically viable, environmentally sound and socially responsible.

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Suggested Citation: Schlub, R.L. 2011. Soil Fertility and Nutrient Management for Guam and the Northern Mariana Islands. Guam Cooperative Extension Service University of Guam, Mangilao, Guam. 60 pp.

Cover: Guam-Yigo Complex, in northern Guam provided by Dr. Robert Gavenda of NRCS.

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Of the 92 naturally occurring chemical elements, seventeen (C, O, H, N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Mo, Cl, and Ni) have been shown to be essential elements, for plant growth and development. Three additional elements are considered beneficial but not required (Co, V, and Si). Although Al is not considered an essential plant element, Al is included in this section because there is an overabundance of Al ions in the acid soils of the Mariana Islands which is harmful to roots of many plants, particularly the dicotyledonous plants. Plants obtain the essential elements of carbon (C), hydrogen (H) and oxygen (O) largely from the photosynthetic assimilation of carbon dioxide (CO_2) from the atmosphere and from water (H_2O) from the soil.

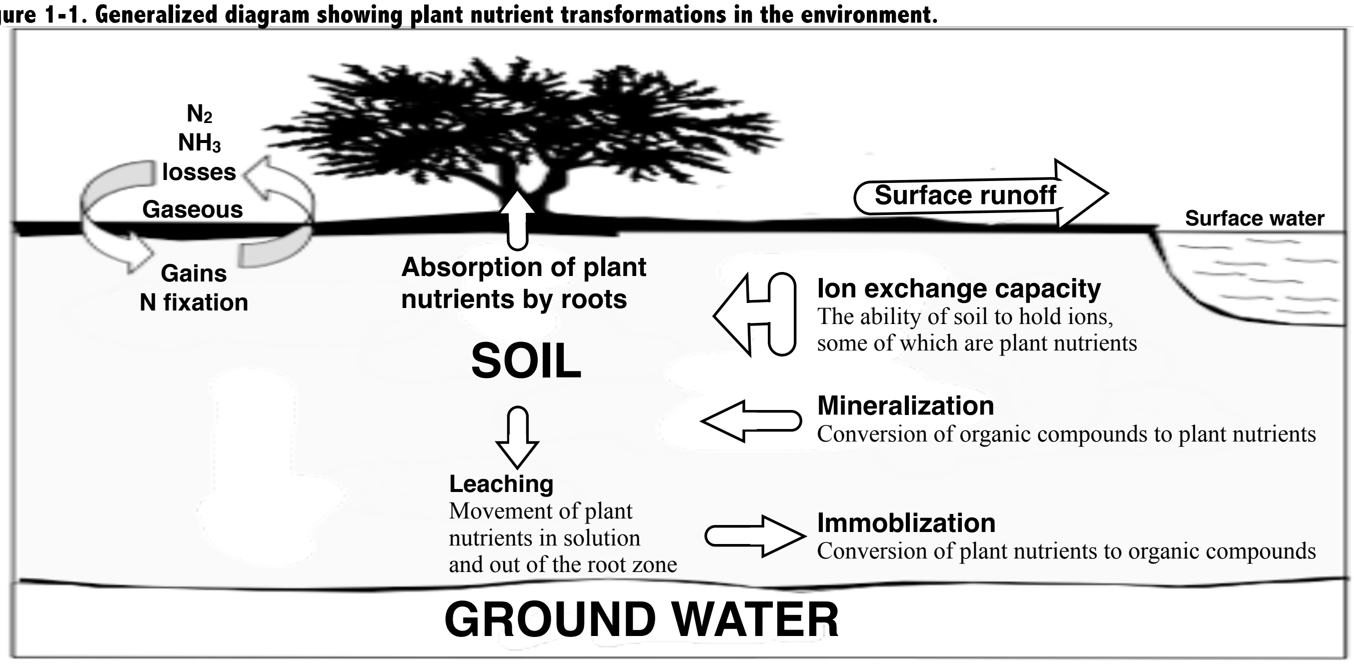
The 14 essential plant nutrients that are most likely limiting in a particular soil are listed in Table 1-1 along with their critical metabolic function. Macronutrients (N, P, K, Ca, Mg and S) are plant nutrients required in the largest amounts. Micronutrients (Fe, Cu, Mn, Zn, B, Mo and Cl) are required in relatively smaller amounts. The availability of these elements is a measure of a soil's fertility level.

Soil fertility is the combined effects of three major interacting components. These are the chemical, physical and biological characteristics of the soil. The way soils are managed can improve or degrade their natural fertility.

Table 1-1. Relative concentration and function of ionic and non-ion molecules absorbed by plants.

Name	Chemical symbol	Form(s) absorbed	Concentration in dry matter		Function
			ppm	%	
PRIMARY MACRONUTRIENTS					
Nitrogen	N	NH_4^+ NO_3^-	5,000 – 60,000	0.5 – 6	Proteins Chlorophyll Nucleic acids
Phosphorus	P	$H_2PO_4^-$ HPO_4^{2-}	1,500 – 5,000	0.15 – 0.5	Nucleic acids Coenzyme ATP
Potassium	K	K^+	8,000 – 80,000	0.8 – 8	Catalyst and ion transport
SECONDARY MACRONUTRIENTS					
Calcium	Ca	Ca^{2+}	1,000 – 6,000	0.1 – 0.6	Cell wall component
Magnesium	Mg	Mg^{2+}	500 – 1,000	0.05 – 0.1	Part of chlorophyll
Sulfur	S	SO_4^{2-}	1,000 – 1,500	0.1 – 0.15	Amino acids
MICRONUTRIENTS					
Iron	Fe	Fe^{2+} Fe^{3+}	20 – 600		Chlorophyll synthesis
Copper	Cu	Cu^{2+} Cu^+	2 – 50		Component of enzymes
Manganese	Mn	Mn^{2+} Mn^{3+}	10 – 600		Oxidation-reduction
Zinc	Zn	Zn^{2+}	10 – 250		Activates enzymes
Boron	B	BO_3^{3-} H_3BO_3	0.2 – 800		Cell wall component
Molybdenum	Mo	MoO_4^{2-}	0.1 – 10		Involved in N fixation
Chlorine	Cl	Cl^-	10 – 80,000		Photosynthesis reactions
Nickel	Ni	Ni^{2+} $Ni(OH)^+$	0.05 – 5		Enzyme function
Others					
Silicon	Si	H_2SiO_4	1,000 – 100,000	0.1 – 10	Enzyme function
Aluminum	Al	Al^{3+} $Al(OH)^{2+}$	100 – 5,000		Not essential Al toxicity reduces root elongation

Figure 1-1. Generalized diagram showing plant nutrient transformations in the environment.



Biological-geological-chemical transformations are constantly changing plant nutrients from one form to another. Many of the soil processes can make these minerals unavailable or slowly available for plant absorption (Figure 1-1).

Soil is a natural body comprised of solids (organic matter and minerals), liquid, and gases that occurs on the land surface. It occurs in horizons or layers and support rooted plants. Soil organic matter consists of living organisms and their remains. Mineral particles are inorganic materials derived from rocks and are extremely variable in size.

The weathering of minerals affects the composition of the soil solution because it can contain plant nutrients as well as toxic substances. The term essential mineral elements (or mineral nutrients) refers to those minerals that plants use for growth. Organic compounds are generally different from mineral compounds because they contain carbon. The agriculture soils of the Mariana Islands are considered minerals soils because they have 20 to 35 percent organic matter, by weight, and have properties that are more aligned with mineral soils than with organic soils. **Primary minerals** are formed at high temperature and pressure, under reducing conditions without free oxygen. These minerals are mainly present in soils as sand and silt particles. **Secondary minerals** are formed at low temperature and pressure through oxidation. They are the weathering product of primary minerals. Secondary minerals in the Mariana Islands soils include silicate clay minerals, oxides and hydrous oxides of iron and aluminum clay minerals, and carbonates.

Mineralization is the process by which organic nutrients are converted to inorganic forms which plants can take up through their roots and use for growth (Table 1-1). For example, the nitrogen (N) contained in protein is mineralized to ammonium (NH_4^+). This process is controlled by the activity of microbes (bacteria and fungi), and, therefore is affected by environmental factors such as temperature, pH (Table 1-3), and moisture.

Immobilization or assimilation is the uptake of inorganic plant nutrients from the soil and incorporation into organic compounds in microbes. This is why adding woody materials to soil without added N fertilizer can result in short-term N deficiency in plants. The general rule is that organic materials with a C to N ratio of greater than 30 will cause N immobilization.

Ion exchange capacity: The internal and external surfaces of soil colloids carry positive and / or negative charges. Exchangeable ions is used to refer to the ions that can exchange places with those moving freely about in the soil solution. Most plants nutrients must be in an ion form in soil water to be absorbed by plant roots (Table 1-2). Refer to the section on Essential Plant Nutrients in this unit for more examples of absorbable ions. An ion with a negative charge (–) is called an anion and a positive charged (+) ion is called a cation. For agricultural purposes, the cations are divided into acidic cations and basic cations. The acidic cations, which produce acidity in water, include (H^+) and the $^{+3}$ cations such as (Al^{+3}) and (Fe^{+3}). The basic cations, which produce an alkaline reaction in water, include (K^+), (Ca^{+2}), (Mg^{+2}), (Na^+) and (NH_4^+). Percent base saturation is a measure of the exchange sites which are occupied by the basic cations. Acidity is a measure of the total cation exchange capacity (CEC) occupied by the acidic cations. In acidic soils, the exchange sites are dominated by acidic cations. The region's acidic volcanic soil have Al-saturation percent values of 15 in their top soil and as high as 50% in their subsoil, where as the region's limestone soil have 0% Al-saturation. The limestone soils of the Mariana Islands have basic conditions with average pH values ranging from 7 to 8. This is primarily due to the presence of base cations associated with carbonates and bicarbonates found naturally in these soils and their associated water reservoirs.

Table 1-2. Solubility of plant-available ions in soil water.

Name	Chemical symbol	Plant-available ions in soil water	Solubility
Primary Nutrients			
Nitrogen	N	NH_4^+ NH_3^- NO_3^-	High
Phosphorus	P	HPO_4^{--} $H_2PO_4^-$	Very low
Potassium	K	K^+	Low
Secondary Nutrients			
Sulfur	S	SO_4^{--}	High
Calcium	Ca	Ca^{++}	Low
Magnesium	Mg	Mg^{++}	Very low
Micronutrients			
Zinc*	Zn	Zn^{++}	Very low
Iron*	Fe	Fe^{++} Fe^{+++}	Very low
Copper*	Cu	Cu^{++} Cu^{++}	Very low
Manganese*	Mn	Mn^{++} Mn^{++++}	Very low
Boron	B	BO_3^{3-}	Moderate
Molybdenum*	Mo	MoO_4^{--}	Low
Chlorine	Cl	Cl^-	High

Adapted from Soil Nutrient Management for Maui County: http://www.ctahr.hawaii.edu/mauisoil/a_factor_mineralogy.aspx

* Chelated forms of Cu, Fe, Mn, and Zn are mobile in soil; however, they are also resistant to leaching.

In addition, many tropical soils (highly weathered) also have an anion exchange capacity. Under neutral and alkaline conditions, weathered soils usually have more cations than anions on exchange sites similar to less weathered soils. However, under acidic conditions and extreme weathering, these soils generate a net positive charge or AEC. This means that the soil becomes positively charged and attracts, retains, and supplies negatively charged anions, such as sulfate, phosphate, nitrate, and chloride. For soils with AEC, proper management of pH is crucial in order to provide sufficient amounts of the nutrient cations (calcium, magnesium, ammonium, and potassium).

Minerals that exhibit AEC are highly weathered kaolinite, halloysite, aluminum and iron oxides, organic matter, and the allophanes and imogolites of volcanic soils. Highly weathered Ultisols and Oxisols, volcanic Andisols, and organic Histosols all have AEC under acidic conditions. The pH at which these soils develop AEC differs depending upon the minerals within the soil. Since organic matter only generates AEC at a very low pH, it is still a good source of CEC.

Leaching is the downward movement of materials dissolved in water. The form of nutrients, which leach, are highly water-soluble, and are not readily retained by soil through processes such as cation exchange and nutrient fixation. Nearly all nutrients must first dissolve in order to be available for absorption by plant roots. However, once a nutrient goes into solution it is subject to leaching and movement out the root zone. The higher a nutrient's solubility in soil water, the more likely it will leach (Table 1-2). Groundwater contamination occurs when excess amount of nutrients leach below the root zone and into groundwater. Some leaching needs to occur to prevent large accumulations of nutrients and other ions that would prevent plant growth (high salt levels). Solubility and availability of nutrients for plant growth are both influenced by pH. With the exception of P, which is most available within a pH range of 6 to 7, macronutrients (N, K, Ca, Mg, and S) are more available within a pH range of 6.5 to 8, while the majority of micronutrients (B, Cu, Fe, Mn, Ni, and Zn) are more available within a pH range of 5 to 7. Refer to the section on Soil pH and Optimum Range for Local Crops for more information.

Surface runoff: Losses of nutrients from surface water runoff can be significant when soil erosion occurs. Nutrients may be carried in a dissolved form, attached to eroded soil particles, or contained in organic matter that is flushed away in runoff water. Phosphorus in the Mariana Islands is almost entirely associated with soil particles. When soil particles are carried to a river or lake, the water often acts as a sink for P and a source of P for aquatic plants. The process by which a body of water acquires enriched levels of phosphorus and nitrates is called eutrophication.

Gaseous losses and gains of nutrients: Losses of nutrients through transformation to gaseous nutrient forms include the processes of volatilization, denitrification and oxidation/reduction. Ammonia volatilization occurs when ammonium-based fertilizer is added to the soil surface and the ammonium (NH_4^+) is converted to ammonia (NH_3) gas. This process usually occurs under hot, windy conditions in alkaline soils. Denitrification is the process by which nitrate (NO_3^-) is converted to gaseous N forms. This process is favored in high organic soils under saturated conditions. The biological conversion of gaseous N to inorganic N in the soil is called nitrogen fixation and results in a gain of N in the soil. Legume plants, such as long beans, form a symbiotic relationship with a bacteria located in the plant roots in which the bacteria fix the N from air and the plant supplies carbohydrate to the bacteria. Legumes require only low level of nitrogen fertilizer (roughly 30 lb/A) for optimum growth. Excess N will reduce nodulation. Refer to green manure crops in the section on Protecting the Soil in Chapter 3 for more examples of nitrogen-fixing legumes.

Chapter 1: Soil Fertility • Soil pH and Optimum Range for Local Crops

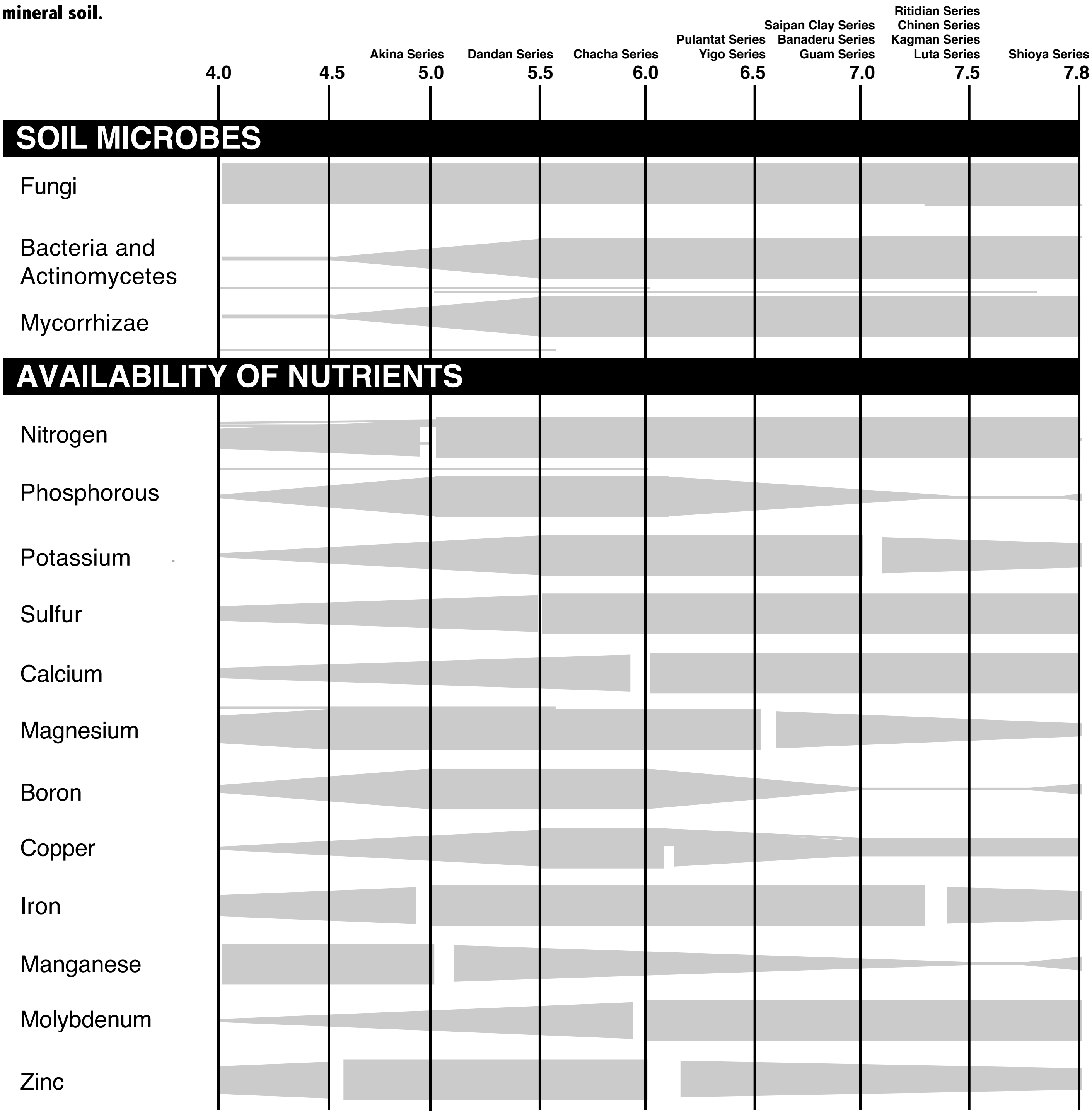
Modification of Peter Motavalli and Thomas Marler - College of Agriculture and Life Sciences - University of Guam - 1988 Fact Sheet

Availability of nutrients are strongly affected by soil pH due to reactions with soil particles and other nutrients. A generalization of its impact is shown in Table 1-3. The actual impact of soil reaction will vary from soil to soil. Soils may be acid, neutral, or alkaline in reaction.

Acidity is caused by the presence of hydrogen (H^+) ions in water. The higher the concentration of H^+, the higher the acidity. The pH scale which ranges from 0 to 14 is a measure of the amount of H^+ in a solution. A difference in one pH unit represents a ten-fold difference in H^+ concentration. If a solution has a pH lower than 7 it is considered acidic. If the pH of the solution is equal to 7 it is neutral, and if the pH is greater than 7 the solution is basic. Examples of pH of common household: vinegar 3, orange juice 4, and milk of magnesia 11.

The pH of the Mariana soils should be kept between 5.5-7.5 for maximum nutrient availability (Table 1-3) and for good crop production (Table 1-4). At high soil pH, the

Table 1-3. The pH of soil series of the Mariana Islands and the influence of pH on plant nutrient availability and soil organisms in mineral soil.



Widest parts of the shaded areas indicate maximum availability of each element.
Adapted from L. B. Nelson (ed.), *Changing Patterns in Fertilizer Use*, Soil Science Society of America, Madison, WI (1968).

availability of plant nutrients such as P, Fe, K, Mg Mn, Zn, Cu, and B are reduced whereas at low soil pH, the availability of plant nutrients such as P, K, Ca, S, Cu, B, N, and Mo are reduced. An important point to note is that technically a high pH soil solution only makes refers to its hydrogen ion content where as high alkalinity soil solution refers to the presents of bases (carbonates, bicarbonates, ammonia, borates, phosphates, and silicates) that neutralize acids. The availability of nutrients shown in Table 1-3 is strictly a hydrogen ions effect and not the effect of alkalinity.

As soil nutrients become more available, nutrients generally become more soluble as well. The fact that all the nutrients are available between pH values of 5.5 and 6.5 can be problematic in low CEC soil such as in the Mariana Islands due their increased likelihood of leaching. The high content of Al in oxisols in the region can lead to Al toxicity when pH drops below 5.5 due to increases in Al availability and solubility. Marler and Lawrence at UOG (2004) determined that Ca deficiency and Al toxicity are both involved in limiting root growth of yoga (*Elaeocarpus joga*), a limestone forest tree species. They found that root growth increases when the pH of Akina soil was adjusted above the critical value (6.0) for Al toxicity. It was also determined that root growth occurs without pH adjustment if sufficient Ca is available. Marler and Cruz (2001) drew similar conclusions when papaya was grown in subsoil obtained from the Akina soil series.

Although calcium carbonate has low solubility, it acts to increase soil pH. Soils in the Mariana Islands with pH above 7 can be described as being calcareous (contains calcium carbonate, $CaCO_3$). Other carbonate minerals include dolomite, ($CaCO_3$ & $MgCO_3$) and sodic (Na_2CO_3). In addition to the effect of pH, carbonate and bicarbonate in the soil further reduce the availability of N, P, K, Mg, Mn, Zn, and Fe as a result of nutrient fixation. In calcareous soils above 7.5, Ca induced iron chlorosis is common on susceptible plants.

Table 1-4. Optimum pH ranges for local crops.

Optimum pH range	Crop
5.0 - 6.0	Pineapple
5.0 - 6.8	Watermelon, Carambola
5.2 - 6.0	Sweet Potato
5.5 - 6.5	Banana, Cassava, Eggplant, Taro, Yam
5.5 - 6.8	Summer Squash
5.5 - 7.0	Cucumber, Mango, Sweet Pepper
5.5 - 7.5	Cantaloupe, Sweet Corn, Pumpkin, Tomato
5.8 - 7.0	Onion
6.0 - 7.0	Bean, Bittermelon, Papaya
6.0 - 7.5	Cabbage, Chinese Cabbage, Okra, Lemon
6.0 - 8.0	Citrus, Sugar Cane
6.7 - 7.5	Orange

Factors that accelerate acidification of field soil include applying ammonium-based nitrogen fertilizers to naturally acid soils at rates in excess of plant requirements; leaching of nitrate nitrogen out of the root zone; and continual removal of plant and animal produce and waste. Changing farm practices to decrease pH bring with it the risk of reducing soil fertility. An excellent way to lower the pH of small beds or garden areas is the addition of sphagnum peat. (The pH of Canadian sphagnum peat generally ranges from 3.0 to 4.5). Granular sulfur, aluminum sulfate, iron sulfate, and acidifying fertilizers include ammonium sulfate, diammonium phosphate, monoammonium phosphate, urea, and ammonium nitrate can all be used to lower soil pH. Soils, which are most sensitive to change, are the lighter-textured silica sands and loams with low organic matter levels, and the naturally acidic clay loam soils. Soils least sensitive are coral sands and the neutral to alkaline clay soils. Therefore, lowering the pH of high pH soils in the Mariana Islands using acidifying amendments is not economically feasible. However, pH adjustments to part of a plant's root zone can be done economically if an acidifying fertilizer is banded or applied by fertigation.

Factors that increase alkalinity include the application of lime and wood ashes. The term lime is a general term for calcium containing inorganic materials predominantly containing carbonates, oxides and hydroxides. The principle acid-neutralizing power of agricultural lime is caused by the carbonate (CO_3). This is why gypsum ($CaSO_4 \bullet 2(H_2O)$) neither neutralize acid soils nor effectively raise pH level.

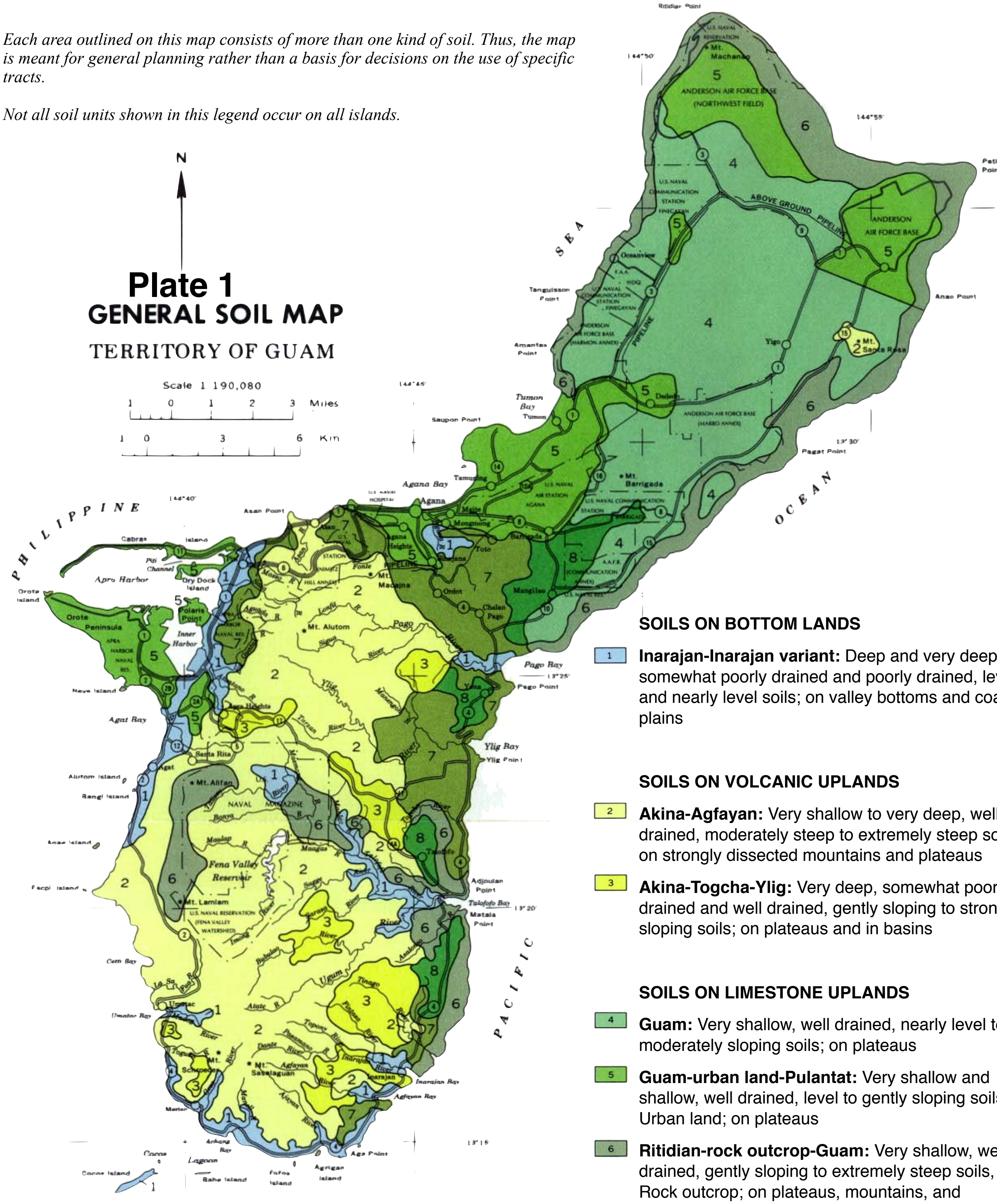
An important characteristic of lime is the finer its particles the quicker it can dissolve and hence raise the pH of the soil. However, even if one were to use very fine powdered lime, it still takes at least one month of rainy weather before the lime has dissolved far enough to increase pH. If lime cannot be worked into the soil at a depth of 6 inches, apply proportionately less initially and the remainder after a few months. With the use of very fine lime materials, there is a greater risk of over liming. Excess lime is likely to result in iron chlorosis in plants. In extreme cases, lime can modify soil structure making the soil unsuitable for agricultural purposes. Applying lime and phosphate fertilizer together is not recommend as insoluble calcium phosphate may form which will depress the uptake and effectiveness of the fertilizer.

Wood ash, which contain small amounts of potassium, phosphate, boron and other elements, can also be used to raise soil pH. They are not as effective as limestone but with repeated use, they can gradually raise the pH value of a soil, especially if the soil is sandy in texture.

To determine the liming requirements of your soil, submit soil samples to your regional Soil and Plant Testing Laboratory. The laboratory will be able to recommend the appropriate rate of liming depending on your soil characteristics and the type of plant you wish to grow. For additional information, refer to the section on Soil Sampling and Testing in Chapter 3 Nutrient Management.

Each area outlined on this map consists of more than one kind of soil. Thus, the map is meant for general planning rather than a basis for decisions on the use of specific tracts.

Not all soil units shown in this legend occur on all islands.



