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CATION EXCHANGE PROPERTIES of the HAWAIIAN GREAT SOIL GROUPS

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INTRODUCTION

Since the discovery by Way and Thompson in 1850 that soil removed ammonia from solution, many aspects of cation exchange have been studied. Today, this study of cation exchange is one of the most important phases to be considered in assessing soil fertility. The nutrients held by the soil colloids in an exchangeable form and the capacity of a soil to retain the nutrients are of practical importance in any fertilizer or liming program. Furthermore, because cation exchange is involved in soil-forming and weathering processes, the study of the fundamental character of soil colloids is materially aided. The degree to which a soil has been subjected to weathering can often be ascertained by studying the cation exchange properties. Consequently, cation exchange data provide valuable clues in classifying a soil, and also help present a picture of soil in equilibrium with its environment.

There have been earlier studies on cation exchange properties of Hawaiian soils. Ayres (*1*) made an extensive report on this subject for the high rainfall soils of the Hilo and Hamakua coasts. The cation exchange status of paddy soils was investigated by Sherman (*16*). Gill and Sherman (*5*) reported on this phase for the gray hydromorphic soils. Matsusaka and Sherman (*8*), Sherman *et al.* (*18*), and Tanada (*21*) have also included incidental data on cation exchange as part of their studies.

It is the objective of this survey to present typical cation exchange data of the major soil families from the different soil groups occurring in the Hawaiian Islands, and also to study cation exchange relationships.

GENERAL DESCRIPTION OF CLIMATE AND SOILS

As classified according to the recent soil survey of Cline *et al.* (*2*), there are about 120 soil series, 44 soil families, and 17 great soil groups in the Hawaiian Islands. Such numbers give an insight as to the variety of soils that exist in a rather limited area. The parent materials are derived from volcanic lavas, cinders, and ash, and, to a limited extent, from coral reefs. The fact that there are volcanoes that are still active while there are others that ceased activity many thousands of years ago means that there is a varying age pattern existing in the soils that have evolved throughout the island chain. Furthermore, there is a tremendous variation in average annual rainfall within relatively short distances. The amount varies from about 10 inches in the driest sections to more than 400 inches on the wettest mountain peaks. There is also a great variation in the distribution pattern of this annual rainfall. There are areas that receive less than one inch per month for greater than six months of the year, and also areas that receive more than 10 inches per month almost every month of the year. It would be safe to say that rainfall plays the dominant role in the overall climatic effect on soil formation. Temperature varies little throughout the year within a given locality, and also between different localities.

The humid, tropical climate that exists in most parts of the islands causes rapid chemical weathering of the parent materials. Vegetation has been noted to take foothold on lavas only a few months old. The amount of silica in Hawaiian lavas is considered to be relatively low, and with laterization dominating the different soil-forming processes, silica is further leached from the soil. On the other hand, the amount of iron, aluminum, and titanium is considered high by temperate-region standards.

By mechanical analysis classification, most of the Hawaiian soils would be considered clays. In the fields, however, these soils exhibit properties that are similar to those of silty clay loams. The typical Hawaiian latosol would be workable a few hours after a fairly heavy rain. Usually, it is only the soils that are located in low coastal and valley areas that exhibit stickiness and high plasticity. These are properties which are ordinarily associated with soils high in clay.

Matsusaka and Sherman (*9*) found all stages of clay mineral breakdown in Hawaiian soils. There are youthful soils that have been found to be dominated by primary minerals. There are those in the intermediate stages in which either the montmorillonitic or kaolinitic type of mineral predominates in the soil. Finally, there are soils in the advanced stage of weathering in which the clay minerals have broken down to the free oxides. Under a continuously wet condition, aluminum is stabilized and becomes the dominant oxide of the soil. Under alternating wet and dry conditions, iron oxides and, in some cases, titanium oxides, become stabilized and are concentrated in the soil.

EXPERIMENTAL PROCEDURES

Sampling methods

Typical soil profiles were collected from 39 soil families from the five largest islands in the Territory. These soils represent the major agricultural families as mapped by Cline *et al.* (*2*). Unless otherwise specified, analysis was restricted to the soil solum, with the depths of the different layers being indicated for each sample. The analytical determinations were done on the freshly-sampled soils that were ordinarily screened through a 20-mesh sieve. The hydrol humic latosols and some of the humic latosols and gray hydromorphics were screened through a 10-mesh sieve, because of extreme difficulty when handled with a 20-mesh sieve.

Analytical methods

A Beckman pH meter was used to obtain pH readings, using a 1:1 soil-water mixture, which was allowed to stand for 24 hours with occasional stirring. Cation exchange capacity was measured by using normal ammonium acetate solution adjusted to pH 7.0 as prescribed by Piper (*15*). The leachate of this determination was analyzed for the different exchangeable cations. Calcium was determined by precipitating as the oxalate with subsequent titration with standard potassium permanganate. Analysis of magnesium was made by precipitating it from the calcium filtrate as magnesium ammonium phosphate, which was then ignited in a muffle and weighed as magnesium pyrophosphate. Potassium and sodium were determined by utilizing the Beckman flame photometer. Manganese was determined colorimetrically, oxidizing it to permanganic acid with potassium periodate. Exchangeable hydrogen was obtained by difference; that is, the difference remaining when the sum of the above basic cations subtracted from the cation exchange capacity was considered to be exchangeable hydrogen. For soils very high in soluble salts and carbonates, modifications were made in the ammonium acetate extraction procedure. The water-soluble salts were removed by leaching the soil with a 40 percent ethyl alcohol solution prior to the extraction. A double ammonium acetate extraction method as prescribed in Piper (*15*) was used to take care of the carbonates.

Since the soil analysis was done on the freshly-sampled soil, a separate subsample was dried overnight in an oven at 105°C. The analytical values were then converted from the fresh to the oven-dry basis by using a moisture factor.

Rainfall records

Rainfall records were obtained from the Meteorology Department, which is jointly sponsored by the Hawaiian Sugar Planters' Association and the Pineapple Research Institute.

EXPERIMENTAL RESULTS

Cation exchange data from 39 soil families of the major Hawaiian great soil groups are shown in table 1. A representative soil family profile was selected for each of the 39 soils.

Low humic latosols

The low humic latosols are the most extensively cultivated soils in the Hawaiian Islands, and the bulk of sugar cane and pineapples is grown on them. They are found at elevations ranging from sea level to 2,100 feet. The annual rainfall for this group measures from 10 to 80 inches per year. About six to eight months of the year are considered dry. Iron and aluminum oxides are found in high amounts throughout the profile, whereas silica and the bases are low. The buffering capacity has been found to be the lowest for this group aside from the humic ferruginous latosols (*8*). The clay content may be as high as 80 percent and yet the field behavior of this soil is considered to be that of a silty clay loam.

The data in table 1 show that aside from the soils of the Waimanalo family, the cation exchange capacity values are typical of soils that are dominated by a kaolinitic type of clay mineral. Matsusaka and Sherman (*9*) have found that kaolinite is the predominant mineral in the low humic latosol. Furthermore, the amount of kaolinite was found to increase with depth. It is interesting to note that, in most of the profiles, there is a general decrease in cation exchange capacity with depth.

A close look at the low humic latosol figures of table 1 will also show that there is a decrease in base saturation and pH as one goes from the soils of the Molokai family, formed under the lowest rainfall, to the soils of the Kohala family, formed under the highest rainfall. When observed together with the rainfall values, it can be seen that this decrease in base saturation and pH is inversely related to the amount of rainfall. Soils of the Waialua family do not fit into this pattern since they are found in a low rainfall area. The base saturation is high, especially the magnesium saturation, and this result is reflected by the highly plastic characteristic associated with this family. Soils

TABLE 1. Cation exchange properties of major Hawaiian soil families.

