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Chapter 5

Use of Information from Soil Surveys and Classification

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The purpose of soil classification is to organize what we know about soils so that this knowledge can be used to predict the behavior and performance of soils. Such predictions are of value to growers, engineers, land owners, extension agents, and government officials.

As an illustration of this concept, consider the example of a soil that can be said to "behave" like a sponge by holding a large amount of water against the force of gravity; such a soil would not need to be irrigated as frequently as a soil that behaves like a sieve. Or, consider that a wetland-taro grower wants a soil that can be wetted and made to behave like a viscous liquid, whereas an engineer prefers a soil that can be compacted to behave like an elastic solid.

We want to be able to predict soil behavior because behavior also tells us something about soil performance. We need to know whether a soil will "perform" well for such various uses as a taro patch, vegetable farm, orchard, road, reservoir, embankment, cemetery, or foundation for a building.

Because the many different kinds of soils behave and perform differently, soil scientists have devised standard procedures to describe, characterize, and name all possible kinds of soils that might occur. Names are useful because they help us recall the characteristics of an object, whether it be an animal, plant, person, or soil.

Before soils can be named, an inventory of the kinds of soils that occur in a region must be made. Such an inventory is called a soil survey. The purpose of a soil survey is to acquire knowledge of the spatial distribution of the kinds of soils that occur on the landscape. A trained soil surveyor draws boundaries around different kinds of soils to produce a soil map for the region. Because abrupt boundaries between soils are rare, the surveyor draws a line between two different soils that vary continuously from one to the other. This immediately tells us that the soils within a boundary cannot be homogenous and pure. The purity of a mapped soil increases with the intensity (or detail) of the survey. Where land is expensive, a very high-intensity survey may be conducted, whereas in mountainous areas, a low-intensity or "reconnaissance" survey may be more likely.

In a soil survey, a detailed description is kept of each kind of soil that is mapped. An example of such a description is shown in Table 5-1. It is evident from the description that this soil, like most, is naturally organized into layers called horizons, and that each horizon differs from the one above and below it. Each horizon is designated by its depth, color, particle size distribution, structure (the way soil particles are bound together and arranged in the horizon), consistency (stickiness and plasticity), pore size distribution, quantity of roots, and other features that the surveyor considers important to the eventual naming of the soil. Such descriptions enable soil scientists to see similarities and differences among soils, just as we see them in plants and animals. But unlike plants and animals, the characteristics of soils that set them apart are not entirely discernable by eye and must be measured in the labo-

Table 5-1. Example of a soil description.[z]

PAALOA SILTY CLAY
S58Ha-7-1

Location: Island of Oabu, Honolulu County, Hawaii; .81 km (1/2 mile) northwest of Wahiawa, turn northeast from Highway 80 on to Highway 804 leading to Wahiawa Naval Radio Station. Sample pit is located in Naval Reservation about 1.2 km (3/4 mile) east of main gate, 60 m (200 feet) south on road to Poamoho Tunnel. **Date of sampling:** 1958.
Description by: D. Womack. **Collectors:** D. Womack and J. M. Williams.
Classification: Humoxic Tropohumult, clayey, oxidic, isothermic.
Vegetation: Broomsedge (*Andropogon virginicus*), hilograss (*Paspalum conjugatum*), ricegrass (*Paspalum orbiculare*), Glenwoodgrass (*Sacciolepis contracta*). Along edges of drainageways on both sides of upland is cover of koa (*Acacia koa)*, Molucca albizzia (*Albizia falcata*), and staghorn fern (*Gleichenia linearis*). **Climate:** Average annual precipitation is about 175 to 250 cm (70–100 inches). The mean annual temperature is 21.1℃ (70℉), the mean January temperature 19.4℃ (67℉), the mean July temperature 22.8℃ (73℉). **Parent material:** Weathered olivine basalt. **Topography:** Nearly level, narrow medial upland slopes of Koolau Range. Slope 2 percent convex to southwest. **Elevation:** 354 m (~180 feet).
Drainage: Well drained; moderately rapid permeability; slow runoff. **Soil moisture:** Moist.
Remarks: Textures are apparent field textures. Colors are for moist soil. Paired sample number S58Ha-7-2.

HORIZON	DESCRIPTION
Ap BSL No. 59574	0 to 23 cm (0-9 inches), dark reddish brown (5YR 3/2) silty clay; strong medium granular structure; firm, sticky, plastic; many roots; many fine and very fine interstitial pores; common wormholes and casts; few small highly weathered pebbles; few small pieces of charcoal; very slight reaction with hydrogen peroxide; abrupt wavy boundary.
B21 BSL No. 59575	23 to 53 cm (9-21 inches), dusky red (1OR 3/3) silty clay; strong very fine subangular blocky structure; firm, sticky, very plastic; many roots; many fine and very fine tubular pores; continuous thin glaze on all peds (possibly oxide coating); no reaction with hydrogen peroxide; abrupt wavy boundary.
B22 BSL No. 59576	53 to 95 cm (21-38 inches), dark red (2.5YR 3/6) silty clay; strong very fine subangular blocky structure; firm, sticky, very plastic; few roots, mostly following cleavage planes; root mat on top of this horizon; many fine and very fine tubular pores; this horizon is firm in place; dusky red (1OR 3/3) glaze on most peds and in pores, some of which look like clay film; many small fragments of highly weathered rock; no reaction with hydrogen peroxide; gradual wavy boundary.
B3 BSL No. 59577	95 to 155 cm (38-62 inches), reddish brown (5YR 4/4) silty clay; moderate fine subangular blocky structure; friable, sticky, very plastic; very few roots; many fine and very fine tubular pores; dark red and dusky red glaze on most peds and in pores, some look like clay film and some appear to be oxide coatings; many small highly weathered rock fragments; no reaction with hydrogen peroxide; clear wavy boundary.
C BSL No. 59678	155 to 165 cm (62-66 inches), yellowish brown and brown highly weathered rock. This appears to be highly weathered material around a solid boulder core; abrupt boundary.
R Not sampled	165 cm (66 inches), basic igneous rock.