Fred J. Young 1988 Soil Survey of Territory of Guam
http://soildatamart.nrcs.usda.gov/Manuscripts/PB640/0/guam.pdf

SOILS ON BOTTOM LANDS

1 **Inarajan-Inarajan variant:** Deep and very deep, somewhat poorly drained and poorly drained, level and nearly level soils; on valley bottoms and coastal plains

SOILS ON VOLCANIC UPLANDS

2 **Akina-Agfayan:** Very shallow to very deep, well drained, moderately steep to extremely steep soils; on strongly dissected mountains and plateaus

3 **Akina-Togcha-Ylig:** Very deep, somewhat poorly drained and well drained, gently sloping to strongly sloping soils; on plateaus and in basins

SOILS ON LIMESTONE UPLANDS

4 **Guam:** Very shallow, well drained, nearly level to moderately sloping soils; on plateaus

5 **Guam-urban land-Pulantat:** Very shallow and shallow, well drained, level to gently sloping soils and Urban land; on plateaus

6 **Ritidian-rock outcrop-Guam:** Very shallow, well drained, gently sloping to extremely steep soils, and Rock outcrop; on plateaus, mountains, and escarpments

7 **Pulantat:** Shallow, well drained, gently sloping to steep soils; on dissected plateaus and hills

8 **Pulantat-Kagman-Chacha:** Shallow, deep, and very deep, somewhat poorly drained and well drained, nearly level to strongly sloping soils; on plateaus and hills

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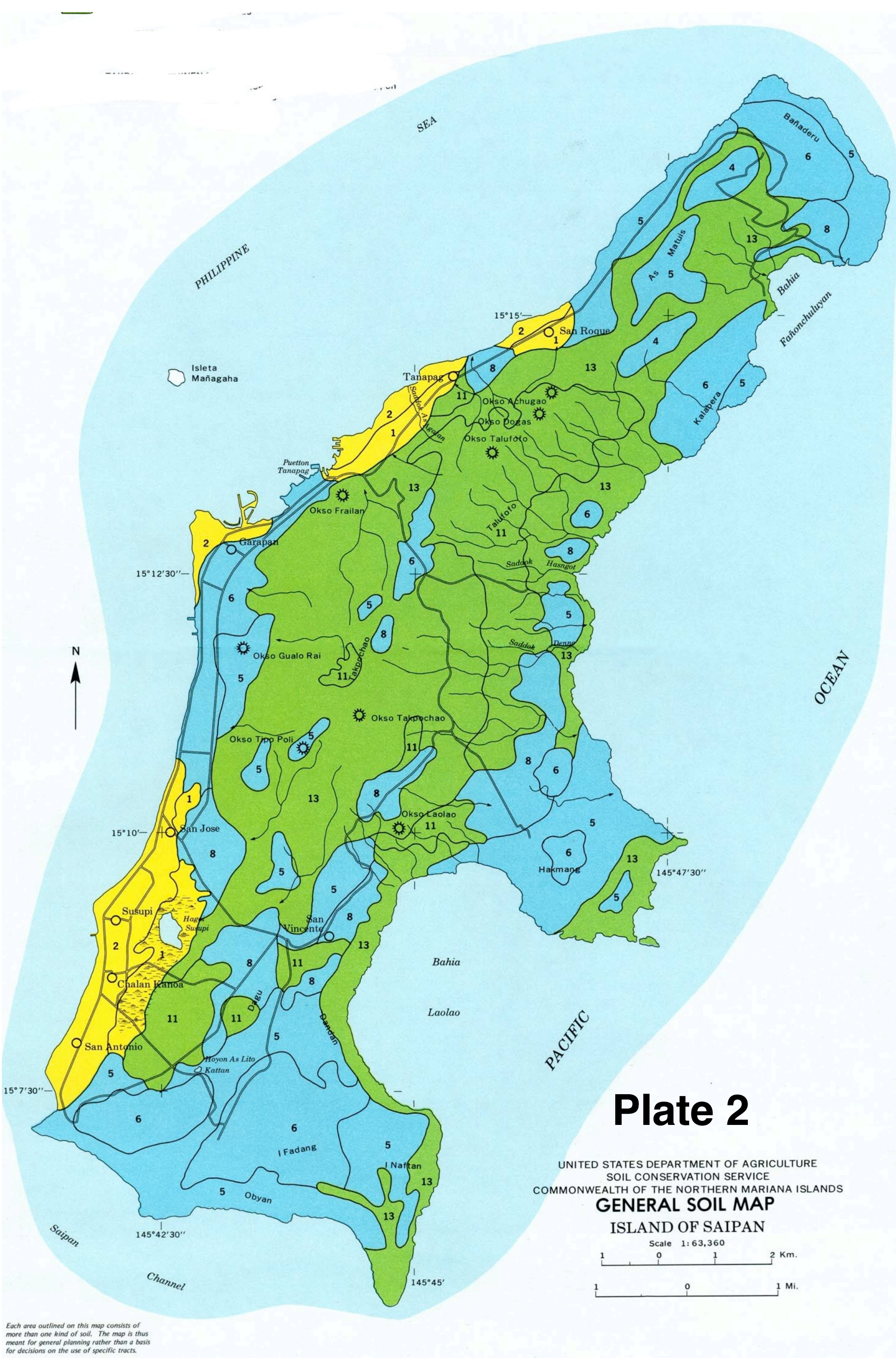

Plate 2

Fred J. Young 1988 Soil Survey of the Islands of Aguijan, Rota, Saipan, Tinian, Commonwealth of the Northern Mariana Islands
http://soildatamart.nrcs.usda.gov/Manuscripts/PB645/0/aguijan.pdf

SOILS ON LOWLANDS

1 **Mesei variant:** Moderately deep, very poorly drained, level soils; in depressional areas

2 **Shioya:** Very deep, excessively drained, level to nearly level soils; on coastal strands

3 **Takpochao variant-Shioya:** Very shallow and very deep, excessively drained, level to gently sloping soils; on coastal strands and coastal plateaus

SOIL ON LIMESTONE PLATEAUS

4 **Banaderu-Rock outcrop:** Shallow, well drained, nearly level to moderately steep soils, and Rock outcrop; on limestone plateaus

5 **Chinen-Takpochao:** Very shallow and shallow, well drained, nearly level to strongly sloping soils; on limestone plateaus and side slopes

6 **Chinen-urban land:** Shallow, well drained, nearly level soils, and Urban land; on limestone plateaus

7 **Dandan-Chinen:** Shallow and moderately deep, well drained, nearly level to strongly sloping soils; on limestone plateaus

8 **Kagman-Saipan:** Deep and very deep, well drained, nearly level to strongly sloping soils; on limestone plateaus

9 **Luta:** Very shallow, well drained, nearly level to strongly sloping soils; on limestone plateaus

10 **Saipan-Dandan:** Moderately deep and very deep, well drained, nearly level to gently sloping soils; on limestone plateaus

SOILS ON UPLANDS

11 **Laolao-Akina:** Moderately deep, well drained, strongly sloping to steep soils; on volcanic uplands

12 **Rock outcrop-Takpochao-Luta:** Shallow and very shallow, well drained, strongly sloping to extremely sloping soils, and Rock outcrop; on limestone escarpments and plateaus

13 **Takpochao-Chinen-rock outcrop:** Shallow, well drained, strongly sloping to extremely steep soils, and Rock outcrop; on limestone escarpments and plateaus

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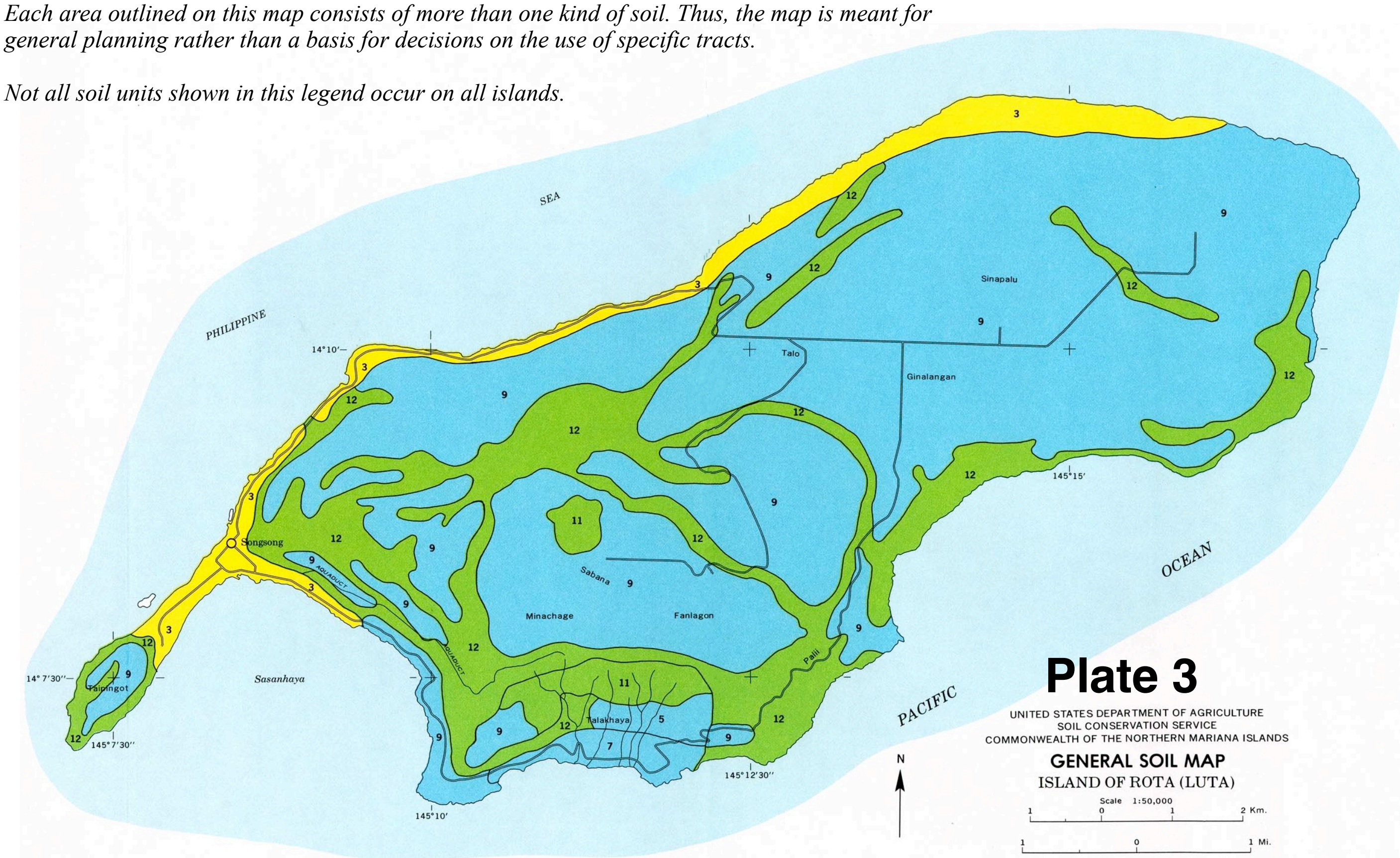

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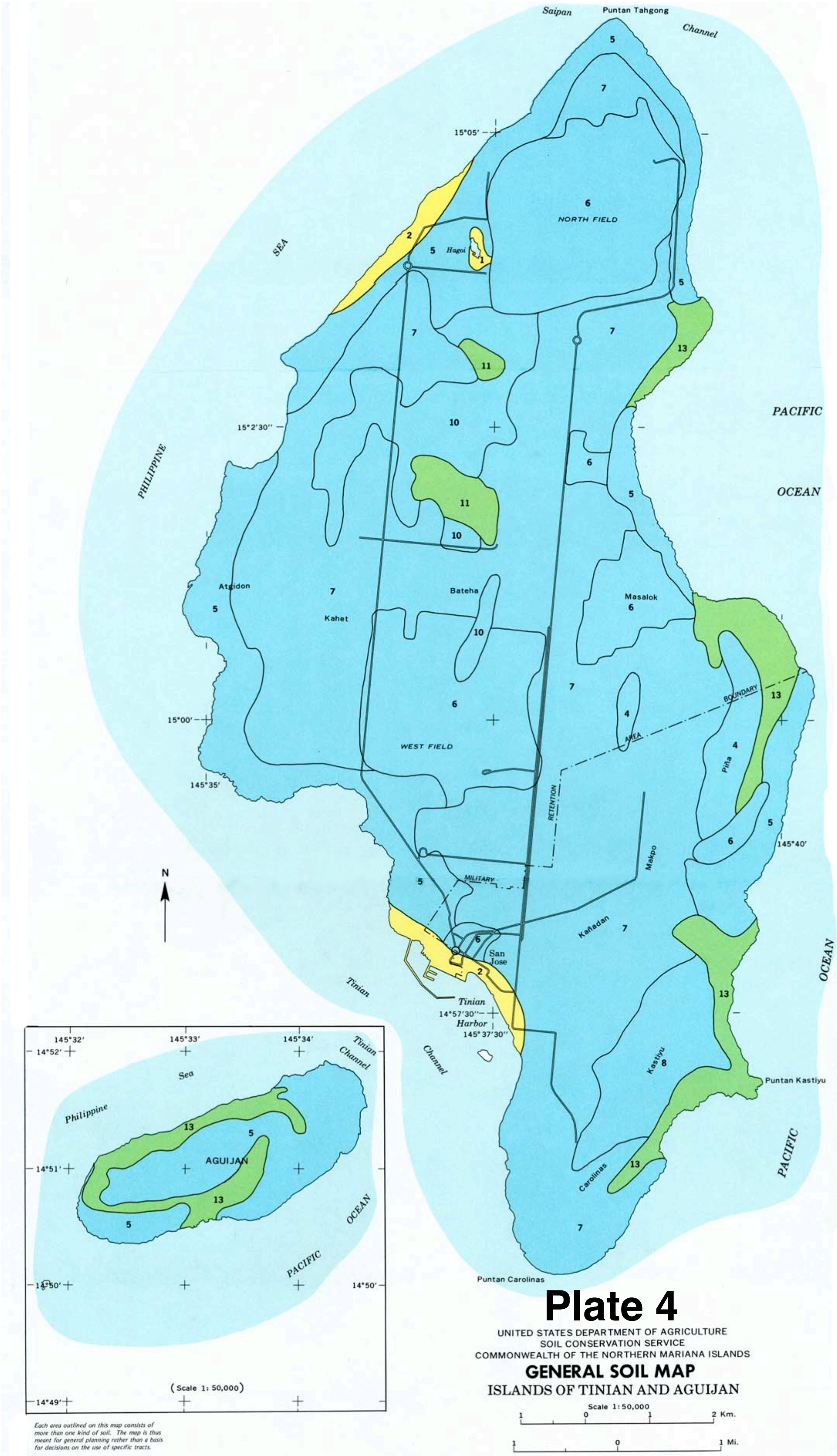

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11 **Laolao-Akina:** Moderately deep, well drained, strongly sloping to steep soils; on volcanic uplands

12 **Rock outcrop-Takpochao-Luta:** Shallow and very shallow, well drained, strongly sloping to extremely sloping soils, and Rock outcrop; on limestone escarpments and plateaus

13 **Takpochao-Chinen-Rock Outcrop:** Shallow, well drained, strongly sloping to extremely steep soils, and Rock outcrop; on limestone escarpments and plateaus

Chapter 2: Soils of the Mariana Islands • Origin of Soils

Excerpts from Fred J. Young 1988 USDA Soil Survey of Territory of Guam and 1989 USDA Soil Survey of the Islands of Aguijan, Rota, Saipan, Tinian, Commonwealth of the Northern Mariana Islands. Excerpts also from Western Pacific Tropical Research Center Website: www.wptrc.org

The islands of Guam and the Commonwealth of the Northern Mariana Islands are an example of a volcanic island arc, extending about 900 km north-south along the edge of the Marianas Trench in western Micronesia. The 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 to considerable heights above sea level forming terraces and high cliffs.

The islands have three broad landform categories each with their own set of soil parent materials: bottom lands (alluvium, coral sand, organic materials); limestone uplands (residuum and volcanic ash); volcanic uplands (volcanic tuff and tuff breccia, tuffaceous sandstone). The limestone residuum is primarily reef complex and reef detritus. Limestone is a sedimentary rock composed of different crystal forms of calcium carbonate ($CaCO_3$). The igneous volcanic material of the Mariana Islands is primarily andesite with some basaltic flows. The limestone and coral sand soils are generally high in Ca and neutral to moderately alkaline in reactivity, whereas the volcanic soils are acidic to strongly acidic. The bottom lands soils derived from alluvium of volcanic and marine sediments material deposited are generally slightly acidic to neutral in pH (Table 2-1).

Intense weathering coupled with the moderately rapid permeability of the underlying limestone resulted in the removal of silica from the Guam soils and the residual accumulation of iron and aluminum oxides. Some of the soils on the limestone plateaus are secondary silicate clays, as a result of insoluble components of weathered limestone. Common red ‘dirt’ is most likely derived from volcanic ash, now totally transformed from glassy ash to silicate clays. Various impurities contained within the various limestone soils allow for the combining of silica and aluminum to form clay minerals. The Mariana Islands all have a volcanic core, upon and around which limestone has been deposited. Akina soils are mainly kaolinite aluminosilicate clay. Pulantat soils have montmorillonitic minerology. Alluvium is an important parent material of Inarajan soils, Togcha, and Ylig soils. Shioya soils are beach sand deposits derived from coral sand.

Table 2-1. Summary of soil parent materials and soil series of the Mariana Islands with those most suitable for agriculture highlighted.

	SOIL SERIES	SOIL TEXTURE	pH	GUAM	SAIPAN	ROTA	TINIAN
			BOTTOM LANDS AND DEPRESSIONS				
✓	**Inarajan**	**clay**	**5.3 – 7.2**	**1,899 ha**	**68 ha**	**0**	**0**
	Mesei	muck	7.0	0	192 ha	0	13 ha
	Troposaprists	peaty muck	7.0	86 ha	0	0	0
	Ylig	clay	5.5	1,029 ha	0	0	0
			PERCENT OF ISLAND:	4%	2%	0%	<1%
			VOLCANIC				
	Agfayan	clay	5.8 – 6.4	6,804 ha	153 ha	0	0
	Akina	silty clay	5.0 – 5.6	6,901 ha	412 ha	63 ha	0
	Atate	silty clay	5.5	1,916 ha	0	0	0
	Laolao	clay	5.3	0	899 ha	140 ha	127 ha
	Sasalaguan	clay	5.5	333 ha	0	0	0
✓	**Togcha**	**silty clay**	**5.4**	**1,609 ha**	**0**	**0**	**0**
			PERCENT OF ISLAND:	35%	12%	2%	1%
			LIMESTONE AND COASTAL STRANDS				
	Banaderu	clay loam	7.0	0	242 ha	0	203 ha
	Chacha	clay	6.0 – 7.6	455 ha	112 ha		10
	Chinen	clay loam	7.6	0	5,364 ha	66 ha	3,661 ha
✓	**Dandan**	**clay**	**5.6**	**0**	**0**	**56 ha**	**4,298 ha**
	Guam	cobbly clay loam	7.1	18,973 ha	0	0	0
✓	**Kagman**	**clay**	**7.4**	**0**	**793 ha**	**0**	**257 ha**
	Luta	cobbly clay loam	7.4	0	0	6,711 ha	0
	Pulantat	clay	6.5	6,185 ha	0	0	0
	Ritidian	cobbly clay loam	7.6	6,481 ha	0	0	0
✓	**Saipan**	**clay**	**7.0**	**0**	**1,002 ha**	**0**	**175 ha**
	Saipan	silty clay	7.2	341	0	0	0
	Shioya	loamy sand	7.8 – 8.4	546 ha	571	22	156 ha
	Takpochao	cobbly clay	7.8	0	2,242 ha	1,463 ha	1,275 ha
	Yigo	silty clay	6.5	493	0	0	0
	Other		7.2				
			PERCENT OF ISLAND:	61%	86%	98%	99%
			Water	80 ha	15 ha	0	0
			Total hectares	54,913	12,065 ha	8,521 ha	10,176 ha
			Highest point	407 m	466 m	496 m	187 m

Guam: Guam's three main map categories (bottom lands, volcanic uplands, and limestone uplands) are further subdivided into 8 major soil units (Plate 1). Of these groups, agricultural production is mainly suited to four units (Plate 1-1, -3, -4, -8).

Inorganic commercial fertilizer is needed in most commercial farming operations on Guam. Generally, a balanced fertilizer that includes nitrogen, phosphorus, and potassium should be used. All soils in Guam are initially low in phosphorus and will tend to fix about a quarter to a third of added phosphorus, releasing it slowly over time. For this reason, and because phosphorus does not move in the soil like nitrogen, phosphorus should be banded directly into the root zone.

The **Inarajan-Inarajan variant soils** are well-suited for agriculture requiring minimal watering during the dry season. These soils are deep, clay throughout and subject to flooding (Plate 1-1).

The **Akina-Togcha-Ylig soils** are high in clay which may limit root growth due to compaction and poor aeration in the root zone. This soil is composed of 40% Akina soils which are red, acidic, infertile and clayey to a depth of 51 – 102 cm. Steep slopes are difficult to cultivate and without adequate management are susceptible to soil erosion. These soils are often too wet to farm in the rainy season. Liming to increase the pH may be necessary for maximum production (Plate 1-3).

The **Guam soil** is too fragile to till, has a low capacity to hold plant nutrients, and requires frequent irrigation due to the fact that it is shallow, porous, and rocky (Plate 1-4).

Pulantat-Kagman-Chacha soils are clay to silty clay over a mixture of limestone and clay. They are moderately suitable for production (Plate 1-8).

Northern Guam is composed of limestone upland soils which are subject to micronutrient deficiencies (Plate 1-4, -5, -6, -7, -8). It is mainly Guam soil series (Plate 1-4), which is alkaline (Table 2-1), shallow (Table 2-6), and a well-drained cobbly clay loam. Special management is needed to farm this soil productively year round. Crop selection should consider the depth and pH of the soil and farm drought management capabilities. Banana, tangerine, and other fruit trees should be planted only in the deeper areas. In most areas the bedrock should be excavated to a depth of at least 50 centimeters and the area backfilled with soil before planting trees. Because limestone is within the root zone, the soil is saturated with calcium carbonate and crops may show deficiencies of such micronutrients as zinc and iron. Because N is quickly leached out of this soil and K is poorly held, split applications of these nutrients are recommended. A fertilizer that includes ammonium as the nitrogen source is suitable because ammonium has an acidifying effect on the mildly alkaline soil. Foliar applications of micronutrients improve yields of many crops.

Southern Guam is mainly acidic clay soils. Many plants will do well in these soils (Table 3-18). Virtually all of the farming soils in the south are clay soils and are limited by wetness during the wet season (July – November). Crops tolerant of acidic soils (Table 1-4) do well in soils such as those of the Akina, Togcha, and Ylig series. Fertility management is very important in Guam's shallow soils. Organic matter with its water and nutrient-holding capacity is critical for the health of these soils. Saipan silt clay and Yigo soils in particular are virtually inert without organic matter; most plant nutrients will be leached out of the root zone with irrigation or rain. The acidic volcanic soils in the south, primarily the Akina, Togcha, and Ylig soils require slightly different fertility management practices. Although split applications of nitrogen are suitable, leaching of nitrogen is not so serious a problem as it is on Guam cobbly clay loam. Ammonium is not recommended as a nitrogen source because it tends to acidify the soil and increase problems of calcium deficiency and aluminum toxicity. Calcium is often limited due to fixation with Al, Fe, and Ca leaching due to Na displacement.

Northern Mariana Islands: Saipan is the largest island of the Northern Mariana Islands. Most of the island is limestone, although the volcanic core is exposed in various places and makes up about 10 percent of the surface area (Plate 2). An extensive swamp is in the southwestern part of the island, which also contains the largest lake in the Northern Marianas. Commercial farmland on Saipan is mostly on Chacha, Chinen, Kagman, and Saipan soils.

Tinian is separated from Saipan by a strait 5 kilometers wide. The island is basically a series of five limestone plateaus that are at various elevations and are separated by steeply sloping areas and escarpments (Plate 4). Its volcanic core is exposed in two places, although only the northern exposure is of significance. On Tinian most of the small commercial farms are in the Marpo Valley area on Chinen and Dandan clays. In the north, farms are on Babaderu, Chinen, Dandan, and Saipan soils.

Rota is also primarily an island of concentric limestone plateaus separated by escarpments (Plate 3). The plateau surfaces are level or gently to strongly tilted. The volcanic core emerges in several areas, two of which are extensive. Farming on Rota is mostly on Luta soils.

Not all of the soil series in the Northern Mariana Islands are suited for agriculture (Table 2-2). Overall, the best agricultural soils in the Northern Marianas are the nearly level areas of Saipan clay on Saipan (Plate 2-10) and Tinian (Plate 4-10). These deep, well-drained soils have few limitations, although field access is often difficult during the rainy season. The moderately deep Dandan soils (Plates 3-7 and 4-7) are probably as productive as the Saipan soils for shallow-rooted vegetables. The deep Kagman soils (Plates 2-8 and 4-8) are well suited for dry season agriculture. Because of slow permeability, these soils are excessively wet and thus are difficult to farm in the rainy season. Chinen clay (Plate 2-5 and 4-5), although shallow, can produce excellent vegetable crops if managed properly. Chacha, Kagman, and Saipan soils have the highest available water capacity of the agricultural soils in the Northern Marianas; other soils have limited use during the dry season. Three of the major agricultural soils in the Northern Marianas are shallow or very shallow on limestone. These soils are those of the Chinen (Plates 2-5, 3-5, and 4-5), Banaderu (Plates 2-4 and 4-4), and Luta series (Plate 3-9). The main effects on shallow soil depth on agriculture are droughtiness, mechanical interferences with tillage, mechanical mixing of limestone material into the soil, and restriction of roots. Luta soils are so droughty that even short dry periods in the rainy season can cause moisture stress in some crops.

Nitrogen fertilizer is quickly leached out of the soils of the Northern Mariana Islands, particularly the Banaderu, Chinen, and Luta soils. A fertilizer with ammonium as the nitrogen source is suitable for these shallow, mildly alkaline soils, because ammonium has an acidifying effect. Animal manure can be an effective source of soil nutrients if properly managed; however, nitrogen can be quickly volatilized and lost as ammonia gas from manure. The use of manures with a high C:N ratio can tie up soil nitrogen and actually cause a short period of nitrogen deficiency (Figure 1-1). Both manure and cover crops should be turned under early to allow for decomposition before the crop is planted. Unlike inorganic fertilizer manure adds organic matter to the soil.

Most soils in the Northern Marianas are like those of Guam. They "fix" about a quarter to a third of added phosphorus, releasing it slowly over time. From years of cultivation of the shallow Banaderu, Chinen, and Luta soils limestone has been mixed into the root zone. Because of this, the soils are saturated with calcium carbonate and some crops show deficiencies of such micronutrients as zinc and iron. These deficiencies can often be corrected with micronutrient foliar sprays. To reduce incorporation of limestone into topsoil, no-till farming practices should be followed.

Table 2-2. Soil information, commercial farming areas and ranking of soils series based on suitability for agriculture in the Northern Mariana Islands.

Soil orders Clay activity	Soil characteristics	Soils	Map unit Plate 2, 3, 4	Ag ranking - COM Farming
Alfisols High	Moderately fertile, clay accumulation in the B horizon, moderate amounts of non-acid cations.	Chacha	8	3-COM
Entisols Moderate	Weakly developed B horizon, low water holding capacity, alkaline pH.	Shioya	2	7
Histosols Moderate	Deep, poorly drained, permanent high water table, formed in marine and alluvial deposits, high in SOM.	Mesei	1	8
Inceptisols High	Relatively fertile, deep, poorly drained, from alluvium.	Inarajan	1	6
Mollisols High	Highly fertile, rich in organic matter, non-acid cations, high CEC, excellent pH.	Banaderu Chinen Luta Takpochao	4 5, 6, 7, 13 12 3, 5, 12, 13	4-COM 5-COM 5-COM 6
Oxisols Low	Fine texture, highly weathered, low capacity to supply Ca, K, and P. Typically acidic with high soluble Al. Exhibits both CEC and AEC characteristics.	Agfayan	11	7
		Akina	11	6
		Dandan	7	2-COM
		Kagman	8	2-COM
		Laolao	11	3-COM
		Saipan	8	1-COM

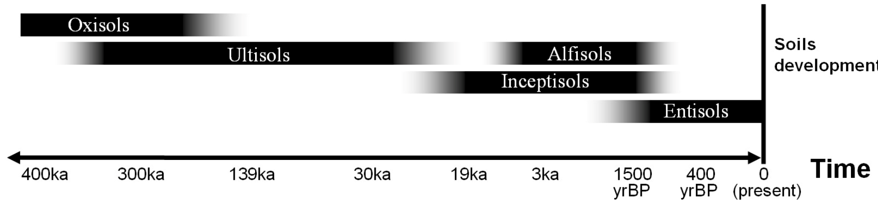
COM: Commercial farming areas.

Ag rank: Agricultural rank (worst 8 – best 1) is applied to only sites where soil slope ranges from 0-6 percent. The ranking criteria is based on but not limited to suitability for picnic areas, habitat elements, seedling mortality, suitability for grazing, soil pH, and organic matter, which were derived from Fred J. Young 1988 USDA Soil Survey of Territory of Guam and 1989 USDA Soil Survey of the Islands of Aguijan, Rota, Saipan, Tinian, Commonwealth of the Northern Mariana Islands.

Clay activity is a measure of the clay minerals ability to hold ions. Soils having appreciable contents of high activity clays (eg., 2:1 expandable clays such as montmorillonite) provide long-term stabilization of organic matter. These clays have a great capacity to retain and supply large quantities of nutrients such as Ca, Mg, P, and Al. Soils with low-activity clays (eg., 1:1 non-expandable clays such as kaolinite and hydrous oxide clays of iron and aluminium) have a much lower ability to stabilize organic matter and consequently respond more rapidly to changes in the soil's carbon balance. Low activity clays of the Mariana Islands hold a low quantity of positive ions (+) under neutral and alkaline conditions and low quantity of negative ions (-) under acidic conditions (refer to the section on Fate of Plant Nutrients in Soil in Chapter 1 for more information).

Summary: Thousands of years are required for parent material to weather into subsoil, hundreds of years to form topsoil, and decades for rich organic matter to build up (Figure 2-1).

Figure 2-1. An estimated time line for the soils of the Mariana Islands.



Adapted from Soilscape of the west-central Taiwan-the footprints on soil pedogenesis and geomorphic environment *Heng Tsai, Zeng-Yei Hseu, Hong-Yu Kuo, Zueng-Sang Chen*, pp. 30-33.

The soils of representative landscapes in Guam and the Commonwealth of the Northern Mariana Islands (CNMI) are summarized in Table 2-3.

Table 2-3. Characteristics of the topsoil and subsoil of the landscapes in the Mariana Islands.

Representative soils Parent materials	pH	SOM	% Sorption of Phosphate	Aluminum Saturation	Exchangeable Bases	CEC for Ca, Mg & K
Akina series Volcanic	5.0 5.0	9 2	26 26	15 49	12 8	10 4
Yigo series Limestone	7.9 7.6	5 1	29 40	0 0	14 2	11 3
Shioya series Alluvium (coral sand)	7.7 8.0	3 <1	60 90	0 0	7 <1	75 2

Topsoil is a general term applied to the surface portion of the soil where organic matter accumulates (A horizon).

Subsoil is the layer beneath the topsoil (B horizon). It consists of substances such as clay and/or sand that has only been partially broken down by the environment. Beneath the subsoil are the relatively unweathered parent materials: limestone, volcanic deposits, and alluvium.

pH stands for the potential (p) of the hydrogen ion (H^+) in water. It is a numerical measure of acidity or hydrogen ion activity in a soil solution. For most cultivated plants, soil ideally should have a pH between 5.6 and 7.8 to maximize soil nutrient availability.

Soil Organic Matter (SOM) or percent organic matter was determined from organic carbon. Soil organic matter generally contained approximately 56% OC. The following equation was used to estimate the total organic matter content of soil from OC measurements: % Organic Matter = % Organic Carbon x 1.78.

Cation Exchange Capacity (CEC) is an expression of the number of cation absorption sites (hydrogen equivalents) per unit weight of soil. The CEC value for the volcanic soil is actually its Effective CEC (ECEC), because the soil sample tested was not adjusted for pH. The other two soils were adjusted to pH 7 before CEC was determined. Humus is responsible for most of the CEC and pH buffering in the topsoil of the soils of the Mariana Islands. The CEC value is a means by which resistance to changes in soil chemistry caused by agriculture use can be measured: <6 very poor resistance, 6-12 low resistance, 12-25 moderate resitance. Volcanic soil with CEC less than 3 are often low in fertility and susceptible to soil acidification.

Exchangeable Bases or base saturation is the percentage of cation exchange capacity that is saturated with Ca, Mg, Na, and K. It provides an indication of potential fertility. The higher the value the more productive the soil: 0-20 very low, 20-40 low, 40-60 moderate. It is also an indicator of leachability: 0-15 very strongly leached, 15-30 strongly leached, 30-50 moderately leached. Values are actually the ECEC for bases Ca, Mg, Na, and K.

Percent phosphate sorption or P-fixation is a measurement of a soil's ability to fix inorganic phosphorus. Because of its particular chemistry, negatively charged phosphorus reacts readily with positively charged Fe, Al and Ca ions to form relatively insoluble substances. When pH is less than 6, plant available phosphorus becomes increasingly tied up in aluminum phosphates. As soils become more acidic (pH below 5), phosphorus is fixed in iron phosphates. When pH values exceed 7.3, phosphorus is increasingly made unavailable by fixation in calcium phosphates. The efficiency of phosphate fertilizers is higher in soils with lower percent phosphate sorption values; therefore, these soils required less P_2O_5 fertilizer or phosphorus rich organic manures.

Aluminum saturation is an expression, that describes the relative abundance of soluble aluminum in the soil. Although the tolerance to aluminum varies among plant species, some crops do not tolerate greater than 15% aluminum saturation.

Soil is a non-renewable resource subject to degradation by natural phenomena and poor farm practices. All processes of soil degradation are grouped into six classes: water erosion, wind erosion, soil fertility decline, salinization, water logging and lowering of the water table. In the Mariana Islands, soil fertility decline and erosion are the forces that are largely responsible for soil degradation.

Soil fertility decline refers to deterioration in a soil's physical, chemical and biological properties. It is primarily caused by reduction in SOM and over use of inorganic fertilizers. In the Mariana Islands' wet tropical climate, fresh organic matter is continuously being transformed into simpler forms by soil organisms. Between 60 and 80 per cent of the carbon from most plant residues is evolved as CO_2 within a year of deposition; 5 to 15 per cent is incorporated into the microbial biomass and the rest remains in soil humus.