LOCATION	GREAT SOIL GROUP	SOIL FAMILY	AVERAGE ANNUAL RAINFALL	DEPTH	pH	CATION EXCHANGE CAPACITY	BASE SATURATION	EXCHANGEABLE CATIONS (*m.e./100 gm.*)						CATION SATURATION	
								H	Ca	Mg	K	Na	Mn	Ca	Mg
			in.	*in.*		*m.e./100 gm.*	%							%	%
Makaweli Kauai	Low Humic Latosol	Molokai	25	0-8	6.5	19.8	89.4	2.1	11.30	5.15	0.80	0.31	0.085	57.1	26.0
				8-17	6.3	19.8	72.8	5.4	9.06	4.93	0.17	0.24	0.045	45.8	24.9
				17-33	6.2	14.0	70.4	4.2	5.97	3.50	0.10	0.26	0.040	42.6	25.0
				33-48	6.5	11.3	57.2	4.8	3.83	2.34	0.052	0.19	0.028	33.9	20.7
				48+	6.6	10.9	57.5	4.6	3.76	2.18	0.082	0.26	0.006	34.5	20.0
Waialua Oahu	Low Humic Latosol	Lahaina	35	0-6	6.9	20.4	89.7	2.1	10.67	5.07	2.24	0.21	0.12	52.3	24.9
				6-11	6.5	16.0	81.0	3.0	6.65	4.49	1.51	0.21	0.058	41.6	28.1
				11-18	6.2	17.4	68.4	5.5	5.96	3.16	2.20	0.58	0.018	34.3	18.2
				18-22	5.9	19.9	75.1	5.0	8.57	4.49	1.26	0.62	0.011	43.1	22.6
Poamoho Oahu	Low Humic Latosol	Wahiawa	40	0-10	6.0	17.8	53.4	8.3	5.56	2.58	0.92	0.31	0.078	31.2	14.5
				10-21	6.2	11.7	60.8	4.6	3.97	2.15	0.31	0.66	0.023	33.9	18.4
				21-42	6.1	14.9	45.9	8.1	3.87	2.18	0.081	0.68	0.020	26.0	14.6
				42+	6.5	14.3	48.6	7.4	4.54	1.87	0.27	0.27	0.009	31.7	13.1
Anahola Kauai	Low Humic Latosol	Kahana	50	0-9	5.7	28.3	39.2	17.2	5.14	2.95	1.41	1.53	0.059	18.2	10.4
				9-18	6.2	21.4	31.3	14.7	2.36	2.12	1.24	0.97	0.005	11.0	9.9
				18-21	6.6	17.8	35.3	11.5	2.41	2.24	1.20	0.44	0.005	13.5	12.6
				21-28	6.6	10.6	51.2	5.2	2.17	2.01	0.93	0.31	0.003	20.5	19.0
				28-34	6.4	10.8	54.1	5.0	2.35	2.32	0.73	0.43	0.005	21.8	21.5
				34-52	6.5	12.8	56.0	5.6	3.43	2.56	0.46	0.71	0.006	26.8	20.0
				52+	5.5	14.4	49.2	7.3	3.37	3.06	0.22	0.44	0.002	23.4	21.2
Koloa Kauai	Low Humic Latosol	Kohala	65	0-14	5.0	21.0	34.8	13.7	4.20	1.93	0.57	0.53	0.022	20.0	9.2
				14-26	5.5	20.4	43.5	11.5	5.60	2.39	0.43	0.42	0.012	27.4	11.7
				26-40	6.3	16.9	40.0	10.1	3.74	1.81	0.60	0.59	0.005	22.1	10.7
				40-80	6.0	12.9	37.8	8.0	2.03	1.05	0.52	1.29	0.002	15.7	8.1
				80+	6.0	12.6	41.5	7.4	1.65	1.27	0.64	1.67	0.002	13.1	10.1
Waialua Oahu	Low Humic Latosol	Waialua	30	0-10	7.2	21.8	65.1	7.6	7.37	5.50	0.11	1.24	0.026	33.8	25.2
				10-24	6.7	16.9	100.0	0	6.56	10.46	0.056	2.13	0.007	38.8	61.9
				24+	6.1	15.6	100.0	0	6.93	6.78	0.28	2.86	0.023	44.4	43.5

TABLE 1.—Continued.

LOCATION	GREAT SOIL GROUP	SOIL FAMILY	AVERAGE ANNUAL RAINFALL	DEPTH	pH	CATION EXCHANGE CAPACITY	BASE SATURATION	EXCHANGEABLE CATIONS (*m.e./100 gm.*)						CATION SATURATION	
								H	Ca	Mg	K	Na	Mn	Ca	Mg
			in.	*in.*		*m.e./100 gm.*	%							%	%
Waimanalo Oahu	Low Humic Latosol	Waimanalo	45	0-12	6.8	43.8	95.4	2.0	25.81	12.90	2.11	0.93	0.028	58.9	29.5
				12-24	6.8	40.9	92.8	2.9	24.73	10.60	0.53	2.11	0.006	60.5	25.9
Kaneohe Oahu	Humic Latosol	Kaneohe	65	0-8	4.5	25.4	9.5	23.0	0.75	0.93	0.18	0.54	0.014	3.0	3.7
				8-24	4.5	27.2	9.3	24.7	0.75	0.68	0.17	0.91	0.008	2.8	2.5
				24-34	4.6	24.1	7.8	22.2	0 63	0.46	0.09	0.69	0.005	2.6	1.9
Helemano Oahu	Humic Latosol	Honolua	80	0-6	4.1	33.5	5.0	31.8	0.53	0.82	0.13	0.19	0.003	1.6	2.4
				12-20	4.6	35.2	8.2	32.3	1.55	0.94	0.18	0.21	0.008	4.4	2.7
Haina Hawaii	Humic Latosol	Paauhau	65	0-7	6.0	58.2	32.3	39.4	12.30	4.72	1.38	0.37	0.001	21.1	8.1
				7-12	6.2	60.4	26.4	44.4	10.45	4.16	0.98	0.36	0.001	17.3	6.9
				12-20	6.3	53.1	10.6	47.5	3.11	1.75	0.58	0.19	0.001	5.9	3.3
				20-30	6.2	52.2	11.5	46.2	3.13	1.94	0.67	0.24	0.001	6.0	3.7
Hakalau Hawaii	Humic Latosol	Ookala	150	0-12	5.5	53.0	10.4	47.5	2.75	0.66	0.16	1.94	0.003	5.2	1.2
				12-40	5.4	65.4	3.4	63.2	0.97	0.55	0.20	0.49	0.009	1.5	0.8
				40-60	5.4	69.4	2.8	67.4	0.81	0.56	0.09	0.47	0.005	1.2	0.8
Kona Hawaii	Humic Latosol	Kapoho	65	0-8	6.3	64.1	58.0	26.9	23.27	10.38	3.32	0.26	0.013	36.3	16.2
				8+	6.7	51.7	30.2	36.1	10.77	3.22	1.51	0.13	0.001	20.8	6.2
Waikolu Molokai	Hydrol Humic Latosol	Koolau	100	0-10	4.2	51.9	6.5	48.5	0.97	1.88	0.072	0.45	0.007	1.9	3.6
				10-16	4.5	57.4	4.5	54.8	0.53	1.44	0.067	0.52	0.006	0.9	2.5
				16-24	4.7	41.8	3.0	40.5	0.31	0.44	0.069	0.44	0.008	0.7	1.1
				24-48	4.9	46.7	3.2	45.2	0.34	0.60	0.040	0.48	0.011	0.7	1.3
				48+	4.9	30.6	6.8	28.6	0.48	0.79	0.25	0.54	0.014	1.6	2.6
Hilo Hawaii	Hydrol Humic Latosol	Hilo	145	0-8	5.1	59.5	4.3	56.9	0.81	1.32	0.12	0.20	0.099	1.4	2.2
				8-40	5.5	90.9	2.3	88.8	0.75	0.88	0.08	0.35	0.010	0.8	1.0
				28-32*	5.6	40.0	4.7	38.1	0.87	0.54	0.28	0.20	0.004	2.2	1.4
Honokaa Hawaii	Hydrol Humic Latosol	Honokaa	90	0-8	6.0	83.2	5.0	79.0	2.48	0.95	0.24	0.48	0.001	3.0	1.1
				8-18	5.9	85.1	3.6	82.1	1.61	0.82	0.19	0.43	0.001	1.9	1.0
				18-28	5.9	94.0	2.1	92.1	0.88	0.48	0.17	0.41	0.001	0.9	0.5
				28-36	6.2	101.1	2.7	98.4	1.48	0.48	0.089	0.66	0.003	1.5	0.5

*Dark Layer

TABLE 1.—Continued.