[z]The information in Tables 1 and 2 is from *Soil survey laboratory data and descriptions for some soils of Hawaii* (1976). Note that in subsequent revisions to the *Soil Taxonomy*, the Paaloa series has been reclassified; see Table 3.

Table 5-2. Example of soil laboratory data.

SOIL FAMILY **Humoxic Tropohumult, clayey, oxidic, isothermic** — U.S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE

SOIL SERIES **Paaloa silty clay** SOIL Nos. S58Ha-7-1 LOCATION Honolulu County, Hawaii

Beltsville Lab Nos. 59574 - 59578

Depth (cm)	Horizon	Mineralogical Analysis: 7A2 Allophane	Montmorillonites	Micas	7A3 Kaolinites	7A3 Gibbsite	Boehmite	Goethite	Amorphous SiO_2	Amorphous Al_2O_3	Magnetite etc.	Anatase	7A2 Quartz	Volcanic glass	Feldspar	Olivine	Pyroxene	Pyrite
		Percent of Whole Soil																
0-23	Ap	-		1X	15	15							1X					
23-53	B21	-		1X	25	15							1X					
53-95	B22	-		-	35	10							-					
95-155	B3	-		-	45	10							-					
155-165	C																	

Depth (cm)		Total Chemical Analysis: SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO_2	MgO	CaO	Na_2O	K_2O	P_2O_5	L.O.I.	Total	Extractable iron 6C1a: Fe	Fe_2O_3	Carbonate as $CaCO_3$ 6E1b	0.5N NaOH Soluble: SiO_2	Al_2O_3
		Percent of Whole Soil																
0-23	Ap	24.26	11.44	17.92	37.84	0.09						14.22	105.8	17.8	25.5			
23-53	B21	13.62	5.84	26.32	42.24	0.08						16.90	105.0	21.2	30.3			
53-95	B22	19.76	6.48	31.28	31.04	0.09						14.86	103.5	12.8	18.3			
95-155	B3	17.24	6.56	31.52	31.92	0.09						15.33	102.7	15.3	21.9			
155-165	C	20.84	7.23	27.92	33.97	0.04						12.70	102.7	11.2	16.0			

Depth (cm)	6A1a a/ Organic carbon Pct.	6B2a Nitrogen Pct.	C/N	Extractable bases 5B1a: 6N2a Ca	6O2b Mg	6P2a Na	6Q2a K	Sum of bases	Extr. acidity 6H2a	CEC 5A3a Sum of Cation	CEC 5A4 by K Sat. pH7	NH_4OAc extr. SO_4	KCl extr. Al^{+++} 6G1D	Base saturation 5C1 NH_4OAc	Base saturation 5C3 Sum	pH 8C1a H_2O 1:1	pH 8C1c KCl 1:1	
				Meq./100 g.										Percent				
0-23	3.19	0.261	12	0.8	0.3	0.2	0.2	1.5	27.8	29.2	24.2				5	4.8	4.5	
23-53	1.26	0.090	14	0.4	0.1	0.2	0.1	0.8	27.5	28.2					2	4.8	4.6	
53-95	0.42	0.048	9	0.6	0.1	0.1	Tr.	0.8	14.9	15.8	13.6				6	5.0	4.6	
95-155	0.46	0.038	12	1.4	0.1	0.1	Tr.	1.6	15.7	17.3					10	5.1	4.7	
155-165	0.54	0.034	16	1.0	0.1	0.1	Tr.	1.2	24.3	25.5	17.0				5	5.2	5.3	

Depth (cm)	Size class and particle diameter (mm) 3A1: Sand (2-0.05)	Silt (0.5-0.002)	Clay (<.002)	Coarse fragments >2mm pct. of whole soil	Atterberg limits: Plastic limit	Liquid limit	Plastic index	Bulk density: 1/3 bar	Oven dry	4A3a Field moist	Particle density	Water content: 4B4 Field moist.	4B1c 1/3 bar	4B2a 15 bar	Extensibility 4D1: COLEf	COLE
	Pct. of 2mm.							g/cc				Pct. of whole soil			cm/cm	
0-23	4.0	33.0	63.0							0.98		37	36.8	33.5		
23-53	4.0	18.1	77.9							1.10		42	40.1	38.2		
53-95	12.5	24.5	63.0							1.11		40	40.4	36.1		
95-155	8.0	37.5	54.5									40	40.1	35.2		
155-165	13.4	73.0	13.6									59	51.6	14.2		

a/ 13.6 kg of organic carbon per square meter to a depth of 1 meter.

ratory. The laboratory data corresponding to the soil described in Table 5-1 are shown in Table 5-2. The field description and laboratory data in Tables 5-1 and 5-2, along with a soil survey, now make it possible to give classificatory, or "taxonomic," names to the soil. As one would expect, soils that are similar have similar taxonomic names.