The physical movement of soil is generally referred to as erosion. Wind, water, waves, animals and tools are all agents of erosion in the islands. The hazard that erosion poses to various soils (Table 2-4) depends on several factors: Risk increases with the slope, soil density, soil compaction, surface exposure and decreases with soil permeability, soil organic matter, depth of top soil, and surface vegetation.

Table 2-4. Summary of soil series susceptibility to erosion and associated factors.

Soil Series	Erosion hazard Guam	Erosion hazard CNMI	Permeability cm/hr	Sheet and rill erosion tons/acre/year	Soil loss tolerance tons/acre/year	SOM
BOTTOM LANDS AND DEPRESSIONS						
Inarajan	Sm.	Sm.	0.2-5.0	0.17	5	4-7
Mesei		Sm.	1.5-5	0.05	1	8-10
Troposaprists					1	12-50
Ylig	Sm.	N/A	0.5-1.5	0.24	5	6-8
VOLCANIC						
Agfayan	Sm.-Sev	N/A	0.5-1.5	0.2	2	2-5
Akina	Sm.-Sev.	Mod.-Sev.	1.5-5.0	0.2	1	6-1
Atate	Sm.-Mod.		1.5-5.0	0.15	4	4-8
Laolao		Sm.-Sev.	1.5-5.0	0.15	3	4-9
Sasalaguan	Sm.		0.02-0.5	0.28	3	4-7
Togcha	Sm.		1.5-5.0	0.15	5	4-7
LIMESTONE AND COASTAL STRANDS						
Banaderu		Sm.-Mod.	1.5-5.0	0.2	1	4-8
Chacha	N/A	Sm.-Mod.	0.02-1.5	0.15	4	4-8
Chinen		Sm.-Mod.	1.5-5.0	0.15	2	4-7
Dandan		Sm.	1.5-5.0	0.15	2	4-7
Guam	Sm.	Sm.	5.0-15.00	0.05	1	10-15
Kagman	Sm.	Sm.	0.5-1.5	0.15	5	4-8
Luta		Sm.-Mod.	5-15	0.1	1	4-8
Pulantat	Sm.-Sev.		0.02-0.5	0.24	2	7-10
Ritidian	Sm.-Sev.		5.0-15.0	0.02	1	6-9
Saipan		Sm.	1.5-5.0	0.10-0.15	3	4-7
Shioya	Sm.	Sm.	15-50	0.15	5	4-5
Takpochao		Sm.	1.5-5.0	0.10	1	4-8
Yigo	Sm.		1.5-5.0	0.2	4	4-8

- Excerpts from Fred J. Young 1988 USDA Soil Survey of Territory of Guam and 1989 USDA Soil Survey of the Islands of Aguijan, Rota, Saipan, Tinian, Commonwealth of the Northern Mariana Islands. Some values were changed to reflect current assessment.
- Small (Sm.), moderate (Mod.), and severe (Sev.) indicate the potential for erosion as it relates to several factors such as steepness and length of slope, surface cover, and crop management factors.
- Permeability: The quality of the soil that enables water to move downward through the profile. Values less than 1.5 cm/hr are considered problematic.
- Sheet erosion is caused by the unconfined flow of water running across the soil surface. Rill erosion is caused by water concentrating into innumerable, closely-spaced small channels that are just a few inches deep. These may consolidate into gullies.
- Soil loss tolerance (T-factor) is the target value (tons/acre/year) which NRCS erosion calculations use to determine whether a management system is or is not sustainable.

Chapter 2: Soils of the Mariana Islands • Clay Soils of Guam

Adapted from Jonathan Deenik's Soil of Guam Properties of Diversity: http://marianasgrazingacademy.org/PDF's/Soils/ soils_guam_2010_notes.pdf

Chemical weathering of primary minerals produce clay minerals. Most of the well-drained uplands soils on Guam, such as those of the Akina and Yigo series, are highly weathered and leached. Soluble bases such as Ca and Mg have been leached from these soils. Primary minerals have weathered releasing Fe, Si, and Al. Iron has formed very stable secondary minerals of iron oxide, which gives these soils their characteristic red color. In the Akina soils, the Si and Al released from the primary rock minerals have recombined to form the secondary clay mineral of kaolinite. In the Yigo soils, even the Si has been leached away and the Al has formed the very stable hydoxides of gibbsite. The Yigo soils are a good example of the result of climatic soil weathering; these soils are composed primarily of very stable oxides and hydroxides of Fe and Al. The high rainfall and leaching cause clay minerals to move from the surface layer into the subsoil and from clay films. Clay films are common in Akina, Atate, Kagman, Togcha, and other upland soils on Guam. Clay films are absent, however, in the Guam and Yigo soils.

High activity clays have a high cation exchange capacity (CEC), due to their large surface area. These clays tend to produce highly fertile soils. Examples of these clays are montmorillonite (and other smectites), vermiculite, illite, and mica. With little additions of nutrients, these soils may be very productive.

However, the shrink and swell potential will result in poorer drainage. And so, proper management of irrigation is required. In the Mariana Islands montmorillonitic clay soil series include Agfayan, Pulantat, and Sasalaguan.

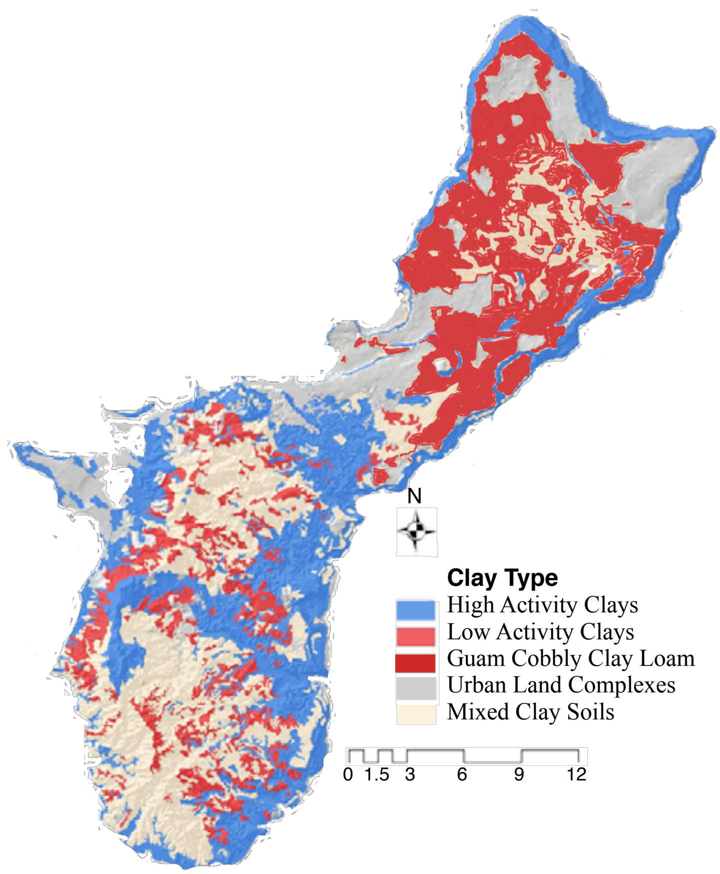
Low activity clays are formed when high activity clays are weathered. Due their lower surface area, low activity clays have a lower capacity to retain and supply nutrients. Under neutral and alkaline conditions, these low activity clays generate a CEC. Depending upon the pH of the soil, low activities clays can also exhibit AEC, Refer to Chapter 1: Fate of Plant Nutrients in Soil for more information on AEC. The AEC causes these clays to retain and supply nutrients, such as phosphate, sulfate, and nitrate.

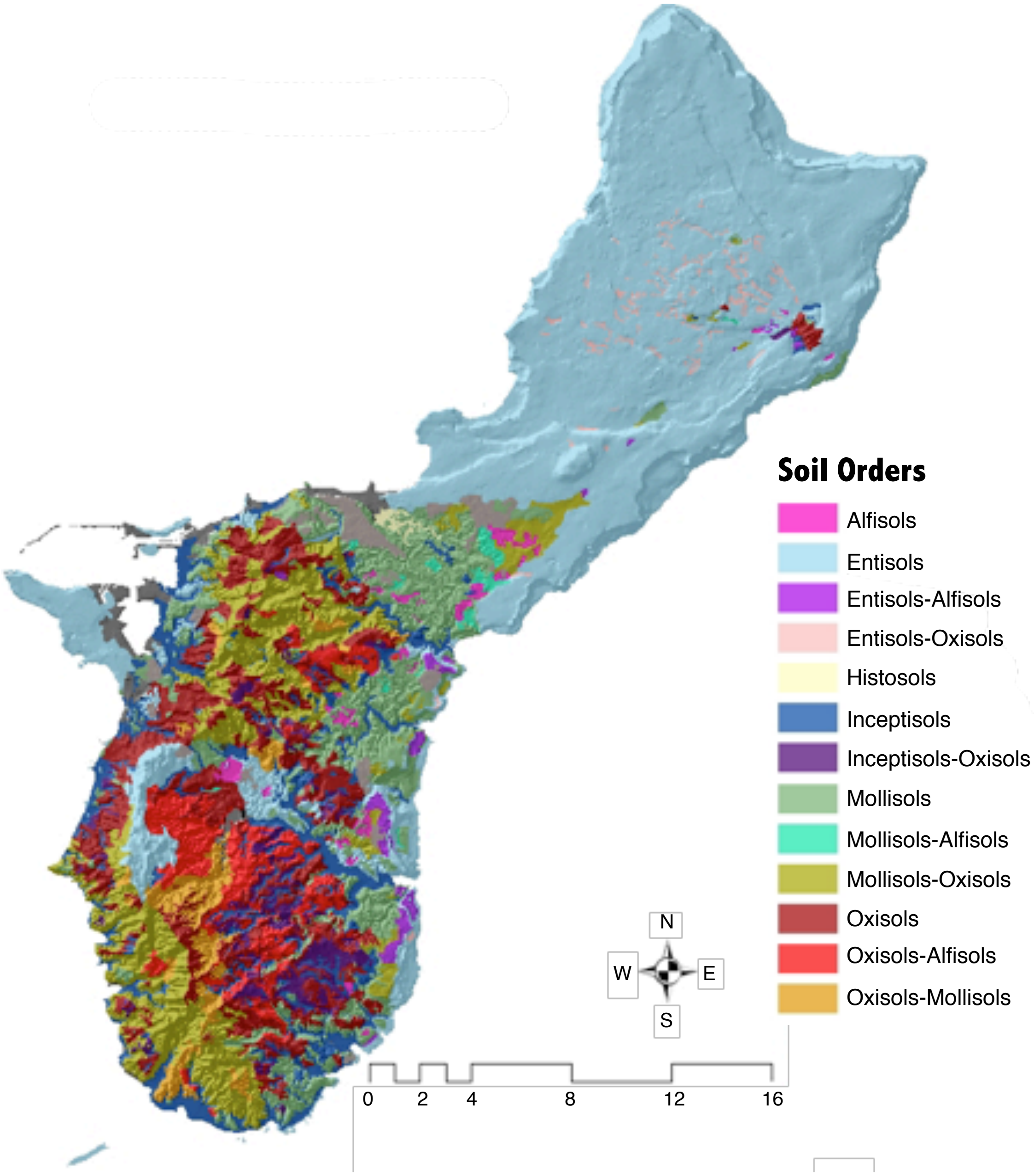
The low activity clay, kaolinite, is a nonexpanding clay with much less surface area than montmorillonite and a low capacity to adsorb cations. However, they have good physical properties making them relatively easy to cultivate. In the Mariana Islands, kaolinitic soil series include Akina, Atate, Chacha, Kagman, and Takpochao.

Guam cobbly clay loam which is extensive on the limestone plateau of northern Guam, is an unusual soil. Based upon mineralogical analysis in the laboratory it is a low activity clay soil, which contains a high amount of gibbsite (Al-oxide clay mineral) but has CEC values typical of a high activity clay. The CEC in this soil is attributed to organic matter and not clay activity.

Mixed clay soils contain a mixture of both montmorillonite and kaolinite clays. In the Mariana Islands mixed clays soil series include Inarajan, Togcha, Ylig, and Saipan. Under intense weathering conditions, gibbsite forms. Gibbsite is an oxide of aluminum and has a very low CEC. In the Mariana Islands, gibbsite soil series include Guam, Ritidian, Yigo, and Banaderu.

Urban land complexes are areas composed of urban soil and another soil. Urban land is soil disturbed by land shaping for urban development. Urban land consists of areas covered by buildings, roads, and park lots. Guam-Urban land complex is on limestone plateaus. Areas usually have a base of crushed coral and a thin layer of clay. This unit is about 55 percent Guam cobbly clay loam and 45 percent Urban land. Pulantat-Urban land complex is also on plateaus. This unit is 70 percent Pulantat clay and 30 percent urban land. Akina-Urban land complex is on volcanic uplands. This unit is about 60 percent Akina silty clays and 30 percent Urban land.





The island of Guam consists of five 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 generally 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 generally very productive soils.

Alfisols are moderately fertile soils that 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.

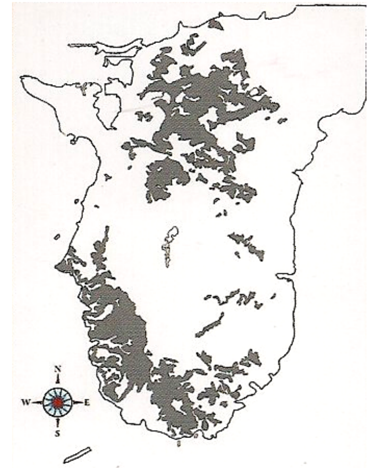
Oxisols are highly weathered soils with low fertility that have developed from volcanic parent material in southern Guam. They are typically acid to very acid with high soluble aluminum in the subsoil. These soils have a low capacity to supply key plant nutrients such as Ca, K, and P. Lime is often required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

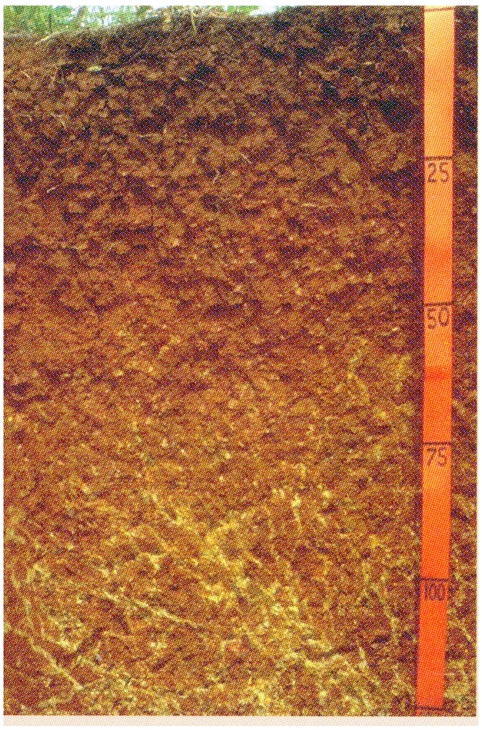
Inceptisols are typically found in the bottom lands of southern Guam and they are formed from alluvial materials. They are typically relatively fertile soils with slightly acidic pH. However, when they occur in association with Oxisols on steep lands they are usually acid and infertile.

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.

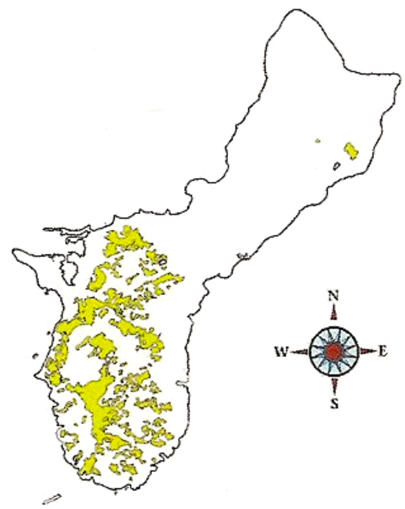
Adapted from Peter Motavalli of UOG and Ken Monroe of NRCS. 1997 Poster-Soils of Guam.

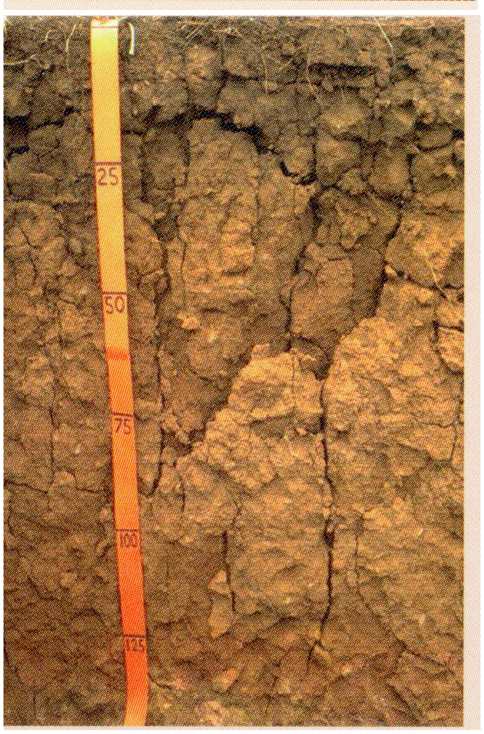
Agfayan series: This soil series is not suited to commercial farming and poorly suited to subsistence farming, and homesite development. The main limitations are the depth to impermeable bedrock, the hazard of erosion, the lack of water during the dry season, and steep slopes. It is moderately suited to grazing. The use of this soil series as wildlife habitat and watershed can be enhanced by protecting the soil from wildfires and by planting adapted trees



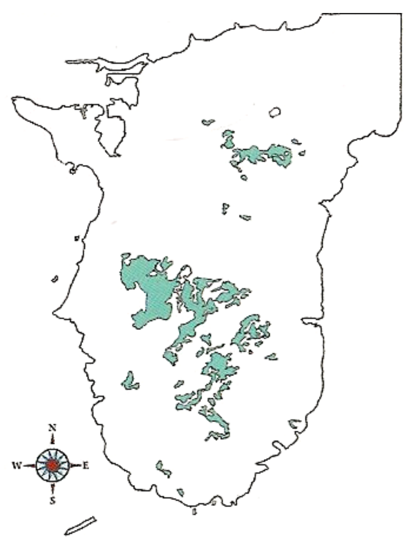


Akina series: This soil series is moderately suited to subsistence and commercial farming, and homesite development. The main limitations are low fertility, high fragility, soil acidity, lack of water during the dry season, and erosion hazard. Subsoil should not be exposed as natural revegetate is unlikely. Exposed subsoil is responsible for the occurrence of badland in slump areas, along ridgelines and on shoulder slopes. Compost can be applied to improve soil fertility. Lime can be mixed into the soil to provide calcium and to reduce soil acidity. Crops adapted to clayey, acid soils include watermelon, Chinese and head cabbage, and some fruit trees.

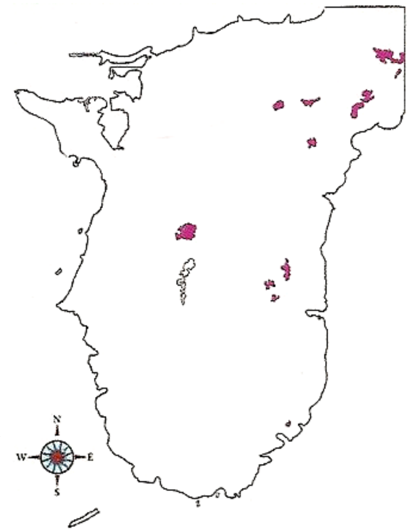




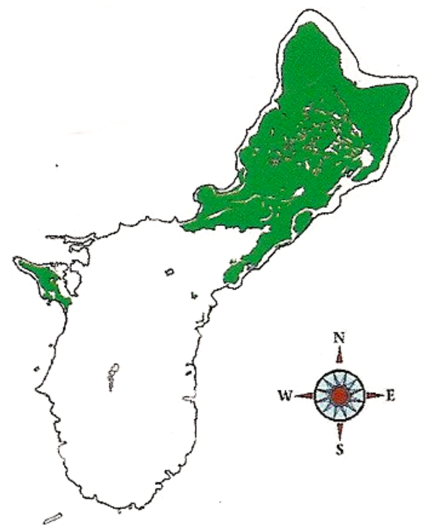
Atate series: This soil series is moderately suited for subsistence and commercial farming, and homesite development. The main limitations are the hazard of erosion, low soil fertility, soil acidity. Lime can be mixed into the soil to provide calcium and to reduce soil acidity. Compost can be added to improve soil fertility. Crops that can be grown are those adapted to acidic soils, including watermelon, head and Chinese cabbage, and some fruit trees. It is well suited for grazing in areas not heavily forested. The use of this soil series as wildlife habitat and watershed can be enhanced by protecting the soil from wildfires and by planting adapted trees. It can be used for recreational development.



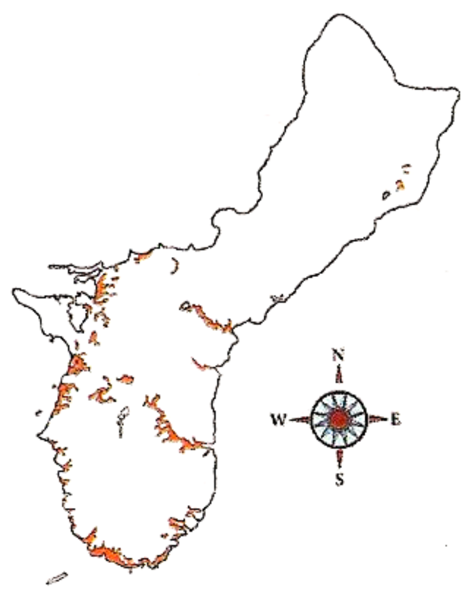
Chacha series: Most areas of this soil are used for commercial and subsistence farming. Vegetable crops grown during the dry season include beans, watermelons, Chinese and head cabbages, cantaloupes and cucumbers. It is moderately suited for banana, tangerine, and other fruit trees that are planted on the upper slopes. A few areas are used for grazing, homesites, watershed, and wildlife habitat. This soil series is moderately suited to commercial and subsistence farming. It is well suited to grazing and poorly suited to homesite development. The main limitations are wetness during the rainy season, the hazard of soil compaction when the soil is wet, and the lack of water late in the dry season. Wetness can be reduced by using raised beds for crop production. Mechanical tillage and vehicle traffic should be avoided when the soil is wet.



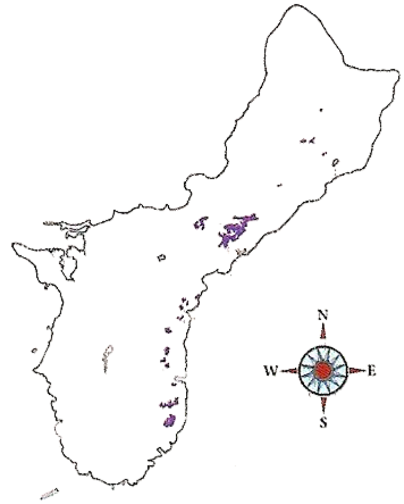
Guam series: This soil series is poorly suited for commercial and subsistence farming. With proper management, (fertilizers and drip irrigation) most vegetables can be grown throughout the year. It is not suited to commercial production of fruit. It is moderately suited for grazing and homesite development. The main limitations are the very shallow soil depth, droughtiness, and rocks. It can be used for wildlife habitat, watershed and recreational development.



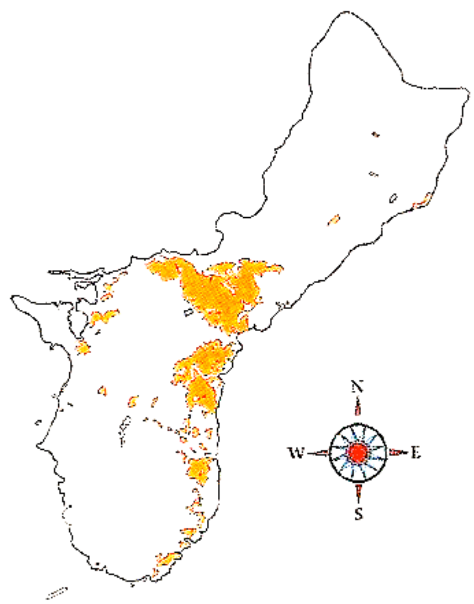
Inarajan series: This soil series is moderately suited to subsistence and commercial farming and grazing. It is poorly suited to homesite development. The main limitations are wetness during the rainy season and lack of water during the dry season. It is well suited to taro and other crops that tolerate seasonal wetness. Most vegetables cannot be grown during the rainy season. Banana, tangerine, and other fruit trees can be grown only on the natural levees along the rivers and on the loose deposits brought by gravity to valley edges (colluvial deposits). This soil can be used for watershed, wildlife habitat, and recreational development.



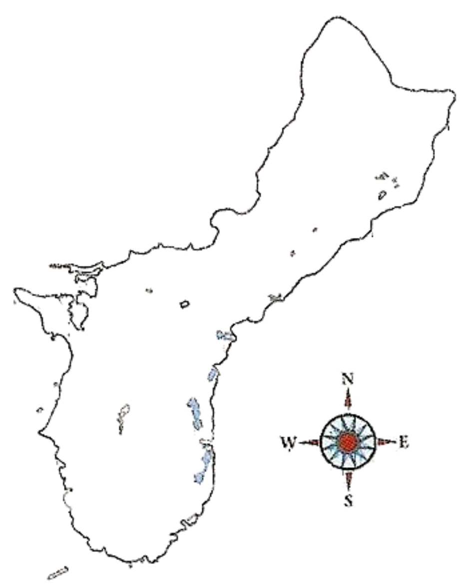
Kagman series: This soil series is well suited to subsistence farming. The main limitation is droughtiness late in the dry season. It is susceptible to compaction during the rainy season. Mechanical tillage and vehicle traffic should be avoided when the soil is wet. It is moderately suited for homesite development, grazing and commercial farming. It can be used for wildlife habitat and watershed.



Pulantat series: This soil series is moderately suited for grazing, homesite development, subsistence and commercial farming. It can be used for wildlife habitat and watershed. The main limitations are the shallow soil depth, the very low available water capacity, and the susceptibility of the soil to compaction when it is moist. It is poorly suited for fruit trees. Field operations should be avoided after heavy rains.



Saipan series: This soil series is moderately suited for subsistence farming, commercial farming, grazing, and homesite development. With proper management, (fertilizers and drip irrigation) most vegetables and some fruit trees can be grown throughout the year. The main limitation of the Saipan soil is the low soil strength.



Togcha series: This soil series is well suited to subsistence and commercial farming. Crops that can be grown are those adapted to clayey, acidic soils, such as watermelons, Chinese and head cabbages, and most fruit trees. The growth and production of banana, papaya, and other fruit trees can be increased by irrigating during the dry season. It is moderately suited to homesite development. It is well suited for grazing and has a small erosion hazard (Table 2-4). The main limitations are soil acidity, and droughtiness during the dry season.

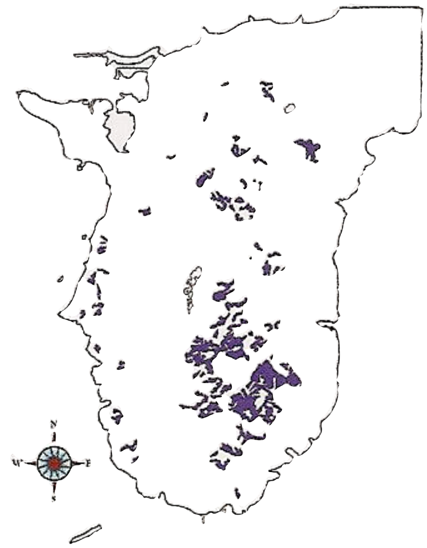


Photo provided by Robert Gavenda of NRCS.

Troposaprist: These deep, very poorly drained soils occur in Guam's Agana Swamp. They formed from decomposed organic material derived dominantly from reeds, sedges, rushes, and other wetland plants. This soil series is only suitable for commercial production of crops that prefer flooded soils. Palauan residents of Guam have cultivated brak/giant swamp taro (*Cyrtosperma chamissonis*) and kukau/taro, (*Colocasia esculenta*) in the peaty soil of the swamp for more than 25 years. Palauan migrants/residents use the dechel cultivation system. In this method, the marsh is cleared of its vegetation (mainly a reed, *Phragmites karka*) and then planted with sets from previously harvested giant swamp taro.

H.I.Manner, 2009, http://www.agroforestry.net/scps/Giant_swamp_taro_specialty_crop.pdf

Yigo series: This soil series is moderately suited to commercial production of vegetables, grazing, and homesite development. It is poorly suited to commercial production of fruit. With proper management, (fertilizers and drip irrigation) most vegetables can be grown throughout the year. The main limitation of the Yigo soil is low soil strength. It can be used for recreational development, wildlife habitat, and watershed.

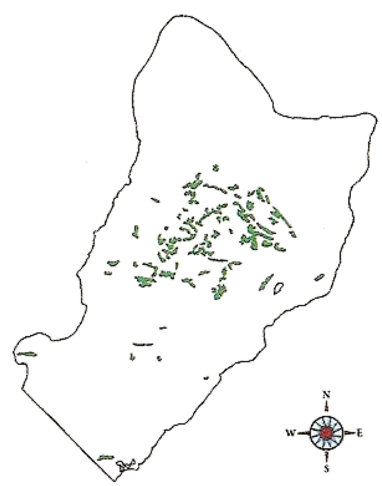
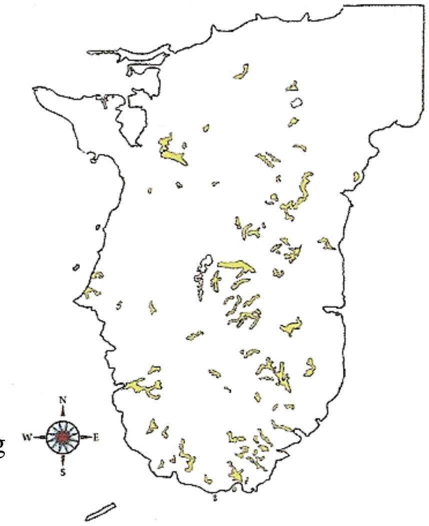


Photo provided by Robert Gavenda of NRCS.



Ylig series: This soil series is very deep, moderately slow permeability, and moderately suited to subsistence farming and grazing. It is poorly suited for commercial farming. Crops that can be grown during the dry season include beans, watermelons, and Chinese and head cabbages. Most areas of this soil series are poorly suited to banana and other fruit trees that are sensitive to wetness. The main limitations are poor drainage (wetness), soil acidity, and droughtiness late in the dry season. It is used as watershed and wildlife habitat. The use of this soil series as wildlife habitat and watershed can be enhanced by maintaining existing wetland vegetation.

Table 2-5. Average soil test analyses conducted by the WPTRC Soil and Plant Testing Laboratory on 950 samples submitted by Guam's farmers from 1984-1993.

Chemical Analysis (mg/kg soil)

Geographic Region	pH	Organic Matter (%)	P	K	Ca	Mg	Na	Zn	Fe	Mn	Cu
North	7.0	7.1	24.8	137	10,053	349	152	39	38	196	6
Central	6.9	6.4	14.2	166	5,559	649	130	33	78	128	8
South	6.5	3.9	6.3	445	4,951	1,707	868	28	296	178	14

P.P. Motavalli, J.A. Cruz, and R.Y. Marasigan; 1996 Guam Soil Test Summary, Agriculture Experiment Station bulletin.