LOCATION	GREAT SOIL GROUP	SOIL FAMILY	AVERAGE ANNUAL RAINFALL	DEPTH	pH	CATION EXCHANGE CAPACITY	BASE SATURATION	EXCHANGEABLE CATIONS (*m.e./100 gm.*)						CATION SATURATION	
								H	Ca	Mg	K	Na	Mn	Ca	Mg
			in.	*in.*		*m.e./100 gm.*	%							%	%
Akaka Falls Hawaii	Hydrol Humic Latosol	Akaka	225	0-12	4.8	82.2	2.0	80.6	0.55	0.69	0.12	0.25	0.010	0.7	0.8
				12-24	5.0	81.2	2.8	78.9	0.98	0.75	0.15	0.38	0.021	1.2	0.9
				24-32	5.1	109.9	2.4	107.2	1.01	0.95	0.16	0.49	0.011	0.9	0.9
				32-38*	5.2	126.7	1.2	125.2	0.79	0.23	0.10	0.32	0.015	0.6	0.2
				38-56	5.1	125.8	2.2	123.1	1.02	0.81	0.16	0.69	0.019	0.8	0.6
Kona Hawaii	Hydrol Humic Latosol	Kealakekua	90	0-8	6.1	61.8	31.9	42.0	15.52	3.38	0.55	0.29	0.009	25.1	5.5
Kokee Road Kauai	Humic Ferruginous Latosol	Mahana	35	0-4	4.2	31.3	5.1	29.7	0.31	0.39	0.43	0.45	0.016	1.0	1.2
				4-9	4.4	11.6	8.0	10.6	0.22	0.30	0.21	0.18	0.010	1.9	2.6
				9-23	4.4	22.0	4.6	21.0	0.23	0.23	0.31	0.22	0.008	1.0	1.0
				23+	4.6	36.4	2.9	35.3	0.33	0.39	0.11	0.23	0.006	0.9	1.1
Kokee Road Kauai	Humic Ferruginous Latosol	Naiwa	35	0-3	4.1	31.8	8.5	29.1	0.94	1.10	0.21	0.43	0.013	3.1	3.5
				3-5	4.2	7.4	13.0	6.4	0.32	0.37	0.091	0.18	0.002	4.3	5.0
				5-11	4.2	2.8	26.4	2.1	0.31	0.29	0.010	0.13	0.005	11.1	10.4
				11-13	4.0	8.8	10.6	7.9	0.41	0.40	0.041	0.092	0.002	4.7	4.5
				13-27	4.3	18.8	2.4	18.3	0.12	0.24	0.032	0.063	0.003	6.4	1.3
				27+	4.3	18.6	4.0	17.8	0.18	0.35	0.032	0.17	0.005	1.0	1.9
Haiku Maui	Humic Ferruginous Latosol	Haiku	70	0-8	4.6	15.0	10.7	13.4	0.51	0.61	0.12	0.38	0.009	3.4	4.1
				8-14	4.2	12.2	8.7	11.2	0.33	0.34	0.052	0.33	0.006	2.7	2.8
				14-17	4.3	17.0	4.9	16.1	0.22	0.26	0.086	0.25	0.005	1.3	1.5
				17-26	4.3	19.6	3.9	18.9	0.23	0.27	0.074	0.18	0.005	1.2	1.4
				26-42	4.5	13.1	10.2	11.8	0.39	0.68	0.074	0.19	0.005	3.0	5.2
				42+	4.4	18.1	7.1	16.8	0.38	0.26	0.11	0.53	0.005	2.1	1.4
Wailua Falls Kauai	Humic Ferruginous Latosol	Puhi	65	0.9	4.8	22.9	23.1	17.6	3.24	1.57	0.17	0.26	0.009	14.1	6.9
				9-23	5.0	21.7	8.8	19.8	0.88	0.73	0.035	0.26	0.005	4.1	3.4
				23-31	4.9	16.3	15.3	13.8	0.74	1.37	0.044	0.34	0.002	4.5	8.4
				31+	4.8	18.1	7.3	16.8	0.41	0.43	0.084	0.40	0.002	2.3	2.4
Kunia Oahu	Humic Ferruginous Latosol	Manana	35	0-10	5.2	19.4	29.4	13.7	3.82	1.21	0.33	0.26	0.050	19.7	6.2
				10-37	4.7	35.4	11.6	31.3	1.95	1.12	0.21	0.81	0.011	5.5	3.2
				37+	4.6	16.7	21.6	13.1	2.04	1.23	0.065	0.27	0.003	12.2	7.4

*Dark Layer

TABLE 1.—Continued.

LOCATION	GREAT SOIL GROUP	SOIL FAMILY	AVERAGE ANNUAL RAINFALL	DEPTH	pH	CATION EXCHANGE CAPACITY	BASE SATURATION	EXCHANGEABLE CATIONS (*m.e./100 gm.*) H	Ca	Mg	K	Na	Mn	CATION SATURATION Ca	Mg
			in.	*in.*		*m.e./100 gm.*	%							%	%
Kawaihae	Red	Kawaihae	10	0-8	7.2	39.2	77.0	9.0	17.60	9.18	2.69	0.74	0.007	44.9	23.4
Hawaii	Desert			8-24	8.4	46.0	69.0	14.3	14.11	12.96	2.62	2.03	0.009	30.7	28.2
Waimea	Reddish	Waikaloa	20	0-9	6.8	66.8	67.2	21.9	31.05	11.05	1.26	1.54	0.007	46.5	16.5
Hawaii	Brown			9-19	7.2	57.7	75.7	14.0	27.03	13.47	0.17	3.02	0.001	46.8	23.3
				19-29	7.6	42.6	79.3	8.8	19.85	9.94	0.17	3.83	0.003	46.6	23.3
				29+	8.3	46.1	72.5	12.7	21.49	8.07	0.18	3.66	0.003	46.6	17.5
Pahala	Reddish	Pahala	40	0-9	7.1	31.4	76.8	7.3	15.88	6.32	1.66	0.24	0.024	50.6	20.1
Hawaii	Prairie			9-15	7.3	52.6	62.1	20.0	27.58	3.21	1.22	0.66	0.014	52.4	6.1
				15-23	7.6	52.1	72.8	14.2	25.58	10.68	0.91	0.71	0.010	49.1	20.5
				23+	7.7	70.5	72.9	19.1	35.85	14.41	0.14	1.00	0.013	50.9	20.4
Haleakala-	Reddish	Waimea	30	0-8	6.7	66.4	70.5	19.6	37.38	7.62	1.26	0.53	0.011	56.3	11.5
Kula Road	Prairie			8-17	7.2	72.0	61.9	27.4	35.90	7.75	0.39	0.51	0.008	49.9	10.8
Junction,				17+	6.9	70.0	52.1	33.4	25.70	9.52	0.54	0.57	0.010	36.7	13.6
Maui															
Naalehu	Reddish	Naalehu	45	0-6	6.6	67.2	51.0	32.9	25.05	7.50	1.35	0.41	0.010	37.3	11.2
Hawaii	Prairie														
Haleakala	Latosolic	Hanipoe	40	0-6	6.0	70.2	58.4	29.2	28.87	10.70	1.20	0.17	0.014	41.1	15.2
Road, Maui	Brown			6-8½	6.8	41.7	44.9	23.0	13.18	4.48	0.91	0.13	0.030	31.6	10.7
(Elevation	Forest			8½-13	7.0	40.3	25.9	29.8	6.85	2.90	0.59	0.070	0.016	17.0	7.2
2500 ft.)				13-14	6.6	60.8	48.8	31.2	23.44	5.18	0.89	0.14	0.016	38.9	8.5
				14-23	6.8	96.1	38.7	58.9	29.36	7.10	0.49	0.26	0.013	30.6	7.4
				23-31	6.6	104.2	35.2	67.6	28.77	7.07	0.51	0.30	0.012	27.6	6.8
				31+	5.9	39.6	18.7	32.2	4.17	2.32	0.72	0.20	0.012	10.5	5.9
Puu Oo	Latosolic	Puu Oo	75	0-3½	6.2	41.4	58.1	17.4	19.69	3.90	0.27	0.14	0.033	47.6	9.4
Hawaii	Brown			3½-8	6.5	42.3	62.8	15.8	22.16	4.10	0.20	0.098	0.010	52.4	9.7
	Forest			8-20	6.7	52.0	57.3	22.2	26.22	3.21	0.24	0.11	0.004	50.4	6.2
				20-36	6.9	54.5	43.3	30.9	19.79	3.41	0.27	0.13	0.009	36.3	6.3
Waimea	Latosolic	Maile	70	0-4	5.6	74.3	16.8	61.8	7.33	3.79	0.84	0.48	0.026	9.9	5.1
Hawaii	Brown			4-22	5.9	71.3	33.3	47.6	17.89	4.69	0.56	0.56	0.006	25.1	6.6
	Forest			2 2-30	6.4	110.8	28.7	79.0	24.71	5.27	0.94	0.89	0.009	22.3	4.8
				30-48	6.5	118.6	20.4	94.4	18.23	4.29	1.09	0.62	0.010	15.4	3.6

TABLE 1.—Continued.