Between 1950 and 1975, soil scientists from the U.S. Department of Agriculture (USDA) developed a comprehensive system for classifying and naming soils. Like the Linnean system of classifying plants and animals, the new system of soil classification is multi-categorical, or hierarchical. If we take humans as an example, as *Homo sapiens* we are the sole extant species of our genus, but in a broader biological category we are taxonomically related to chimpanzees, and to cats and fishes in yet broader categories. One of the important characteristics of a hierarchical classification system is that the information about the object being named increases and becomes more specific as the objects being categorized are more alike.

In 1975, USDA issued a handbook entitled *Soil Taxonomy*. This handbook provides rules and procedures for classifying soils on the basis of analytical data and soil profile descriptions such as are illustrated in Tables 5-1 and 5-2. Much of the data used to classify the soils of Hawaii are contained in another USDA document entitled *Soil Survey Investigations Report no. 29; Soil Survey Laboratory Data and Descriptions for Some Soils of Hawaii* (1976).

The *Soil Taxonomy* consists of six categories, starting with the soil order at the highest level and followed by the suborder, great group, subgroup, family, and series. These are distinguished and illustrated by examples in Table 5-3. Series names are often the names of places where the soil was first described. Thus the Molokai and Lahaina soil series on the Hawaiian island of Oahu obtained their names from similar soils first described on the island of Molokai and in Lahaina on the island of Maui. Hawaii even has a soil named after a location in Puerto Rico.

The aim of soil survey and classification is to give identical names to soils that behave and perform alike. For example, if a soil in Brazil proves to be excellent for producing arabica coffee, we can expect the same of a similarly classified soil in Hawaii. It is no accident that soils of the Molokai series on Oahu and Molokai have been used for nearly identical purposes.

Soils classified in the same series (and thus given the same name) should not only look alike but should behave and perform alike. What about soils with the same family names? Can they be expected to behave alike? It turns out that, next to the series, the soil family is the most useful level for learning from the performance successes and failures of closely related soils. If a crop does well on a particular soil, it is very likely that the crop will also do well on all other soils belonging to the same soil family. Not only will the crop be expected to perform similarly, but the management practices required to achieve a specified level of performance should also be nearly alike. This method of exchanging soil management information among closely related soils is called "technology transfer by analogy." This principle of technology transfer by analogy can be illustrated by the following example, as the soil order Andisol is discussed.

Andisols

The example is the soil family named *medial, isothermic, Typic Eutrustand*. In Hawaii, members of this soil family and their close relatives are the best soils for growing vegetables. We should not be surprised if members of this soil family also turn out to be well suited for growing vegetables elsewhere in the world.

Two local soils that belong to this family are the Kula soil series on Maui and the Waimea soil series on the island of Hawaii. Like siblings, these soils were derived from similar parent materials (volcanic ash) and developed in places where the temperature is even (*iso*-) throughout the year and cool (-*thermic*). A highly prized attribute of these soils—which vegetable growers probably take for granted—is their loose, easy-to-work characteristic, implied by the term *medial*. These soils are also nonacid (*eutr*-) but may not be able to supply fast-growing vegetables with nutrients such as phosphorus and boron, and the fertilizer application rates required to correct deficiencies for phosphorus and boron are higher than one would expect for nonacid soils.

Many of the soil characteristics relevant to vegetable production are not explicitly given in the family name. In fact, there are so many soil factors that can affect soil performance that it is not possible to accommodate them all in a soil name. Soil attributes that are important for a particular land use but not included in the family name should still be inferable from it. These

Table 5-3. Example of relationships among category subdivisions in soil taxonomy.

Category name	Basis for differentiation	Example of class name	Main features of the class
Order	Dominant soil process that developed soil	Ultisol	Clay accumulation; depletion of bases
Suborder	Major control of current processes; climate	Udult	Soil moist most of the time; humid (udic)
Great group	Additional control of current processes	Kandihumult	Fairly constant soil temperature all year; tropical environment
Subgroup	Blending of processes (intergrades or extragrades)	Typic Kandihumult	Temporary wetness in rooting zone
Family	Internal features that influence soil-water-air relationships	Clayey, oxidic, isothermic Typic Kandihumult[z]	Texture and mineralogy in a control section; soil temperature
Series	Nature of materials that affect homogeneity of composition and morphology	Paaloa	Soil forming in weathering diabase

[z]This classification of the Paaloa series is based on revisions to the *Soil Taxonomy.*

inferred characteristics are called "accessory" characteristics. The unexpectedly high phosphorus and boron requirements of soils in this family are accessory features, which can be inferred from the last three letters (-*and*) in Eutrustand. A farmer in Chile, Costa Rica, Indonesia, The Philippines, New Zealand, or Japan who is familiar with this classification system will know how to extract a large amount of information about a soil just from the letters -*and*. The *and*- in Andisol, derived from the Japanese word *ando*, refers to the dark, nearly black, volcanic ash soils of that country. In fact, the accessory characteristics of *ando* soils are so pronounced and unique that volcanic ash soils were recently placed in their own order: Andisols.