Map of Guam showing district and regional boundaries

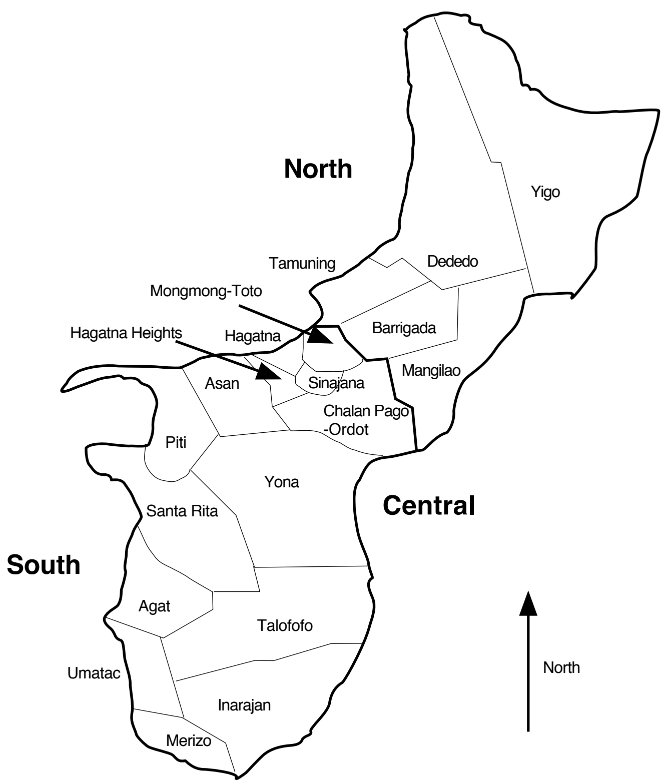


Table 2-6. Summary of Guam soil series and their characteristics.

Soil Series	Depth (cm)	Clay (%)	Moist bulk density (g/cm3)	pH	Organic matter (%)	CEC meq/100g	Extractable P mg/kg	Extractable K mg/kg
Agfayan	0 - 10	60 - 80	0.80 - 0.95	6.7	3.5	——	——	——
Akina	0 - 10	45 - 60	0.85 - 1.0	6.2	8.0	21.6	0.9	35
Atate	0 - 13	40 - 60	0.90 - 1.10	5.5	6.0	17.8	0.7	150
Chacha	0 - 20	50 - 60	1.00 - 1.20	6.7	6.0	24	14.9	240
Guam	0 - 25	35 - 55	0.60 - 0.90	7.2	12.5	22.0	20.2	50
Inarajan	0 - 25	45 - 80	0.90 - 1.10	6.2	6.0	37.7	5.6	140
Kagman	0 - 16	40 - 70	0.90 - 1.20	6.95	6.0	20.0	7.0	44
Pulantat	0 - 16	70 - 90	0.90 - 1.10	7.2	8.5	31.1	16.1	68
Saipan	0 - 15	35 - 60	1.00 - 1.20	6.95	5.5	20.0	14.6	135
Togcha	0 - 13	55 - 60	0.95 - 1.10	5.55	5.5	25.5	1.2	335
Yigo	0 - 15	40 - 60	0.90 - 1.10	6.45	6.0	18.3	10.0	135
Ylig	0 - 13	50 - 70	0.90 - 1.10	5.8	7.0	50.6	0.5	1,100

Soil series are soils that have similar horizons in their profiles. The horizons are similar in color, texture, structure, reaction, consistence, mineral and chemical composition and arrangement. The texture of the surface layer and the substratum can differ within a series.

Depth of soil is from the ground surface to a root-limiting layer.

Organic matter percent is the weight of decomposed plant and animal residue and expressed as a weight percentage of the soil material less than 2 mm in diameter.

pH is a measure of the acidity (low pH) or alkalinity (high pH) of a soil solution related to hydrogen ion concentration. It is numerically equal to 7 for neutral solutions. Availability and solubility of nutrients in the soil are affected by soil pH. They are optimal in most soils at pH 5.6 to 6.5.

Table 2-7. Interpretation of pH values for the production of agronomic crops.

	Very low	Low	Optimum	High	Very High
pH	< 5.0	5.1-5.5	5.6-6.5	6.6-7.5	> 7.5

Extractable nutrients is a measure of the availability of nutrients present in the soil and the availability of those nutrients for plant growth.

Table 2-8. Interpretation of extractable nutrient levels (mg/kg) for the production of agronomic crops.

Nutrient	Very low	Low	Optimum	High	Very High
Phosphorus	< 10	10-30	31-60	61-90	> 90
Potassium	< 50	50-100	101-150	151-190	> 190
Calcium	< 400	401-800	801-1,200	1,201-1,600	> 1,600
Magnesium	< 50	51-100	101-200	201-300	> 300

CEC: Cation Exchange Capacity is a calculated value that is an estimate of the soils ability to attract, retain, and exchange cation elements. It is reported in millequivalents per 100 grams of soil (meq/100g). CEC was analyzed at pH 7. In those soils with pH levels less than 7, such an analysis creates some negative charges on the variable charge components of the soil so CEC values are higher than ECEC. Note the difference between values for Akina series in Table 2-3 and 2-6.

Larger CEC values (>11) indicate that a soil has a greater capacity to hold cations. Therefore, it requires higher rates of fertilizer or lime to charge a high CEC soil. When a high CEC soil has optimal levels of nutrients (refer toTable 2-8), it offers a large nutrient reserve. However, when it is poor, it can take a large amount of fertilizer or lime to correct that soil test. A high CEC soil requires a higher soil test, to provide adequate crop nutrition. Low CEC soils (<11) hold fewer nutrients, and will likely be subject to leaching of mobile "anion" nutrients. These soils may benefit from split applications of several nutrients. The particular CEC of a soil is neither good nor bad, but knowing it is a valuable management tool.

Refer to Table 2-3 and the section on Fate of Nutrients in Soil in Chapter 1: Soil Fertility for additional information.

Chapter 3: Nutrient Management • Soil Sampling and Testing

Adapted from Robert L. Schlub's Eggplant, Pepper, and Tomato Guide for Guam, 2001

Soil testing provides information on the various soil characteristics that determines soil fertility. The routine soil test at the University of Guam includes analysis of the soil pH, available phosphorus, organic matter, and exchangeable K, Ca, and Mg. Special tests include total nitrogen and phosphorus, nitrate, ammonium nitrogen, aluminum, zinc, iron, manganese, copper, sodium, and boron. Electrical conductivity for soluble salts and particle-size analysis is also available. A particle-size analysis will determine the texture class of the soil at the site. Knowing soil texture (such as clay, silty clay, or sandy clay loam) is important as it will influence fertilizer, irrigation, and variety recommendations.

The laboratory's current soil analysis intepretations for P, K, Ca, Mg, and organic matter are in Table 2-9.

Table 2-9. Relative soil test levels given in ppm of elemental soil nutrients as determined by the Guam Western Pacific Tropical Research Center Soil and Plant Testing Laboratory.

P x 2.29 = P_2O_5	Low	Medium	Ideal	High	Very High
P Phosphorus	10	25	50	100	150+
K Potassium	35	70	140	200	250+
Ca Calcium	500	1,000	1,500	2,000	2,500+
Mg Magnesium	50	100	150	200	250+
S.O.M. Soil Organic Matter	3	5	8	10	12+

Conversions	
P x 2.29 = P_2O_5	ppm = lbs/acre x 0.5
K x 1.20 = K_20	lbs/acre x 1.12 = kg/ha
lbs/acre (6 inch depth) = ppm x 2	lbs/acre = kg/ha x 0.891

Analytical Methods
Organic matter determined by the Walkley-Black method; phosphorus extracted with 0.5 M sodium bicarbonate (Olsen method); potassium, calcium, and magnesium by 1 N ammonium acetate.

The probability of response to applied fertilizer can conceptually be determined from relative soil test levels. As shown in Table 2-10, the higher the soil test level, the lower the probability of response to applied fertilizer. Conversely, a low soil test level would have a high probability of response to applied fertilizer.

Table 2-10. Probability of response to applied fertilizer for a given relative soil test.

Relative soil test level	Probability of response to applied fertilizer
low	Greater than 90%
medium	60 to 90%
medium–high	30 to 60%
high	10 to 30%
very high	Less than 10%

Soil sampling: The area you sample should be uniform in texture, crop history, slope, and depth. If your site is not uniform, then split up the field and submit multiple samples. The following steps should be taken:

1. With a spade or trowel, make a hole in the soil to the depth at which you cultivate, 10 cm (4 inches) for shallow soil and 25 cm (10 inches) for deep soils.
2. Place the sample in a clean plastic bucket.
3. Repeat the above procedure 9 to 10 times at different areas in your field.
4. Mix thoroughly in the bucket.
5. Take out approximately one pint of soil from the bucket and place it in a clean plastic bag. Write your name and field identification on the outside of the bag with a permanent marker.
6. Record your field identification so you will be able to remember which area the sample came from.
7. Bring the sample to the WPTRC Soil and Plant Testing Laboratory or UOG Cooperative Extension.

Soil nutrient credits: Soil nutrient credits are the amounts of nutrients in a soil that can support plant growth. The soils of the Mariana Islands have all the essential elements (Table 2-5) to grow plants; however, their soil credits are not adequate to produce good garden vegetables. To determine the amount of supplemental fertilizer that is required to produce a crop, subtract the nutrient needs of the crop (Tables 3-13, 3-15, 3-17) from the soil credits. The best way to determine soil credits is through soil testing and evaluation of organic material inputs.

Soil Organic Matter (SOM): The total amount of N in 6 inches of soil is surprisingly large; it can be estimated by multiplying soil organic matter content by 1,000. Thus, a soil with 4% organic matter contains about 4,000 lbs total N per acre. However, very little of the total N is transformed annually into the mineral forms plants can use (mineralized), typically from 1% to 4% each year, depending on the soil and environmental conditions. The mineralization rate depends on microbial activity, which is favored by a pH above 6, warm temperatures, and adequate (but not excessive) moisture. On well managed soils used for vegetable production, a 2% mineralization rate is a reasonable estimate; therefore, a soil with a 2% conversion rate and a total-N of 4,000 lbs/acre would produce 80 lbs of available N/acre. A greater rate of N release can be expected from fresh plant residues and from plowed-down or killed grass and legume sods. For this reason, cropping history is an important consideration when calculating fertilizer requirements.

Soil test laboratory: University of Guam, Western Pacific Tropical Research Center (WPTRC) offers soil analyses for the Mariana Islands. The Soil and Plant Testing Laboratory is located in the agriculture building on the university campus in Mangilao, Guam 96923: Phone 1-671-735-2080.

Chapter 3: Nutrient Management • Soil Amendments

Modif from Peter Motavalli and Thomas Marler – College of Agriculture and Life Sciences – University of Guam - 1998 Fact sheet

There are several factors to consider when choosing your fertilizer material or other soil amendments, such as lime and manure.

Availability: One of the most important factors affecting fertilizer selection on Guam and other Pacific islands may be availability. Suppliers on Guam stock certain types of fertilizers depending on demand and other business reasons. The selection of fertilizers is also limited due to Guam's long distance from fertilizer manufacturers. On many Pacific islands, fertilizers are very difficult to obtain and organic nutrient sources, such as animal manures or plant residues, are more widely available.

If you are located on an island where fertilizer is available and you have a special fertilizer need, you may wish to talk to any one of the fertilizer dealers, garden centers, nurseries, hardware, or discount stores on island to see if they are willing to make a special order for you.

Organic amendments, such as animal manure, shredded paper, wood chips and sewage sludge, are among the wide assortment of organic materials that are periodically available on islands. On Guam, the U.S. Military, the U.S. Natural Resources Conservation Service, and the Government of Guam through several of its agencies, such as the Guam Department of Agriculture, the Guam Environmental Protection Agency and the local mayors' offices, often facilitate distribution of these materials.

Nutrient content: There is a wide array of fertilizers with various nutrient contents (Table 3-1). The nutrient content of a fertilizer material is called the fertilizer "analysis". All fertilizer packages have the fertilizer analysis written on them and by convention are expressed as % nitrogen (N), % P_2O_5 (phosphorus pentoxide) and % K_2O (potassium oxide). To convert % P_2O_5 to % phosphorus (P) multiply % P_2O_5 by 0.44. To convert % K_2O to % potassium (K) multiply % K_2O by 0.83.

Fertilizers are manufactured with various nutrient analyses. Complete fertilizers provide the three primary macronutrients-NPK. Incomplete fertilizers lack one or more of these. Examples of incomplete fertilizers include urea, superphosphate, and diammonium phosphate. Fertilizer blends are mixtures of several fertilizer nutrient sources which produce a desired analysis. For example, banana growers require fertilizers with a high proportion of potassium in them and, therefore, one fertilizer blend produced for these growers has an analysis of 10-5-22. Higher analysis fertilizers contain a higher concentration of nutrients and, therefore, are often more economical because of the high costs of shipping to Guam. Organic amendments are generally low analysis nutrient sources, but often contain a wide variety of macro- and micronutrients.

Nutrient availability and chemical reactivity: Fertilizer and soil amendment characteristics affect the rate at which plant nutrients become available. Chemically complex materials like organic amendments are less soluble than simple compounds such as fertilizer salts and are decomposed by biological activity. Common agricultural and coralline limestones are also not very soluble and may take a number of months to react with the soil. Another category of fertilizers are called controlled or slow-release fertilizers. These fertilizers release their nutrients over time because the fertilizer is usually coated with a material which slowly breaks down in the soil. Fertilizer solubility is also important when fertilizers are used in combination with an irrigation system. Fertilizer injection into irrigation systems requires highly soluble fertilizers. Many of the phosphorus fertilizer sources are not very soluble and often require application methods other than irrigation.

Table 3-1. Some common fertilizer sources and their nutrient analysis.

Nutrient Source	Nitrogen % N	Phosphorus* % P_2O_5	Potassium* % K_2O	Calcium % Ca^{2+}	Sulfur
Sources of one primary macronutrient					
Urea	45-46	0	0	0	0
Ammonium nitrate	33-34	0	0	0	0
Ammonium sulfate	21	0	0	0	21
Single superphosphate	0	16-22	0	20	11
Triple superphosphate	0	44-48	0	15	0
Potassium chloride (muriate of potash)	0	0	60-62	0	0
Potassium sulfate (sulfate of potash)	0	0	50	0	18
Sources of two or more primary macronutrients					
Diammonium phosphate	16-21	46-53	0	0	0
Monammonium phosphate	11	48-55	0	0	0
Triple 16	16-21	15-16	15-16	0	0
10-20-20	10	20	20	0	0

Particle size and form: Smaller particles are usually more rapidly soluble and, therefore, more available for plant absorption. However, granular forms may be easier to apply than powdered forms because of the effects of wind and the method of application. The different particle sizes of several fertilizer sources in fertilizer blends can result in a problem of particle segregation in the fertilizer bag and reduce the uniformity of a fertilizer application. Some fertilizer manufacturers avoid this problem by pelletizing their fertilizers. A "pelletized fertilizer" is a product that is uniform in size and usually globular in shape, and contains one or more nutrients.

Acid, neutral or base forming: The application of ammonium-based fertilizers, such as ammonium sulfate, can increase soil acidity. Other fertilizers, such as potassium sulfate, tend to have no effect on soil pH. Yet others, such as potassium nitrate, can result in a decrease in soil acidity. The differences in the effects of these fertilizers on soil pH are due to the different chemical reactions these fertilizers undergo when applied to soil. Several soil amendments are used primarily to adjust soil pH including those that increase pH (agricultural limestone, slaked lime, marl, and calcium oxide) and those that decrease soil pH (elemental sulfur, aluminum sulfate, iron sulfate, and sulfuric acid).

Salt index: Inorganic fertilizers are forms of salts and therefore contribute to the total soluble salt content of the soil. Salt index (SI) of a fertilizer is a measure of the salt concentration that a fertilizer induces in the soil solution. It also shows which fertilizers (those with a higher SI) will be most likely to cause injury to germinating seeds or seedlings if placed close to or in the row. Nitrogen and potassium fertilizer salts generally have much higher salt indexes compared to phosphorus fertilizers. Although the total SI for a high-analysis NPK mixture may be greater than that for a low-analysis NPK mixture, the SI per unit of plant nutrients may be lower in the high-analyses product. Therefore, the lower fertilizer rate needed to supply the same amount of plant nutrients subjects the germinating seeds to less potentially adverse salt effects. Salts are readily dissolved out of course textured soils whereas salts are more tightly held by clay soils. This means that the same amount of salt will have a greater impact on sandy soils then it will on clay soils. Fertilizer salt damage is less likely to occur in wet seeding conditions and in slow soil-drying conditions.

Fertilizers best suited for seed and transplant application have:

1. low salt index
2. high water solubility
3. contain N, P, K and S, with relatively high P content
4. contain both urea and ammonium-nitrogen
5. minimize content of compounds that liberate NH_3
6. use potassium phosphate instead of KCl as the K source.

Plant species vary in how well they tolerate salt-affected soils. Some plants will tolerate high levels of salinity while others can tolerate little or no salinity. As a general rule, plants that have a low drought tolerance will have low salinity tolerance. With the exception of plants in the onion and pea families, which are highly sensitive to salt, most of the crops grown in the Mariana Islands are moderately sensitive.

Fertilizer salt damage is difficult to distinguish from moisture stress in seedling plants. The general effect of salinity is to reduce the growth rate resulting in smaller leaves, shorter stature, and sometimes fewer leaves. Roots are also reduced in length and mass but may become thinner or thicker. Maturity rate may be delayed or advanced depending on species. Salt damage can be reduced by not allowing fertilizer salt to come in direct contact with plant tissue. This can be achieved by banding the fertilizer two inches to the right and two inches below seeds or transplant.

Solid, liquid and suspensions are easier to handle since they can be applied with irrigation or spray equipment. If liquid fertilizer is combined with pesticide application, consideration must be given to the compatibility of the mixed chemicals. The choice of liquid fertilizers is limited compared to solid fertilizers because only certain fertilizers are sufficiently soluble to remain in solution.

Slow release fertilizers are designed to allow the fertilizer nutrients to slowly dissolve in the soil solution. Many forms of slow release fertilizers exist including those that are coated with sulfur (sulfur-coated urea or SCU) or resin (Osmocote, Nutricote) and those that are combined with another chemical (isobutylidene diurea or IBDU; Ureaform or Polyform).

Natural organic nutrient amendments, such as animal manures, are also a type of slow release nutrient source since a proportion of the organic nutrients in the organic source is slowly mineralized to a plant-available form.

The advantages of slow release fertilizers are that nutrients are available longer over the growing season, fertilizer can be applied less frequently, the risk of fertilizer salt injury is decreased, and the potential loss of fertilizer nutrients due to leaching is decreased. These factors increase fertilizer efficiency and decrease potential for groundwater pollution.

The principal disadvantage of slow release fertilizers is their high cost compared to regular fertilizers. In addition, under certain conditions, plants may require immediately high levels of available nutrients, which would not be satisfied by slow release fertilizers. Initial research indicates that slow release fertilizers may breakdown faster under the tropical environmental conditions of Pacific islands, lessening the effective time that slow release fertilizers may release nutrients.

M. Hamilton, F. J. Cruz, and J. McConnell (1994) found that total nitrate release was extended 5 five weeks (12 to 17 weeks) in Akina silty clay by using control-release fertilizer (CR) as compared to water-soluble fertilizer (WS). Whereas in Yigo silty clay and Guam cobbly clay soils, it was only extended a week. Authors believe that the potential benefits of the more expensive CR (lower labor costs from fewer applications) over WS may be lost on these porous, high pH soils. Of the CR tested, iso-butylidene-diurea (IBDU) performed the best as a controlled release fertilizer.

Organic chelates versus salts to provide micronutrients: Changes in the chemical forms of added micronutrient fertilizers in soil can reduce the amount of micronutrients available for plant absorption. For example, if the inorganic iron salt, ferric sulfate, is added to the calcareous soils of Northern Guam, much of the iron changes into an unavailable form.

One method to avoid soil transformation of micronutrient fertilizers is by directly spraying plant leaves. Another method is to use micronutrient fertilizers which contain chelating agents. The chelating agent is an organic compound to which the micronutrient binds making it more soluble. Chelated micronutrients are more effective than inorganic salts when applied to soil. However, chelating agents are usually more expensive than inorganic salts.

Among the major chelating agents that are used in agriculture are ethylenendiaminetetraacetic acid (EDTA), diethylenetriaminepentaacetic acid (DTPA), cyclohexanediaminetetraacetic acid (CDTA) and ethylenediaminedi (o-hydroxyphenylacetic acid) (EDDHA). The type of chelating agent recommended depends mainly on the method of application, the crop, and the pH value of the soil or other growth media. In soil application Fe-EDDHA and Fe-EDDHMA are the preferable chelating agents for ensuring iron availability in alkaline soils such as those of the Mariana Islands. Iron chelates of Fe-HEDTA, Fe-DTPA and Fe-EDTA are effective in the regions' acidic soils.

For all other metals, i.e. Ca, Cu, Mg, Mn and Zn, applications to soil as well as foliage are mainly EDTA. In hard water areas, however Fe-DTPA is recommended as a foliar spray. Water described as “hard” is high in dissolved minerals, in the Mariana islands' this is due to calcium. All water from ground sources contained in aquifers beneath limestone are hard were as surface and spring water are not. Surface sources used by Guam Water Authority include the Ugum River and FENA reservoir in southern Guam.

Inorganic fertilizer safety: As is the case with many industrial products, fertilizers, their raw materials and intermediates, need to be handled with care. Avoid storing fertilizers with drinking water, food, fuel, herbicides, seed, animal feeds or protective equipment to prevent contamination Basic safety gear is recommended: long pants and shirt, gloves and dust masks. Some fertilizer products may require special attention due to their toxicity or chemical reactivity; therefore, always read and follow product labels to reduce human and environmental safety concerns.

Granular fertilizers are hygroscopic; that is, they readily absorb moisture at fairly low humidity and temperature. On the other hand, superphosphate or potassium sulfate take up water only at a very high relative humidity. Bags with nitrogen containing granules should not be placed in the sun or stored where temperatures could exceed 40° C. Facilities should be dry and free from water seepage. Exposure to air may be reduced by covering bags with plastic, opening bags only when needed, and resealing bags after use with tape. Aluminum and wood structures are acceptable for storing fertilizers. Since most fertilizers are corrosive, they should not come in contact with unprotected iron, copper, lead, or zinc materials. Protect wood against impregnation by using treated lumber or paint. Bins and storage areas should be kept clean and free of contaminants such as organic chemicals, flammable liquids, corrosive acids, chlorates, and finely divided metals or sulfur, in order to prevent fires. Bagged fertilizer should be placed on pallets. Storage facilities should be self-ventilating. Ensure that you have adequate secondary containment to hold any spills or leaks. This is particularly true for liquid fertilizers and suspensions. Fertilizer suspensions are concentrated liquid fertilizer in which fertilizer crystals are precipitated and kept from settling by a suspension agent. With this form of fertilizer, extra care must be exercised to keep the suspension agitated during application to insure uniformity.

Organic fertilizer safety: There are potentially serious food safety risks to using animal or human manure (night soil) as a fertilizer on your vegetable garden. Some bacteria that are associated with foodborne illnesses can be found in fresh manure because these bacteria are a natural part of animal intestinal tracts. Vegetables can be contaminated if they are grown in soil where manure has been applied.

Selection of the right organic materials and proper handling will reduce food contamination.

- Night soil should not be used under any circumstances without first checking with the local EPA office (Environmental Protection Agency).
- Use sterilized or properly composted manure, available from gardening stores.

- Move your vegetable garden to a location that is not affected by surface runoff from manure storage or from crop land spread with manure.
- If non-composted or fresh manure is applied, make sure there are 120 days between fertilizing and harvesting.

Organic versus inorganic: Fertilizers and other nutrient amendments can contain plant nutrients in either an inorganic or organic form. Most plants only absorb inorganic forms of plant nutrients, and, therefore, organic nutrients must be converted to inorganic forms to become available to a plant. The process by which organic nutrients are converted to inorganic nutrients is called mineralization. This process can take months to complete. On a weight basis, organic matter has a low percent nutrient value (Table 3-2).

Table 3-2. Some common organic nutrient sources and their approximate nutrient analysis (dry weight basis)*.

	Nitrogen % N	Phosphorus** % P_2O_5	Potassium*** % K_2O
Manures			
Cattle	2.20	1.60	2.50
Swine	2.10	2.20	1.40
Poultry	4.40	4.80	3.10
Horses	1.70	0.70	1.80
Other			
Sewage sludge	5.60	5.10	0.40
Seaweed	0.60	0.10	1.30
Fish meal	4.00	23.20	0.00
Wood ash	0.00	1.80	5.50
Bone meal	3.90	22.00	0.00
Grass clippings	4.00	1.10	2.40
Sawdust	0.20	0.00	0.20
Yard compost	1.30	0.40	0.40
Fish scrap	9.50	6.00	0.00
Shrimp waste	2.90	10.00	0.00
Sweetpotatoes	0.20	0.10	0.50
Tomato fruit	0.20	0.10	0.40
Tangantangan (Leucaena)			
Leaves	3.90	0.30	1.80
Stems	1.70	0.20	1.90

*** Actual nutrient analysis may vary.**
**** % P = %P_2O_5 x 0.44**
***** % K = % K_2O x 0.83.**

The soil contains many microorganisms which decompose and mineralize organic nutrients. The rate at which this process occurs will be affected by such factors as climate, soil texture and the amount and composition of the organic material. In general, a wet and hot climate and sandy soils will have higher decomposition rates than other climates and soil types.

Woody materials high in lignin will decompose more slowly than green materials high in organic nitrogen. Inorganic salts, such as ammonium nitrate, release inorganic nitrogen which is immediately available to the growing plant. Organic sources of nitrogen, such as manure, are often converted to inorganic nitrogen slowly over the growing season. A notable exception to this rule is urea which is a manufactured organic form of nitrogen. Urea is rapidly converted to ammonium when added to soil. Inorganic nitrogen in the form of nitrate can be leached down and out of the plant's root zone and be lost for plant uptake and possibly contaminate groundwater. Both organic and inorganic nutrients can contaminate surface waters, such as streams, when the process of soil erosion deposits nutrient-rich soil into the water.

Management of soil organic matter is the key to farming on the low fertility soils common throughout the Mariana Islands. Organic matter improves soil aggregation and structure, which improves aeration and permeability and reduces erosion. It improves water holding capacity and exchange capacity. It complexes with aluminum and reduces Al- toxicity in low pH soils. Organic matter "buffers" soil, making it less prone to swings in pH. This is especially important when farming on the region's oxisols. Organic matter acts as a slow release fertilizer; thereby reducing the likelihood of nutrients being lost due to leaching. Organic mater also promotes a healthy soil environment for beneficial organisms, which reduces the impact of soil pathogens and the diseases they cause.

Chapter 3: Nutrient Management • Composted Organic Waste as an Alternative to Synthetic Fertilizer

Adapted from research conducted by Mohammad H. Golabi

One of the major problems of agricultural soils in the tropical region of the western Pacific islands is their low organic-matter content, which results from rapid decomposition in this hot and humid environment. Low organic soils not only produce low yield as the result of low fertility status but they also become susceptible to water erosion and further degradation.

Composted organic material is applied on agricultural fields as an amendment to provide nutrients and also to increase the organic-matter content and hence to improve the physical and chemical properties of these soils. Composting is most commonly an **aerobic** process, that is, the biological breakdown of the materials takes place in the presence of oxygen (air). The main byproducts of the breakdown are carbon dioxide, water and heat. Composting can also be an **anaerobic** process, where breakdown occurs in the absence of oxygen. In this case, the main byproducts are methane, carbon dioxide, and various low organic acids and alcohols.

Dr. Mohammad Golabi conducted a number of experiments on Guam demonstrating the benefits of aerobic composting as a means to increase soil organic matter. In one such experiment, three successive crops of maize (H1054, hybrid from the University of Hawaii; Brewbaker 2001) were grown on experimental plots in the University of Guam's Agricultural Experiment Station at the Inarajan village in southern Guam (Akina series).

Method: The compost consisted of wood chips from typhoon debris, tree trimmings from the roadsides near the farm; and chicken, hog, and horse manure from local farmers and ranchers. Other organic wastes were added as they became available. Compost was formed using a passive system where air was supplied through perforated pipes embedded in the compost pile; however, the compost was occasionally mixed by using a backhoe. The composted organic material was applied at four rates before each of the three cropping trials. The compost (50% moisture content) was incorporated into the soil about 10 cm (4 inches) one week before planting so that the C/N ratio would have time to stabilize. The crop was harvested at maturity, the ears were oven dried at 65°C for 72 hours, and yield was measured as dry weight of the ears.

Results: The results of this study are presented in Table 3-3 below. Yield increased dramatically (550 to 890 percent) with the application of compost. All measured soil characteristics improved with the addition of compost: bulk density, soil moisture, OM, CEC, and nutrient levels. The greatest increase (136 to 233 percent) occurred in OM.

Conclusion: Amending volcanic field soil of the Mariana Islands with composted organic material can be expected to dramatically increase the yield of annual high nutrient demand vegetables, while making substantial improvements to soil fertility. The levels of compost required to bring about these benefits was considerable and not achievable without considerable effort and expense. The time it takes from initial ingredient mixing through curing to the point of a stable product ranges from 60 to 120 days. A crop that is not as nitrogen-demanding as corn would be expected to yield well with less compost and over more cropping seasons than corn.

Table 3-3. The effects of compost amendment on sweet corn yields and soil characteristics averaged over three consecutive plantings.

Parameter	Units	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Compost	metric tons / hectare	0	74	148	271
	short ton / acre	0	33	66	121
	lbs dry wt. / acre	0	66,012	132,025	241,748
	lbs actual wt. / acre	0	132,024	264,050	483,496
	lbs actual wt. / 100 ft row	0	924	1,848	3,384
Yield	metric tons / hectare	0.72	3.98	7.2	8.91
	lbs dry / acre	642	3,550	6,423	7,948
	lbs / 100 ft row	4.5	24.9	45	55.6
Bulk density	g/cm^3	1.2	1.0	0.99	0.94
Moisture content	%	33	34	38	40
Organic Matter (OM)	%	3.86	5.24	6.47	8.98
Cation Exchange Capacity (CEC)	meq/100 g soil	2.2	2.6	3.3	4.1
Nitrate (NO_3)	ppm	18.60	36.00	46.00	109.00
Phosphate (PO_4)	ppm	22.00	44.00	54.00	67.00
Potassium (K)	ppm	271.00	697.00	1,022.00	1,478.00
Calcium (Ca)	ppm	3,430.00	3,985.00	4,618.00	5,213.00
Magnesium (Mg)	ppm	176.00	337.00	514.00	815.00

Chapter 3: Nutrient Management • Fertilizer Application

Modification of Peter Motavalli and Thomas Marler - College of Agriculture and Life Sciences - University of Guam - 1988 Fact Sheet

There are many existing methods for applying fertilizers. Among these methods are:

Broadcast: Fertilizer is uniformly spread or sprayed over the entire soil surface, often followed by incorporation using a tillage implement.

Localized placement consists of placing the fertilizer in a band or localized point close to the plant. Localized placement includes starter, deep, surface, top-dressing and side-dressing fertilizer placements. This method is used for several reasons including providing fertilizer nutrients to seedlings with immature root systems, overcoming soil processes which reduce nutrient availability such as precipitation of phosphorus and convenience due to the difficulty of application.

Foliar sprays: Fertilizer is sprayed directly on the leaves of the plant. It should be considered as a last resort and temporary solution for correcting a nutrient deficiency (Table 3-4). Fertigation and soil amendment are preferred ways of correcting nutrient deficiencies. The plant leaf is structured in such a way that it naturally resists easy infiltration by fertilizer salts; therefore, without constant foliar applications, the required amount of nutrients that a plant must absorb for optimal growth is not likely to occur. Some benefit from macronutrient foliar sprays probably results when the nutrients are washed by rain or irrigation water off the leaf surface into the soil.

Table 3-4. Recommendations for foliar applications of plant nutrients.