LOCATION	GREAT SOIL GROUP	SOIL FAMILY	AVERAGE ANNUAL RAINFALL	DEPTH	pH	CATION EXCHANGE CAPACITY	BASE SATURATION	EXCHANGEABLE CATIONS (*m.e./100 gm.*)						CATION SATURATION	
								H	Ca	Mg	K	Na	Mn	Ca	Mg
			in.	*in.*		*m.e./100 gm.*	%							%	%
Olinda Maui	Latosolic Brown Forest	Olinda	70	0-7	5.6	39.7	19.1	32.1	4.98	2.16	0.25	0.17	0.016	12.5	5.4
				7-16	5.1	98.9	2.1	96.9	0.66	1.00	0.17	0.20	0.009	0.7	1.0
				16-28	5.2	99.5	2.1	97.4	0.51	1.24	0.24	0.10	0.012	0.5	1.2
				28-40	5.2	68.6	3.1	66.5	0.29	1.49	0.14	0.18	0.008	0.4	2.2
				40+	5.2	75.8	2.8	73.7	0.36	1.38	0.12	0.21	0.012	0.5	1.8
Honouliuli Oahu	Gray Hydro-morphic	Honouliuli	25	0-6	7.5	25.8	100.0	0	17.71	5.72	3.48	0.82	0.020	68.6	22.2
				6-14	7.3	25.1	100.0	0	17.82	5.05	3.33	1.06	0.036	71.0	20.1
Kaloko Oahu	Gray Hydro-morphic	Kalihi	20	0-6	7.2	48.1	94.8	2.5	22.10	19.15	0.98	3.35	0.002	45.9	39.8
				6-12	7.9	52.3	86.9	6.9	18.09	19.14	0.36	7.84	0.004	34.6	36.6
				12-18	7.9	54.2	85.2	8.0	16.77	18.00	0.26	11.16	0.002	30.9	33.2
Honouliuli Oahu	Gray Hydro-morphic	Kaloko	25	0-6	7.6	48.5	91.8	4.0	22.21	17.63	1.45	3.22	0.004	45.8	36.4
				6-9	7.6	52.5	77.8	11.6	18.56	18.69	0.46	3.16	0.004	35.4	35.6
				9-12	7.6	54.4	69.7	16.5	17.84	16.52	0.42	3.14	0.004	32.8	30.4
Waiahole Valley, Oahu	Paddy	Hauula	45	0-6	6.5	41.1	75.4	10.1	15.76	14.30	0.64	0.14	0.14	38.3	34.8
Lualualei Valley, Oahu	Dark Magnesium Clay	Lualualei	20	0-6	7.7	51.7	100.0	0	39.24	13.24	2.86	0.31	0.092	75.9	25.6
				6-12	7.7	45.2	100.0	0	33.76	13.83	2.07	0.43	0.059	74.7	30.6
				12-18	7.8	42.6	100.0	0	29.03	13.17	1.58	0.67	0.053	68.1	30.9
				18-24	7.8	40.6	100.0	0	28.41	12.75	1.42	0.58	0.077	70.0	31.4
Kihei Maui	Solonchak		15	0-6	7.8	16.8	100.0	0	11.95	7.24	5.76	6.20	0.013	71.1	43.1
Wailuku Maui	Alluvial	Kawaihapai	30	0-6	7.4	30.7	86.0	4.3	17.28	7.44	1.09	0.56	0.002	56.3	24.2
Anahola Bay Kauai	Alluvial	Hanalei	45	0-6	5.5	26.9	56.1	11.8	8.59	5.65	0.65	0.22	0.029	31.9	21.0

of the Waimanalo family are considered to be intergraded into the dark magnesium clays and have many physical and chemical properties which are characteristic of them. The soil is darker and more sticky than a typical low humic latosol. The high exchange capacity and the high calcium and magnesium saturation values are approaching those of a soil of the dark magnesium clay group which has montmorin clay.

One of the prominent characteristics of a low humic latosol is the occurrence of high amounts of manganese dioxide throughout the profile. Although the data given in table 1 show that exchangeable manganese contents for this group of soils are not much higher than those of other soils, Fujimoto and Sherman (*4*) have shown that certain conditions, like heating and drying, release considerable amounts of exchangeable manganese. Their findings were verified in this work and the results are presented in table 2 for a limited number of soils. Dried soils (oven-dried overnight at 105°C.) showed increases in

TABLE 2. Effect of oven-drying on the exchangeable manganese content of some Hawaiian soils.

LOCATION AND GROUP	SOIL FAMILY	DEPTH	EXCHANGEABLE MANGANESE	
			Freshly-sampled soil	Oven-dried soil*
		in.	*p.p.m.*	*p.p.m.*
Helemano (Humic latosol)	Honolua	0-6	0.9	123.4
		12-20	2.2	89.0
Kaloko (Gray hydromorphic)	Kalihi	0-6	0.5	73.7
		6-12	1.1	20.0
		12-18	0.5	6.7
Waialua (Low humic latosol)	Lahaina	0-6	32.3	90.0
		6-11	15.6	40.2
		11-18	4.8	9.6
		18-22	3.0	6.0
Kilauea Volcano Farm (Latosolic brown forest)	Puu Oo	0-6	2.6	30.0
		6-12	2.4	5.4
Poamoho (Low humic latosol)	Wahiawa	0-10	21.0	156.0
		10-21	6.2	21.6
		21-42	5.4	7.9
		42+	2.4	4.0
Honouliuli (Gray hydromorphic)	Kaloko	0-6	1.1	34.2
		6-9	1.1	40.2
		9-12	1.1	61.1

*Overnight in oven at 105°C.

exchangeable manganese as compared to the freshly-sampled soils. In nearly all cases, the upper levels of the soil yielded a greater increase in manganese upon drying than the lower depths.

Humic latosols

Soils of the humic latosol group are found from sea level up to 3,500 feet in elevation. They are developed under a heavier rainfall than the low humic latosols, the range being from 40 to 150 inches annually. Associated with the wetter and cooler climate, the soils of the humic latosol group are in a more advanced stage in the weathering sequence than the low humic latosols. Matsusaka and Sherman (*9*) have found that the kaolinite content has decreased to about 25 percent with a corresponding increase in the hydrated oxides. The clays, however, do not dry irreversibly as they do in the hydrol humic latosols. Organic matter usually ranges between 5 and 12 percent. Buffering capacity of these soils has been found to be relatively high (*8*). One of the distinctive properties of soils of the humic latosol group is a very granular A horizon and the aggregates have been found to be very water-stable.

The data presented in table 1 show that typical profiles of soils of the Kaneohe, Honolua, and Ookala families are very acidic and have a very low base saturation. The soil profile of the Paauhau family is not as acidic as the above three profiles and is also higher in bases. It presumably was derived from the same parent material as the soils of the Ookala family, but being situated in the drier section of the Hamakua Coast it consequently does not show the effects of leaching as the latter profile. Ayres (*1*) has shown that there is an overall increase in acidity and base depletion as one moves in the direction from Honokaa to Hakalau along the Hamakua Coast. The soil profile of the Kapoho family is not as acidic as the other humic latosols and it contains much more exchangeable calcium and magnesium, especially in the surface layer. This characteristic can be attributed to the fact that this family is comprised of relatively youthful and shallow soils.

Accompanying the breakdown of kaolinite to hydrated oxides in the humic latosols, there is an increase in cation exchange capacity over that of the low humic latosols. The low content of kaolin may be due to the lack of soluble silica for its formation in the weathering materials. The increase in cation exchange capacity may also be partly attributed to higher content of organic matter. In the wetter soils this group, there is some loss of this cation exchange capacity upon dehydration. This phase of the work was reported by Kanehiro and Sherman (*7*) and some of the typical results are reproduced in table 3. It was shown that this loss of cation exchange capacity appears to be permanent in a wet soil like the Ookala soil profile.

Hydrol humic latosols

Soils of the hydrol humic latosol group belong to the wettest major soil group in the islands. Most of the soils of this group receive an annual rainfall that ranges from 120 to 300 inches; furthermore, there is no pronounced dry season during the year. Developing under such extremely wet conditions, the soils exhibit certain distinctive properties that are not found in soils of the other groups. The soils of the hydrol humic latosol group can be readily

TABLE 3. Effect of dehydration on cation exchange capacity in some Hawaiian soils.