Returning to our example of a Eutr*ustand*, Ustands are Andisols that occur in areas with a pronounced dry season (*ust* = to burn, as in "combust"). Anyone who has been to Kula or Waimea knows that vegetable production there requires irrigation. Having read this, the reader may wonder how the soil taxonomy system accommodates volcanic ash soils that occur in wetter or drier regions. On Maui and Hawaii, the Ustands turn into Udands (humid) in the wetter zones. Logic would suggest that *id* should be chosen over *ud* to represent humid, but it turns out that there is already a soil order that uses *id* in its name. That order is Aridisol, representing soils of arid regions.

Most of the soils that occur in deserts are classified as Aridisols. Water is so important in determining the character of a soil that its absence or presence is given priority in the classification scheme. In Aridisols, water is considered the most important factor in the soils' development, behavior, and performance. How would one classify a soil derived from volcanic ash in a desert? What is more important, water or parent material? In the *Soil Taxonomy*, parent material wins out in the case of volcanic ash soils. A desert Andisol is named Torrand. The prefix *torr*- is taken from "torrid," meaning hot and dry. In Hawaii we have Andisols that occur in the rainforest, in open grassland, and near deserts. Their names—from the wettest to the driest—are Udands, Ustands, and Torrands. We say that these soils occur in "udic," "ustic," and "torric" moisture regimes. One would expect their fertility to decrease with increasing rainfall and wetness. One would also expect soil acidity to increase with rainfall. Nature produces acid, infertile soils in wet zones and nonacid, fertile soils in dry areas. In the original *Soil Taxonomy*,

Table 5-4. Changes in soil pH and the contents (centimoles per kilogram) of calcium (Ca), magnesium (Mg), potassium(K), and sodium (Na) at various soil depths (cm) with rainfall.

Waikoloa Series, 30–40 inches annual rainfall

Depth	Ca	Mg	K	Na	∑	pH
0–13	27.9	7.8	4.80	0.40	40.9	6.6
13–25	28.0	6.4	5.60	0.40	40.4	7.1
25–50	32.6	7.1	4.80	0.80	45.3	7.3
50–63	34.6	9.8	3.00	1.10	48.5	7.5
63–78	33.3	12.8	0.60	1.60	47.7	7.6
78–98	33.0	15.9	0.30	2.20	49.2	7.8
98–125	34.0	12.4	0.50	5.40	52.3	8.l
125–163	33.3	14.4	1.30	6.10	55.0	8.2

Paahau Series, 60–80 inches annual rainfall

Depth	Ca	Mg	K	Na	∑	pH
0–25	14.8	4.5	0.28	0.42	20.0	5.8
25–45	9.9	3.5	0.10	0.44	13.9	6.4
45–70	7.2	3.3	0.09	0.28	10.9	6.4
70–85	4.9	2.2	0.08	0.24	7.4	6.3
85–118	4.2	1.7	0.10	0.25	6.3	6.5
118–143	4.6	1.6	0.09	0.27	6.6	6.5
143	4.7	1.4	0.02	0.19	6.3	—

Hilo Series, 175–200 inches annual rainfall

Depth	Ca	Mg	K	Na	∑	pH
0–38	2.6	2.2	0.2	Tr.	5.0	5.4
38–48	1.4	0.3	0.1	0.1	1.9	5.9
48–50	0.9	0.1	0.1	Tr.	1.1	6.0
50–58	0.9	0.1	Tr.	0.1	1.1	5.9
58–80	1.8	0.3	Tr.	0.1	2.2	6.1
80–85	1.5	0.1	Tr.	Tr.	1.6	6.4
85–100	1.4	0.1	Tr.	Tr.	1.5	6.2
100–133	0.6	0.1	Tr.	Tr.	0.7	6.2
133–153	1.6	0.1	Tr.	0.1	1.8	6.1

∑ refers to the sum of bases. Note that in the Hilo soil, pH remains relatively high even when the sum of bases is very low.

the inherent fertility of soils was often designated at the great group (third category) level. The Kula and Waimea soils were named Eutrandept in the original classification and Eutrustand in the revision. We said that "eutric" implied a nonacid condition, but it also suggests enrichment, as in *eutro*phication of rivers and lakes. As we move beyond the wetter limits of the Kula and Waimea soils, we come to soils like the Maile series of Maui and Hawaii. The Maile series was once known as a Dystrandept (*dystrophy* = faulty nutrition) and is now called Hapludand (*hapl* = simple). As relatives of these soils occurring in the rainforests on the slopes of Haleakala or Mauna Kea are classified, the name Dystrandept can no longer do justice to them. These soils were called Hydrandepts but are now called Hydrudands, and they are among the most unusual soils in the world. As implied by their name (*hydr*-), they consist mainly of water. With the exception of the surface 10 inches, the underlying soil is 60–70% water by volume. And yet these soils have supported a sugar industry for over a century. While these soils are infertile by almost any criteria, their productivity is constrained more by excess rain and cloud cover than by lack of nutrients. This is because soil infertility can be easily corrected by fertilizers.