Foliar spray	Elements absorbed	lbs/acre	Dry oz. /1,000 sq ft
Borax	B	2.0 to 5.0	0.74 to 1.84
Solubor	B, Na	1.0 to 1.5	0.37 to 0.55
Copper sulfate	Cu,S	2.0 to 5.0	0.74 to 1.84
Ferrous sulfate	Fe	2.0 to 3.0	0.74 to 1.10
Chelated iron	Fe, S	0.75 to 1.0	0.28 to 0.37
Manganous sulfate	Mn, S	2.0 to 4.0	0.74 to 1.47
Sodium molybdate	Na, Mo	0.25 to 0.50	0.09 to 0.18
Zinc sulfate	Zn, S	2.0 to 4.0	0.74 to 1.47
Chelated zinc	Zn	0.75 to 1.0	0.28 to 0.37
Calcium chloride	Ca, Cl	5.0 to 10.0	1.84 to 3.67
Calcium nitrate	Ca, N	5.0 to 10.0	1.84 to 3.67
Magnesium sulfate	Mg, S	10.0 to 15.0	3.67 to 5.51

From E.H. Simonne and G.J. Hochmuth. Soil and Fertilizer Management for Vegetable Production in Florida; http://www.hos.ufl.edu/vegetarian/10/Jan/VPH%202010-2011/Chap %202.pdf

* Mention of a trade name does not imply a recommendation over similar materials.

Fertigation is mixing fertilizer with irrigation water. Drip irrigation has become a very important water management tool for the Mariana Islands. Many drip irrigation users have turned to fertigation to gain better fertilizer management capability. In most situations, N and K are the nutrients injected through the fertigation line. Split applications of N and K through irrigation systems offer a means to capture management potential and reduce leaching losses. Demand early in the season is small and thus application rates are small; usually on the order of $^1/_2$ to $^3/_4$ lbs of N or K_2O per acre per day. Other nutrients, such as P and micronutrients, are usually applied to the soil rather than by injection. This is because chemical precipitation (which may block emitter holes) can occur when these nutrients are combined with northern Guam's high calcium carbonate ground water. For further information on fertigation, refer to Schlub and Yudin's 2002 Eggpant, Pepper, and Tomato Production Guide for Guam.

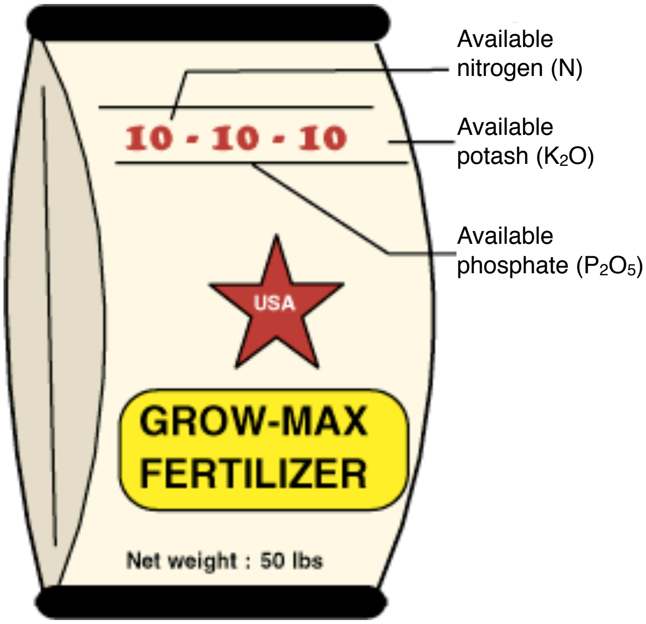
Injection: Fertilizer or manure is placed into the soil using a tanker and an implement which cuts through the soil and injects the fertilizer behind the cutting edge of the implement. The most common fertilizer applied in this manner is anhydrous ammonia, which is not currently available on Guam or other Pacific Islands. Manure can also be applied using this method.

Precision application of fertilizer uses advances in mapping technology to apply fertilizer in varying amounts to a field based on previous soil sampling. This method requires sophisticated computer software to allow the fertilizer spreader to recognize its geographic position in relation to the soil test results and then adjust the amount of fertilizer applied. Use of this method requires a significant investment in equipment and is currently not used in the region.

Excessive application of micronutrients, in addition to toxicities, can lead to micronutrient deficiencies. Deficiencies in this case are due to antagonisms between micronutrients during plant uptake. When two nutrients are antagonistic, a super-optimal concentration of one in the substrate (soil) will suppress plant uptake of the other (Table 3-5). Thus, it is possible to encounter deficiencies of iron, manganese, copper or zinc as a result of excess application of other micronutrients. These deficiencies can occur even when a normally sufficient concentration of the deficient micronutrient exists in the substrate.

Table 3-5. Common micronutrient antagonisms.

High soil level of:	Results in low plant level of:
iron	manganese, zinc
manganese	iron, zinc
copper	zinc
zinc	copper



Fertilizer applications rates are dependent on a fertilizer's grade or analysis. All fertilizer labels have three bold numbers. The first number is the percent nitrogen (N), the second number is the percent phosphorus pentoxide (P_2O_5) and the third number is the percent potash (K_2O).

To determine how many pounds of an active ingredient is in a bag of fertilizer, it is necessary to multiply the weight of the bag by its chemical analysis.

Pounds of active ingredient per bag of fertilizer = (Weight of bag in pounds) (percent active ingredient)

For example a 50 lbs bag of 10-30-20 contains:

5 pound of active N = (50 lbs)(0.10)
15 pounds of active P_2O_5 = (50 lbs)(0.30)
10 pound of active K_2O = (50 lbs)(0.20)

To calculate how many pounds of fertilizer is necessary to produce a desired number of pounds of active material, it is necessary to divide the desired pounds of active material by the chemical analysis of the nutrient.

Pounds of fertilizer required = (desired pounds active ingredient) / (chemical analysis of the ingredient)

For example to provide 150 lbs. of active N using 10-30-20 fertilizer will require:

1,500 lbs. of 10-20-30 fertilizer = 150 / 0.10

Most fertilizer recommendations are given in units such as pounds per acre or Kg / ha. In ether case such units are not practical for the size of farms in the Mariana Islands. A unit that is more practical is the 100 ft row. Converting lbs / acre to lbs /100 ft row is as easy as multiplying lbs per acre by a conversion factor. Conversion factors for standard row spacing can be found in Table 3-6. For example, if a grower had 48 inch or 4.00 ft row spacing, the conversion factor would be .009. The conversion factor for someone with 38 inches between rows would be .007. Therefore, 150 N per acre is equivalent to 1.05 lbs N per 100 ft of row when rows are spaced 38 inches apart:

1.05 = 150 x .007

Table 3-6. Conversion factor for converting pounds per acre to pounds per 100-foot row with various row spacing.

Distance between rows in inches	Distance between rows In feet	Conversion factor*
30	2.50	0.006
36	3.00	0.007
38	3.16	0.007
40	3.33	0.008
42	3.50	0.008
45	3.75	0.009
48	4.00	0.009
52	4.33	0.010
60	5.00	0.011
70	5.83	0.013
72	6.00	0.014
80	6.67	0.015
84	7.00	0.016
96	8.00	0.018
108	9.00	0.021
120	10.00	0.023
144	12.00	0.028

*** Conversion Factor = Distance between rows in feet x 100 feet Divided by 43,560 sq. ft./acre**

http://www.agr.state.nc.us/cyber/kidswrld/plant/label.htm

Chapter 3: Nutrient Management • Field Detection of Plant Nutrient Deficiencies and Toxicities

Developing proper soil management practices is perhaps the most difficult task facing farmers, because management strategies need to be modified constantly as the crop develops. The occurrence of visual symptoms can be useful in determining the nutrient needs of crops, especially when they are specific for or sensitive to a particular nutrient. Symptoms plus plant and soil analyses together with a general knowledge of crop needs and the chemistry of the soil should all be used in determining crop nutrient needs.

The mobility of an element within a plant usually determines where deficiency symptoms first develop. Nutrients such as N, P, K, and Mg are considered mobile elements and are readily translocated from old leaves to new growth. Hence, symptoms of these deficiencies occur initially in the older leaves. Elements Cu, Zn, S, Mn, Mo, Fe, and Cl have variable mobility and may retranslocate from old leaves to new growth only under some conditions. Nutrients such as Ca, B, and Ni do not appear to be retranslocated from old leaves to new growth under any circumstances; hence, deficiency symptoms occur generally in young growing areas of the plant.

Table 3-7. Nutrient deficiency symptoms.

Nutrient	Deficiency symptoms	Occurrence
Nitrogen (N)	Lower leaves affected first. Stems thin, erect, and hard. Leaves small, yellow; on some crops (tomatoes) undersides are reddish.	In shallow and low clay soils especially after heavy rain or after overirrigation.
Phosphorus (P)	Older leaves affected first. Stems thin and shortened. Leaves develop purple color. Plants stunted and maturity delayed.	In acidic soils or very basic soils. In soils with low extractable P.
Potassium (K)	Older leaves develop gray or tan areas on leaf margins. Eventually a scorch appears on the entire margin.	In shallow and low clay soils following leaching rains or overirrigation. In soils with low extractable K.
Magnesium (Mg)	Initially older leaves show yellowing between veins, followed by yellowing of young leaves. Old leaves soon fall.	In strongly acidic soils or in shallow or low clay leached soils.
Chlorine (Cl)	The most common symptoms of chlorine deficiency are chlorosis and wilting of the young leaves.	Chlorine is very abundant in soils. Plants are generally tolerant of chloride. Some species such as avocados, citrus, bean, cucumber, melon, lettuce, chili, and onion are sensitive to chlorine and can show toxicity at low concentrations.
Zinc (Zn)	Small reddish spots on cotyledon leaves of beans; light areas (white bud) of corn leaves.	Where excessive P is present.
Boron (B)	Growing tips die and leaves are distorted.	In calcareous soils with pH above 6.8 or in shallow or low clay leached soils or low OM soils or on plants with very high demand for B such as cole crops, peanut, and some palms.
Calcium (Ca)	Growing-point growth restricted on shoots and roots. Specific deficiencies include blossom-end rot of tomato, pepper, watermelon, and cabbage tip burn.	In strongly acidic soils, during severe droughts, or following the application of ammonium fertilizers. Associated with poorly developed roots or damaged root tips.
Copper (Cu)	Yellowing of young leaves, stunting of plants. Onion bulbs are soft with thin, pale scales.	In organic soils or occasionally in new mineral soils.
Iron (Fe)	Distinct yellow or white areas between veins on youngest leaves.	In soils with pH above 6.8.
Manganese (Mn)	Yellow mottled areas between veins on youngest leaves, not as intense as iron deficiency.	In soils with pH below 5.4 or in shallow or low clay leached soils.
Molybdenum (Mo)	Pale, distorted, narrow leaves with some interveinal yellowing of older leaves, e.g. Whiptail disease of cauliflower. Rare.	In very acidic soils.
Sulfur (S)	General yellowing of younger leaves and reduced growth.	In very shallow soils, low in organic matter, especially following continued use of sulfur-free fertilizers and especially in areas that receive little atmospheric sulfur.

* University of Florida Vegetable Production Guide. SP# 170. Don Maynard and George Hochmuth.

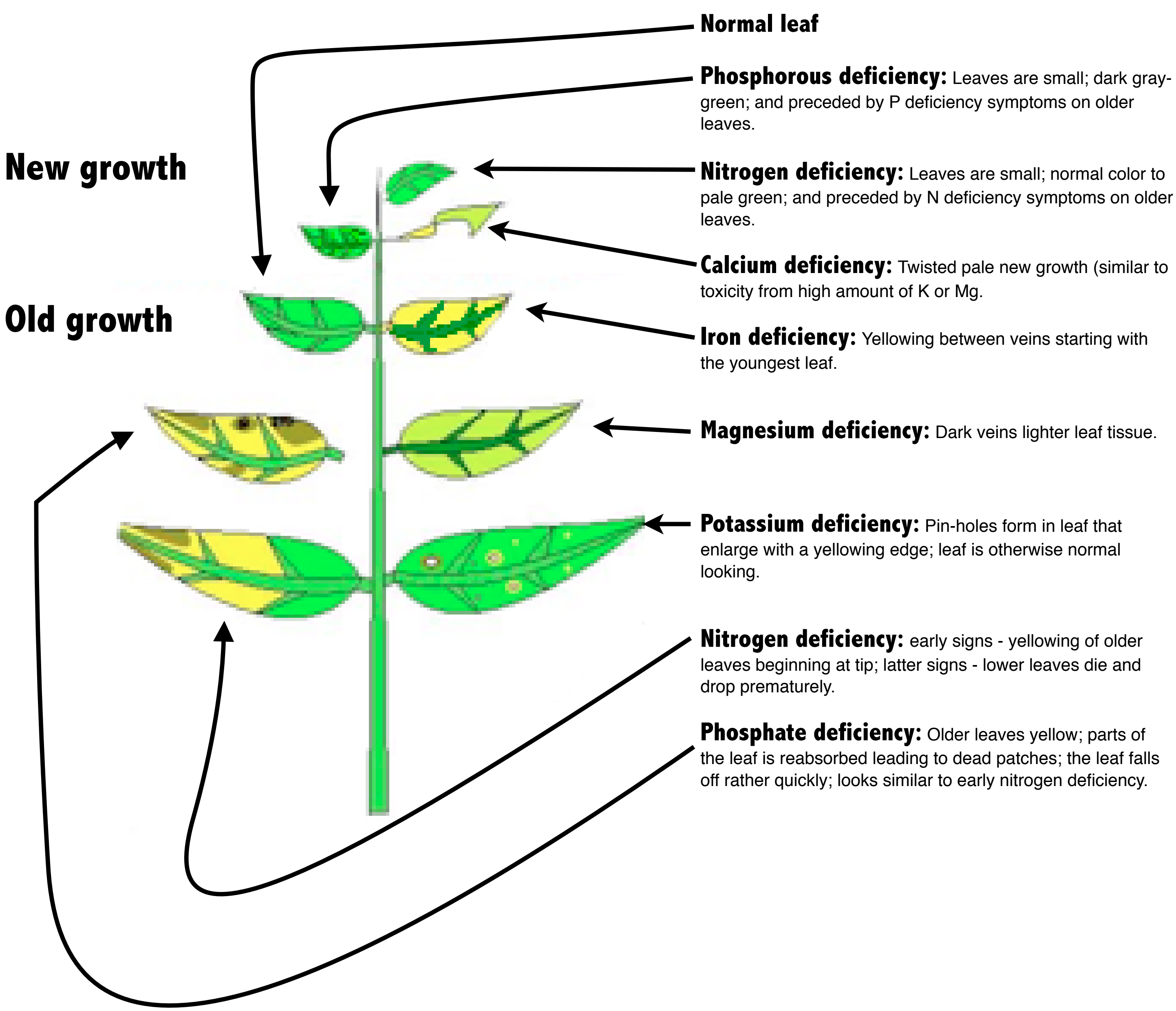


Figure adapted from: http://www.plantedtank.net/forums/fertilizers-water-parameters/98529-plant-deficiency-diagram.html

Though the occurrence of visual symptoms is a good indicator of a nutrient deficiency, its corollary may not be due to a phenomena known as hidden hunger. Even when no distinctive deficiency symptoms are present, crop yield losses may still occur. From field observations and yield values taken on crops of eggplant, tomato, hot pepper, and cucumbers at the Yigo UOG Agriculture Research Station in 2008 and 2009 it was concluded that hidden hunger for N, P, and K was least in cucumber, followed by eggplant, tomato, and hot pepper. Even at a 50% yield reduction, hot pepper, other than a reduction in size of the plant, did not produce visual distinct symptoms for N, P, or K deficiencies. However with respect to iron, hot pepper produced dramatic deficiency symptoms whereas the other three crops did not. In general those plants that have large yield responses to small changes in nutrients would be expected to have visual symptoms to that nutrient rather than harboring hidden hunger.

Visual diagnosis of field grown crops: Visual symptoms are only reliable for diagnosing plant nutrient deficiencies or toxicities under test conditions or when a particular crop is highly sensitive (Table 3-7). Under field conditions, many symptoms can be caused by any one of several nutrients or other conditions. Yellowing and interveinal chlorosis of young leaves could be due to S deficiency or it could indicate a deficiency of one of the metal micronutrients, such as Fe, Zn, Mg, or Cu. Certain herbicides, diseases, insects, and unfavorable environment can cause similar symptoms (Table 3-8, 3-9). Symptoms may also be masked by symptoms of other nutritional disorders, by nutrient interactions (Table 3-5), by unfavorable environments or by stress caused by plant pests.

Table 3-8. Common symptoms in cucurbit plants associated with soil nutrient imbalances and other causes, starting with the likeliest.

Cucurbit part	Likely causes (see key)
Seedling	
Yellowish coloration	C9, C3, C7
Wilted	C6, C9, D3, D5, C11
Poor germination	C13, C9, C6, D3, A1, C11
Stems or vines	
Stunted	D8, C4, C6, D9, C2, C3
Weak or shriveled	D5, C6, D8, A4, C5, C8, C3
Fruits and flowers	
Aborting of flowers and fruits	C5, C8, C12, C9, A7, D1
Few fruits	C10, C8, D9, D8, C12, D2, D4, C3, C4, C5
Flower end of fruit rotten	D1, C12, C8, D4
Misshapen fruits or sunken areas	C10, D9, A4, A3, C5
Bitter fruit	D9, C5
Roots	
Poor development	C5, C9, D3, C6, A6, C8
Leaves	
Curled leaf surface	A5, A2, D9, A7, C5, C11
Yellowing of older leaves	C3, D7, C7, C4, C5, C2
Slow growth with purplish veins	C4, C3, C5, D8
Young leaves yellowish, green veins	C1, C2
Wilted	D5, D6, C6, C9, D8, A6

Cucurbit part	Likely causes (see key)
Leaves	
Curled leaf surface	A5, A2, D9, A7, C5
Yellowing of older leaves	C3, D7, C7
Slow growth with purplish veins	C4
Young leaves yellowish, green veins	C1, C2
Wilted	D5, D6, C6, C9, D8, A6

Causal agent key

Animal pests	
A1	Ants
A2	Melon aphids
A3	Leaf-footed bug
A4	Melon fly
A5	Mites
A6	Pumpkin beetle
A7	Melon thrips
Unfavorable factors	
C1	Deficiency: Fe–Iron
C2	Deficiency: Mg–Magnesium
C3	Deficiency: N–Nitrogen
C4	Deficiency: P–Phosphorus
C5	Deficiency: K–Potassium
C6	Deficiency: Water
C7	Deficiency: Light
C8	Excesses: N–Nitrogen
C9	Excesses: Water
C10	Poor pollination
C11	Fertilizer Burn
C12	Weather/Time of year
C13	Poor seed quality
Plant pathogens	
D1	Blossom-end rot
D2	Cercospora leaf spot
D3	Damping-off or root rot
D4	Fruit rots
D5	Fusarium wilt
D6	Gummy stem blight
D7	Powdery mildew
D8	Root knot
D9	Viruses

Table 3-9. Common symptoms in eggplant, pepper, and tomato associated with soil nutrient imbalances and other causes, starting with the likeliest.

Plant part	Likely causes (see key)
Seedling	
Yellowish coloration	D3, D9, D7
Rotted at the soil line	A4, D9, D10, A6
Poor emergence	A4, D16, D9, D6, C9, C2, D10
Wilt	D6, D9, A2, D10, D14
Plant/stem	
Stunted	D5, A7, D6, A10, C1, A1, C8, D4, D3
Weak or shriveled	D6, A2, D4, C8, D5, D3
Fruits and flowers	
Irregular areas of discoloration on fruit	C3, C4, D5, D13, D4
Cracks or surface blemishes	D15, D12, C7, C8, C6, D8
Flower end of fruit rotten	D11, A6
Fruits, small or few	D5, C8, C2, D15, C6, D4, D3, A10
Misshapen fruits	C7, C8, D5, D15, C6, D3, D4, A10
Off flavor	D6, D15, D4, A10
Dropping of flower and/or fruits	D6, D3, C8, D15
Roots	
Blackened and rotten	A4, D8, D10, A2
Shoots/leaves	
Leaf yellowing	D3, D2, D7, D5, D1, C5, A10, A7, A8
Young leaves yellowish, green veins	D1
Older leaves yellowish, green veins	D2
Slow growth	D4, D3, D5, A7, A10
Younger leaves small and dark or leaf tip burned	D8, D10, D4
Brown areas at leaf edge	D10, D5, C5, A7
Dropping of leaves	D4, A5, A3, A9, D5, D3, C6
Wilted	A2, D6, D14, D9

Causal agent key

Plant pathogens	
A1	Anthracnose
A2	Bacterial wilt
A3	Cercospera leaf spot
A4	Damping-off or root rot
A5	Early blight
A6	Phomopsis blight
A7	Root knot
A8	Southern blight
A9	Target leaf spot
A10	Viruses
Animal pests	
C1	Aphids
C2	Ants
C3	Fruit piercing moth
C4	Leaf-footed bug
C5	Leafhoppers or fleahoppers
C6	Mealybugs
C7	Mites
C8	Thrips
C9	Chicken/bird
Plant pathogens	
D1	Deficiency: Fe–Iron
D2	Deficiency: Mg–Magnesium
D3	Deficiency: N–Nitrogen
D4	Deficiency: P–Phosphorus
D5	Deficiency: K–Potassium
D6	Deficiency: Water
D7	Deficiency: Light
D8	Excesses: N–Nitrogen
D9	Excesses: Water
D10	Fertilizer burn
D11	Blossom-end rot
D12	Growth cracks
D13	Sunscald
D14	Wind
D15	Weather/time of year
D16	Poor seed quality

Field quick tests: Laboratory analyses are the most accurate way to determine nutrient levels in soil and plant tissue. Unfortunately such tests have a high per sample cost and a slow turnaround time. Results from laboratory to laboratory are not always comparable due to differences in techniques and analyses employed. These shortcomings can partially be remedied by the use of quick field tests. The usefulness of quick tests for plant nutrient management depends on the quality of research that support their application. For field tests to be useful, they need to be supported by research which takes into account soil, climate, crops, varieties, and cultural practices.

Due to the current lack of research in the Mariana Islands, Cardy and Chlorophyll meters are not being recommended as tools for determining fertilizer application levels. In experiments conducted by Mari Marutani (2003), it was found that the Cardy Ion meter readings were linearly related to actual nitrate-N in tissue and N soil levels; however, variation between crop readings proved the Cardy Ion meter values were not of use as an indicator of nitrogen deficiency in Chinese cabbage. From field observations and yield values taken on crops of eggplant, tomato, hot pepper, and cucumber at the Yigo UOG Agriculture Research Station in 2008 and 2009, researchers Robert Schlub and Zelalem Mersha concluded that Cardy and Chlorophyll meters are not useful in detecting hidden hunger for N, P, and K in eggplant, tomato, and hot pepper, and only somewhat useful in the case of cucumber. Compounding the poor fit between meter readings and N, P, and K is the fact that those plants that are sensitive to Fe deficiency can produce severe yellowing when Fe is unavailable in the soil.

Due to variability of readings from season to season, Cardy and Chlorophyll meters are most useful for determining nutrient deficiencies within a given field. These meters can be used to develop customized fertilizer recommendation for specific fields and crops. This can be accomplished through exposing various portions of a crop to various levels of fertilization and recording their meter readings. The plant readings can then be used as a standard to determine nutrient deficiencies or excess in the remainder of the field. Development of site-specific fertilizer recommendations should be the goal of all producers. It reduces the purchase and application of unnecessary fertilizer; thereby, reducing costs and the likelihood of environmental damage caused by nutrient leaching and runoff.

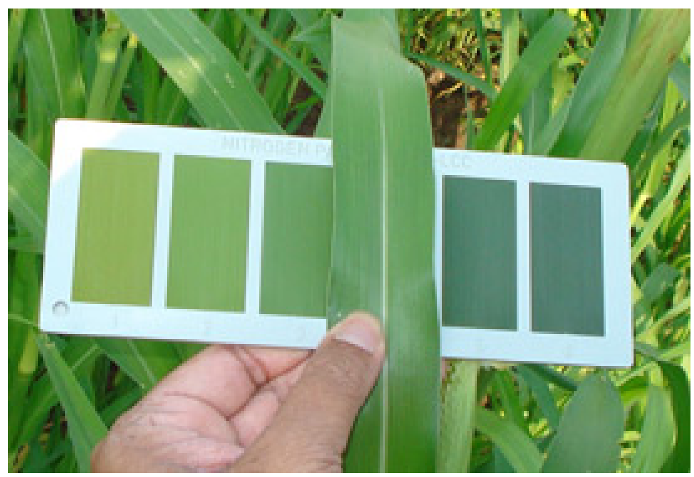
Changes in foliar color are a valuable indicator of plant nutrition and health. Leaf color can be measured with visual scales (leaf color charts) and with plant color guides; however such methods are not very rigorous. With the use of digital color analysis, a camera can be used in place of the human eye. Sophisticated instrumentation including chlorophyll meters, reflectometers, and spectrophotometers are also means by which foliar color can be analyzed.

All these methods have the inherent problem of not being able to identify the various causes for yellowing and the fact that leaves' color changes with age, time of day, and a host of environmental conditions. Nitrogen is not the only nutrient that can cause yellowing of plant leaves. Potassium, sulfur, zinc, magnesium and iron deficiencies can all present themselves with yellowing plants and leaves. Herbicide injuries or soil water imbalances can also cause yellowing of plant leaves.

The **Leaf Color Chart** or LCC is a handy plastic "ruler" with strips of four to six shades of green that are used to compare the color of leaves of selected crops under field conditions. It is a cheap, fast, and handy field instrument to measure leaf green color intensity, which is related to the plant's nitrogen content. Yellowish green represents a low nitrogen concentration and dark green an excessive one. Though first developed to evaluate rice for nitrogen levels, it has since been modified for use on other crops.

Advantages: It does not destroy the sample, it is low cost, portable, and very low maintenance.

Disadvantages: The card was developed and evaluated extensively only for rice production. It should not be read in direct sunlight. The same person should read all the samples. Samples should be read at roughly the same time each day. A major disadvantage is that leaf color is impacted by factors other than nitrogen availability.



Leaf Color Chart
Photo courtesy of Spectrum Technologies, Inc.
P.B. No. 8707, A32 III Floor Avaram Block Shanthi Niketan 1 City Link Road Adambakkam Chennai 600 088 India.
Telefax: (+9144) 22442305 Tel: 64614580 Mobile: +91 98842 22269
http://www.nitrogenparameters.com
business@nitrogenparameters.com

Digital color analysis: Research conducted by U.S. Department of Agriculture Forest Service and University of Vermont scientists detail how a digital camera or scanner in combination with a computer and Scion Image software can be used to photograph, scan, and evaluate leaves for color with relative ease and at an affordable cost. In the online publication, available through the USDA Forestry Service, step-by-step instructions are given on the use of Scion Image software to measure the percentage of green and red in leaves as an indicator of plant nutrition and health.

http://nrs.fs.fed.us/pubs/gtr/ne_gtr327.pdf

Advantages: It provides an accurate means of quantifying foliar color and estimating pigment concentration in multicolored leaves. It can be used for any host and is moderate in cost.

Disadvantages: Digital imagery is still a new tool in plant color analysis and is constantly changing. To use digital color analysis to estimate pigment (chlorophyll and anthocyanin) concentrations requires considerable research and the use of outside equipment and expertise.

Chlorophyll meters estimate the amount of chlorophyll contained in a leaf, which is the green pigment that captures the sunlight that is used in photosynthesis. Nitrogen is a key element in chlorophyll molecules. The meter estimates the amount of chlorophyll present by measuring the amount of light that is transmitted through a leaf. In essence, it determines "how green is this plant." There are at least two types of handheld chlorophyll meters available. One type (SPAD 502) uses thumb pressure to close a chamber and measure light transmittance/absorbance (T/A) to determine chlorophyll content. Another type (Field Scout CM 1000®) measures reflectance. Ambient and reflected light is used to calculate the relative chlorophyll index with this R chlorophyll meter.

In general, chlorophyll meters are not a sensitive indicator of plant N excess. Their greatest potential is when used as a complementary in-season tool for detecting plant N stress and to fine-tune supplemental N-fertilizer rate and/or timing. Their usefulness as a comparative tool is best achieved with the establishment of reference strips. It is advised that the standard recommended amount of nitrogen for a crop be reduced by $^{1}/_{4}$ to $^{1}/_{2}$ across the field. Reference strips then should be established by applying additional N fertilizer so the total is equal to the recommended values. Several reference strips of at least 4 plants should be established in each field to accurately represent conditions in that field. By comparing the average chlorophyll meter reading from the reference strips to those from the rest of the field, the need for additional N can be determined. As a general rule, only apply additional fertilizer if the difference between averages of the reference plants and the rest of the field is greater than 10%. Additional N can be applied by banding or by fertigation provided the reference strips are on different irrigation lines.

The chlorophyll meter enhances a producer's ability to make good N management decisions but does not replace other aspects of good N management. Environmentally and economically sound N management must begin with a representative soil sample and a realistic value for expected yield. It is not reasonable to expect that crop yields on infertile soil will match crop yields on fertile soil merely by applying the same amount of fertilizer.

Advantages: Chlorophyll meters can provide instantaneous, on-site information in a nondestructive manner. Fields can be monitored easily throughout the year. The chlorophyll meter is user friendly and can compute the average value of several samples.

Disadvantages: Chlorophyll meters are more reliable for field crops than horticulture crops and on monocotys than dicots. Chlorophyll meter readings can be influenced by many factors other than nitrogen alone. Anything that can alter the color of plants (e.g., diseases, nutrient deficiencies, variety differences) can influence chlorophyll meter readings.

Konica Minolta SPAD-502 Plus chlorophyll meter
http://www.geneq.com/catalog/en/spad-502.html
Photo courtesy of Spectrum Technologies, Inc.

Quick-test kits for use in petiole sap nitrate-N (and potassium) determinations. Currently, the University of Guam Cooperative Extension Service only recommends quick-test sap tests as a comparative tool when used with reference plants (refer to above section on more information on the use of reference plants). The amount of research conducted on plant nutrient management in the Mariana Islands is not adequate to support their use in determining either actual nutrient sap concentration or their interpretation for fertilizer application rates.

Plant sap analysis kits are available in a wide variety ranging from simple, hand-held "colormeters" and ion-specific electrodes to sophisticated portable laboratory units that can test for a multitude of nutrients and chemicals. Growers interested in plant sap testing should evaluate their goals and purchase the equipment needed to meet their needs. Often a $50 kit will suffice. But some growers who have the personnel, could benefit from larger, more diverse testing kits.

For the nutrients to be determined, the user needs to evaluate his or her need for speed versus accuracy. For example, a sap test kit may not have the desired accuracy for certain micronutrients compared to traditional laboratory analyses using whole leaves.

Currently, plant sap test kits appear to be best for mobile nutrients such as N, P, and K. These elements, particularly N and K, make up the bulk of nutrients applied as fertilizers to vegetable crops. They are the ones most often managed during the growing season, which makes plant sap testing particularly attractive for these elements. The routine use of a calibrated plant sap quick test could help in fertigation scheduing of N for a crop. Proper management of N could reduce the overall fertilizer applications to that crop.

Recent studies at the University of Florida, Institute of Food and Agricultural Sciences (IFAS), have provided calibration data for commercially available nitrate and K quick tests. The initial work was conducted for tomato, although some work has been done for other crops (cantaloupe, broccoli, cucumber, squash, and collards). Kits calibrated for use in Florida are described in Table 3-10.

Table 3-10. Quick-test kits for use in petiole sap determinations.