LOCATION AND GROUP	SOIL FAMILY	ANNUAL RAINFALL	DEPTH	H_2O	CATION EXCHANGE CAPACITY Freshly dug soil	Sun-dried soil (100 days)	LOSS DUE TO SUN-DRYING
		in.	*in.*	%	*m.e./100 gm.*	*m.e./100 gm.*	%
Hakalau (Humic latosol)	Ookala	150	0-12	72.7	53.0	40.8	23.0
			12-40	143.6	65.4	32.9	49.7
			40-60	195.9	69.4	28.3	59.2
Akaka Falls (Hydrol humic latosol)	Akaka	225	0-12	130.1	82.2	36.8	55.2
			12-24	274.5	81.2	36.2	55.4
			24-32	305.7	109.9	37.1	66.2
			32-38	217.0	126.7	32.1	74.7
			38-56	307.3	125.8	37.6	70.1
Olinda (Latosolic brown forest)	Olinda	70	0-7	8.7	39.7	30.4	23.4
			7-16	40.8	98.9	67.7	31.5
			16-28	49.3	99.5	72.9	26.7
			28-40	13.4	68.6	57.9	15.6
			40+	30.5	75.8	62.4	17.7

smeared under pressure and can be pressed between the fingers to form a smooth, slippery ribbon. They also possess an unusually low bulk density and a very high water-holding capacity. The clays dry irreversibly, and a dehydrated soil cannot be remoistened back to its original characteristics. Matsusaka and Sherman (*9*) and also Tamura *et al.* (*19*) have found little or no kaolin in these soils, in which the clays are stabilized as gibbsite and allophane. Ayres (*1*) has reported that most of these soils range in organic matter from 15 to 30 percent for the surface layer. Buffering capacity of these soils has been found to be high (*8*).

The data given in table 1 show that soils of the hydrol humic latosol group reflect the intense weathering conditions under which they have developed with the exception of the soils of the Kealakekua family. The base saturation of the soils of this group is below 10 percent. There is an inverse relation between base saturation and rainfall within this soil group and this finding is in agreement with that of Ayres (*1*). Several surface soils of this group were reported to be within 0.5 pH unit of ultimate acidity (*1*).

The soils of the Kealakekua family exhibit cation exchange properties that are very similar to those of the soils of the Kapoho family of the humic latosol group. These two families usually occupy adjacent positions, with the Kealakekua family being situated in the wetter location of the two. This subjection to a wetter climate is reflected by a slightly more acidic reaction and a lower base status in the soils of the Kealakekua family.

Soils of the hydrol humic latosol group have very high cation exchange capacity values as can be seen by table 1. In any profile of this group there is an increase in moisture and cation exchange capacity with increasing depth. In a previous work (*7*) the soil was found to lose an appreciable amount of this high cation exchange capacity upon dehydration, with the greatest loss occurring in the lower depths. Some of the results are reproduced in table 3.

Furthermore, the dehydrated soils of this group do not rehydrate and consequently they do not regain their original cation exchange capacities with extended remoistening.

Humic ferruginous latosols

Soils of the humic ferruginous latosol group occur under a wide range of elevation, from sea level to 4,000 feet, and have developed under an annual rainfall ranging from 25 to 150 inches. These soils are characterized by the presence of a horizon of heavy minerals, mainly iron and titanium oxides. This heavy mineral layer sometimes appears as a crust and may approach a bulk density figure of 3.0, and the particle density value may be greater than 4.0. The crust is hard and structureless and may or may not be cemented. Soils of the humic ferruginous latosol group are the most highly leached soils of the Hawaiian Islands and are found only in the geologically older islands. They have formed under an alternating wet and dry type of climate and represent the end product of this type of weathering environment. Most of the kaolin has been decomposed to oxides of iron or titanium. Matsusaka and Sherman (*8*) have found that this group is the least buffered soil of the islands.

The data in table 1 reflect the advanced stage of weathering that has been attained by the soils of the humic ferruginous latosol group. The soils are extremely acidic and have a very low base saturation. The soils of the Mahana, Naiwa, and Haiku families are especially low in calcium. Furthermore, the base saturation of the Naiwa family may be deceiving. The values go over 10 percent in certain depths, not because of increased amounts of bases, but only because the cation exchange capacity values are extremely low. The cation exchange capacity of 2.8 m.e./100 gm. for the 5–11-inch layer is the lowest exchange capacity reported in this survey. This layer is part of the crust horizon and shows how senile and inert this type of soil can be. Sherman *et al.* (*18*) have reported that the removal of vegetative cover with subsequent exposure of the soil to the elements hastens the formation of a crust. It was observed that two profiles, one vegetative-covered and the other barren, which were located within three feet of each other, showed extremely varied chemical and physical properties. Among the differences, the covered profile had a cation exchange capacity of 40.5 m.e./100 gm., while the cation exchange capacity for the corresponding depth of the crust was the aforementioned 2.8 m.e./100 gm.

Soil profiles of the Puhi and Manana families are not as acidic and show higher amounts of bases than the above three profiles. They, however, show evidences of being closely related to the other three families. Soils of the Manana family show profile characteristics akin to those of the soils of the Naiwa family, which have an indurate crust.

Reddish prairie soils

Soils of the reddish prairie group are youthful soils developed from volcanic ash and are found at high elevations which range from 500 to 4,500 feet. Rainfall is relatively low for this elevation and ranges from 25 to 70 inches. Associated with the youthfulness of the reddish prairies is a relatively low clay content, which may be as low as 38 percent for the A horizon (*9*). Organic matter is usually found to be between 5 and 10 percent for the surface. Differential thermal curves suggest that the clays may be either montmorillonite or some related 2:1 type minerals or some amorphous materials. Matsusaka and Sherman (*8*) have found an almost identical titration curve for this soil as for the two other young zonal soils, the red desert and reddish-brown soils. The soils of the reddish prairie group, as found in the Hawaiian Islands, show the influence of latosolisation by having a silica-sesquioxide ratio of less than 1.2.

As shown by the data given in table 1, soils of the reddish prairie group possess excellent chemical properties. The cation exchange capacity is high and the soil is well saturated with exchangeable bases, especially calcium, which may be as high as 37 m.e./100 gm. of soil. This very favorable exchangeable base picture is complemented with a soil reaction that is in the range of neutrality. The overall excellent chemical properties plus suitability of location make the reddish prairie soils among the best agricultural soils of the Hawaiian Islands.

Latosolic brown forest soil

Soils of the latosolic brown forest group resemble the soils of the reddish prairie group in many ways. Both groups are young soils formed from similar volcanic ash parent material. However, soils of the latosolic brown forest group are found at a higher elevation and also have developed under a higher rainfall than soils of the reddish prairie group. There is a consequent greater degree of weathering and greater intensity of leaching of the former group of soils. The silica-sesquioxide ratio of the clay fraction of soils of this group is lower than that of soils of the reddish prairie group and may approach a ratio of 0.3 in some cases. In spite of this relatively low ratio, soils of the latosolic brown forest group exhibit the greatest buffering capacity of all Hawaiian soils (*8*). The clays show a greater content of hydrated oxides than soils of the reddish prairie group.

The data reported in table 1 show that soils of the latosolic brown forest group are more acidic and have a lower base saturation than soils of the reddish prairie group. Soils of the Hanipoe, Puu Oo, and Maile families have a relatively high content of exchangeable bases. The cation exchange capacity values are high, especially for the Hanipoe and Maile soil profiles. These two soils were also reported to undergo some degree of reduction of exchange capacity upon dehydration, although not as drastic as the loss exhibited by the hydrol humic latosols (*7*). Soils of the Olinda family appear to have weathered much more intensely than the first three families. The contents of exchangeable calcium and magnesium are low, especially the exchangeable calcium in the lower depths. The removal of the bases is reflected by a more acidic reaction in this profile as compared to the other soils of this group. Soils of the Olinda family were found to lose some of their cation exchange capacity upon dehydration (*7*). Tamura *et al.* (*20*) have reported appreciable amounts of gibbsite, goethite, and hematite, as well as vermiculite in the soils of an Olinda profile. The distribution of these minerals in great amounts in a soil suggests a well-weathered soil.

Red desert and reddish-brown soils

Soils of the red desert group are found at elevations ranging from sea level to 2,500 feet. The rainfall is sparse and consequently these soils have weathered only slightly. The soils of this group are shallow and usually rocky. Calcium carbonate is present in the profile usually as coatings on soil granules. The data given in table 1 show that the reaction in this soil is neutral at the surface and basic in the subsoil because of the calcium carbonate accumulation. As could be expected under the limited weathering condition, the soil is adequately supplied with exchangeable bases. The cation exchange capacity is moderately high.