We can see from Table 5-4 how calcium, magnesium, potassium, and sodium levels vary as we go from the dry zone to the wet. The dry zone is characterized by an abundance of nutrients, but in the high-rainfall areas, nutrient levels reach near-undetectable levels. Most soil scientists trained in Europe or North America would expect the Hilo soil (a Hydrudand) to be very acid. A soil so depleted of bases should show pH values between 4 and 5. What we see are pH values approaching 6. Should such a soil be limed? This question needs a qualified answer. A soil with a pH of 6 but having only detectable amounts of calcium requires lime not as an amendment but as a nutrient. The distinction is important, because application levels for amending soil pH may be 10 times higher than for correcting calcium or magnesium deficiency. Also, because calcium and magnesium added as lime are relatively immobile, better results can often be obtained by applying the sulphate salts of calcium and magnesium, which are more soluble and mobile.

Oxisols

The Andisols described in the previous section are important agricultural soils of Maui and Hawaii. What about other soils, on other islands? Understanding the soil taxonomy in these cases should be easier now, because while the names may be different, the principles for naming soils remain the same. A very important group of soils on Molokai, Lanai, Oahu, and Kauai fall in the Oxisol order. Most of the saddle area between the Koolau and Waianae ranges of Oahu is occupied by Oxisols. If we begin at the intersection of Kunia Road and H-1 freeway and drive toward Schofield Barracks, we first encounter the Molokai soil near the HSPA field station. As we rise in elevation and head toward Wahiawa, we enter a narrow strip occupied by the Lahaina soil series. This is followed by a complex intermingling of the Kunia, Kolekole, and Wahiawa series. To the untrained eye, all the soils look alike. But if we look westward towards the Waianae Range we see large alluvial fans emerging from the mouths of ancient gullies. These fans extend eastward towards Kunia Road and beyond, covering soils developed from lavas of the Koolau Mountains. The Kolekole and Kunia soils are believed to have formed on the eastern edges of the fan. Both soils are classified at the great group (third category) level as Humitropepts. *Humi*- refers to the comparatively high humus content, -*trop*- to the tropical climate, and -*ept* to the Inceptisol order to which they belong. Inceptisols are soils that possess characteristics of youth, which is implied by the term *inception,* or beginning. The soils buried by the fan should be older than the soils developed on the fan and, accordingly, the older Molokai, Lahaina, and Wahiawa soils show signs of old age. This is evident in the subsoil and is characterized by a low capacity of the soil material to retain nutrients such as calcium, magnesium, potassium, and sodium. Soil scientists refer to this characteristic as "low cation-retention capacity." There are many coarse-textured soils with low cation-retention capacity, but what makes the Oxisols unique is that they are that way even though they are heavy-textured (high-clay) soils. In old age they have lost their capacity to retain bases such as calcium, magnesium, potassium, and sodium. But in losing cation- retention capacity, they have gained the capacity to retain anions such as phosphate, sulfate, and nitrate. The 10-30-10 fertilizers sold in local stores reflect this high capacity of many of our soils to retain and immobilize phosphorus and to render much of it inaccessible to plants. The often-heard phrase "high phosphate-fixing soils" refers to this characteristic.

In Oxisols, phosphate fixation is attributable to their high content of iron and aluminum oxides. The red color of the soils of the Wahiawa plateau is primarily due to the iron oxide hematite. Moving from the central plateau into the flanks of the Koolaus, the bright red color fades and turns brownish. This is because another iron oxide of a different color is replacing hematite. The brown iron oxide is a hydrated iron oxide called goethite. The content of goethite increases as rainfall increases, as is the case as you move upslope on the Koolaus.

Oxisols are old soils, but the Lahaina and Wahiawa soils are Oxisols that retain youthful features. They may be past their prime, but they still show considerable vigor, as evidenced by their performance as agricultural soils. This youthful quality is indicated in the fourth (subgroup) level of their original name, before it was revised: very fine, kaolinitic, isohyperthermic, Tropeptic Eutrustox. The syllable -*eptic* in Tropeptic indicates that the Lahaina and Wahiawa soils have Inseptisol-like qualities. Inceptisols, if you recall, are young soils. The feature that makes the Lahaina and Wahiawa soils Tropeptic, or young looking, is the way the soil particles are clumped into well defined aggregates. The aggregates in our Oxisols are especially stable because of the cementing action of iron oxides.

Stable soil aggregates allow heavy, wheeled vehicles to transport cane or pineapple on unpaved roads shortly after a heavy rain. Stable aggregates make our soils less erodible by enabling rain water to seep into the soil surface rather than flow over it as run-off.

In the revised classification, the Wahiawa series is now a Rhodic (red) Eustrutox, and the Lahaina series is a Typic Haplustox. *Typic* indicates the norm, and *haplu*- means *simple,* which on the Lahaina soil indicates its lower fertility. (The Lahaina series is classified as a Haplustox on the basis of only limited laboratory data, but there is no good reason to believe that more laboratory data will show it to be an Eutrustox.)