Hach colorimeter
HACH Company PO Box 389, Loveland, CO 80539
Kit determines nitrate-N directly from a small hand-held "comparator" or colormeter. There is a range in test-kit sophistication available from HACH and test kits for several other plant nutrients are available.
http://www.environmental-expert.com/
Merckoquant test strips
Chemicals, Analytics & Reagents 480 South Democrat Rd, Gibbstown, NJ 08027.
Kit tests for total nitrates in test solution by comparison of color developed on test strip with a color chart. Available also is a "reflectometer" to assist in more quantitative reading of the color developed on the strips.
http://www.emdchemicals.com/
Cardy Meters
Spectrum Technologies, Inc. 12010 S. Aero Dr., Planfield, IL 60544.
Ion-specific, hand-held meters for nitrate-N or potassium ions. Measure ion concentrations in undiluted plant sap with digital read-out.
http://www.specmeters.com/Nutrient_Management/ Cardy_Plant_Nutrient_Meters.html

For sap testing, petioles collected from most-recently-matured leaves (MRML) are used for analyses. These leaves have essentially ceased to expand and have turned from a juvenile light-green color to a darker-green color. A random sample of a minimum of 25 petioles should be collected from each “management unit” or “irrigation zone.” Management units larger than 20 acres should be subdivided into 20-acre blocks. Leaves with obvious defects or with diseases should be avoided. Sampling should be done on a uniform basis for time of day (best between 10 AM and 2 PM), and for intervals (after rainfall or fertilization).

For tomatoes, the sample is usually the fifth or sixth leaf from the tip. Whole leaves are collected and then the leaf blade tissue and leaflets are stripped from the petiole. The remaining petiole should be six to eight inches in length. Petioles are chopped into approximately $^1/_2$ inch segments. If analysis will not be conducted immediately in the field, then whole petioles should be packed with ice and analyzed within a few hours of collecting. Given more extreme environmental field conditions (high temperature and bright sun), more dependable results are obtained by making measurement in the lab or office than outdoors.

Chopped petiole pieces are mixed and a random subsample (about $^1/_4$ cup) is crushed in a garlic press, lemon press, or hydraulic press (obtainable from HACH Co., Table 3-10). Expressed sap is collected in a small beaker or juice glass and stirred.

Early in the season, when sap nitrate-N concentrations are high, the sap might need to be diluted. Dilution makes it possible to read the nitrate-N levels within the scales of some test kits. Dilution also will minimize the interference of the green chlorophyll color of the sap on the reading of colorimetric testing systems. Some users have reported success with charcoal-filtered sap. This procedure is particularly good for dark sap that does not need to be diluted. Slightly different results will be obtained with filtered and unfiltered sap. Users should standardize procedures with one method. With tomatoes, a dilution of 50 or 60 parts deionized or distilled water to one part sap is needed. Later in the season, a dilution of 20 to 1 will usually suffice. Diluting can be accomplished by using a laboratory pipette and graduated cylinder or less precisely, with an eyedropper. The pipette method is recommended for highest accuracy. Diluted sap is stirred completely prior to use in the test kits.

To use the Merckoquant or Quant strip test, a test strip is removed from the container (keep strips cool when not in use) and dipped for one second into the diluted sap. After 60 seconds, the pink or purple color developed on the test pad on the end of the strip is compared to the calibrated color chart provided with the kit. Interpolation will be needed for readings between any two color blocks on the chart. An alternative is to use a newly developed strip color reader. This reflectometer provides for more quantitative evaluation of the color on the strip. Readings are made in parts per million (ppm) nitrates which can be converted into ppm nitrate-N by dividing by 4.45.

For the HACH colorimeter, two viewing tubes are filled with diluted sap. One tube is placed in its slot in the "comparator." Contents of one powder reagent pillow are emptied into the second diluted sap sample and the tube mixed for one minute. After mixing, the tube is placed in its slot in the "comparator" and left for one minute. After one minute, the colors in the viewing slots are matched by rotating the color wheel, and the resulting ppm of nitrate-N read from the dial.

For the Cardy meters, plant sap is pressed from the petioles and a drop is placed on the Cardy meter, covering both electrode spots on the meter. The meter must be calibrated with standard ion solutions before measuring ion concentration in the sap and again between every 6 or 8 measurements. There are specific meters for nitrate-N and K.

Current interpretations for these test kits for several vegetables are presented in Table 3-11. Work is continuing to provide data for additional crops and for other nutrients. Details on use and care of these sap measuring systems are presented in the publication "Plant Petiole Sap-Testing Guide for Vegetable Crops". Fla. Coop. Ext. Circ. 1144. *http://edis.ifas.ufl.edu/CV004*

Table 3-11. Adequate nitrate-N and K concentrations in fresh petiole sap of most recently matured leaves for several vegetable crops at various periods in the season using the Hach or Quant-strip methods, or Cardy meter.

Crop	Stage of growth	Fresh petiole sap concentration (ppm)	
		K	Nitrate-N
Cucumber	First blossom	N/A	800 - 1,000
	Fruits, 3 inches long		600 - 800
	First harvest		400 - 600
Broccoli Collards	Six-leaf stage	N/A	800 - 1,000
	Just prior to harvest		500-800
	At first harvest		300 - 500
Eggplant	First fruit 2 inches long	4,500 - 5,000	1,200 - 1,600
	First harvest	4,000 - 5,000	1,000 - 1,200
	Mid harvest	3,500 - 4,000	600 - 800
Muskmelon (Cantaloupe)	First blossom	4,000 - 5,000	1,000 - 1,200
	Fruits, 2 inches long	3,500 - 4,000	800 - 1,000
	First harvest	3,000 - 3,500	700 - 800
Pepper	First flower buds	3,200 - 3,500	1,400 - 1,600
	First open flowers	3,000 - 3,200	1,400 - 1,600
	Fruits, half grown	3,000 - 3,200	1,200 - 1,400
	First harvest	2,400 - 3,000	800 - 1,000
	Second harvest	2,000 - 2,400	500 - 800
Potato	Plants, 8 inches tall	4,500 - 5,000	1,200 - 1,400
	First open flowers	4,500 - 5,000	1,000 - 1,400
	50% flowers open	4,000 - 4,500	1,000 - 1,200
	100% flowers open	3,500 - 4,000	900 - 1,200
	Top falling over	2,500 - 3,000	600 - 900
Squash	First blossom	N/A	900 - 1,000
	First harvest		800 - 900
Strawberry (in Florida)	November	3,000 - 3,500	800 - 900
	December	3,000 - 3,500	600 - 800
	January	2,500 - 3,000	600 - 800
	February	2,000 - 2,500	300 - 500
	March	1,800 - 2,500	200 - 500
	April	1,500 - 2,000	200 - 500
Tomato (Field)	First bud	3,500 - 4,000	1,000 - 1,200
	First open flowers	3,500 - 4,000	600 - 800
	Fruits, 1 inch diameter	3,000 - 3,500	400 - 600
	Fruits, 2 inch diameter	3,000 - 3,500	400 - 600
	First harvest	2,500 - 3,000	300 - 400
	Second harvest	2,000 - 2,500	200 - 400
Watermelon	Vines, 6 inches long	4,000 to 5,000	1,200 - 1,500
	Fruits, 2 inches long	4,000 - 5,000	1,000 - 1,200
	Fruits, one-half mature	3,500 - 4,000	800 - 1,000
	At first harvest	3,000 - 3,500	600 - 800

* Adapted from G. Hochmuth, D. Maynard, C. Vavrina, E. Hanlon, and E. Simonne, 2010. Plant Tissue Analysis and Interpretation for Vegetable Crops in Florida Publication #HS964 http://edis.ifas.ufl.edu/ep081

Adapted from Robert Schlub and Lee Yudin's Eggplant, Pepper, Tomato Guide and the Guam Cucurbit Guide

Fertilizer requirements depend on a number of factors such as farm practices, soil type, crop selection and density, fertilizer application methods, field history, and plant tissue nutrient levels. Therefore, fertilizer recommendations should be considered only as a guideline. The response to fertilization will be greatest at lower levels with decreasing benefits and eventually harmful at excessive levels.

There are several methods of applying fertilizer. For phosphorus (P) fertilization, the method that is recommended for Guam is banding (localized placement of the fertilizer in a band). Banding lessens the chance that P will be bound by the soil and made unavailable to the plant. Place fertilizer in a band about 8 cm (3 inches) below seeds and 10–13 cm (4–5 inches) below transplants. If the band is placed too close, seedling roots can be burned. If drip irrigation is used, place band between the seed row and the dripline. To prevent burning the plant, exercise care at all times so that the fertilizer does not come in contact with leaves, stems, and roots. In broadcasting (uniformly distributing the fertilizer over the field), the fertilizer needs to be worked into the soil prior to planting. Fertilizer can be applied through drip irrigation but it must be water soluble (fertigation).

Nitrogen (N) fertilizer applications must be made throughout the season because it readily leaches out of the root zone. Depending on the soil, potassium (K) will also leach; therefore, as a general recommendation, the crop's N and K requirements should be divided into 2–3 applications. The number of applications can be reduced if a controlled-release fertilizer is used. Results from an experiment indicated that nitrate nitrogen from conventional fertilizer is held in most Guam soils for about 9 to 10 weeks with the majority of it being lost to leaching within 4 weeks. When used in Guam's Akina silty clay soil (pH 5.0), controlled-release fertilizer allowed nitrate-N to be released to the soil 5 weeks longer than when water soluble fertilizer was used. No benefits from controlled-release fertilizers were noted on Yigo silty clay (pH 7.8) or Guam cobbly clay (pH 7.8).

Other application methods include foliar sprays (spraying of the fertilizer on the leaves) and fertigation (mixing fertilizer with the irrigation water). Fertigation and soil amendment are preferred over foliar sprays for correcting deficiencies. These methods vary in their efficiency. Foliar spraying with a micronutrient fertilizer is recommended for deficient plants in strongly acid or strongly alkaline soils. From field observations and yield values collected on crops of eggplant, pepper, tomato, and cucumbers at the Yigo UOG Agriculture Research Station (shallow Guam cobbly clay) in 2008, 2009 by researchers Robert Schlub and Zelam Mersha, it was determined that weekly foliar applications of a water soluble fertilizer with micronutrients such as Grow More™ 20-20-20 can boost yield of cucumber by 20% and tomato by 10%. Crops were sprayed to point of run off with a solution (1 teaspoon / gallon). Estimated active ingredients (lbs / acre) for each of the nutrients is: 0.7 for N, P, and K; 0.35 for Fe; 0.1 for Cu; 0.175 for Mn and Zn; 0.07 for B; and 0.00175 for Mo.

Application of micronutrients to the soil is best accomplished by adding a chelated form of the micronutrient or an organic manure. Micronutrients, if applied as salts, are often changed to forms which are unavailable to the plant due in part to soil pH and soil components. For example, if the inorganic iron salt, ferric sulfate, is added to the calcareous soils of northern Guam, much of the iron changes into a form which is unavailable to the plant.

The response to fertilization is greatest at low levels (Table 3-12) and eventually ceases at high levels. In a tomato trial on Guam clay (9.7% organic matter), it was reported that 67.3 kg N and 134.5 kg N/ha (60 lb N and 120 lb N/acre) treatments resulted in the same yield. In 1982, it was reported that tomato treated with 50 kg N/ha (44.6 lb N/acre) had a higher yield than 100 kg N/ha (89.2 lb N/acre).

Table 3-12. Response of Solar Set tomato to nitrogen applications.

Nitrogen	Market yield/plant
50 lb/ acre (56 kg/ha)	14.0 lb (6.4 kg)
100 lb/acre (112 kg/ha)	14.8 lb (6.7 kg)
200 lb/acre (224 kg/ha)	15.7 lb (7.1 kg)
400 lb/acre (448 kg/ha)	17.0 lb (7.7 kg)

The experiment was conducted in Guam's Pulantat soil (limestone uplands in 1993–1994 during the dry season. Results provied by Dr. Mari Marutani.

In yield trials on Guam on cherry tomatoes in clay soil containing 75 ppm K_2O, growth response at 25 kg/ha was as great as that from 50, 100, and 200 kg K_2O/ha. In a similar experiment in clay soil containing 1.6 ppm P_2O_5, it was found that there was no substantial growth response with the addition of P_2O_5 when N and K_2O were added at a rate of 100 kg/ha.

Organic fertilizers can be used in place of man-made fertilizers (inorganic), but they are generally low in nitrogen. In an experiment conducted by Mari Marutani (2003) where sunnhemp (*Crotalaria juncea*) was evaluated as a green manure crop in the production of Chinese cabbage in Pulantat soil, it was shown that the yield effect from incorporating sunnhemp into the soil was greater with the addition of N-fertilizer and that the improvement was beyond what could be produced with N-fertilizer alone. Based on this study, it is not cost effective to apply any more than 112 Kg/ha of N-fertilizer for the production of Chinese cabbage and that increased yields beyond that level can only be achieved by increasing soil organic matter. In trials conducted on bell pepper on Guam, growth response of incorporation of chicken manure at 10.2 tons

(9.3 metric tons) (25.1% moisture) or 12 tons (10.9 metric tons) of fresh *Leucaena leucocephala* (tangantangan) leaves and stems (50.9% moisture) into the soil was equivalent to the response produced by 100 kg N/ha (89 lb N/acre) from chemical fertilizer. In a 1979 experiment conducted on tomato in Inarajan, the growth response from 6 tons/ha chicken manure was less than that from 100 kg of N from ammonium sulfate $(NH_4)_2SO_4$.

Soil nutrient recommendations for solanaceous crops: Eggplants, peppers, and tomatoes can be expected to have a growth response to a fertilizer containing N-P-K. Conservative levels of N-P-K should be used if no soil analysis data is available (refer to highlighted section of 3-13). It is recommended that all the P_2O_5 and half the N and K_2O fertilizers be applied at the time of transplant. Side dress at flowering with the remaining. For sustained production over a long period, apply additional N at 22 kg/ha (20 lb/acre) every two weeks after first harvest. Apply additional fertilizer if nutrient deficiencies develop. To convert pounds of P_2O_5 to pounds to P, multiply P_2O_5 by 0.44. To convert pound of K_2O to pounds of K, multiply K_2O by 0.83. Continuous application of fertilizer may lead to a buildup of P in the soil which can only be determined with a soil test. With experience and additional information, fertilizer requirements can be fine-tuned. When soil data are available, then the general guidelines in Table 3-13 should be followed. If a heavy rain follows application, then additional fertilizer will be needed since N and K tend to leach. Supplement with additional application of N and K at 28 kg/ha (25 lb/acre) only if nutrient deficiencies develop.

For the home garden, a balanced fertilizer such as 10-20-20, 16-16-16, or 10-30-10 may be applied at 4.5 kg (10 lb) per 100 ft (30.5 m) row. One pound of fertilizer is approximately equal to 1 pint. On a per plant basis use 68 gm (2.4 oz) per plant which is approximately 5 tablespoons. Side dress every two weeks after the first harvest with nitrogen (21-0-0) at 1.4–2.3 kg (3–5 lb)/100 ft row or 28–56 gm (1–2 oz)/plant. Use ammonium sulfate if soil is alkaline. If you use chicken manure, apply 0.23–0.45 kg (0.5–1 lb) per plant at transplanting and side dress with 21-0-0 if nitrogen deficiency symptoms develop.

Table 3-13. Granular fertilizer recommendations for eggplant, pepper, and tomato production based on University of Guam Soil and Plant Testing Laboratory results for N, P, and K.

When Test Shows	< 7% SOM		> 7% SOM		
Add N lb/acre	120	**100**	80		
Add N kg/ha	135	**113**	90		
When test shows K (ppm)	**< 50**	**50–100**	**101 – 150**	**151 – 190**	**> 190**
Add K_2O lb/acre	180	**125**	50	20	10
Add K_2O kg/ha	202	**140**	56	22	11
When test shows P (ppm)	**< 10**	**10 – 30**	**31 – 60**	**61 – 90**	**> 90**
For high clay soil					
Add P_2O_5 lb/acre	200	**180**	160	100	20
Add P_2O_5 kg/ha	224	**202**	179	112	22
For low clay soil					
Add P_2O_5 lb/acre	100	**80**	60	25	10
Add P_2O_5 kg/ha	112	**90**	67	28	11
Unknown clay level					
Add P_2O_5 lb/acre	180	**150**	130	90	15
Add P_2O_5 kg/ha	202	**168**	146	101	17

- Add 10% more fertilizer if applied by broadcasting. Reduce by 20% if plastic mulch and drip irrigation is used.
- Apply all P_2O and half the N and K_2O at transplanting; side dress at flowering with the remaining.
- For sustained production over a long period, add additional N at 22 kg/ha (20 lb/acre) every two weeks after first harvest. Apply additional fertilizer if nutrient deficiencies develop.
- Organic matter determined by the Walkley-Black method; phosphorus extracted with 0.5 M sodium bicarbonate (Olseon method); potassium, calcium, and magnesium by 1 N ammonium acetate.
- High clay refers to soil with a textural class name of clay. All others are referred to as low clay.
- If N-P-K soil values are unknown use the highlighted values in the dotted box.

Soil nutrient recommendations for cucurbit crops: Cucurbit crops require high nutrient inputs for maximum production. The yield of cucurbits such as cucumbers, melons, and watermelon drop sharply when fertilization is inadequate. Conservative levels of N-P-K should be used if no soil data are available (refer to highlighted section in Table 3-15). Routine analysis should be done before each season and special tests need only be requested if you suspect that the soil may be deficient or be in excess of a specific nutrient (Table 3-14). If soil test values are below the indicated optimum levels in Table 3-14, consult with your agricultural extension agent for micronutrient fertilizer recommendations.

Soil salinity is mainly the result of the accumulation of fertilizer in the soil and salt spray from the ocean. Though cucurbits are only moderately sensitive to salts, some yield reduction can be expected when soluble salt concentration reaches 512 ppm with severe losses above 2,049 ppm.

Table 3-14. Recommended levels of soil nutrients for optimum production of cucurbits on Guam.

Nutrient	ppm in Soil
Calcium	801–1,200
Magnesium	101–200
Iron	2.5–5.0
Manganese	1.0–5.0
Zinc	0.5–5.0
Copper	0.1–0.6
Boron	0.5–2.0

Table 3-15. Granular fertilizer recommendation for cucurbit crops based on University of Guam Soil and Plant Testing laboratory results for N, P, and K.

When Test Shows S.O.M.	< 7% SOM		> 7% SOM		
Add N lb/acre	150	**125**	100		
Add N kg/ha	168	**140**	112		
When test shows K (ppm)	**< 50**	**50–100**	**101 – 150**	**151 – 190**	**> 190**
Add K_2O lb/acre	220	**110**	60	30	10
Add K_2O kg/ha	246	**123**	67	34	11
When test shows P (ppm)	**< 10**	**10 – 30**	**31 – 60**	**61 – 90**	**> 90**
For high clay soil					
Add P_2O_5 lb/acre	300	**200**	100	80	40
Add P_2O_5 kg/ha	336	**224**	112	90	45
For low clay soil					
Add P_2O_5 lb/acre	150	**100**	50	40	20
Add P_2O_5 kg/ha	168	**112**	56	45	22
Unknown clay level					
Add P_2O_5 lb/acre	225	**150**	75	60	30
Add P_2O_5 kg/ha	252	**168**	84	67	34

- The N-K should not be applied at one time but divided over the season.
- Bittermelon and sponge gourd require 10% less N-P-K. For trellised cucumber, increase by 50%.
- For deep rooted crops such as pumpkin and watermelon, increase levels by 10%. Reduce by 20% if plastic mulch and drip irrigation is used.
- If N-P-K soil values are unknown use the highlighted values in the dotted box.
- High clay refers to soil with a textural class name of clay. All others are referred to as low clay.

Tissue analysis for cucurbit crops: To determine if nutrients are being absorbed properly, a tissue analysis is required. Tissue analysis is highly dependent on the crop, tissue being sampled, and stage of growth. The following procedures should be followed:

1. Check with your local extension agent or the University of Guam's Soil and Plant Testing Laboratory to determine for your particular crop which plant part to sample, when it should be sampled, and how many samples to collect. Special quarantine procedures are required if you are submitting samples from outside the island of Guam.
2. Cut or pick the appropriate plant part, dust off any soil or foreign matter and place it in a paper bag. If the sample is placed in a plastic bag, it must be refrigerated in a few hours to prevent rotting. Record field location, the date, presence or absence of nutrient symptoms, plant part sampled, and crop growth stage. Some of this information will be later transferred to the submission sheet.
3. Mark your name and field location on each bag using an indelible marker.
4. Drop off your sample at the offices of the Cooperative Extension Service or the University of Guam Soil and Plant Testing Laboratory. Fill out a submission sheet and pay any dues.

For an example of a tissue analysis for cucumber, refer to Table 3-16.

Table 3-16. Recommended tissue nutrient ranges for cucumber.

Nutrient	Sufficiency Range
N %	4.0–5.5
P %	0.25–1.0
K %	3.5–4.5
Ca %	1.5–4.0
Mg %	0.3–1.2
S %	0.3–1.0

Nutrient	Sufficiency Range
B, ppm	30–100
Cu, ppm	8–20
Fe, ppm	50–300
Mn, ppm	50–400
Mo, ppm	0.8–3.3
Zn, ppm	25–300

- Collect leaf samples from at least 20–30 plants.
- Nutrient content of leaf tissue may be affected by the growth stage of the plant. Sample the 5th leaf from the tip (omit unfurled leaves) during small fruit to harvest stage.
- *Jones, Jr., J.B., B. Wolf and H.A. Mills. 191. Plant analysis handbook: A practical sampling, preparation, analysis and interpretation guide. Micro-Macro Publishing, Inc. Athens, GA.*

Table 3-17. Additional fertilizer recommendations made by the University of Guam.

Crop	Recommendation *
Small trees: Papaya, banana, mulberry, pomegranate, surinam cherry	0.5 lb. / month of a complete fertilizer such as 16-16-16, 10-20-20, or 10-30-10.
Intermediate trees: Starfruit, citrus, star apple, soursop, star fruit	1 lb. / month of a complete fertilizer such as 16-16-16, 10-20-20, or 10-30-10.
Large Trees: Mango, breadfruit, avocado, jackfruit	1.5-2 lb. / month of a complete fertilizer such as 16-16-16, 10-20-20, or 10-30-10.
Turf Grass: If turf is yellow after fertilization, add iron.	
Bermuda	8-16 lb/1000 ft^2 of 12-4-8 / month.
Zoysia	4 lb/1000 ft^2 of 12-4-8 / month.
Centipede	2 lbs /1000 ft^2 of 12-4-8 / month.
• **Garden plants (transplants):** Plants that are to be transplanted should be watered with plant starter solution (2 oz. of dry fertilizer or two teaspoons of liquid fertilizer per gallon). In the field, it is recommended that a complete fertilizer (16-16-16, 10-30-10 or 10-20-20) be banded 4-5 inches below transplants. Sidedressing of fertilizer is done after the plants are well established. To side dress, place the fertilizer (1 lb / 100 ft row of a high nitrogen fertilizer such as ammonium sulfate) in a shallow band 4-6 inches away form the plant. Cover with soil after fertilizer application and apply water (if rain is not likely).	
Papaya	Sidedress with a 1/2 cup of complete fertilizer per plant every two weeks
Eggplant & pepper	Sidedress after first fruit set.
Green onion	Sidedress when tops are 6 inches.
Sweet potato	No sidedress needed.
Tomatoes	Sidedress 1 to 2 weeks before first tomato ripens and two weeks after picking first ripe tomato.
Garden plants (seeded): In the field, it is recommended that a complete fertilizer (16-16-16, 10-30-10 or 10-20-20) be banded 2-3 inches below seeded plants. For large seeded plants and for seeds planted in hills fertilizer should also be place 2-3 inches below the seed and to 2-3 inches to the side. Sidedressing of fertilizer is done after the plants are well established. To side dress, place the fertilizer (1 lb / 100 ft row of a high nitrogen fertilizer such as ammounium sulfate) in a shallow band 4-6 inches away form the plant. Cover with soil after fertilizer application and apply water (if rain is not likely).	
Sweet corn (large seed)	Sidedress when plants are 8-10 inches tall and one week after tassels appear.
Peas & beans (large seed)	Sidedress after heavy bloom and pod set.
Okra (small seed)	Sidedress after bloom and every three weeks.
Chayote, watermelon, cantaloupe, and similar melons (large seed)	Sidedress one week after blossoming begins, and three weeks later.
Chinese cabbage, radish, onions, and mustard greens	These small seeded plants will require thinning after emergence. Sidedress after plants are 1/3 fully grown.

* It is recommended that you have your soil tested and that you consult with your local agriculture extension agent for suggestions to optimize production while keeping cost low and the environmental impact to a minimum.

Soil degradation, which is mainly the result of erosion and insufficient soil organic matter, initiates a downward spiral of poor plant production. Some soil degradation processes are natural phenomena but their impact can be reduced through the adoption of soil conservations practices. A mere inch of soil can take centuries to build up, but if mistreated may be blown or washed away in a few seasons.

Although many of the soils of the Mariana Islands have inherently low erosion hazard by virtue of their topography and structure (Table 2-4), they still remain vulnerable due to the islands' aggressive climate of highly erosive rainfall and cyclic wet and dry seasons. On Guam erosion is greatest in the southern and central parts of the island, where clay or argillaceous limestone soils retard water percolation and permit surface waters to accumulate. In contrast, the northern limestone plateau allows rapid water seepage; consequently, only a few marshy areas and ephemeral streams exist.

Cover crop is a short-term crop planted to protect exposed soil surface. Low maintenance vine crops such as sweet potato (*Ipomoea batatas*) and squash (*Cucurbita pepo*) are examples. Other examples include soybean (*Glycine max*), mung bean (*Vigna radiata*), and sudangrass (*Sorghum bicolor*).

Green manure is a short-term crop (usually a nitrogen-fixing legume) that is killed while green to add nutrients for the next crop: tropic sun /sunnhemp (*Crotalaria juncea*), jack bean (*Canavalia ensiformis*), lablab (*Lablab purpureus*), and cowpea (*Vigna unguiculata*).

Conservation cover or **permanent cover crop** is a long-term crop grown year-round to smother weeds and protect topsoil: Tropic Lalo paspalum (*paspalum hieronymii*) St. Augustine grass (*Stenotaphrum secundatum*), piligrass (*Heteropogon contortus*), and *Arachis pintoi* (perennial or forage peanut).

Vegetative barriers are permanent strips of stiff, dense grasses grown across a slope or across a drainage way: vetivergrass (*Vetiveria zizanioides* syn. *Chrysopogon zizanioides*), piligrass or tanglehead (*Heteropogon contortus*), lemongrass (*Urochloa maxima*).

Shoreline plantings are used to reduce the effects of wave motion: retotoput (*Sporobolus virginicus*), and vetiver grass (*Veliveria zizanioides* syn. *Chrysopogon zizanioides*).

Recreation area covers: Zoysiagrass (*Zoysia japonica*), seashore paspalum (*Paspalum vaginatum*), bermudagrass (*Cynodon dactylon*), centipedegrass (*Eremochloa ophiuroides*).

Grass waterways: Shallow grassed channels, designed for draining runoff water from adjacent cropland: zoysiagrass (*Zoysia japonica*), Bermudagrass (*Cynodon dactylon*), digitgrass (*Digitaria eriantha*).

Crop rotation is the farm practice of switching crops. When crops are grown in the same place year after year, the soil is slowly depleted of specific nutrients needed for growth. Without rotation, weeds, pests, and diseases problems intensify. Crop rotation is most effective when a single crop is not grown more than 3 years in a row, when similar crop groups (Table 3-18) are not planted in sequence, and when a green manure crop is part of the rotation. For example, crops traditionally rotated with sweetpotato in Hawai'i include lettuce, spinach, beets, radish, kai choy, sweet corn, cowpea, peanut, bean, sorghum, alfalfa, and pigeon pea.

Table 3-18. Crop families and members grown in the Mariana Islands.

Onion family *Alliaceae*	onion, green onion, garlic, leek, chives
Sunflower family *Asteraceae*	sunflower, lettuce, endive, salsify
Mustard family *Brassicaceae*	mustard greens, cabbage, chinese cabbage, radish
Pineapple family *Bromeliaceae*	pineapple
Papaya family *Caricaceae*	papaya
Bindweed family *Convolvulaceae*	sweetpotato, Chinese water spinach (kang kong)
Aroid family *Araceae*	taro, giant taro
Mint family *Labiatae*	sage, mint, basil
Gourd family *Cucurbitaceae*	gourd, cucumber, squash, melons, watermelon, pumpkin, bittermelon
Yam family *Dioscorea*	yam
Pea family *Fabaceae*	pea, snap bean, soybean, cowpea, peanut, bush bean, wing bean, yardlong bean
Mallow family *Malvaceae*	okra
Grass family *Poaceae*	corn, bamboo, lemon grass, sugarcane
Nightshade family *Solanaceae*	tomato, pepper, eggplant, tomatillo, chillies
Ginger family *Zingiberaceae*	ginger, cassava
Banana family *Musaceae*	common banana, plantains

Chapter 3: Nutrient Management • Management of Calcareous Soils in Miami-Dale County, Florida

Adapted from Yuncong Li's Fact Sheet SL 183, a publication of the Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: July 2001. Reviewed July 2009.

Calcareous soils in Miami-Dade County are derived from Miami limestone. Over 85% of Florida's tropical fruits are grown on calcareous soils in the southern part of the state. This is done because of favorable temperatures, rather than favorable soil characteristics. Careful management of nutrients is critically important to the successful production of crops on calcareous soils.

The marl and rocky calcareous soils in Miami-Dade County usually contain from 30% to 94% $CaCO_3$. The pH values of calcareous soils are greater than 7, usually in the range of 7.4-8.4. Textures of calcareous soils can be sandy, loamy or gravelly. Soil depths range from less than five inches to several feet. These soils are important for production of vegetable, fruit, and ornamental plants in Florida.

Acidification of calcareous soils: To date no research data have been generated to establish a beneficial effect of applications of any acidic products (elemental sulfur (S), sulfuric acid, triosulfate salts, etc) on calcareous soils in Florida.

Nitrogen (N): The loss of nitrogen through the volatilization of ammonia is significant for ammonium N fertilizer applied on calcareous soils. Ammonium N fertilizer should be incorporated or introduced into the soil through irrigation. Also, nitrate N fertilizer is readily leached through gravelly calcareous soils, as a result of over-irrigation or heavy rainfall.

Phosphorus (P): Phosphorous fertilizers applied in calcareous soils are fixed by calcium carbonate (calcite) through adsorption and precipitation. Consequently the availability of P in calcareous soils is relatively low. However, repeated applications of large amounts of P fertilizer results in the accumulation of P in most cultivated calcareous soils. Accumulated P is slowly released into the soil solution to become available to plant roots. Therefore growers should use less P fertilizer if their soils already have high residual P.

Potassium (K): Potassium deficiency is not common for crops grown in calcareous soils in Miami-Dade County. However, K is readily leached out of the root zone in sandy or gravelly soils. Therefore split applications of K fertilizer are recommended.

Calcium (Ca): Calcareous soils have an abundance of calcium available for plant uptake. Application of calcium fertilizer is not necessary.

Magnesium (Mg): Although Mg concentrations in calcareous soils are not low, crops grown on calcareous soils often show Mg deficiency symptoms. The high calcium concentrations in calcareous soils suppress Mg plant uptake and its translocation from the roots to the upper plant parts. Magnesium can be applied as a dry fertilizer or as a foliar application. Foliar applications of magnesium nitrate and magnesium sulfate have been shown to be efficacious.

Iron (Fe): Iron chlorosis is the most frequent nutritional disorder encountered in crops grown on calcareous soils. Inorganic forms of Fe in calcareous soils are largely or almost totally unavailable for plant uptake. High concentrations of bicarbonate in the soil solution can prevent Fe uptake by the plant, as well as its translocation within the plant. Most fruit crops are susceptible to Fe deficiency. On the other hand, most vegetable crops commonly grown on calcareous soils in Florida have been selected for good adaptation to high pH soils. Thus vegetable crops generally do not suffer from Fe deficiency. Application of EDDHA chelated Fe is commonly practiced to improve the Fe nutrition of both fruit and vegetable crops. Generally, it is applied as a soil drench (water plus iron) or through the micro-irrigation system (fertigation).