Soils of the reddish-brown group are found at elevations comparable to those of the red desert soils. However, they are developed under a range of rainfall (20–60 inches) which is higher than that for the red desert soils, and they, therefore, have deeper profiles. Organic matter content is also higher in the reddish-brown soils. Like the soils of the red desert group, these soils show evidences of the presence of abundant primary minerals and also have calcium carbonate accumulation. The silica-sesquioxide ratio is about the highest found in a zonal soil and may be as high as 3.6 (*2*). Matsusaka and Sherman (*8*) reported that the soils of the reddish-brown group show very similar buffering curves to the soils of the red desert and reddish prairie groups. The data in table 1 show a cation exchange picture that is similar to that found for soils of the red desert group. There is a rise in pH with depth and the cation exchange capacity is fairly high throughout the profile of the soils. Exchangeable potassium is low in the lower depth; otherwise, the soil is well supplied with the major bases.

Dark magnesium clays, gray hydromorphics, and paddy soils

Soils of the dark magnesium clays, gray hydromorphics, and paddy groups are all lowland soils found either at the bottoms of valleys or on coastal areas. By the nature of the topography, these soils receive seepage water that is high in calcium and magnesium from the higher elevations. Drainage is poor and the exchangeable magnesium content is relatively high in these soils. The combination of these factors gives rise to a very plastic soil that is dispersed readily when wet. As a consequence, management of these soils is often very difficult. Matsusaka and Sherman (*8*) found that the buffering capacity of a dark magnesium clay and a gray hydromorphic to be almost identical. The buffering curve was found to be a typical curve of a montmorin type of clay mineral.

Soils of the dark magnesium clays are found in very dry regions and usually there is no presence of drainage water in the profile, nor is there a high water table as in the gray hydromorphics. Thermal analyses and dehydration curves suggest the presence of minerals of the montmorin type (*9*). The swelling and shrinking which accompany the wetting and drying are especially pronounced in the soils of the dark magnesium clays. The massive, structureless nature of these soils when wet makes their management very difficult. The data in table 1 show that a soil of the dark magnesium clay group is basic in reaction and has a high cation exchange capacity. The soil is completely saturated with bases in this profile and a previous study of these soils sampled from a number of locations has revealed this similar exchangeable base picture (*17*). In this report the calcium-magnesium ratio is slightly over 2.0. Sherman *et al.* (*17*) have reported that this ratio in some soils of the dark magnesium clays approaches 1.5 or below. They have also reported on the formation of dolomite and gypsum in this soil group.

Soils of the gray hydromorphic group are usually found in areas of restricted drainage with a high water table. Usually present are appreciable quantities of soluble salts. Matsusaka and Sherman (*9*) have shown that the mineral make-up in this group of soils is very similar to that found in soils of the dark magnesium clays. But in the case of soils of the gray hydromorphic group, there is an appreciable amount of kaolin present, especially in the Honouliuli family. This soil family is transitional to the low humic latosols and the data in table 1 bear out this relationship. The cation exchange capacity of this soil family is lower than that of the other two families of this group, showing the influence of the presence of the fair amount of kaolin. Furthermore, in spite of the high base saturation, due to the relatively low cation exchange capacity, the amounts of exchangeable calcium and magnesium are appreciably lower than in soils of the Kalihi or Kaloko families. The ratio of calcium to magnesium for the soils of the Honouliuli family is very similar to that of a typical soil of the low humic latosol group. In the case of the Kalihi and Kaloko profiles, the cation exchange capacity and the exchangeable calcium and magnesium are relatively high. The ratio of calcium to magnesium is in the neighborhood of 1.0 throughout the profiles. Gill and Sherman (*5*) concluded that the gray hydromorphic soils are capable of becoming dispersed and plastic when the magnesium saturation exceeds 30 percent in the presence of adequate content of organic matter, provided that the ratio of calcium to magnesium is approximately 1.0. Another feature of the soils of Kalihi and Kaloko families is the relatively high amounts of exchangeable sodium. The contents of exchangeable sodium for the soil of the Kaloko family increase with depth and are the highest reported in this survey.

Paddy soils are soils that are kept flooded by man for the cultivation of certain specialized crops like taro and rice. These soils are usually found at lowlands where there is an abundant supply of water. The soils are montmorillonitic in nature and hence will swell readily with wetting. The swelling will provide an impervious character to the soil, a requirement that is necessary to keep the water from being lost by percolation. The cation exchange capacity and exchangeable cations of a typical paddy soil, which has been reported by Sherman together with many other paddy soils (*16*), are shown in table 1. As is true with most paddy soils, this soil is slightly acidic in reaction and well saturated with bases. The cation exchange capacity content is similar to that found for soils of the gray hydromorphic group or other related montmorillonitic types of soils. The calcium-magnesium ratio is very close to 1.0, a characteristic that is true for most paddy soils. Another distinct feature of these soils is the exceedingly high content of exchangeable ferrous iron and manganous manganese (*16*). The magnitude of the amounts of these two exchangeable cations cannot be found in a well-drained soil.

CATION EXCHANGE RELATIONSHIPS

The data of the 39 families that were presented in table 1 were further studied to reveal any possible cation exchange relationships, embracing such factors as rainfall and types of soil. The study of these relationships was restricted to the surface sample of each profile.

Role of rainfall

Rainfall plays a dominant role in determining the type of soil that can be found in a given location. The soil type in turn will govern the cation exchange status. For this study only the total annual rainfall was taken into consideration, although it was recognized at the same time that the distribution of this annual rainfall also exerts its influence in soil development.

In figure 1 is presented a scatter diagram of the relationship between rainfall and base saturation. There is an overall decrease in base saturation with increasing rainfall. The base saturation percentages are lowest in areas of high rainfall and highest in areas of low rainfall. With the very wet soils, like some soils of the humic latosol group and most of the soils of the hydrol humic latosol group, the base saturation values tend to be below 10 percent. Similarly for the dry-area soils, like soils of the dark magnesium clay group, the corresponding saturation values approach 100 percent. There are certain soils that do not fit the overall pattern of decrease in base saturation with increase in

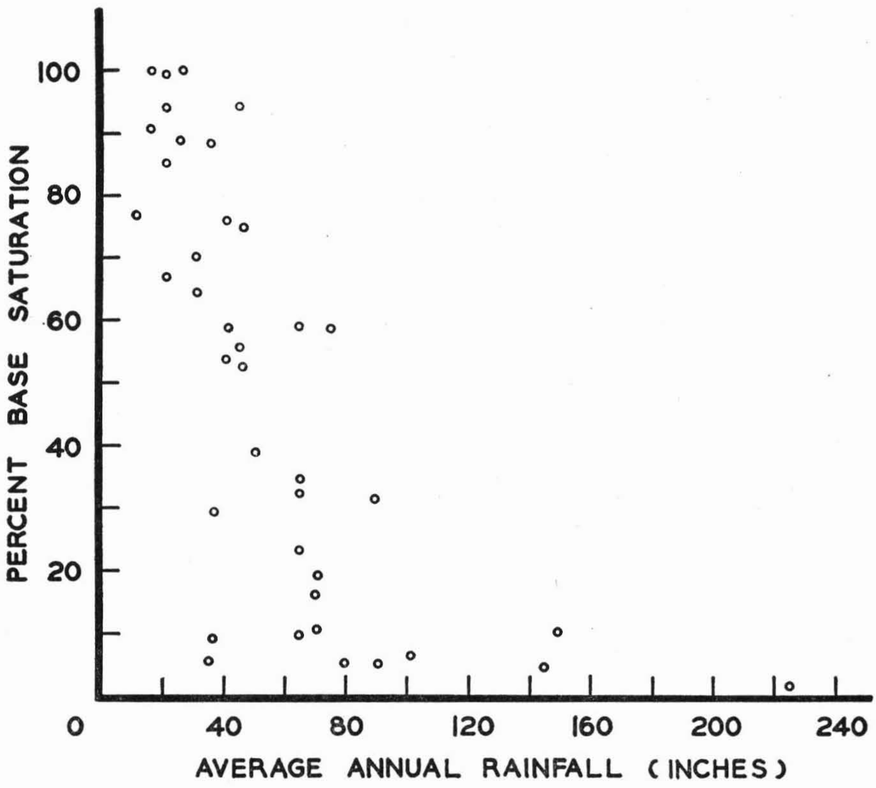

FIGURE 1. Relation between rainfall and degree of base saturation in surface soils.

rainfall. Young soils, like soils of the Kealakekua and Puu Oo soil families, which are found in relatively wet areas, are fairly well base-saturated. Conversely, there are old soils like some soils of the humic ferruginous latosol group in which the bases are almost totally depleted without benefit of a very high rainfall. At any rate, there appears to be a hyperbolic curve relationship of rainfall with respect to base saturation in this diagram. Unfortunately, not enough high rainfall soils were encountered in this study to "balance" one end of the apparently hyperbolic curve.