If the youngest soils are found on the youngest Hawaiian island and the middle-aged soils on the intermediate-aged islands, we should expect to find the oldest soils on Kauai. On Kauai we have soils so rich in iron and aluminum oxide that aluminum companies have looked into the feasibility of mining the soils for aluminum ore. The oldest soils of Kauai are not only chronologically old, they are genetically old as well. These are the prematurely old soils associated with lavas of Mt. Kilohana. By Kauai standards, Mt. Kilohana is young just as Diamond Head and Mt. Tantalus are young by Oahu standards. Under warm and humid conditions, the lavas of Mt. Kilohana and Mt. Tantalus weather comparatively quickly into clay and oxides. The rock, already low in silicon, is stripped of this element through the leaching action of rainwater. What remains after a geologically brief period is the insoluble residue of iron and aluminum oxide. In some cases, the silicon content falls below one percent, an unheard-of amount in an agricultural soil. These are soils that benefit greatly from application of lime in the form of calcium silicate. Calcium silicate rejuvenates these soils by raising soil pH, supplying calcium, and reversing the desilication process associated with aging. Resilication with calcium silicate restores cation retention capacity, reduces phosphate fixation, and provides a source of silicon for plants. Silicon is not considered an essential plant nutrient, but sugarcane agronomists consider this element to be "agronomically" essential. Most plants—especially grasses, including sugarcane—need silicon for strength, resilience, and protection against pests. The Kapaa and Pooku soils of Kauai are prime examples of the type we have just described. Both are classified as very fine, ferruginous, isohyperthermic Typic Acrudox. The name tells us that they are high in clay, rich in iron oxide, and occur in regions with warm and even temperatures throughout the year. The name also tells us that members of this Oxisol family occur in humid (udic) environments.

The prefix *acru-* carries a special meaning. In Greek, *acro* refers to "extremity." In soil science, *acro-* implies extreme weathering. The Kapaa and Pooku soils are as extremely weathered as any soil one can find in the world. We now know that these soils, however old, can be rejuvenated through good management. The soil family name helps us to diagnose their deficiencies and prescribe treatment for improvement.

Vertisols

Vertisols do not occur extensively in Hawaii or the world, but knowing something about their behavior and performance is helpful because that knowledge applies to a large group of related soils. The Vertisols have many of the characteristics of soils from the temperate regions, so that what we learn from standard textbooks on soil science applies better to our Vertisols than to the Andisols or Oxisols we have just described.

A good example of a Vertisol is the Lualualei soil from the Waianae area of Oahu. It is dark, nearly black, and forms deep shrinkage cracks during the dry summer months. Loose surface material falls into the cracks and is trapped in the subsoil when the soil swells with water from winter rains. This annual recycling of material from top to bottom eventually inverts the soil, thus the name Vertisols. The creeping soils that wreck homes, warp sidewalks, and rupture sewage and water mains are Vertisols or their close relatives. On Oahu, they create havoc in Kalihi, Manoa, Palolo, Aina Haina, and Kuliouou valleys. The problem areas are localized and almost always occur on the talus slopes half-way into the valleys. Landslides are rare deep in the valleys because the soils there behave like Oxisols, and they are also rare near the valley entrances because rainfall is low and talus slopes are short and shallow or absent.

Vertisols are also fertile soils. Their dark color is often mistakenly attributed to organic matter, but our Vertisols have lower organic matter contents than most other soils in the state. When they occur in large, level tracts of land (as in Lualualei Valley on Oahu), they make excellent agricultural land. We can learn a great deal about the Lualualei soil from its family name: very fine, montmorillonitic, isohyperthermic Typic Chromustert. Starting from the end of the name, we learn that the Lualualei soil is a Vertisol from the last three letters of Chromustert. We were introduced to the next three letters (*ust*) in Ustox and Ustand, so we know that an Ustert is a Vertisol that occurs in places with a pronounced dry season. The Black Cotton soils of India and the Tropical Black Earths of Australia are Usterts. *Chrom*usterts are readily recognized by their dark colors. A *Typic* Chromustert is one that represents the typical Chromusterts. We have seen the word *isohyperthermic* in other soils, and the term describes the temperature regime associated with the soil. Growers wishing to produce leafy vegetables in an isohyperthermic temperature regime normally make provisions to protect their crops from sun and heat, sometimes with frequent sprinkler irrigations.

Another distinguishing characteristic of the Lualualei soil is its low requirement for phosphorus. This characteristic is associated with its high silicon content. Unlike the low-silica Oxisols of Kauai that benefit from calcium silicate application, the Lualualei soil is naturally rich in silica. Silicon and phosphorus are closely related elements, so that a given amount of phosphorus will go a long way to keep a soil well supplied with this nutrient in soils high in soluble silicon. The high-silicon soils are, as one would expect, found in valley bottoms where silicon, calcium, magnesium, potassium, and sodium dissolved from the surrounding rocks accumulate. This concentration of riches creates a chemical environment that favors the syntheses of *very fine, montmorillonitic* soils indicated in the family name. *Very fine* refers to the high clay content of the Lualualei soil, and *montmorillonitic* to montmorillonite, the clay mineral that imparts the shrink-swell characteristic. Montmorillonitic soils have high cation-retention and water-retention capacities. They are stonehard when dry and soft as warm butter when wet, so that the water content range over which very fine, montmorillonitic soils can be cultivated is very narrow. You can contrast this with the very fine, kaolinitic Wahiawa soil that is able to support heavy traffic a few hours after a heavy rain, or the medial Kula and Waimea soils that remain loose and friable even when baked dry in the sun. This again illustrates the intent of *Soil Taxonomy*'s authors: to enable its users to visualize a soil's appearance and behavior from its name.