Some iron-efficient crops release organic acids from their roots to neutralize the bicarbonate and to mobilize soil Fe. Other iron-efficient crops possess high Fe-reductase activity, or other superior physiological and biochemical characteristics. Marler, Cruz, and Blas at UOG (2002) concluded from their research that papaya roots are highly efficient in inducing Fe reductase activity and the occasional Fe deficiency symptom seen on papaya in the Mariana Islands is likely due to a temporary disruption of this activity.

Zinc (Zn) and Manganese (Mn): The solubilities and availabilities of Zn and Mn are very low in calcareous soils. However, most vegetable crops have the ability to take up sufficient quantities of both Zn and Mn. Applications of fungicides containing Zn and Mn also provide available Zn and Mn to plants. Nevertheless, deficiencies of Zn and Mn are very common in crops grown on calcareous soils. Foliar applications with Zn and Mn fertilizers can effectively correct these deficiencies.

Nitrogen and Plant Disease:

Adapted from Don M. Huber and Ian A. Thompson's chapter in Mineral Nutrition and Plant Disease 2007 by the American Phytopathological Society.

Nitrogen is by far the most extensively reported element affecting plant disease development. The effect of nitrogen on plant disease within the Mariana Islands is unknown; however, there are some generalities that are applicable based on the region's crops.

- The amount of N available, relative to the needs of the plant, and the time of N application may have a pronounced effect on disease expression (Table 3-19).
- The application of ammonium as the nitrogen source will generally result in decreased disease severity. Part of the effect is likely due to the fact that the ammonium form of N results in a decrease in soil pH and most profoundly in the rhizosphere (root zone).
- The application of nitrate as the nitrogen source will generally result in an increase in disease severity. Part of the effect is likely due to the fact that the nitrate form of N results in an increase in soil pH and most profoundly in the rhizosphere.
- The severity of infection by many obligate pathogens (downy mildews, powdery mildews, smuts, and rusts) and foliar pathogens (*Magnaporthe*, *Xanthomonas*, *Botrytis*, and *Cerspora*) is commonly observed to increase as the rate of N increases. The effect is greatest when nitrate is the source of nitrogen.

Strategies for reducing disease with nitrogen

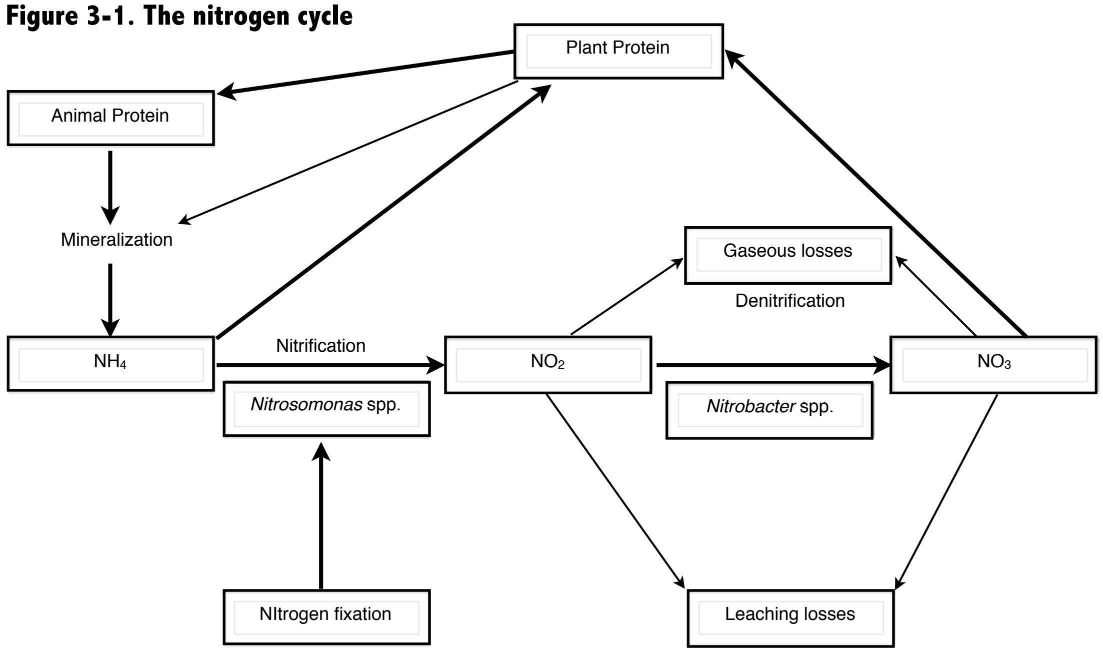
- Maintain a balanced fertilizer program with a full sufficiency of N for optimum plant growth and yield.
- Make timely applications of N to avoid periods of excessive N, high N loss, or predisposing environmental conditions for pathogens. Side-dressing nutrients avoids potential early-season losses to leaching and denitrification and also reduces the predisposition of seedlings to damping-off pathogens such as *Rhizoctonia* or *Pythium.*
- Use different forms of N to enhance disease control.
- Modify environment conditions (crop rotation, changing soil pH, application of nitrification inhibitor) to influence the predominant form of N that is optimum for plant resistance or less conducive to the pathogen (Figure 3-1).

Table 3-19. Influence on disease severity of increased nitrogen with and with out accompanying increases in soil alkalinity or acidity.

Host	Disease or disorder	Pathogen or causal agent	Unspecified nitrogen	NH_4	NO_3	NO_3 with alkalinity	NH_4 with acidity
Bean, snap	Damping off	*Rhizoctonia solani*	I	–	–	D	–
	Root-knot	*Meloidogyne incognita*	–	–	–	–	D
	Root root and hypocotyl rot	*Fusarium solani* *Rhizoctonia solani*	–	–	–	D	–
Cabbage	Clubroot	*Plasmodiophora brassicae*	D	D	–	D	–
	Yellows	*Fusarium oxysporum*	–	–	–	D	–
Corn	Gray leaf spot	*Cercospora zeae-maydis*	I	–	–	–	–
	Stalk rot	*Gibberella zeae*	–	–	–	–	D
Cucumber	Wilt	*Fusarium oxysporum*	–	–	–	D	
Eggplant	Wilt	*Verticillium dahliae*	–	D	I	–	D
	Wilt	*Fusarium oxysporum*	–	–	–	–	D
Onion	White rot	*Sclerotium rolfsii*		–	–	–	D
Peanut	Black rot	*Cylindrocladium crotalariae*	D	–	–	–	–
	Pod rot	*Phythium, Rhizoctonia, Fusarium* spp.	I	–	–	–	–
Pepper	Wilt	*Fusarium oxysporum*	–	–	–	D	–
Philodendron	Leaf blight	*Erwinia chrysanthemi*	D	–	–	–	–
Soybean	Stem canker	*Diaporthe phaseolorum*	D	–	–	–	–
Sunflower	Stem rot	*Sclerotinia sclerotiorum*	D	–	–	–	–
Tomato	Anthracnose	*Gloeosprium phomoides*	–	–	–	–	D
	Blossom end-rot	Physiological disorder	–	I	–	–	–
	Corky root	*Pyrenochaeta lycopersici*	I	I	I	–	–
	Crown and root rot	*Fusarium oxysporum*	–	I	D	–	–
	Gray mold	*Sclerotinia* spp.	–	–	–	D	–
	Potato virus X	*Potato virus X*	–	–	–	–	D
	Root rot	*Phytophthora parasitica*	I	–	I	–	–
	Sclerotium blight	*Sclerotium rolfsii*	–	–	–	D	–
	Southern wilt	*Pseudomonas solanacearum*	–	–	–	–	D
	Wilt	*Verticillium dahliae*	–	–	–	–	D
	Wilt	*Fusarium oxysporum*	–	–	–	D	D
Turfgrass	Nematodes	*Criconemella* spp. and others	–	–	I	–	–
Various plants	Rot	*Sclerotium rolfsii*	D	D	D	–	–
Various plants	Wilt	*Verticillium dahliae*	D	D	–	–	–

D=decreased severity, I=increased severity, – = No effect or not reported.

Figure 3-1. The nitrogen cycle



Iron and Plant Disease: *Adapted from Dominique Expert's chapter in Mineral Nutrition and Plant Disease 2007 by the American Phytopathological Society.*

Iron almost never exists in a free form in living tissue; therefore, it cannot move from older to the newer leaves. Soils usually do not lack Fe, unless they are alkaline which is due to solubility and fixation with Ca. The solubility of Fe^{3+} increases 1,000-fold with each one unit decrease in pH. In alkaline soils of the Marianas, available iron is mainly the result of microbiological breakdown of organic matter and the subsequent formation of soluble iron complexes. The dissolution of the soil mineral ferric oxides is another source of soluble iron to plant roots.

Plants may be classed as 'Fe-efficient' if they respond to Fe-deficiency stress by inducing biochemical reactions that transform soil Fe into a useful form, and 'Fe-inefficient' if they do not. Fe-efficient species have a greater tendency to lower the pH of the rhizosphere due to their ability to accumulate phenols. These reactions enable Fe efficient species to absorb more Fe rapidly and be relatively tolerate to iron deficiency. Crops include sunflower, peppermint, and rye. Crops moderately susceptible to iron deficiency include cabbage, corn, peanut, and alfalfa. Crops that are susceptible to iron deficiency and therefore, highly response to supplemental iron include beans, spinach, and tomato.

In plants, as in animals, the availability of iron may be one of the factors limiting the growth of pathogenic microorganisms. As an element of competition in plant defense, iron could induce mechanisms causing pathogens to be deprived of nutritional iron. Nodule formation induced by rhizobia involves different steps during which iron may be a critical nutrient.

Sulfur and Plant Disease: *Adapted from Silvia Haneklaus, Elke Bloem, and Ewald Schnug's chapter in Mineral Nutrition and Plant Disease 2007 by the American Phytopathological Society.*

Sulfur and sulfur compounds affect disease incidence and severity directly by enhancing plant resistance and increasing the availability of other elements. The fungicidal effect of foliar-applied elemental S has been know since the end of the 19th century. Sulfur is used under some conditions for the control of leafhoppers, psyllids, mites, and plant bugs. The influence of S on diseases of crops grown in the Mariana Islands can be found in Table 3-20.

Table 3-20. Some reports of interactions of sulfur with plant diseases.

Host	Disease or disorder	Pathogen or causal agent
Corn	Leaf blight	*Bipolaris maydis*
	Stewart's wilt	*Erwinia stewartii*
Crucifers	Clubroot	*Plasmodiophora brassicae*
Peanut	Leaf spot	*Cercospora arachidicola*
Soybean	Root rot	*Rhizoctonia solani*
Tomato	Wilt	*Fusarium oxysporum*
	Wilt	*Verticillium dahliae*
Turfgrass	Patch	*Fusarium nivale*

Phosphorus and Plant Disease: *Adapted from Anne S. Prabhu, Nand K. Fageria, and Rodrigo F. Berni's chapter in Mineral Nutrition and Plant Disease 2007 by the American Phytopathological Society.*

High phosphorus concentrations can either reduce or increase disease development. Phosphorus increases the resistance of plants to different diseases by increasing tissue P content or by accelerating tissue maturity, to protect against pathogens that attack seedlings.

The effect of P on some fungal diseases found in the Mariana Islands are listed in Table 3-21.

Phosphorus management strategies for disease control: The nutrient requirements of a crop vary according to soil, climatic conditions, cultivar, and management practices. Inorganic P sources should be water-soluble to be effective for crop production, because of the immobility of P in the soil. Apply fertilizers with water-soluble P of 50% or greater (check fertilizer bag label). Broadcast incorporation is probably the most common method of soil application. However, in soil with low P availability and high fixation capacity, banding the P below the seeds or transplants is the most effective method when the soil is low in P. Decomposition products of organic matter such as crop residues can possibly increase P availability and hence crop yields in soil with a high P fixation capacity. However, soils rich in iron oxides, such as Oxisols and Ultisols as found in Guam and CNMI, have low levels of available phosphate and would gain little P from organic amendments.

Table 3-21. Influence of increased phosphorus on some fungal diseases.

Host	Disease or disorder	Pathogen or causal agent	Effect of P on disease*
Cabbage	Downy mildew	*Peronospora parasitica*	D
	Yellows	*Fusarium oxsporum* f. sp. *conglutinans*	I
	Clubroot	*Plasmodiophora brassicae*	I
Citrus	Root rot	*Thielaviopsis basicola*	I
Corn	Stalk rot	*Diplodia zeae*	I
	Stalk rot	*Gibberella zeae*	D
	Root rot	*Gibberella saubinetii*	D
Cucumber	Damping-off	*Rhizoctonia solani*	D
	Mildew	*Sphaerotheca fuliginea*	D
Ginseng	Root rot	*Thielaviopsis basicola*	D
Lentil	Wilt	*Fusarium oxsporum* f. sp. *lentis*	I
Lettuce	Mildew	*Bremia lactucae*	I
Soybean	Root rot	*Rhizoctonia solani*	D
Sugarcane	Rust	*Puccinia melanocephala*	D
	Eyespot	*Helminthosporium sacchari*	D
Tomato	Early blight	*Alternaria solani*	D
	Leaf spot	*Septoria* spp.	D
	Wilt	*Fusarium oxsporum* f. sp. *lycopersici*	I, D
Turf	Patch	*Gaeumannomyces graminis*	D

*** D = decrease in disease. I = increase in disease.**

Foliar sprays of P can confer local and systemic protection against some diseases common in Guam and the CNMI: powdery mildew, rust, and *Phytophthora*. The foliar application of P against these diseases offers a means by which diseases can be reduced with minimal impact on the environment while providing an essential plant element.

- Powdery mildew on mango caused by *Oidium mangiferae.*
- Powdery mildew on nectarine caused by *Sphaerotheca pannosa.*
- Powdery mildew on cucumber caused by *Sphaerotheca fuliginea.*
- Powdery mildew on pepper caused by *Leveillula taurica.*
- Leaf blights and root rot on forest community plants caused by *Phytophthora* spp. Note: betel nut trees in Guam and CMNI are commonly injected with Potassium phosphonate to control *Phytophthora* bud rot.

Boron and Plant Disease: *Adapted from James C. R. Stangoulis and Robin D. Graham's chapter in Mineral Nutrition and Plant Disease 2007 by the American Phytopathological Society.*

The suppression of xylem-penetrating pathogens by inducing boron deficiency in plants has been shown in a number of cases. It has been observed that when B is deficient, the plant's xylem is disrupted which in turn impedes colonization of xylem infecting pathogens such as *Fusarium* and *Verticillium*. Strategies to maintain low disease incidence of soilborne pathogens through the use of fertilizers should be considered where applicable. Such strategies would apply generally to soils that tend to be boron deficient (acid and tropical soils). The influence of B on diseases reported in the Mariana Islands can be found in Table 3-22.

Table 3-22. Effect of added boron on the incidence of plant diseases.

Host	Disease or disorder	Pathogen or causal agent	Effect of B on disease*
Bean	Tobacco mosaic virus	Tobacco mosaic virus (tobamovirus)	D
	Lesion	*Pseudomonas putida*	D
	Lesion	*Fusarium solani*	D
Bean, pea, cowpea	Rot and seedling rot	*Rhizoctonia solani*	D
Chinese cabbage	Clubroot	*Plasmodiophora brassicae*	D
Crucifers	Clubroot	*Plasmodiophora brassicae*	D
Groundnut (peanut)	Hypocotyl rot	*Rhizoctonia bataticola*	D
Tomato	Fusarium wilt	*Fusarium oxysporum* f. sp. *lycopersici*	D
	Powdery mildew	*Leveillula taurica*	D
	Yellow leaf curl virus	*Tomato yellow leaf curl virus*	D
	Wart	*Synchytrium endobioticum*	D

*** D = decrease in disease.**

Potassium and Plant Disease: *Adapted from Anne S. Prabhu and Nand K. Fageria's chapter in Mineral Nutrition and Plant Disease 2007 by the American Phytopathological Society.*

Potassium alone or in combination with nitrogen, phosphorus, and other nutrients alters the severity of diseases caused by many soil-borne and air-borne pathogens. Generally, the application of K to deficient soils usually increases host resistance to diseases. The effect of K on bacterial diseases, fungal diseases, viral diseases, and nematode diseases of crops grown in the Mariana Islands can be found in Table 3-23.

Application of potassium: Generally, K fertilizer is applied as a basal application at the time of planting. However, Oxisols and Ultisols have a very low cation exchange capacity and do not contain K-fixing minerals; thus under these conditions, a split application of K may be more appropriate.

Incorporation of crop residues into the soil after harvest allows a substantial amount of the plant's K to be recycled. Returning crop residues to the soil prolongs benefits from applied K. In acid Oxisols with low cation exchange capacity, it was found that one application of K at the rate of 150Kg ha^{-1} provided enough K for five crops of corn when stover was returned to the soil (stem and leaf parts of corn fodder after the removal of ears).

Low soil water reduces K uptake by plant roots because K diffusion rate decrease as soil moisture decreases. Thus, placement of fertilizers in soil zones that are susceptible to drying may limit plant uptake.

Table 3-23. Disease severity as effected by the application of potassium.

Host	Disease or disorder	Pathogen or causal agent	Effect of K on disease*
BACTERIAL DISEASES			
Bean, Snap	Bacterial blight	*Pseudomonas syringae*	D
Cabbage	Soft rot	*Erwinia carotovora*	D
Cassava	Bacterial blight	*Xanthomonas manihotis*	D
Cucumber	Angular leaf spot	*Pseudomonas lachrymans*	D
	Bacterial wilt	*Erwinia tracheiphila*	I
Tomato	Bacterial disease	Unknown	D
	Blotchy ripening	*Erwinia herbicola*	D
	Canker	*Corynebacterium michiganense*	I
	Graywall	*Erwinia herbicola*	D
	Soft rot	*Erwinia carotovora*	D
	Wilt	*Psuedomonas solanacearum*	D
FUNGAL DISEASES			
Banana	Fusarium wilt	*Fusarium oxysporum* f. sp. *cubense*	D
Bean, Mung	Leaf spot	*Mycosphaerella cruenta*	I
Bean, Snap	Root rot	*Rhizoctonia solani*	I
Bermuda-grass	Leaf blight	*Helminthosporium cynodontis*	D
Cabbage	Clubroot	*Plasmodiophora brassicae*	I
	Downey mildew	*Peronospora parasitica*	I
	Gray mold	*Botrytis cinerea*	D
	Yellows	*Fusarium oxysporum* f. sp. *conglutinans*	D
Citrus	Brown rot gummosis	*Phytophthora parasitica*	I
Cowpea	Damping-off	*Rhizoctonia solani*	I
	Rust	*Uromyces phaseoli*	None
Corn	Northern leaf blight	*Exserohilum turcicum*	D
	Stalk rot	*Fusarium moniliforme*	D
	Stalk rot	*Gibberella zeae*	D
	Stalk rot	*Diplodia zeae*	D
	Stem rot	*Fusarium culmorum*	D
Melon	Wilt	*Fusarium oxysporum* f. sp. *melonis*	D
	Gummy stem blight	*Mycosphaerella melonis*	I
Muskmelon	Downy mildew	*Pseudoperonospora cubensis*	I
Onion	Purple blotch	*Alternaria porri*	I
Palm	Wilt	*Fusarium oxysporum* f. sp. *elaeidis*	D
	Boyomi	*Fusarium bulbigenum*	I
Peanut	Pod rot	*Rhizoctonia solani*	I
	Leaf spot	*Mycosphaerella arachidis*	D
Pineapple	Root rot	*Phytophthora cinnamomi*	D
Pumpkin	Stem rot	*Sclerotina sclerotiorum*	D
Soybean	Pod rot	*Diaporthe sojae*	D
	Root rot	*Phytophthora megasperma*	I
	Pod rot	*Diaporthe sojae*	None
	Purple seed stain	*Cercospora kikuchii*	D
Squash	Foot rot	*Fusarium solani* f. sp. *cucurbitae*	D
Sugarcane	Eyespot	*Helminthosporium sacchari*	D
Tomato	Leaf blight	unknown	I
	Wilt	*Fusarium oxysporum*	I
	Wilt	*Fusarium oxysporum* f. sp. *lycopersici*	D
Turf	Fusarium patch	*Fusarium nivale*	D
	Ophiobolus patch	*Ophiobolus graminis*	D
	Leaf spot	*Helminthosporium* spp.	D
	Wilt	*Fusarium oxysporum f.* sp. *niveum*	I

Host	Disease or disorder	Pathogen or causal agent	Effect of K on disease*
VIRAL DISEASES			
Bean	Mosaic	*Tobacco mosaic virus*	D
Bean, Lima	Root-knot	*Meloidogyne incognita*	D
Cassava	Mosaic	*African cassava mosaic virus*	None
Soybean	Mosaic	*Soybean mosaic virus*	I
Squash	Virus disease	*Tobacco ringspot virus*	D
Tomato	Blotchy ripening	*Tobacco mosaic virus*	D
NEMATODE DISEASES			
Bean, Lima	Root-knot	*Meloidogyne incognita*	D
Cucurbits	Root-knot	*Meloidogyne incognita*	I
Soybean	Root-knot	*Meloidogyne incognita*	I
	Soybean-cyst	*Heterodera glycines*	I
Tomato	Reniform nematode	*Rotylenchulus reniformis*	I
	Root-knot	*Meloidogyne incognita*	I

D = decrease in disease. I = increase in disease.

Magnesium and Plant Disease: *Adapted from Jeff B. Jones's chapter in Mineral Nutrition and Plant Disease 2007 by the American Phytopathological Society.*

Magnesium nutrition can increase some diseases and decrease others whether the Mg is supplied to the soil as dolomitic lime or as a foliar spray. Its effect on diseases of common crops grown in Guam and the CMNI are shown in Table 3-24.

Table 3-24. The effect of adding magnesium to soil or foliage on disease severity.

Host	Disease or disorder	Pathogen or causal agent	Effect of Mg on disease*
Bean	Root rot	*Rhizoctonia solani*	D
Cabbage	Clubroot	*Plasmodiophora brassicae*	D
Castor bean	Leaf spot	*Botrytis* spp.	D
Corn	Southern leaf blight	*Bipolaris maydis*	I
Crucifers	Clubroot	*Plasmodiophora brassicae*	D
Peanut	Pod rot	*Fusarium* spp.	I
	Pod rot	*Pythium myriotylum*	I
	Pod rot	*Rhizoctonia solani*	I
Pepper	Bacterial spot	*Xanthomonas campestris* pv. *vesicatoria*	I
Potato	Tuber rot	Various fungi	D
Soybean	Root rot	*Rhizoctonia solani*	D
	Twin stem	*Sclerotium* spp.	I
Tomato	Bacterial spot	*Xanthomonas campestris* pv. *vesicatoria*	I
	Seedling disease	*Pythium myriotylum*	I
	Wilt	*Fusarium oxysporum*	I

*** D = decrease in disease. I = increase in disease.**

Molybdenum and Plant Disease: Unlike some of the other essential micronutrients, Mo is not strongly linked to disease incidence in higher plants, neither increasing nor decreasing it. Molybdenum has been shown to suppress *Verticillium* wilt of tomato, angular leaf spot of bean, *Xanthomonas* on cowpea, and *Fusarium oxysporum* diseases.

Manganese and Plant Disease: *Adapted from Ian A. Thompson and Don M. Huber's chapter in Mineral Nutrition and Plant Disease 2007 by the American Phytopathological Society.*

Manganese is the 10th most abundant element in most surface environments. Fungal and, to a large extent, bacterial diseases are often reduced with increased Mn availability, while viral diseases may be enhanced by higher Mn levels in plant tissue. Soil treatments that increase Mn plant content (mulching, no-till, cover cropping, and green manuring) generally suppress disease. Manganese containing fungicides such as Mancozeb™, Maneb™ and Dithane™ are generally more effective than Zineb™ or Ferbam™. The influence of Mn on diseases of crops reported in the Mariana Islands can be found in Table 3-25.

Table 3-25. Some plant diseases affected by increasing manganese availability.

Host	Disease or disorder	Pathogen or causal agent	Effect of Mn on disease*
Avocado	Root rot	*Phytophthora cinnamomi*	I
Banana	Anthracnose	*Colletotrichum musae*	I
Bean	Virus disease	*Tobacco mosaic virus*	D
Bermuda-grass	Root rot	*Curvularia ramosa*	D
Cabbage	Clubroot	*Plasmodiophora brassicae*	D
Citrus	Greasy spot	*Mycosphaerella citri*	D
Coriander	Stem gall	*Protomyces macrosporus*	I
Cowpea	Mildew	*Erysiphe polygoni*	D
	Virus disease	*Cowpea chlorotic mottle virus*	I
Cucumber	Mildew	*Erysiphe* sp.	D
Lentil	Wilt	*Rhizoctonia solani*	D
Onion	Rot	Storage fungi	D
	White rot	*Sclerotium cepivorum*	D
Palm	Leaf spot	*Exserohilum rostratum*	D
Peanut	Collar rot	*Aspergillus niger*	D
Pumpkin	Mildew	*Erysiphe cichoracearum*	D
	Rot	*Sclerotinia sclerotiorum*	D
Soybean	Blight	*Pseudomonas syringae* pv. *glycinea*	D
Sugar cane	Whip smut	*Ustilago scitaminea*	D
Sweet potato	Root rot	*Streptomyces ipomoeae*	D
Tomato	Bacterial speck	*Pseudomonas syringae*	D
	Wilt	*Fusarium oxysporum*	D
	Early blight	*Alternia solani*	D
Turfgrass	Take-all patch	*Gaeumannomyces graminis*	D

*** D = decrease in disease. I = increase in disease.**

Calcium and Plant Disease: *Adapted from M. Rahman and Z.K. Punja's chapter in Mineral Nutrition and Plant Disease 2007 by the American Phytopathological Society.*

Other than N, Ca is perhaps the most important nutrient in the management of diseases. A crop's natural internal mechanisms of resistance to decay can be enhanced by elevating Ca concentrations in its tissues. Calcium increases resistance to microbial enzymes by stabilizing plant cell walls and cell membranes. Calcium salts, including $CaCl_2$ and $Ca(NO_3)$, significantly reduced powdery mildew colony counts on tomato leaves.

In addition to agronomic benefits gained by maintaining adequate levels of Ca in plant species, numerous researchers have reported that the application of Ca to soils, foliage, and fruit reduced the incidence and severity of several diseases of economically important crops species of Guam and CNMI (Table 3-26).

Calcium deficiencies: Calcium, unlike most elements, is absorbed and transported by a passive mechanism. The transpiration process of plants is important in the transport of Ca. Once in the plant, Ca moves toward areas of high transpiration rate, such as rapidly expanding leaves. Most of the uptake of Ca occurs in a region on the root just behind the root tip. This has practical importance for vegetable culture because growers must keep root systems healthy with numerous actively growing root tips. Root diseases and nematodes may severely limit Ca uptake by the plant.

With severe Ca deficiency, new growth of roots, leaves, and fruit are impaired. The most visible Ca deficiency symptoms are associated with the fruit. In Ca-deficient fruit of watermelon and cucumber, the blossom end of the fruit wall becomes thinner, and water-soaked, and brown necrotic spots develop. Maintaining the soil at an adequate water concentration and avoiding application of excessive K and ammonium–N in the fertilizer increases plant Ca uptake and reduces symptoms.

Table 3-26. Plant diseases reported to be reduced by the application of calcium.

Host	Disease or disorder	Pathogen or causal agent	Calcium source
Avocado	Root rot	*Phytophthora cinnamomi*	Calcium sulfate
Cabbage	Clubroot	*Plasmodiophora brassicae*	Calcium carbonate
Citrus	Phytophthora root root	*Phytophthora nicotianae*	Calcium oxide Calcium carbonate
	Greasy spot	*Mycosphaerella citri*	Calcium carbonate
Cucumber	Root rot	*Pythium splendens*	Calcium carbonate
	Gray mold	*Botrytis cinerea*	Calcium sulfate
Eggplant	Gray mold	*Botrytis cinerea*	Calcium sulfate
Melon	Fruit rot	*Myrothecium roridum*	Calcium chloride
Nectarine	Rhizopus rot	*Rhizopus stolonifer*	Calcium chloride
Peanut	Pod rot	*Pythium myriotylum* *Rhizoctonia solani*	Calcium sulfate
	Aflatoxin	*Aspergillus flavus*	Calcium sulfate
Pepper	Gray mold	*Botrytis cinerea*	Calcium sulfate
Soybean	Twin stem	*Sclerotium* sp.	Calcium carbonate
Tomato	Wilt	*Fusarium oxysporum* f. sp. *lycopersici*	Calcium chloride
Vinca	Root rot	*Phytophthora parasitica*	Calcium chloride Calcium nitrate

Copper and Plant Diseases: *Adapted from Ieuan Evans and Elston Solberg's chapter in Mineral Nutrition and Plant Disease 2007 by the American Phytopathological Society.*

Organic, sandy soils, and high pH soils are most likely to be Cu-deficient. High rates of N fertilizer can accentuate Cu deficiency. Copper deficiency causes various symptoms, depending on the plant species and interaction with other nutrients. In grain crops, copper deficiency affects grain formation much more than vegetative growth. Inorganic Cu-based fungicides and bactericides were among the earliest and are still some of the most widely used disease control products in agriculture and horticulture. The influence of Cu on diseases that occur in the Mariana Islands can be found in Table 3-27.

Table 3-27. Effects of adding copper to soil or leaf tissue on disease severity.

Host	Disease or disorder	Pathogen or causal agent	Effect of Cu on disease*
BACTERIAL DISEASES			
Bean	Halo blight	*Pseudomonas phaseolicola*	D
Citrus	Canker	*Xanthomonas citri*	D
Tomato	Bacterial speck	*Pseudomonas tomato*	D
	Bacterial spot	*Xanthomonas vesicatoria*	D
	Bacterial wilt	*Clavibacter michiganensis*	D
FUNGAL DISEASES			
Bean	Anthrachnose	*Colletotrichum lindemuthianum*	I
Citrus	Leaf spot Fruit spot	*Septoria citri*	D
Grapefruit	Greasy spot	*Mycosphaerella citri*	D
Onion	Storage rot	*Alternaria porri*	D
	Storage rot	*Aspergillus niger*	D
	Storage rot	*Botrytis alii*	D
	White rot	*Sclerotium cepivorum*	D
Orange	Brown rot	*Phytophthora citrophthora*	D
	Brown rot	*Phytophthora syringae*	D
Tomato	Collar rot	*Alternaria solani*	D
	Early blight	*Alternaria solani*	D
	Target spot	*Corynespora caasiicola*	D
	Wilt	*Fusarium oxysporum* f. sp. *lycopersici*	D
	Mildew	*Phytophthora infestans*	D
VIRUS DISEASES			
Cucumber	Mosaic	*Cucumber mosaic virus*	I
Mosaic	Mosaic	*Tomato mosaic virus*	I
ABIOTIC DISEASES			
Grapefruit	Melanose	Frost	D

*** D = decrease in disease. I = increase in disease.**

Nickel and Plant Disease: *Adapted from Bruce W. Wood and Charles C. Reilly's chapter in American Phytopathological Society.*

Nickel (Ni) is an important cofactor and/or enzyme activator of metabolic and disease defensive pathways in plants. Nickel generally plays a more important role in woody perennials than in other plants. Generally the trace amount of Ni required for proper growth can be found in most soils. However, a key factor noted in all orchards exhibiting Ni deficiency is that an excessive amount of another metallic cation was present. Application of Ni through foliar applications bypasses this problem. In pecan orchards, the other metal is usually Zn, but excessive amounts of Cu, Ca, Mn, or Mg all contribute. Ni deficiency was induced in potted greenhouse-grown pecan trees by the addition of Fe, Mn, Zn, or Cu to the soil. Manipulation of soil chemistry by the addition of one or many different nutrient elements have been observed to influence replant or short-life disorders of trees in particular in pecan. These disorders are typically most severe in monoculture. Pathogenic factors, such as nematodes, fungi, and bacteria, are commonly associated with replant or short-life type disease.