The effect of rainfall on the degree of calcium saturation is given in figure 2. The distribution of points in this diagram shows that this relationship is almost identical with the previous one between rainfall and base saturation. The effect of rainfall on the degree of magnesium saturation was also found to be very similar to the effect of rainfall on the degree of base saturation. The above findings involving the relationships between rainfall and the bases are in general accord with those of Ayres (*1*) in his report on the Hilo and Hamakua Coast soils. Craig and Halais (*3*) found similar type of relationships in the soils of Mauritius.

The foregoing relationships emphasize the dominating roles that calcium and magnesium play in the exchangeable base picture. This effect is further shown in figure 3 in which it is found that there is a very significant straight-line relationship between calcium and base saturation. As shown in the figure, the correlation coefficient "r" was found to be 0.969. When magnesium was correlated with base saturation, it showed a similar type of very significant straight-line relationship. As could be expected, however, the domination was

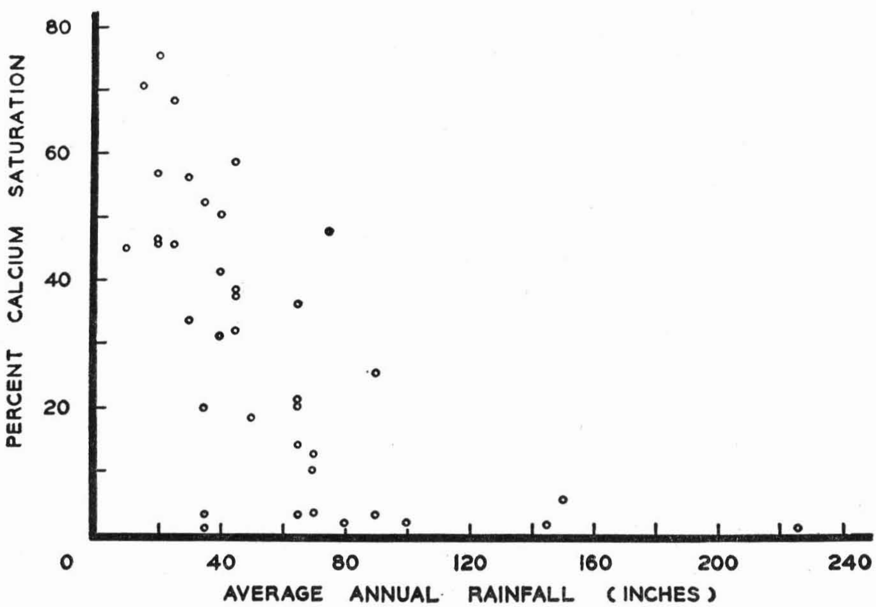

FIGURE 2. Relation between rainfall and degree of calcium saturation in surface soils.

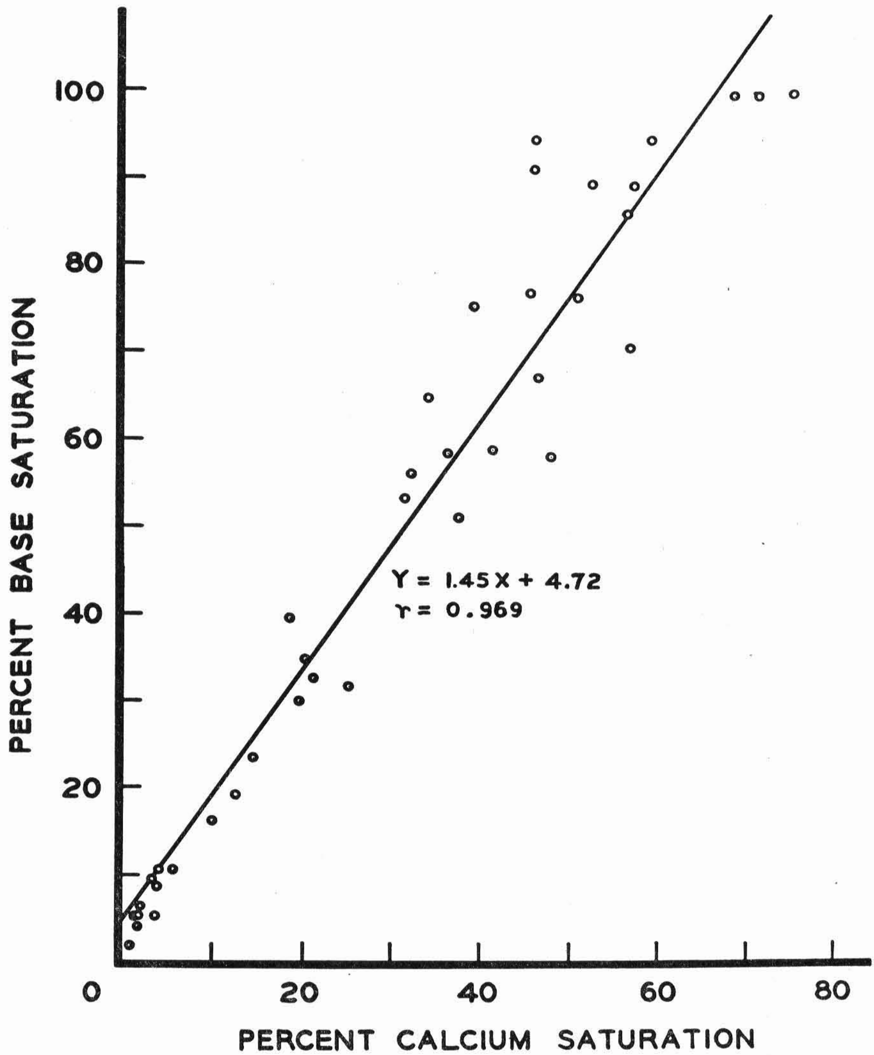

FIGURE 3. Relation between percent calcium saturation and percent base saturation in surface soils.

not as complete as that found with calcium. The corresponding "r" value was calculated to be 0.913.

pH vs. base saturation

The presence of exchangeable hydrogen accounts for soil acidity; therefore, it might be expected that a correlation would exist between hydrogen-ion concentration of soils and percent base saturation. A soil with a very large amount of active hydrogen ions, or low pH, would be associated with low base saturation, while a soil with a high pH would similarly be associated with high base saturation. Numerous mainland soil investigators (*6, 10, 11, 12, 13*) have reported correlations existing between pH of soils and their degree of base saturation. Sherman (*16*) reported a similar correlation with Hawaiian paddy soils. Mehlich (*10*) has made use of such correlations to aid in identifying the type of clay minerals present in the cation exchange complex. Liming needs of soil are often estimated by studying such a relationship.

In figure 4 is presented the relationship existing between pH and percent base saturation for Hawaiian surface soils. The linear correlation coefficient "r" of 0.891 was found to be very significant. At this point, however, it should be cautioned that this linear relationship is general. It would be fallacious to try to "predict" percent base saturation with great accuracy of any soil just by knowing its pH (or vice versa) without knowledge of the origin of the soil. A study of table 1, for example, will show that a soil of a humic ferruginous latosol group may have a pH of 4.1 with a base saturation of below 10 percent, while another soil of the hydrol humic latosol group may have a pH of 6.0 at the same base saturation. Pierre and Scarseth (*14*) have noted the same type of observation; they reported that highly weathered soils were found to have a lower degree of saturation at given pH values than less weathered soils.