Histosols

Histosols are organic soils, and in our state most of them occur on the Island of Hawaii. Most Big Island residents would be surprised to learn that one acre in every four of their island is occupied by a Histosol, because the vast majority of Histosols in Hawaii do not fit the layman's image of an organic soil.

A typical Histosol from the Big Island is the Malama series. This soil, like its close relatives, occurs on forested lava lands. It typically consists of 2 to 8 inches of organic material resting on undecomposed lava. In their natural, forested state they indeed look like organic soils, but after land clearing and leveling with heavy bulldozers, much of the surface organic matter disappears between the clinkers, leaving little trace of the original organic layer. Hidden from view, the organic matter serves as a sponge for water and nutrients, enabling our lava lands to support viable papaya and macadamia nut industries.

The Malama soil is classified as a *dysic, isohyperthermic, Typic Tropofolist*. It might be useful to repeat again how information about a soil can be extracted from its name. For the Malama soil, the last term, *Tropofolist,* condenses in a single word the knowledge we have about it at the order, suborder, and great group levels. The syllable -*ist* tells us that the Malama soil is a Histosol. That alone tells us a great deal about the soil. The suborder *Folist* indicates that the Malama is a kind of shallow, organic soil in which a relatively thin organic layer rests on unweathered rock. This implies that Folists are not the usual organic soils one encounters in swamps and marshes, such as the Alakai Swamp on Kauai or Kawai Nui marsh on Oahu. With the prefix *tropo*-, we specify that this soil can only occur in the tropics. In Alaska, where Folists also occur, they would be called Cryofolists, indicating freezing temperatures. When we reach the subgroup level of the name, we see the term *Typic*. In Hawaii, Typic Tropofolist refers to a Tropofolist on a‘a lava. Tropofolists are typically more common on a‘a than on pahoehoe lava. A Tropofolist on pahoehoe lava is called a Lithic Tropofolist. We know from experience that Typic Tropofolists are better suited for agriculture than their Lithic counterparts.

If you wish to find suitable a‘a land for papaya production, a Typic Tropofolist is necessary, but still may not qualify. A suitable one should also be an isohyperthermic Typic Tropofolist. Isohyperthermic soils occur in places where the mean annual temperature is 72°F or higher. Papaya prefers warm regions and produces malformed fruits in the cooler, upper elevations. Recall that the Kula and Waimea soils, noted for vegetable production, occur in regions with isothermic temperatures. Vegetables, as everyone knows, grow best in cool environments. An isothermic Typic Tropofolist may not be well suited for papaya production but allows macadamia to flourish. If we go further up in elevation, we enter the even colder isomesic temperature zone, where macadamia trees produce few nuts.

We finally come to the word *dysic*. Most Histosols are categorized as either euic or dysic. Histosols with soil pH 4.5 or higher are called euic, and those below 4.5 are named dysic. In Greek, *euic* means "good" and *dysic* means "bad." This is not to suggest that dysic Histosols are bad soils, but rather that euic soils are less acid than dysic ones. Some may wonder why a pH as low as 4.5 was chosen to differentiate euic from dysic Histosols. Why not pH 5.0, 5.5, or 6.0? If vegetable growers in Waianae were to permit the pH of their Vertisols to approach 4.5, they would be out of farming long before that value was attained. But for Histosols, pH 4.5 is not considered too acid. Why this is so is explained elsewhere in this manual, but we need to point out that the differentiating criteria employed by *Soil Taxonomy* to group soils into similar behavioral and performance classes are based upon this type of knowledge.

Inceptisols

The Inceptisols are juvenile soils that have not yet acquired the distinct features of mature soils. Until recently, Inceptisols occupied the largest area in the state, but they were reduced to a minor soil when the volcanic ash soils, or Andisols, of Maui and the Big Island were placed in a new order.

Inceptisols often occur on alluvium, on steep lands where constant exposure of new surfaces prevents soils from aging, and in poorly drained areas where soil development is delayed by stagnant waters. No generalizations about soil fertility are possible for Inceptisols, but terms such as *eutr*- (rich) and *dystr*-(infertile) in the taxonomic names of these soils are intended to convey those qualities to the users of soil survey reports.

Mollisols

The Mollisols and their close relatives make up the breadbaskets of the world. They are the dark, organic-matter rich, fertile, short-grass prairie soils of the Great Plains of the USA and Canada, the Steppes of Russia and the Ukraine, and the Pampas of Argentina.

In Hawaii, the Mollisols are closely associated with the Vertisols but do not shrink and crack or harden to the same degree. The word *mollis,* which is Greek for "soft," points to one property that makes Mollisols so desirable for agriculture. An example of a Mollisol is the Waialua soil on Oahu. It is a Mollisol that can be mistaken for a Vertisol. On the other end of the Mollisol spectrum we have the Mamala series, which is a shallow, red soil formed in alluvium deposited on the raised coral reefs of the Ewa plains.

In Hawaii, the Mollisols are fertile soils that require irrigation for cultivation of most crops.