Silicon, Aluminum and Plant Disease: *Adapted from Lawrence E. Datnoff's chapter on Silicon and Plant Disease and H.D. Shew, E.J. Fichtner, and D.M. Benson's chapter on Aluminum and Plant Disease in the American Phytopathological Society.*

Silicon (Si) is the second most abundant mineral element in soil. Silicon reinforces cell walls and acts as a signal to elicit plant mediated disease resistance. During the weathering process, silicates are gradually removed from the soil, which allows increased activity of Al^{3+}. In acid soils, the heightened level of available Al is a major factor limiting plant growth and development. Exchangeable Al is absorbed nonspecifically to negatively charged sites on clay minerals and hydrous oxides of Fe, Al, and Mn, by electrostatic forces.

Aluminum can be highly toxic to plants and microorganisms which may be beneficial or harmful. In many agricultural soils in tropical regions, Al rhizotoxicity in surface and subsurface soils can limit taproot extension and lateral root development. Secondary effects include reduced nutrient uptake, tolerance of drought stress, and overall reduction of productivity. Nearly all toxicities found in the volcanic uplands are related to soil pH and Al. Lime is the proper solution to those problems however lime is not very soluble and therefore should be incorporated into the soil. If incorporation is not possible, such is the case with subsoil Al toxicity in Akina soils (Table 2-3), then it is best to add gypsum (hydrated calcium sulfate) to the topsoil. Because gypsum is highly soluble, its Ca and SO_4 ions can move into the subsoil where they replace Al ions on clay and organic matter surfaces. This allows a majority of the Al ions to leach away. Some of the free Al ions will combine with the SO_4 to form a complex ($AlSO_4^+$) which renders the aluminum non-toxic.

The amount of soluble Si decreases in soil as the pH increases and water availability decreases. The beneficial effects of Si, directly or indirectly, on plants under biotic and abiotic stresses have been reported to occur primarily in monocots. The influence of Si on diseases reported in the Mariana Islands can be found in Table 3-28. The region's highly weathered oxisols (Table 2-2) would be expected to show the greatest benefit to added Si.

Table 3-28. Effect of added silicon on plant diseases.

Host	Disease or disorder	Pathogen or causal agent	Effect of Si on disease*
MONOCOTS			
Corn	Stalk rot	*Pythium aphanidermatum* *Fusarium moniliforme*	D
	Corn smut	*Ustilago maydis*	D
Sugarcane	Rust	*Puccinia melanocephala*	—
	Ringspot	*Leptosphaeria sacchari*	D
Bermuda-grass	Leaf spot	*Bipolaris cynodontis*	D
Creeping bentgrass	Root rot	*Pythium aphanidermatum*	D
	Brown patch	*Rhizoctonia solani*	D
	Dollar spot	*Sclerotinia homoeocarpa*	D
St. Augustine grass	Gray leaf spot	*Magnaporthe grisea*	D
Zoysiagrass	Leaf blight	*Rhizoctonia solani*	D
DICOTS			
Cucumber	Powdery mildew	*Sphaerotheca xanthii*	D
	Anthracnose	*Colletotrichum orbiculare*	D
	Anthracnose	*Colletotrichum lagenarium*	—
	Leaf spot	*Corynespora citrullina*	D
	Crown rot	*Pythium ultimum*	D
	Root rot	*Pythium aphanidermatum*	D
	Gray mold rot	*Botrytis cinerea*	D
	Black rot	*Didymella bryoniae*	D
	Fusarium wilt	*Fusarium oxysporum* f. sp. *cucumerinum*	D
Lettuce	Pythium root rot	*Pythium* spp.	—
Muskmelon	Powdery mildew	*Sphaerotheca xanthii*	D
Pumpkin	Powdery mildew	*Sphaerotheca xanthii*	D
Soybean	Stem canker	*Diaporthe phaseolorum* f. sp. *meridionalis*	D
Strawberry	Powdery mildew	*Sphaerotheca macularis* f. sp. *macularis*	D
Tomato	Fusarium wilt	*Fusarium oxysporum* f. sp. *lycopersici* races 1 and 2	—
	Fusarium crown and root rot	*Fusarium oxysporum* f. sp. *radicis-lycopersici*	—
	Powdery mildew	*Odiopsis sicula*	D —*
	Bacterial wilt	*Ralstonia solanacearum*	D
Zucchini squash	Powdery mildew	*Erysiphe cichoracearum*	D

D = decrease in disease.

*** Silicon decreases disease intensity if sprayed on leaves but has no effect on disease if added to the nutrient solution.**

Zinc and Plant Disease: *Adapted from Brion Duffy's chapter in Mineral Nutrition and Plant Disease 2007 by the American Phytopathological Society.*

Zinc deficiency is one of the most widespread plant deficiencies worldwide and is a major constraint on crop production. However, since zinc is required by plants at such low levels, evaluating whether a plant is deficient in this element can be difficult. Zinc is relatively immobile in plants, and deficiency symptoms are typically manifested first in new growth. Seedling are most sensitive to zinc deficiency, but plants generally out grow it. Soilborne diseases of tomato, corn, avocado, potato, and watercress have been reduced with the application of Zn. The influence of Zn on diseases reported in the Mariana Islands can be found in Table 3-30.

Table 3-30. Effect of zinc amendments on some plant diseases and biological control agents.

Host	Disease or disorder	Pathogen or causal agent	Effect of Zn on disease*
DISEASES			
Citrus	Citrus blight	Unknown etiology	Accumulates in phloem of affected trees
Tomato	Crown and root rot	*Fusarium oxysporum*	I
	Tobacco mosaic		D ($ZnSO_4$)
Various Hosts	Vascular wilt	*Fusarium oxysporum*	I
Bean	Tobacco mosaic		I ($ZnSO_4$)
Cowpea	Rhizoctonia root rot	*Rhizoctonia solani* *Rhizoctonia bataicola*	D
Corn	smut	*Ustilago maydis*	D
Coconut	Lethal yellowing	*Phytoplasma*	Induces regreening of foilage
BIOLOGICAL CONTROL AGENTS			
Tomato	—	*Pseudomonas fluorescens*	Improves biocontrol of *Fusarium oxysporum* by repressing pathogen toxin that blocks production of antagonist antibiotic
Tomato	—	*Pseudomonas fluorescens*	Improves biocontrol of *Meloidogyne incognita* by repressing *Rhizoctonia* metabolite that blocks antinematicidal activity of antogonist
In vitro		*Pseudomonas fluorescens*	Stimulates siderophore and salicylate production
Mung bean, tomato		*Pseudomonas fluorescens*	Stimulates production of nematicidal compounds; improves biocontrol of *Meloidogyne javanica*
***In vitro* and cucumber**		*Pseudomonas fluorescens*	Stabilizes mutation rate in *gacS/A* regulatory genes
Tomato		*Psuedomonas aeruginosa*	Improves control of *Macrophomina* and *Fusarium* and *Meloidogyne javanica*

*** D = decrease in disease. I = increase in disease.**
Zinc effects are dependent on dosage, and excess or insufficiency can have markedly different results.

Chlorine and Plant Disease: *Adapted from Wade H. Elmer's chapter in Mineral Nutrition and Plant Disease 2007 by the American Phytopathological Society.*

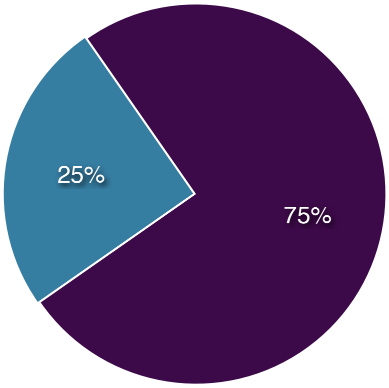
Chlorine (Cl) suppressed diseases on crops that are tolerant of Cl such as asparagus, beets, celery, and corn perhaps by enhancing Mn uptake. Long before herbicides were available, growers used rock salt (NaCl) to suppress weeds in various crops that have a high tolerance for chloride. In acid soils, chloride has the ability to inhibit the nitrification of NH_4 to NO_3, presumably as a result of inhibitory effect on species of *Nitrosomonas* bacteria. Most reports demonstrate disease suppression with chloride fertilization. Coconut and date palms are likely to have evolved in saline soils and grow in proximity to shoreline habitats, so it may not be surprising that they have a positive response to NaCl. It has been reported that applications of NH_4Cl, KCl, and NaCl are a major factor in restoring infertile soils in the Philippines. NaCl applications are effective against leaf spot of coconut caused by *Bipolaris incurvata* and Fusarium wilt of date palm caused by *F. oxysporum* f. sp. *albedinis*. The influence of Cl on diseases that occur in the Mariana Islands can be found in Table 3-29.

Table 3-29. Diseases and pathogens suppressed by chloride amendment.

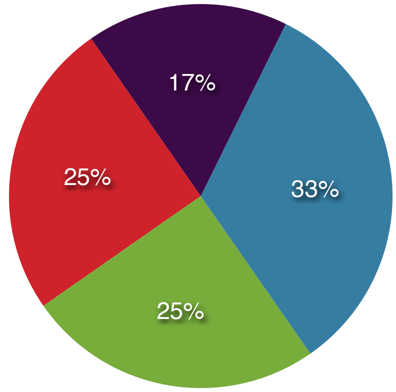
Host	Disease or disorder	Pathogen or causal agent
Coconut	Leaf spot	*Bipolaris incurvata*
Corn	Stalk rot	*Giberella zeae* *G. fujikuroi*
	Smut	*Ustilago maydis*
Date palm	Fusarium wilt	*Fusarium oxysporum* f. sp. *albedinis*
Soybean	Soybean cyst nematode	*Heterodera glycines*
	Sudden death	*Fusarium oxysporum* f. sp. *albedinis*

Survey results from twenty farmers in 2002 and twelve in 2010. The objective of the survey was to determine farmers' current practices as they related to crop production and soil nutrient management.

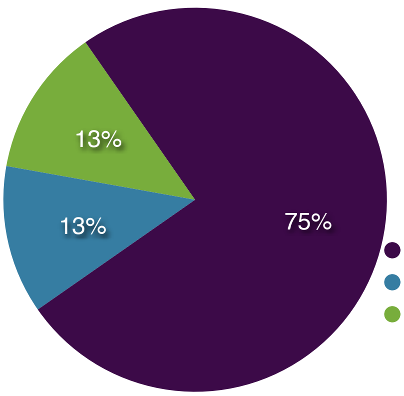
Farmer profile



Farmers who had their soil tested (2010).

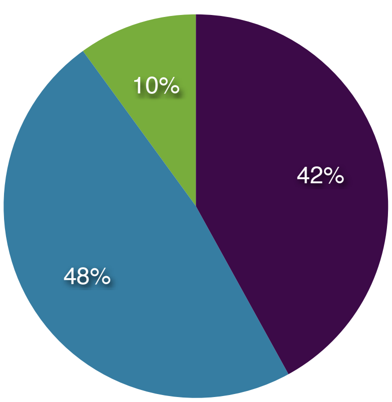


Farmers who had knowledge of their farm's pH (2010).

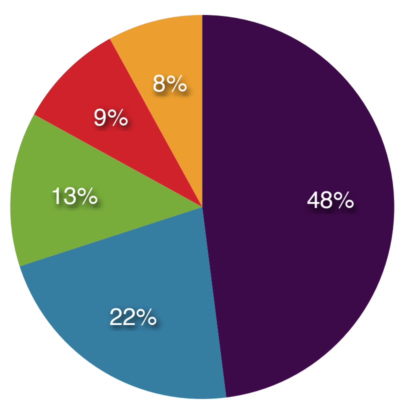


Farmers who have been advised by University of Guam and/or Guam Department Agriculture personnel on fertilizer practices (2010).

Seasonal preference and main production problems



Farmer's seasonal preference for growing eggplants, peppers, and tomatoes (2002).

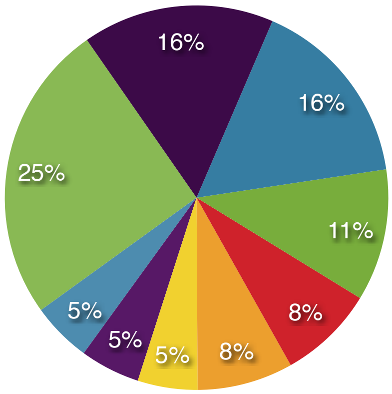


Farmer's main production problems with eggplants, peppers, and tomatoes (2002).

Dry season advantages:
- Easier to work soil
- less cracking in tomatoes
- higher tomato/pepper yield
- rainfall is not excessive

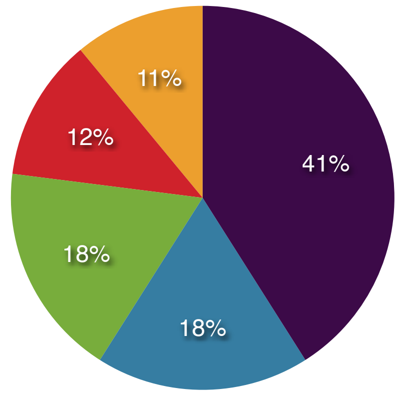
Wet season advantages:
- reduced need for irrigation

Crops and harvest



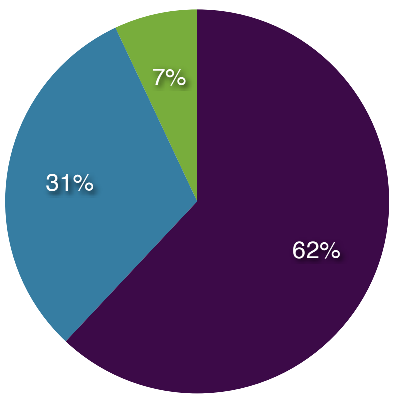
Most common crops grown (2010).

- Eggplant (16%)
- Cucumber (16%)
- Tomato (11%)
- Watermelon (8%)
- Beans (8%)
- Banana (5%)
- Papaya (5%)
- Pepper (5%)
- Other (25%)



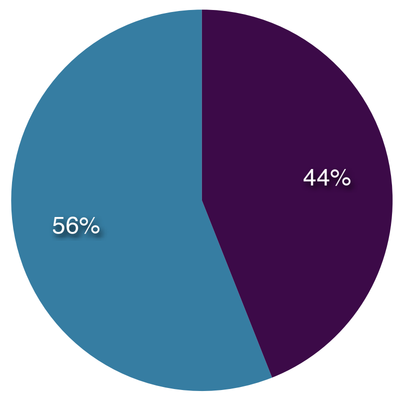
Length of harvest for eggplants (2002).

- 1 year
- 2–3 months
- 4 months
- 6–8 months
- 2 years



Length of harvest for tomatoes (2002).

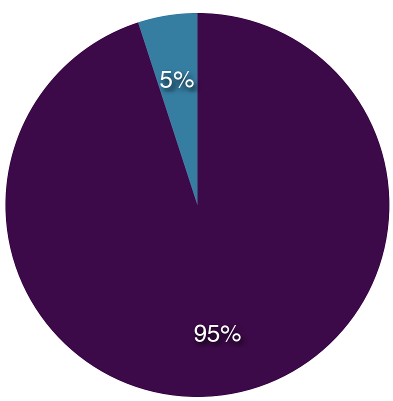
- over 4 months
- 3–4 months
- 1–2 months



Length of harvest for peppers (2002).

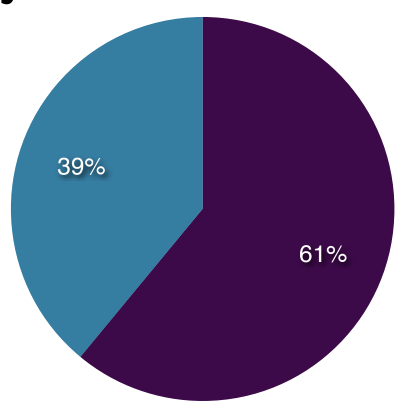
- 1 year
- 2–6 months

Irrigation



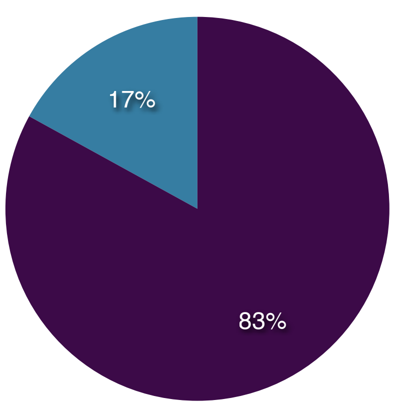
Farmers that use irrigation (2002).

- Yes
- No



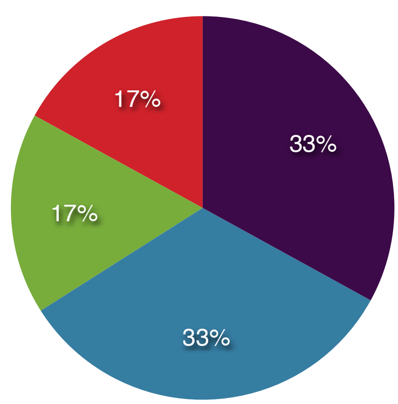
Farmer's irrigation preference (2002).

- Drip line
- Sprinkler/hose



Frequency of sprinkler/ hose irrigation sessions(2002).

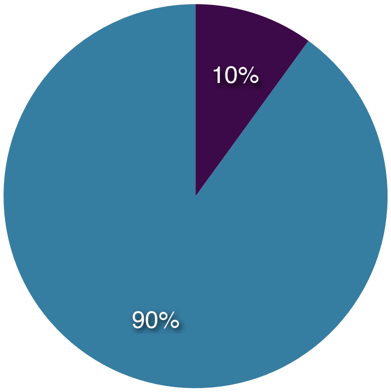
- every day
- 3 times a week



Duration of sprinkler/ hose irrigation session (2002).

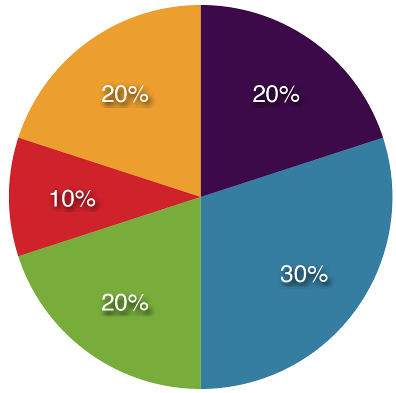
- 1 hour
- 2 hours
- 1–2 hours
- 1–3 hours

Irrigation (continued)



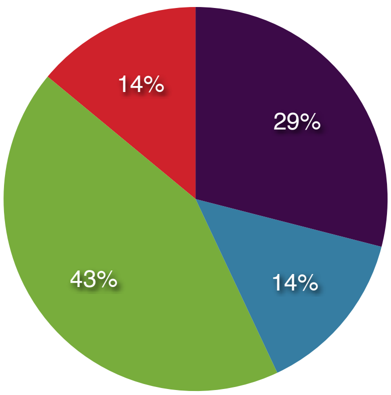
Type of drip line used (2002).

- other
- turbulent flow



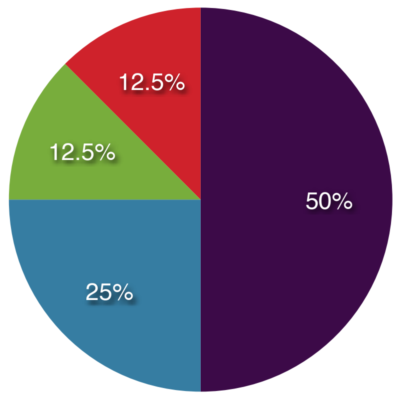
Frequency of drip line replacement (2002).

- 1 year
- 2 years
- 3–4 years
- 5–6 years
- as infrequent as possible



Duration of drip line irrigation session (2002).

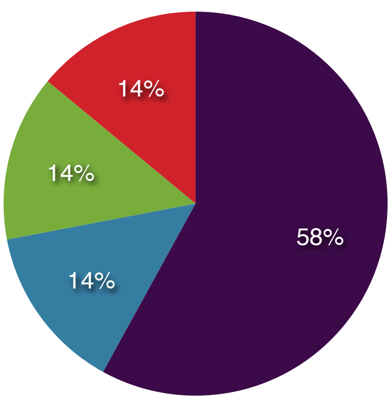
- 24 hours
- 5 hours
- 2–4 hours
- 1 hour



Frequency of drip line irrigation sessions (2002).

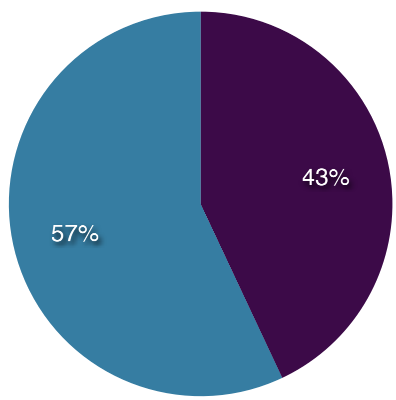
- every other day
- every day
- 3 times a week
- every 2 days

Fertilization



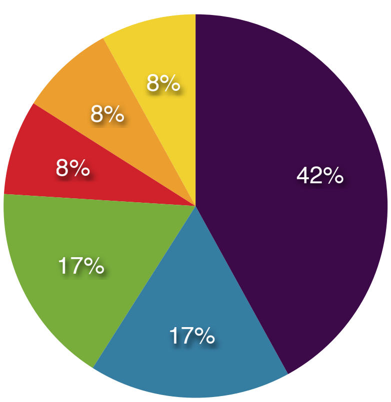
Frequency of fertigation (2002).

- once a week
- every 2 weeks
- once a month
- 3 times a season



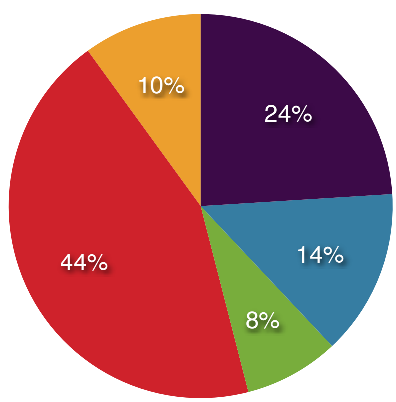
Frequency of farmers experiencing trouble with clogging drip lines.

- yes
- no



Frequency of banding or broadcasting of fertilizers (2002).

- once a week
- once a month
- preplant & during harvest
- 1–2 times a week
- every 5 days
- one time only

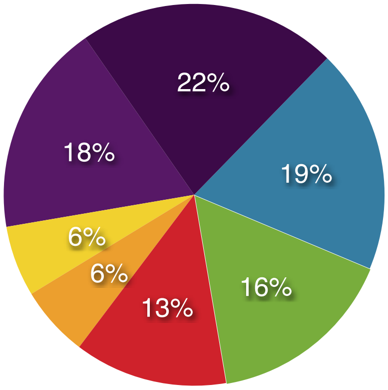


Commonly used fertilizers reported in 2002.

- 16-16-16
- 10-20-20
- 21-0-0
- 10-0-10
- Other

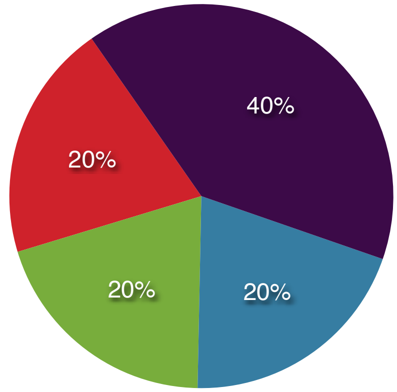
  10-30-30
  46-0-0
  chicken manure

Fertilization (continued)



Types of chemical fertilizers reported (2010).

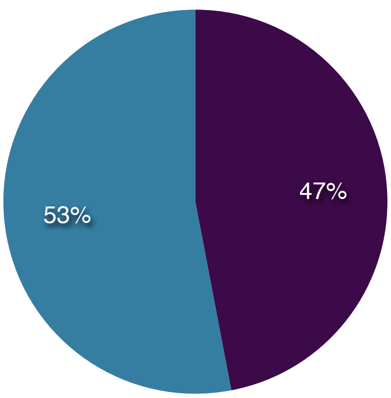
- 10-20-20 (22%)
- 16-16-16 (19%)
- 46-0-0 (16%)
- 0-0-62 (13%)
- 0-45-0 (6%)
- 21-0-0 (6%)
- Others (18%)



Types of organic fertilizer reported (2010).

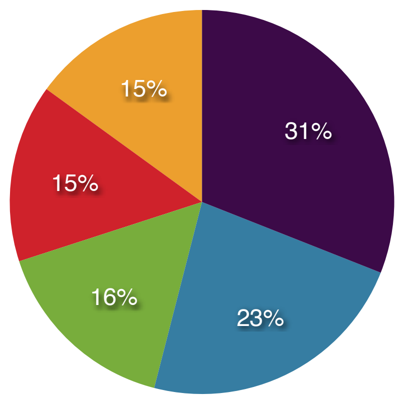
- Chicken manure
- Other animal manures
- Compost/shredded paper
- Green manures

Mulching



Growers that apply mulch (2002).

- yes
- no



Mulch materials used by farmers (2002).

- grass clippings
- dry leaves
- plastic
- newspaper
- woodchips

This publication provides what the contributors feel to be the core information that agriculture professionals and advanced students should know about soil fertility and nutrient management in plant health and disease suppression. Though the information in the guide is derived from scientific research, we should keep in mind that our ancestors were cultivating crops for thousands of years without such information; however largely at the mercy of the soil environment. Through the application of modern soil science, today's producers have the ability to control the soil environment to their advantage and produce yields that a century ago were impossible.

To produce a successful crop, a crop's needs must be matched with the proper environment. Matching crop requirements to the soil reduces the chance of a crop failure. There are many different soils in the Mariana Islands each with its own characteristics and its own crop suitability. Using the principles of soil science and the application of technology, most crops of the tropics and subtropics can be grown here. The soil is like a collection of sponges from which plants must obtained their nutrients and water. A good sponge for nutrients would be slightly acidic, would be largely clay or clay loam in content and would have a cation exchange capacity (CEC) of 40 or greater. A good sponge for water would be soil that is 30 cm or more in depth and contains a minimal amount of sand.

Irrigation is an essential part of farming year-round in the Mariana Islands. This is due to their uneven yearly rainfall (wet and dry season) and shallow soils. When plant growth is limited by lack of water then its N requirement is lower. It is important to remember that the vast majority of soil nutrients are absorbed by plants as ions in solution and that the concentration of these ions in the soil may be deficient or excessive depending on water availability. A nutrient with a low soil diffusion rate, such as K, can be adequate in the soil but limiting in a crop because the amount of water was inadequate to move it to the roots. On the other hand, too much water is harmful as it will leach highly mobile nutrients such as N.

A synopsis of Guam agriculture soil tests from 1984-1993 in the 1994 Guam Agricultural Experimentation Annual Report sums up some of what is known about Guam's soils.

Organic matter	4 – 6%
pH	7.0 – 8.0
P	0 – 10 ppm
K	40 – 80 ppm
Ca	3,600 – 4,800 ppm
Mg	0 – 280 ppm
Fe	0 – 15 ppm
Zn	0 – 10 ppm
Na	75 – 100 ppm
Mn	0 – 50 ppm
Cu	0 – 2 ppm

The authors of the report (P.P. Motavalli, J.A. Cruz, and R.Y. Marasigan) suggest that a large proportion of farms on Guam may be experiencing deficiencies in P, K, Zn, and Mn. They also felt that problems related to high pH, such as low P, Fe, Zn, Mn, and Cu availability, may also be common. Soils submitted from northern districts generally were higher in pH, organic matter and P content and lower in K, Mg, Fe and Cu than soils submitted from the southern districts.

Pacific basin soils characteristics	Explanation
Infertile	Soils are highly weathered resulting in soils low in organic matter and with minerals that have a low ability to hold nutrients.
Nutrients in topsoil	Most islands were formally forested. Nutrient cycling has put most of the soil nutrients in the top soil.
Subsoils are poor	Barrier to roots, low fertility, Al-toxicity
Low ability to hold nutrients	Soils are shallow and have a low exchange capacity.
Positive and negative charged sites	Charge sites are pH-dependent.
Fragile	Soils are thin and have low resistance to disturbance.
Absorb phosphate fertilizer	Soluble phosphorus reacts with clay, iron, calcium, and aluminum compounds in the soil and is converted easily to less available forms.

Plant nutrition influences a plant's growth as well its associated microbes. Of particular interest to farmers is the impact of plant nutrition on pathogens and their associated diseases. The interaction of nutrition and plant disease is dynamic; therefore, recommendations that deviate from those of optimum nutrition should be given with caution until confirmed by research in the Mariana Islands. A particular element may decrease the severity of some diseases, but increase others, and some have an opposite effect in different environments. For now in the Mariana Islands, attention, should be focused primarily on those nutrients that are limited in a particular environment. For example, the application of K to deficient soils often increases host resistance to a number of diseases. Fungal and, to a larger extent, bacterial diseases are often reduced with increased Mn availability.

Be reminded that in general, the greatest benefit to a crop is provided when its full nutrient sufficiency is provided. Though it has been shown that crops can be produced under less than optimal conditions, there is always a trade-off in yield or quality. Any soil in the Mariana Islands can be productive and can remain that way for generations, provided the proper crop is planted, the water supply is adequate, the weeds are controlled, the soil is protected from degradation, and the soil nutrient levels are properly managed.

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Motavalli, P.P., **Cruz, J.A.**, and **Marasigan, R.Y.** 1996. Guam Soil Test Summary, 1984-1993. Soil and Plant Testing Laboratory, Guam Agriculture Experiment Station, University of Guam, Mangilao, Guam. 17 pp.

Young, F.J. 1988. Soil survey of the territory of Guam. USDA Soil Conservation Service, National Cooperative Soil Survey.

Young, Fred J., **Dean W. Burkett**, and **Terry L. Huff**. July 1989. Soil Survey of the Islands of Aquijan, Rota, Saipan, and Tinian, Commonwealth of the Northern Mariana Islands. Soil Conservation Service, U.S. Department of Agriculture

Selected Web Sites

Natural Resources Conservation Service (NRCS), Pacific Islands Area (PIA) http://www.pia.nrcs.usda.gov/

Soil Survey Division of NRCS is at http://soils.usda.gov/

Institute of Pacific Islands Forestry Pacific Island Ecosystems at Risk (PIER) at www.hear.org/pier/

IPM (Integrated Pest Management) Center, Crop at www.ipmcenters.org/cropprofiles/

WPTRC (Western Pacific Tropical Research Station), University of Guam (UOG), at http://www.wptrc.org/

UOG (University of Guam), Cooperative Extension Service (CES), Agriculture Natural Resources (ANR) at http://www.uog.edu/

EDIS Electronic Date Information Service (University of Florida IFAS Extension) at http://edis.ifas.ufl.edu/

For additional information, please contact an agricultural extension agent at the Guam Cooperative Extension, College of Natural and Applied Sciences, University of Guam, you may call 734-2080 or write to the Guam Cooperative Extension, College of Natural Applied Sciences, University of Guam, UOG Station, Mangilao, Guam 96932.

Issued in furtherance of Cooperative Extension Works, Acts of May 8 and June 13, 1914, in cooperation with the United States Department of Agriculture (USDA), Dr. Lee S. Yudin, Dean/Director, Guam Cooperative Extension, College of Natural and Applied Sciences, University of Guam, 2011.