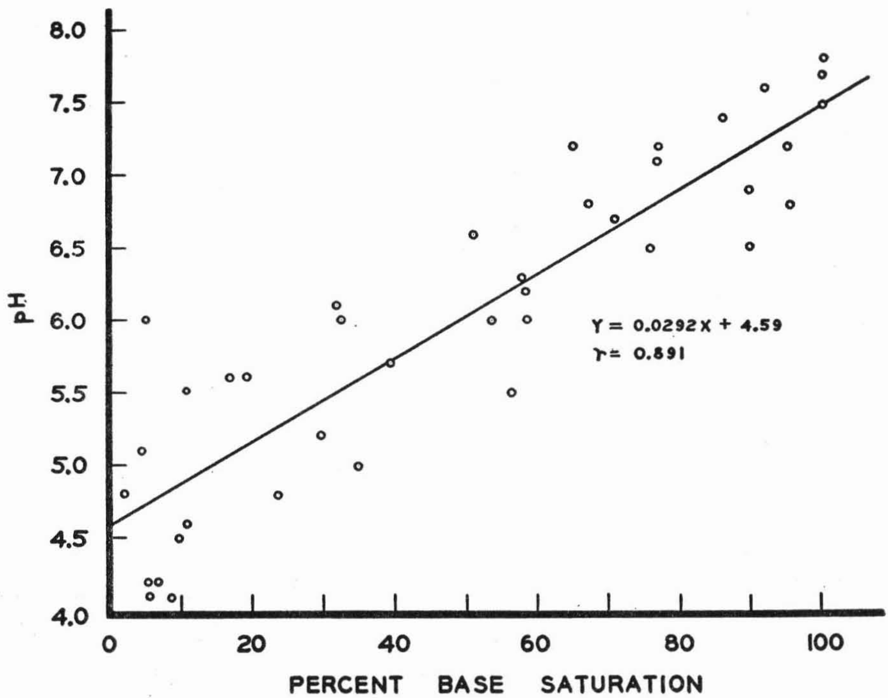

FIGURE 4. Relation between percent base saturation and soil reaction in surface soils.

The same type of relationship as above, but now between pH and calcium saturation percentage is presented in figure 5. It is seen that this comparison is very similar to the previous linear relationship between pH and percent base saturation. When magnesium was substituted for calcium and then correlated with pH, the same type of relationship was obtained, but to a lesser degree. These relationships involving calcium and magnesium saturation in the overall base picture further emphasize the dominating roles played by the two elements. Of the two, exchangeable calcium expresses this domination more forcibly.

Buffering capacity and cation exchange capacity relationship

In figure 6 is presented the relationship that exists between buffering capacity and cation exchange capacity of a soil. The comparisons were limited to the surface soils of 31 families. The value used to represent the buffering capacity of a soil was taken as the amount of sodium hydroxide in milliequivalents needed to bring a 100-gram sample of base-free soil to pH 7.0. There appears to be a direct relationship existing between the buffering capacity and the cation ex-

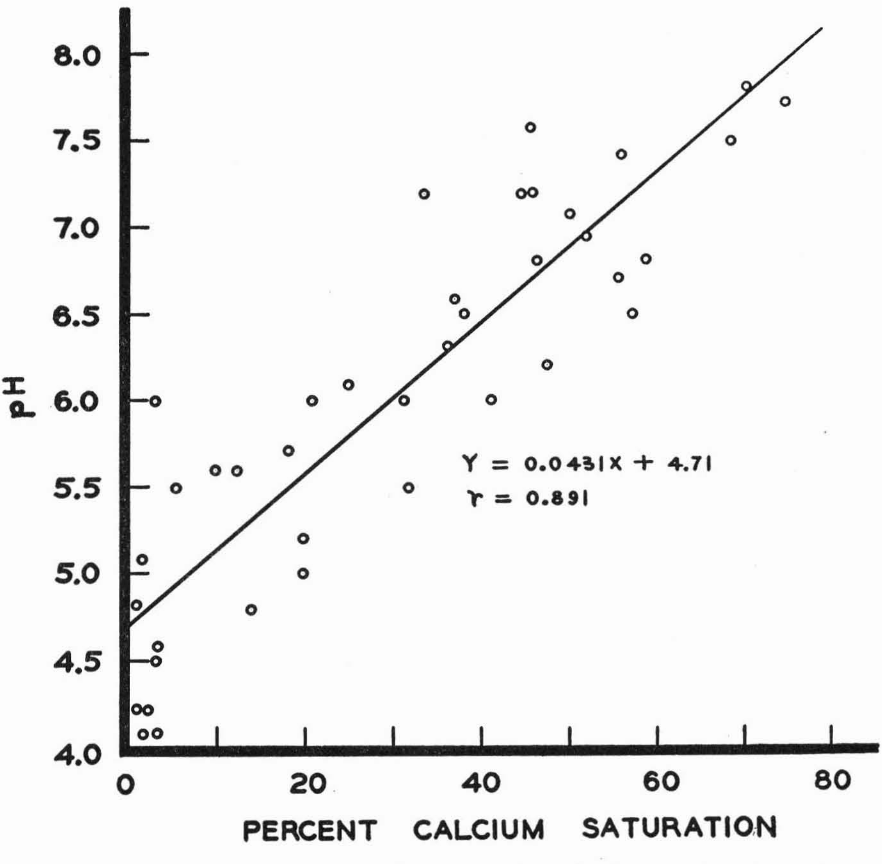

FIGURE 5. Relation between percent calcium saturation and soil reaction in surface soils.

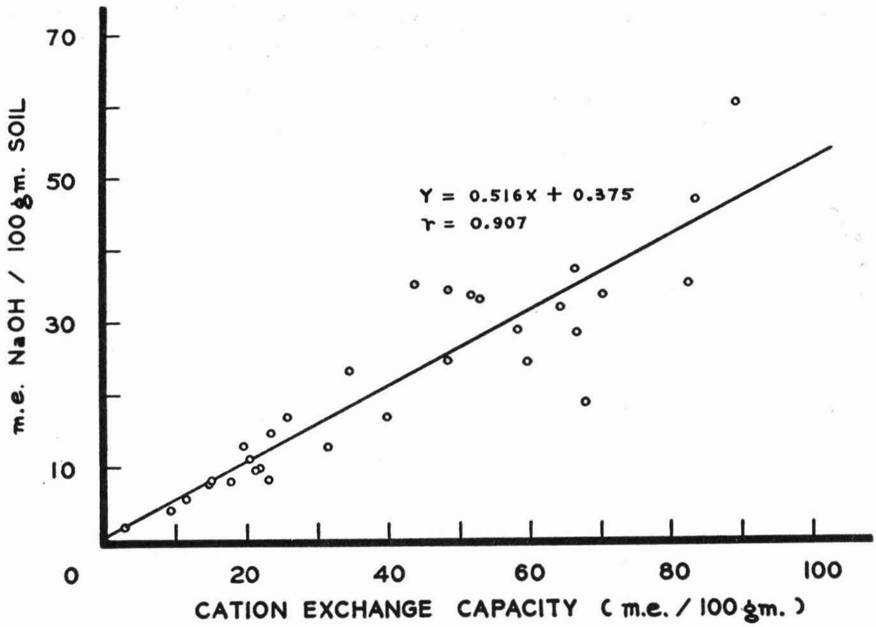

FIGURE 6. Relation between cation exchange capacity and buffering capacity in surface soils. (Data on buffering capacity provided from file of Yoshito Matsusaka.)

change capacity of Hawaiian soils. This finding is in agreement with that of Matsusaka and Sherman (8).

Other relationships

An attempt was made to correlate the clay content of a soil and cation exchange capacity. No direct relationship was found. Similarly, no correlation was found to exist between silica-sesquioxide ratio and cation exchange capacity. Matsusaka and Sherman (8) have also found that buffering capacity is not related to their the silica-sesquioxide ratio or amount of clay in the soil. It is generally held that a close relationship exists between these factors for temperate region soils.

SUMMARY

The results of the study on the cation exchange properties of Hawaiian soils may be summarized as follows:

There is a very great range in cation exchange capacity in Hawaiian soils. The nature of the soil clay determines the magnitude of this capacity value of a soil. This value is lowest in the crust layer of the soils of the humic ferruginous latosol group. It is also low in typical soils of the low humic latosol group, this low value being associated with the high kaolinite content found in this group. The young zonal soils and other soils of the montmorillonitic type possess fairly high cation exchange capacity values. The highest values are found in the subsoils of the hydrol humic latosol group.

Dehydration will cause a soil to lose some of its cation exchange capacity. This effect is most pronounced in the wet soils.

There appears to be a direct relationship between the buffering capacity and the cation exchange capacity of a soil.

No correlation was found to exist between the cation exchange capacity and the amount of clay content nor the silica-sesquioxide ratio of a soil.

There is an overall decrease in base saturation with increasing rainfall. The relationship between the two appears to be a hyperbolic curve in a scatter diagram. The very wet soils, like some soils of the humic latosol group and most soils of the hydrol humic latosol group, tend to have base saturation values of below 10 percent. The dry soils, like soils of the dark magnesium clay group, have base saturation values approaching 100 percent. Highly weathered soils like those of the humic ferruginous latosol group tend to have low base saturation values.

There is a straight-line relationship between pH and base saturation of surface soils.

The exchangeable calcium and magnesium cations dominate the base picture, with calcium expressing this domination more forcibly.

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