Ultisols

Ultisols are by definition acid soils. In Hawaii they usually occur in the high-rainfall zone. They are not found on the Big Island because, as the name implies, Ultisols are old, or "ultimate," soils. Many thousands of years from now, some soils on the Big Island now classified as Inceptisols may turn into Ultisols as nutrients are leached and clay accumulates in the subsoil. As a group, the Ultisols are the least fertile of our soils. But their value as agricultural soils is lowered even more by their usual occurrence on steep, dissected landscapes on the windward sides of the older Hawaiian islands. A combination of steep slopes, strong soil acidity, low fertility, and heavy cloud cover renders our Ultisols marginal for crop production.

Alfisols

When soil scientists first began studying the soils of the continental USA, they came across a group of soils rich in aluminum and iron oxides. They named them Pedalfers to indicate their higher aluminum (Al) and iron (Fe) contents. Today, many of these soils are called Alfisols.

Alfisols are the nonacid counterparts of Ultisols. Soils in both orders have an accumulation of clay in the subsoil. The importance soil scientists attach to clay movement is reflected in the creation of two soil orders based on this property alone.

Alfisols are not extensive in Hawaii, but when they do occur, they are generally associated with the nonacid Oxisols (Eutrustox). When they occur together, the Alfisols are generally found on the steeper slopes near valley edges.

In Hawaii, Alfisols are fertile soils but require irrigation to support most types of crop production.

Aridisols

Aridisols are our desert soils. They are mainly found in the rainshadows of Haleakala and Mauna Kea. Although quite fertile, they are primarily used for grazing, owing to aridity and lack of irrigation water.

Spodosols

In contrast to the Aridisols of our driest areas is the soil of the wettest spot in the state, which has the only Spodosol in Hawaii. In parts of Alakai swamp on Kauai, soil conditions are just right to move organic matter-bound iron and aluminum down into the subsoil. A vertical cross section would reveal a surface organic layer, followed by a bleached horizon showing little trace of the discoloring iron oxide so commnon in our soils, and finally an ashy-colored horizon of humus accumulation. Spodosol derives its name from *spodos*, the Greek word for wood ash. Spodosols are commonly associated with temperate evergreen forests and are not common in the tropics.

Entisols

If Inceptisols are juvenile soils, the Entisols are infant soils. Their extreme youth is indicated by the prefix *Ent*- borrowed from the word "recent." In Hawaii we have recent soils developing on beach sand. They are called Psamments, which is derived from the Greek word *psammos*, meaning "sand." The Jaucas (pronouced hwa-ca) series found along the North Shore of Oahu and the neck of Maui is an example of a Psamment. The Spanish name *Juacas* is from a site in

Puerto Rico where the soil was first identfied.

Entisols are also commonly found in river deltas where new land is created by sediment deposition from annual floods. Some of the world's most productive soils are Fluvents, which are Entisols formed by fluvial processes. The ancient societies that emerged along the Tigres, Euphrates, Nile, and Indus rivers were supported by the richness of Fluvents.

The principal criterion for placing a soil into the Entisol order is the absence of organization of the soil materials. They show little or no structure or horizon development and resemble material in a pile of freshly screened sand or soil.

How to use the soil survey reports

The soils of Hawaii have been mapped and classified twice. Field work for the first survey was completed before World War II but was not released until 1955 (Cline 1955). In that report, soils were classified according to the now-obsolete Great Soil Group system. In 1975, the U.S. Department of Agriculture issued a handbook entitled *Soil Taxonomy*. Hawaii was the first state in the USA to complete its soil survey based on *Soil Taxonomy*. The soil survey report appeared in two parts, one for the Island of Hawaii (Sato et al. 1972) and the other for Kauai, Oahu, Maui, Molokai, and Lanai (Foote et al. 1972). The fact that our soil survey reports predate the publication of *Soil Taxonomy* stems from the wide distribution of draft copies of *Soil Taxonomy*—and the long delay in its publication. The delays were caused by last-minute efforts to improve the classification system before sending it to the publisher. Since its publication, *Soil Taxonomy* has undergone numerous modifications, which are on-going.

To use the soil survey, follow these steps:

- Identify the island and select the appropriate *Soil Survey Report*.
- Identify the soil's location on the index to the survey's map sheets. There is an index map for each island, and each map sheet is numbered.
- Locate the map sheet (aerial photograph) and pinpoint the site of interest. The point will fall in a bounded area (mapping unit) designated with a map symbol.
- Each soil survey report contains a soil legend, which relates the map symbol to a soil name. For example, the map symbol LaE3 refers to the Lahaina silty clay, 25 to 40 percent slopes, severely eroded. *La* stands for the Lahaina series, *E* for the slope class, and *3* for the erosion class.
- The full name of the soil series in question is also listed in the report. In the *Soil Survey Report for Kauai, Oahu, Maui, Molokai, and Lanai*, the Lahaina series is classified as a clayey, kaolinitic, isohyperthermic, Typic Torrox, which is not the current classification. The name has been changed as more knowledge about the characteristics and behavior of the soil is gained.

The soil survey report provides a brief description of each soil, including the environmental setting in which the soil is found, and other soils that are often associated with it.

The most useful parts of the soil survey report are the tables that relate soil names and map symbols to land use suitability for agricultural and nonagricultural uses. The report, for example, specifies whether the Lahaina soil is suitable for use as top soil, road fill, highway location, farm ponds, foundations for low buildings, septic tank fields, etc. Soil survey reports are especially useful when land use changes at a rapid pace. Its aim is to enable land owners and policy makers to make the best use of land.

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